THE FACE OF THE EARTH

(DAS ANTLITZ DER ERDE)

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CHAPTER I

ENTRY OF THE ALTAIDES INTO EUROPE

The European Altaides. The horst of Azov. Prolongation of the Caucasus. The Crimea and Bulgarian platform. Balkans and Carpathians. The Cimmerian mountains. Summary. Alien fractures in the Variscan arc.

The European Altaides. Almost the whole of Europe must be assigned to the Asiatic system. The boundary is the Caledonian disturbance (II, p. 51; III, 388). Beyond it lie the outer Hebrides appertaining, together with the several peninsulas of the mainland, to another system—the Atlantic (III, 386). The volcanic region of Iceland, with Jan Mayen, the Faeröes, St. Kilda, and an offshoot extending to the north-east of Ireland, lies partly in the Atlantic region, partly in the zone of the Caledonian disturbance. Save for these exceptions, the whole of Europe is morphologically a part of Asia.

We have already called attention to the presence of two Asiatic elements in Europe, namely, the Dinarides (III, 316) and the Russian platform with the Uralides (III, 358).

The Dinarides are a part of the marginal arcs of the periphery, and the Russian platform may be regarded as a fragment of the Sayan portion of the ancient vertex. Between these two lie the chains of the western Altaides; extending through western Asia they advance to the boundary of Europe, and are represented in Europe itself by a vast mountain system, which may also be recognized outside this continent, even beyond the Atlantic Ocean and the Mediterranean Sea. The relations, disposition, and other characteristics of this system lead us to regard it as the natural continuation of the Altaides of Asia, and we shall designate it by the same name [1].

[1] The term 'Altaides' is not synonymous with 'Hercynian,' now so much in use. Marcel Bertrand writes: 'The term *Hercynian chain* which I have proposed for the whole of the Carboniferous folds of northern Europe has been criticized, not without reason, since the meaning I have attached to it is an extension of its original application, and consequently a departure from it. I shall continue to use it without defending it, but in the hope that some one will propose a better' (Bull. Soc. géol. de Fr., 1892, 3e sér., XX,

We may commence by recalling the evidence already adduced to show the original continuity of the pre-Permian horsts of Europe (II, p. 129); the sketch-map (Pl. V, I, p. 463) representing the relations of the Asiatic to the European chains, so far as we could determine them; the diagram of the Alpine trend-lines (I, p. 232, fig. 26), in which the Dinarides are distinguished from the Alps (I, p. 497); and the sketch (I, p. 480, fig. 47), which includes the Balkans and the Carpathians of Roumania.

In western Asia a marked divergence in direction gradually arises between the trend-lines which strike to the north-west and remain true to the vertex, and those, proceeding chiefly from the Thian-shan, which run more to the west-north-west. This divergence becomes at last so considerable that the Yergeni mountains, the last formed of the Uralides, meet the Caucasus, which is a branch of the Altaides, almost at right angles (III, 361).

In Asia, as in Europe, there are some folds which are older and others which are younger than the upper Carboniferous or the Permian. This distinction is often emphasized by unconformity, but in Asia the younger folds are incorporated with the older in the same mountain system, and *are not sharply separated from them in space.* An example is furnished by the observations of Merzbacher and Keidel on the river Kok-shal in the south Thian-shan, where the unconformity at the base of the lower Carboniferous is as clearly marked as in Brittany or Silesia, and that at the base of the upper Carboniferous is no less evident. The folding has not proceeded without interruption, but on the whole it has been repeated along the same lines, and the common outer border has been driven southwards over the Gobi beds[1]. A similar example is afforded by the marginal arc of the Himálaya as represented by the Siwalik zone; and many other instances might be cited.

In Europe the case is different.

In that southern part of the Russian platform known to Russian geologists as the *horst of Azov* two great tectonic changes set in.

In the first place the chains of the Altaides, hitherto folded towards the south, now become folded towards the north, and this reversal is *the more*

p. 119, note). The name has subsequently been extended to pre-Permian chains in many other parts of the world. It was used by the great master in contradistinction to the Alps. The important point for L. von Buch, when he created the 'Hercynian system', was the (orographical) north-westerly direction, for Marcel Bertrand it was the tectonic age; in this work, where we are seeking to determine the main lines of the structure, it is the connexion with the Altai (III, pp. 196, 197), and there are very many pre-Permian chains which do not belong to the Altaides, such, for example, as the Carnic sub-structure of the Dinarides. It would, besides, have been difficult to employ a term which is used at the same time both in its original and in a different sense (cf. Lepsius, Geologie von Deutschland).

[1] H. Keidel, Geologische Untersuchungen in Süd-Tian-Schan etc., N. J. f. Min., 1906, Beilage-Band XXII, pp. 266–384, map; in particular p. 277.

remarkable since in the south of Europe the Dinarides, and in the north the continuations of the Timan-Kanin chain, still retain the Asiatic folding towards the south. Thus the intervening Altaides present themselves as an exception.

In the next place those chains of the Altaides which are younger than the upper Carboniferous and the Permian are *separated sharply in space.* They lie almost wholly within subsided areas of the Altaides, framed in by lines which frequently cut across the strike of these mountains. We may regard the *chains thus framed in* as posthumous Altaides. The Alpine chains (Alpides) are their most important member.

The Alpides are bordered by a Tertiary zone. Nothing analogous to this is to be seen in the outer margin of the Variscan arc, i. e. outside the Belgian coal-fields. Indeed the younger folding occurs but seldom in the horsts of the European Altaides, and is then only feebly developed. *It is as though the frame had become rigid, and the folding, from the upper Carboniferous onwards, had been confined to the downthrown areas.*

Nowhere else on the face of the earth has a like case yet been observed, unless perhaps in Manchuria, where older fragments are said to occur with alien folding within the younger folds.

Each of these tectonic changes stands in need of explanation.

The long range of the Adak mountains (III, p. 370), as it proceeds through the Grosslands tundra, follows, even north of the Ussa, the direction of the principal chain of the Urals, which here runs about north-east [1]. The Uralides give off first a branch to the north-west, which passes through Waigatz to Nova Zembla, and then a second in the direction of the Timan-Kanin range (III, p. 374). In 1891 Reusch observed that brown and grey sandstone and slate are thrown into folds on the Varanger fjord and the Tana fjord, and that they form the continuation of certain rocks met with by Böthlingk in Fisher peninsula, off the north coast of Kola. They contain intercalated beds with glaciated boulders [2]. At the time these observations were made the sandstone was regarded as faulted down against the Archaean complex lying to the south. But Ramsay, in a study of the north coast of Kola, has since shown that this sandstone belongs to the border of a folded range driven towards the south, and represents, indeed, the continuation of the Timan chain.

The island of Kildin is the first indication of this mountain border;

[1] T. N. Tschernyschew, Additional observations on the Bolschesemelskaja Tundra; Izviestija Acad. Imp. Sci. Saint-Pétersb., 1907, pp. 205–208. Pytkov (not Rutkov) Kamen, east of the mouth of the Petchora (III, p. 370), is composed, like Kanin, of sericite schists.

[2] H. Reusch, Det Nordlige Norges Geologi, Norg. Geol. Undersög., No. 4, 1892, pp. 22–51 (also op. cit., No. 1, 1891, pp. 78–85); A. Strahan, On Glacial Phenomena of Palaeozoic Age in the Varanger Fiord, Quart. Journ. Geol. Soc., 1897, LIII, pp. 137–146.

Fisher peninsula is the second; in the constriction which separates the Srednij-Puostrov (middle peninsula) from the mainland lies the boundary of the Archaean complex. The strike is north-north-west; the dip of the beds is to the north-west, and indicates an overthrusting of the mountain border[1].

Dal's investigations show that the folds strike across the whole breadth of the Varanger peninsula into the Tana fjord[2].

The age of the sandstone is unknown; it is supposed to be Devonian; but in any case it must be later than the Caledonian dislocations of north Norway, since its folds cross the direction of these dislocations.

In the north of Europe, therefore, the dominant movement is towards the south. That this is also the case with the Dinarides, in the south, has already been shown. The folding directed to the north, which characterizes the Altaides lying west of the horst of the Azov, is thus obviously exceptional; but it persists even across the Atlantic Ocean and beyond.

We must now consider the downthrown areas of the Altaides, and the horsts surrounded by them which form the outer frame.

We are already familiar with the horsts of the *Variscan* and the *Armorican* arcs (II, pp. 97 and 86).

Another important part of the Altaides is the *Iberian Meseta* (II, p. 122). The basin of Asturias (fig. 14, II, p. 125) has been explained as the innermost part of an ancient region of torsion, a region like the bend of Gibraltar. Termier believes that the overthrusting of recumbent sheets affords a better explanation of the structure. Further observations are necessary to decide this question. A long straight line running from Oporto to the south-south-east marks the western boundary between the Meseta and the Mesozoic sediments; but beyond this line some little islands of granite and gneiss, *the Berlengas*, rise from the sea off cape Carvoeiro, as though the ancient rocks were continued beneath the ocean.

The *Montagne Noire* is an independent branch of the Altaides, sharing a common outline with the southern part of the Central Plateau, but distinguished from it by a divergent strike to the west-south-west and by well-marked overthrusts. The Cevennes form its continuation to the east-north-east. The hills of Barcelona, beyond the Pyrenees, possess a similar structure. The Montagne Noire will be discussed in greater detail in connexion with the Pyrenees.

The *Corsardinian* branch, like all the horsts so far described, reveals

[1] W. Ramsay, Neue Beiträge zur Geologie der Halbinsel Kola, Fennia, 1899, XV, No. 4, pp. 6–11.

[2] Adolf Dal, Geologiske jagttagelser omkring Varanger fjorden, Norg. Geol. Undersög., No. 28, Aarbog f. 1896 til 1899, Kristiania 1900, No. 5, 16 pp., map; H. Reusch, Ein Theil des timan'schen Gebirgssystems innerhalb Norwegens, Geogr. Zeitschr. von Hettner, 1900, VI, pp. 391, 392.

itself as part of the Altaides by the unconformable superposition of the upper Carboniferous. It includes the greater part of Corsica and the whole of Sardinia, strikes to the south-south-east, and may be traced through $3\frac{3}{4}$ degrees of latitude. It is distinguished by peculiar Mesozoic transgressions, which we shall refer to when describing the northern Apennines.

A divergent mass is formed by Calabria and the Peloritan mountains in the north-east of Sicily; above the ancient rocks it exhibits a Cenomanian transgression of African type, indications of which have also been observed in Sardinia. Great overthrusts affecting whole regions have been recognized in Sicily; it is not known whether, or to what extent, they make themselves felt in this mass.

In addition to the examples mentioned above, ancient fragments are to be seen rising out of the younger folded ranges. This is the case particularly in the Pyrenees, but also in the Pelvoux, the Tödi, and elsewhere. In the Styrian alps the fossiliferous series beginning with the plant-bearing beds of the middle or upper Carboniferous is sometimes met with.

Under these circumstances it is very difficult to picture to ourselves the original plan of the western Altaides, but the configuration of the Appalachians, the relation of the Montagne Noire to the Central Plateau, and the course of the Altaides in Africa, might lead us to suppose that it formed a great virgation open towards the south-west and south.

In some cases *the subsidences suffered by this great system did not afford sufficient room for the younger chains which came crowding in upon them;* in others, as in South Germany, vacant spaces were left between the irregular outer frame and the great curves swept out by the chains. Even the southern scarp of the Meseta extends to the west far beyond the arc of Gibraltar[1]. The new folds, however, occasionally strike right across the ancient folds, as, for instance, when they meet the Sudetes or the Great Atlas.

The most striking example, however, is afforded by the Alps. After the first mighty bends at the Iron gate and in the south-east of Transylvania, the Carpathians swell out in a broad arc over the southern part of the Russian platform and overwhelm the Sudetes. Then Bohemia forces the folds into the frame formed by the Variscan horsts as into a funnel. Not being able, like the Carpathians, to surmount the foreland or to disburden themselves by thrusting out an unimpeded branch, they achieve the most stupendous overthrusts.

The Alps terminate in the Balearic islands, but to the north lies another downthrown area within which the folds of Provence arise; these enter into connexion with the Pyrenees under peculiar circumstances. The

[1] T. Fischer, Orographie der Iberischen Halbinsel, Peterm. Mitth., 1894, pp. 249–256 and 277–285, map. Chffoat thinks that a connexion with the border in Algarve is not proved.

Meseta does not reach the sea across Santander; but is divided from it by a range of younger folds, which probably form the border of another subsidence.

In the subsidence of western Portugal younger folding likewise occurs. There the Culm, the unconformity of which is the earliest precursor of the formation of the Altaides, plays an important part in the structure of the Meseta. A number of granitic intrusions confuse the picture, and conclusions drawn from the configuration of the surface must be received with more than usual reserve. From Choffat's accounts it appears that here, as in the northern part of the East Alps, the younger folded series begins with the Trias; the folds are on the whole gentle and not very long, but in the Aralida chain, which reaches the sea in cape Espichel, strongly marked imbricate structure occurs, with movement to the south-south-east. Unfortunately, this chain is so short that it is scarcely possible to form any decided opinion as to the nature of this exceptional movement to the south [1].

The subsided area of London and Paris likewise exhibits younger folds (the Weald among others).

The occurrence of younger posthumous folds in the more important subsidences of the Altaides, and especially in regions where there is no direct connexion with Asia, points to the existence of a very general folding force, which only finds expression within the frame.

Subsidences of a similar kind have also occurred outside the Altaides. That of Venice, and the Aegaean inbreak, lie in the Dinarides. Beneath the south-eastern part of the Mediterranean a fragment of the desert platform of Africa has been let down. But none of these subsidences which lie outside the Altaides shows signs of younger folding.

The Alpine foldings have been preceded or accompanied by subsidence, which, judging from the evidence afforded by Radiolarian rocks, must have amounted during the Jurassic epoch to at least 4,000 meters. But subsidences have also followed the folding. As instances, we may cite the Vienna basin with its belt of thermal springs, Hungary with its arc of Tertiary volcanos, and the clearly defined downthrown area of western Italy, also with its volcanos. We have already suggested the possibility that the subsidence of the Tyrrhenian Sea may be on the verge of extending itself even at the present day (I, p. 86). Caldron fractures have occurred at a very late period, as, for instance, in the Roussillon. There are however several isolated windows in the midst of the Alps which do not owe their origin to subsidence, and these suggest the question whether there may not exist a *secondary folding of the frame* within the Alps.

[1] P. Choffat, Pli-faille et chevauchements horizontaux dans le Mésozoïque du Portugal, C. R. Acad. Sci. Paris, 31 Juill. 1905, pp. 335–337, and, in particular, Notice sur la Carte hypsométrique du Portugal, Comm. serv. géol. Portugal, 1907, VII, 71 pp., map.

It will appear from the preceding remarks that there is no part of the face of the earth which presents greater difficulties to an exact analysis than that part of the Altaides which lies west of the horst of Azov. Such an analysis is the task reserved for the following chapters. The Pontic region, the immediate link with Asia, is of such importance that it must be given precedence. But it is not only in the form of great folded ranges that Asia advances towards Europe. There are many reasons for regarding certain long lines of fracture (Karpinsky's lines), which strike to the west-north-west or north-west, as of Asiatic origin.

We may first consider Karpinsky's lines and the regions surrounding the Black Sea.

Then we will proceed to the Altaides in Europe, with their continuations in North America and North Africa, and conclude with a discussion of the younger chains within the frame.

The horst of Azov. From the south of the Russian platform we may mark off a horst (III, p. 383). Its boundaries have been precisely determined by Teisseyre[1] and Laskarew[2]. It is known as the *Podolian horst* or the Podolian platform.

The border of the Carpathians reveals great overthrusts. Nothing, indeed, could be more manifest than the overriding of the Sudetes across their whole breadth (I, p. 186, fig. 24). For the region which lies next to the east, the course of two rivers, the Weichsel and San, appears to possess particular significance.

The towns of Cracow, Sandomir, and Przemysl mark out a triangle, covered by recent sediments, which includes these two rivers and the border of the Carpathians (I, pp. 184, 469). At its apex, near the mouth of the San, the Sandomir range makes its appearance. From here on towards the south-west a fault is supposed to accompany the course of the Weichsel, along which the Sudetes are thrown down. In any case the Sandomir mountains represent a frontal chain of the Sudetes, comparable in some degree with the Jura.

The course of the San, however, corresponds approximately with a line continuing the direction of the north-east border of this frontal chain. Near Przemysl the river issues from the Carpathians, and along the whole sweep of the Carpathians, from the west up to this point, boulders are found which belong to the Sudetes or the Sandomir mountains. Wójcik has shown in particular that all the stages of the foreland, from the Devonian to the Kimeridge, are represented in the boulders which occur

[1] W. Teisseyre, Versuch einer Tektonik des Vorlandes der Karpathen, Verh. k. k. geol. Reichsanst., 1903, pp. 289–308; Der palaeozoische Horst von Podolien und die ihn umgebenden Senkungsfelder, Beitr. Paläont. Oesterr.-Ung., 1903, XV, pp. 101–126, maps.

[2] V. Laskarew, Geological Investigations in the Districts Ostrog and Dubno, Volhynia, Bull. Com. géol. Russie, 1904, XXIII, pp. 425–461, and Observations on the Tectonic Structure of the Crystalline Platform of South Russia, op. cit., 1905, XXIV, pp. 235–295, map.

in the neighbourhood of Przemysl. They lie in Oligocene Flysch, either loose or as conglomerate, and Wójcik explains them as parts of the faulted-down foreland carried up to the surface from below [1].

They are intra-telluric erratics, and indicate that as far as Przemysl—that is, up to the river San—the foreland still belongs to the Variscan system, the boundary of which is reached by the border of the Carpathians, 200 kilometers east of Cracow. Indeed even the great fragments of ancient Coal-measures—sometimes erroneously regarded as workable—which have long been known in the Flysch of the East Carpathians, are met with, as Professor Niedzwiezki informs me, as far as Delatyn on the Pruth (long. 22° 20′ E.).

We will now leave the border of the Carpathians.

A boring at Lemberg failed to reach the base of the Senonian at a depth of 501 meters.

On the Dniestr, near Nizniov (east of Stanislau), a gradual transgression of the uppermost part of the Jurassic occurs, and probably extends from the north-east side of the Sandomir mountains as far as this point [2].

More to the north, on the Zlota Lipa (left tributary of the Dniestr), coralliferous Devonian dolomite, resembling that of the Sandomir range, occurs above the Devonian sandstone [3].

Then the western characters disappear, and on the Dniestr the Palaeozoic series of the horst is exposed. It dips gently towards the Carpathians, but is separated from them by the broad valley of the Pruth. In Moldavia the distance between the horst and the Carpathians increases rapidly. The Pruth makes a bend to the east, and near Radautzi enters a Cretaceous plateau. This has led Simionescu to conclude that the horst also extends across the Pruth [4]. The southern boundary of the horst reaches the sea of Azov near Berdiansk. North of this town it terminates, appearing in the landscape as an extensive hilly land rising from amidst a flat country. Morozewicz has given a map of this region [5] (III, p. 385).

This hilly land is the horst of Azov; it is a part of the Podolian horst.

Let us again turn our attention to its north-western extremity. Here according to Laskarew, in the districts of Dubno and Ostrog, indications of two subsidences may be found. The first, that of Peltcha, is bordered by the marine upper Devonian of the western mountains; the second is associated near Rovno with some completely isolated exposures of basaltic

[1] K. Wójcik, Exotische Blöcke im Flysch von Krubel Wielki bei Przemysl, Bull. Acad. Sci. Cracov, 1907, pp. 499–527.

[2] J. v. Siemiradzki, Über die Gliederung und Verbreitung der Jura in Polen, Jahrb. k. k. geol. Reichsanst., 1889, XXXIX, pp. 45–54, in particular p. 46.

[3] A. Alth i. Fr. Bieniasz, Atlas geol. Galicyi, Bl. 8, XIII, Monasterzyska, Krakau, 1887, Text, p. 49.

[4] J. Simionescu, Erreicht die russische Tafel Rumänien? Centralbl. f. Min., 1901, pp. 193, 194, also Ann. Sci. Univ. Jassy, 1902, pp. 4–6.

[5] Morozewicz, Bull. Com. géol. Russie, 1901, XX, p. 574, tab. vi.

rock. The boundary of the Podolian horst then turns towards the north, and afterwards pursues a course to the south-east, following at some distance the right bank of the Dniepr. It crosses the river near Krementchug, and finally reaches the north side of the horst of Azov.

This fragment of an ancient mountain system has played an important part in determining the configuration of Europe.

Karpinsky has expressed the opinion that the deflexion of the Caucasus towards the Crimea is to be attributed to it (III, p. 386). It is a remarkable fact *that the behaviour of the trend-lines as they enter this region from Asia differs according as they pass south or north of the horst.*

The Caucasus maintains its direct course to the west-north-west or north-west, a trend so characteristic of the great branches of the Asiatic virgations, till they approach the Crimea. At this spot the conditions suddenly change.

The Carpathians cannot unite with the Asiatic lines except on the south of the horst; the Russian platform leaves us in no doubt on this point. From the horst onwards the folding turns to the north; and in place of the straight lines of the Caucasus we have the winding trend-lines of Central Europe.

The case is altogether different on the north of the horst. The direct course to the west-north-west or north-west, and, so far as can be made out, the Asiatic movement to the south also, are maintained unchanged. It is here that Karpinsky's lines begin. (I, Pl. V, *mm*).

The fold of Kulandy at the north-west extremity of the Sea of Aral and the scattered occurrences in the Astrachan steppe are isolated phenomena which for the present we may leave out of account.

Of much greater importance is the *line of the Alai* (I, p. 468). The Alai mountains, the Turkestan range—the Malgusar—the Nuratau (Pl. III, III, p. 281), the Scheich Djeli—Mangishlak—the Coal-measures on the Donetz (6 on Pl. V, I, p. 463)—such is the series of coulisses which, striking at first in an arc slightly convex to the south and then in a straight line to the west-north-west, starts from the north border of the Pamír, and runs along the north side of the horst of Azov.

In confirmation of Karpinsky's conjectures, Bogatschew has found fragments of fossiliferous upper Carboniferous rocks in Tertiary sands on the southern slope of the Sal-Manytch watershed (close to lat. 42° 30′ E.), and in such abundance that we must suppose a reef of this limestone to exist a little below the surface. The direction of the watershed if produced beyond Novo-Tcherkarsh will be found to meet the axis of the principal anticline which runs through the Carboniferous of the Donetz [1].

[1] W. Bogatschew, The Steppes of the Fluvial Region of the Manytsch, Bull. Com. géol. Russie, 1903, XXII, pp. 13–162, map, in particular pp. 105, 153 et seq. Folds of the Ural group appear far to the west; cf. A. W. Pawlow, Some new facts concerning the

The coal-bearing Carboniferous beds crop out no further away than a point north-east of Konstantinovskaia on the Don; and in the south near Taganrog the upper Devonian has been reached by boring; it occurs as a band between the south side of the Carboniferous and the ancient crystalline horst. This Carboniferous area, which forms the *coal-field of the Donetz*, is already known to extend in a north-westerly or west-north-westerly direction for about 370 kilometers, with a maximum breadth of 160 kilometers. An admirable account of it has been given by Tschernyschew and Lutugin. From the upper Devonian, with which the great series begins, up to the base of the horizontally bedded Tertiary, there is a complete absence of unconformity. Nevertheless certain members, as, for example, the Trias and lower Cretaceous, are without definite representatives. Even at the base of the upper Carboniferous or the Permian, so frequently characterized by unconformity, no sign of disturbance is to be found in this area. The more southerly parts of the coal-field consist, at least in the basin of the Kalmjuss, of older sediments, such as the upper Devonian and the lower divisions of the Carboniferous, and are characterized by comparatively horizontal bedding, strike faults, and troughs. It is only towards the middle of the region that folding sets in, and there a so-called master anticline occurs, as well as elliptical dome-shaped saddles (brachy-anticlines), saddles with a steeper south limb, and finally close and crushed folds which owe their character to repeated alternations of rocks of very different degrees of resistance, and to the formation of thrust-planes and fractures [1].

Borissjak has described the manner in which these close folds disappear to the north-west in the direction of Ussjum. They are completely worn down to a plain, on the surface of which the anticlines appear as isolated ellipses striking to the north-west, and presenting a more or less concentric structure, generally with a steeper south limb. The older sediments are more intensely folded, the younger—at any rate the Cretaceous—less so. Finally the whole system descends below the surrounding Oligocene [2].

structure of the basin of the River Medwjeditza and the Lower Volga, Bull. Soc. Imp. Nat. Moscou, 1901, pp. 221–231; Traces of mountain-forming processes on the Don, between the plains of Kljetzkaia and near the Three Islands, Izviestija Imp. Obsch. Lubet. Estest. Antrop. Etnogr. Moskwa, 1901, pp. 1–5, Bull. Com. géol. Russie, 1903, XXII, p. 250. The meeting-place of the Yergeni mountains and the Manytch probably lies in about lat. 44° 50′ E. (III, p. 361).

[1] T. Tschernyschew et L. Loutougin, Le Bassin du Donetz, Guide des Excurs. du VII[e] Congrès Géol., 1897, XVI, 55 pp., maps. It is true that in some places in the south the Cretaceous rests directly upon the Carboniferous, although it there presents steep angles of inclination. P. P. Piatnitzky, Observations on the Cretaceous Beds of the Don and the left bank of the Dnjepr, Report of the University of Charkow, 1889, III, 178 pp., in particular p. 145. In the interior of European Russia, Karpinsky suspects the presence of similar traces, Bull. Acad. Imp. Sci. Saint-Pétersb., 1907, pp. 243–246. I did not think that the Sandomir mountains should be referred here.

[2] A. Borissjak, Ueber die Tektonik des Donez-Höhenzuges in seinen nordwestlichen

The Dniepr follows the south margin of the coal-field, and even as far up this river as Kanev disturbances have been observed in the Jurassic and Cretaceous [1].

Here, according to existing data, between lats. 31° and 32° E., the zone of dislocations which starts from the Manytch comes to an end.

Prolongation of the Caucasus. Let us turn next to the south side of the horst of Azov.

In our first attempt to determine the course taken by the Asiatic trend-lines, as they proceed towards the west, we marked one of them as extending from the Caucasus towards Kertch, with a bend in the Crimea from north-west to south-west (I, p. 463, Pl. V). At the same time we called attention to the greater age of the Crimean fragment as compared with the later movements of the Caucasus. The mountains of Matchin in the Dobrudja were left as an unsolved problem (I, pp. 472, 476).

The Caucasus is distinguished from other chains by many peculiarities of structure. Its rectilinear course seems, as previously pointed out, to mark it as a branch of the Thian-shan. Sarmatian beds have been carried up with the chain to a height of 2,200 meters. Its middle part may be described as a great fold, overturned to the south-west. In the south-east the southern part disappears below the valley of the Riom.

Recent observations—in particular the discovery of *Pseudomonotis ochotica* and the Rhaetic stage—have added many details to our knowledge of this range [2], but they have scarcely modified the general description which we owe to Abich, at least as regards its leading features. Yet with such a structure it is still perplexing to find the Mesozoic sediments of the south so different in character from those of the north. Probably the amount of the overthrusting towards the south is very considerable.

Folds of Sarmatian age, and even of more recent date, are present on both sides of the mountains. In the south they are overfolded from the north along with the older sediments. They follow the north border of the mountains with considerable regularity, as may be seen, for instance, near Derbent [3] and Stavropol. Abich was aware that the folds of the

Ausläufern, Centralbl. f. Min., 1903, pp. 644–649, map, and Geologische Skizze des Kreises Isjum, Mém. Com. géol. Russie, Nouv. sér., Livre 3, 1905, 423 pp., map. Some of these domes form an exception and are steeper towards the north; the last, lying furthest to the north-west, is cut through transversely by a meridional flaw, which is later than a part of the Tertiary series.

[1] I, p. 468; Karitzky thought he only perceived local downslips, Rep. Univ. Charkow, 1888, IX, pp. 381–394. Laskarew seems to include them in the marginal disturbances of the Podolian horst.

[2] T. Tschernyschew, Discovery of the Upper Trias in the North Caucasus, Izviestija Acad. Imp. Sci. Saint-Pétersb., 1907, pp. 277–280. The occurrence of *Spirigera Manzovinii* and other species which belong to Asia Minor is remarkable.

[3] A steep isolated fold of Sarmatian rocks which is overturned above Derbent in the

north side are continued in an arc slightly convex to the north across the north-western extremity of the range, and the trend-line on Pl. V is based on this observation.

The Caucasus terminates near Anapa in ranges of Cretaceous Flysch with a north-west strike [1]. North of this locality we enter the region investigated by Andrussow [2].

Parallel to the Caucasus runs a northern group of late Tertiary folds which passes through Temriuk into the northern half of the Taman peninsula, assuming at the same time an east and west strike; with this direction it crosses the strait of Kertch, forms the northern half of the peninsula, and bends in a gentle arc to the west-south-west; it then loses in importance, and terminates on reaching the Crimean steppe.

A southern group of folds adapts itself at first to the northern group and fills the interval between this and the north foot of the Caucasus. It strikes into the southern half of Taman, gradually diverges from the direction of the northern folds, and, assuming a south-westerly direction along the south-west coast of Taman, proceeds into the south-east part of the peninsula of Kertch, to disappear beneath the Black Sea.

The angle between these divergent groups of folds is occupied by a plain which forms the south-west of Kertch, and is separated from the folds by the *Parpatsh* scarp. This plain may be regarded as a sort of apron or as a glacis of the eastern extremity of the Crimean mountains. Near Theodosia this eastern extremity shows an outcrop of Tithonian rocks.

Andrussow originally supposed that the folds were formed during the interval between the Sarmatian and the Maeotic stages. Subsequently unconformities observed at different horizons led him to conclude that the folding and denudation might have been to some extent simultaneous, and might perhaps have continued even into post-Pontic times. Overfolding has taken place in the direction of the principal chain, i. e. in the *Asiatic direction* towards the south or south-east.

Here nature offers us an instructive illustration of the way in which recent folds are divided into divergent fascicles, instead of being dammed

opposite direction to the north-west suggests by its curious structure the gliding back of inclined beds. D. W. Golubiatnikow, Geological observations in the Naphtha regions of the district of Kaïtago-Tabasaran, Bull. Com. géol. Russie, 1902, XXI, pp. 697–754.

[1] S. Nikitin, Geological structure of the district of Noworossiisk, Bull. Com. géol. Russie, 1902, XXI, pp. 653–670.

[2] N. Andrussow, Geotectonics of the Peninsula of Kertsch, Matér. Géol. Russie, 1893, XVI, pp. 1–272, map; Environs de Kertsch, Guide du Congr. géol., 1897, XXX (map of the trend-lines); Geological investigations in the Kuban region, Travaux Soc. Nat. Saint-Pétersb., 1899, XXVIII, pp. 179–214; Geological observations on the Peninsula of Taman, Matér. Géol. Russie, 1904, XXI, pp. 257–381, map et passim.

back, by an alien ancient range (Theodosia). The northern fascicle terminates in free ends, the southern descends beneath the sea.

At Opuk, off the south coast of Kertch, close to where the Parpatsh scarp reaches the sea, there emerge a number of small and difficultly accessible 'Klippen', the *Korabli* (caravels, ships). Dubois was already aware that they consist of a crystalline rock, foreign to the neighbourhood. Andrussow mentions loose fragments of amygdaloidal rock with zeolites, phyllites, &c., as occurring on the adjacent coast; von Vogdt regards the Korabli as a remnant of the Crimean mountains.

Crimea and the Bulgarian platform. The bifurcation of the younger folds of the Caucasus has been caused by the fragment of a larger chain. If, in proceeding to the south, we approach this fragment from the

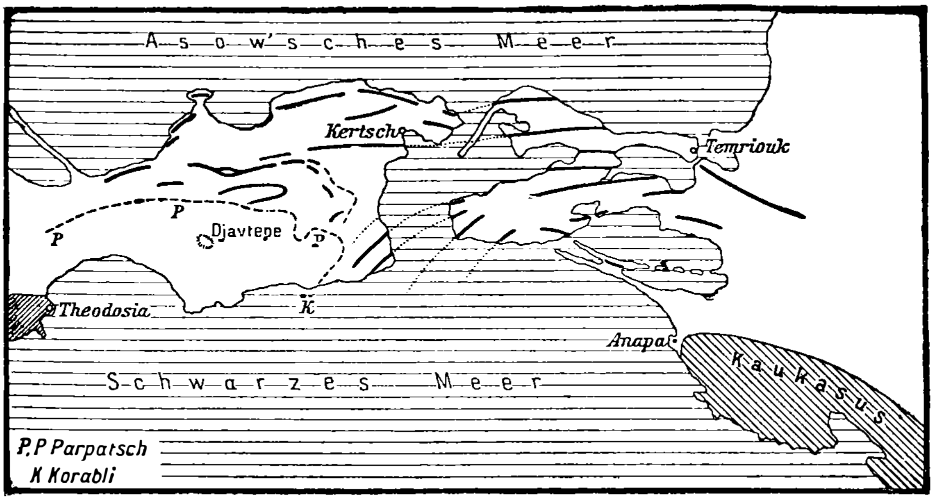


FIG. 1. *The Strait of Kertch* (after Andrussow). The strong lines indicate late Tertiary anticlines.

Crimean steppe, we shall pass over Miocene beds, Nummulitic limestone and the entire Cretaceous system, including the lower Neocomian, all dipping very gently to the north. The Caprotina limestone (lower Cretaceous) rises in steep basset edges, which face towards the south—that is, in the direction of the mountains.

The Neocomian lies unconformable and fairly flat on folded Lias and Oolites (I, p. 474). These beds, together with some remarkable laccolites, look as though they formed the whole folded range of the Crimea, but this is not the case, since von Vogdt has discovered at Simpheropol and east of this town an older series. This includes upper Carboniferous limestone with Schwagerina, conglomerate and sandstone with land plants, shales with *Pseudomonotis ochotica*, and lower Lias of the Hierlatz type (East Alps). Then follows the widely extended Jurassic system [1]. Patches of Lias rest unconformably upon Trias. Von Vogdt compares the mountains of the Crimea with those of Matchin (Dobrudja); both are of a relatively great age, and present a similar succession of strata. In the south-western extremity of the coast, near Phoros, Borissjak still observed *Pseudomonotis ochotica* [2]. To the east, near Theodosia, the strike of the folds is east and west, near Simpheropol it is N. 75° E., and towards the south-west of the peninsula it becomes north-east. The folds form an arc slightly convex to the north-west. At the same time two considerable disturbances of different date may be recognized, one between the Trias and Lias, the other between the Jurassic and Neocomian. Unconformities have been observed in even younger beds. Their number is surprisingly great; it looks as though the folding had been repeatedly renewed under different conditions.

At several places in Bulgaria the upper Jurassic, which is unknown at the base of the Crimean steppe, has been observed by Peters and Athanasiu at the base of the limestone plateau which joins on to the mountains of Matchin on the south [3]. Above the upper Jurassic there is a remarkable correspondence between the stratified series of the Crimean steppe and of the Bulgarian platform.

The Requiena limestone (lower Cretaceous) has been mentioned above as cropping out on the south side of the steppe; Toula recognized it near Tchernavoda, and yet further away, extending over a very wide area.

Near Inkermann and Sebastopol, Senonian of the northern type overlies lower Cretaceous of the southern type; it also extends over the Bulgarian platform [4].

The Nummulitic limestone of Varna has been described by Favre as

[1] K. K. von Vogdt, Travaux Soc. Nat. Saint-Pétersb., 1901, XXXII, Protocol, pp. 302–304 (sitting of Nov. 3, 1901). Crystalline rocks mentioned as coming from the Crimea appear to be inclusions in the Neocomian. I am indebted to Herr von Vogdt for valuable letters and sketches.

[2] Borissjak, Bull. Com. géol. Russie, 1904, XXIII, p. 20.

[3] Michel was probably the first to recognize Neocomian in this region (Bull. Soc. géol. France, 1855–1856, XIII, pp. 539–542), and his view has been adopted by Toula; Peters thought he identified upper Jurassic. V. Paquier (Bull. Soc. géol. de Fr., 1901, 4e sér., I, pp. 473 and 541), and Douvillé (tom. cit. p. 474), have gone into this question. Both formations are present. Athanasiu has recognized Rauracian, Sequanian, and Kimeridge beneath the limestone with Monopleura (op. cit., 1896, 3e sér., XXIV, pp. 595–601), also upper Jurassic near Costanza (Guide du Congr. de Pétrole, 1907, V, p. 248). See in particular Simionescu, Stud. geol. si pal. din Dobrogea I, Acad. Bucur., 1907, No. XXI, 97 pp. (in the Roumanian language).

[4] E. Favre, Étude stratigraphique de la partie sud-ouest de la Crimée, 4°, Genève, 1877, p. 30; Hébert, La craie de la Crimée comparée à celle de Meudon et à celle de l'Aquitaine, Bull. Soc. géol. Russie, 1876, 3e sér., V, pp. 99–102; F. Toula, Geologische Untersuchungen im Ost-Balkan, Denkschr. k. Akad. Wiss. Wien, 1890, LVII, p. 381, section of the table mountain at Provadia.

the direct continuation of the Nummulitic limestone of the south-western part of the Crimea [1].

Toula has shown the identity of the Miocene series of Varna with that of Sebastopol (Helix-beds, Pecten-oolite, Spaniodon beds, Sarmatian) (I, p. 489) [2].

Up the Danube, as at Silistria and Rustchuk, Toula still met with the Requiena limestone. At Sistov, Zlatarski and Toula collected fossils of the Aptian stage. At Nikopoli, Senonian occurs on the river with *Belemnitella mucronata* and *Ostrea vesicularis*.

The lower divisions of the Tertiary are not visible, and at Plevna the second Mediterranean stage rests on Senonian and Turonian [3].

Following the Danube towards the interior, we meet with beds of increasingly recent age. The enclosed low-lying land to the west, from about Crajova onwards, is termed by Mrazec the *Getan depression*.

The Balkans and Carpathians. The Bulgarian platform, traversed in its western part by only very gentle folds with an east and west strike, represents the foreland of the Balkans, bounded on the west by the great region of torsion which proceeds from the Balkans to the Carpathians.

This vast structure, marvellously clear as regards its principal features (fig. 48, I, p. 482), has recently been made the subject of three comprehensive memoirs which mutually supplement each other. The first is by Cvijič, and refers chiefly to the Balkans and the region south of the Danube. The second is the work of Schafarzik; it describes in detail the middle part of the region of torsion. Finally there is the somewhat earlier treatise by Inkey which links on with the excellent work of the Roumanian geologists [4].

[1] E. Favre, op. cit., p. 34.

[2] Toula in several places, in particular Geologische Untersuchungen im Ost-Balkan, Denkschr. K. Akad. Wiss. Wien, 1890, LVII, p. 369, and op. cit., 1896, LXIII, p. 280.

[3] G. N. Zlatarski, Beiträge zur Geologie des Nord-Balkan-Vorlandes zwischen den Flüssen Isker und Jantra, Sitzb. k. Akad. Wiss. Wien, 1886, XCIII, I. Abth., pp. 249–341, in particular pp. 292 and 307; F. Toula, Denkschr. k. Akad. Wiss. Wien, 1889, LV, pp. 1–108, map, in particular pp. 2 and 91, and Jahrb. k. k. geol. Reichsanst., 1904, LIV, pp. 1–46; Zlatarski, Die Oberkreide-Serie im Central- und West-Balkan, Jahrb. Univ. Sophia, 1904, 1905, 21 pp., and Das Senon in Ost-Bulgarien, im Norden des Balkan, und seine Theilung im Emscher und Aturien, op. cit. (1905, 1906), 1907, 21 pp. In East Bulgaria, Central European Senonian (*Belemnitella mucronata*) almost exclusively north of the Balkans; and, in the Balkans, Mediterranean Senonian (*Orbitoides, Hippurites*) with a gradual transition to the former. (In the Bulgarian language.)

[4] J. Cvijič, Die tektonischen Vorgänge in der Rhodope-Masse, Sitzb. k. Akad. Wiss. Wien, 1901, CX, pp. 409–432, map; Die Tektonik der Balkanhalbinsel, C. R. Congr. géol., 1903, Wien, 1904, pp. 347–370, map; F. Schafarzik, Kurze Skizze der geologischen Verhältnisse und Geschichte des Gebirges am Eisernen Tore, Földt. Közl., 1903, XXXIII, 44 pp., maps; B. von Inkey, Die Transsylvanischen Alpen vom Rothenthurmpasse bis zum Eisernen Thor, Math. u. naturw. Ber. aus Ungarn, 1891, IX, pp. 20–54. For all subsequent publications we may refer to F. Toula, Der gegenwärtige Stand der geologischen Erforschung der Balkanhalbinsel und des Orientes, C. R. IX. Congr. Intern., Wien, 1904, pp. 175–330.

The older range in the middle of the Balkan peninsula approaches from the south through Servia; at Nish it meets the west border of the region of torsion which is overfolded towards the west; then the boundary is formed approximately by the Morava; finally it crosses the Danube and disappears beneath the Hungarian plain.

In the south this ancient range is distinguished from all the more recent deposits by an unconformable mantle which begins with the Priabona stage. The Strandcha range, near the Black Sea[1], is also partly covered, according to Schaffer's accounts, by patches of this mantle. It is separated from the Balkans by the wedge-shaped eruptive mass of Burgas.

In the *eastern Balkans* the folding, as already shown by Toula's surveys, is recent and open. No beds older than the Jurassic occur in the anticlines, and even these but seldom. Broad undisturbed plains intervene between the folds (aptygmatic valleys, Cvijič); and as late as the Levantine period the folding was still in progress. *These are indications of an adjacent free extremity.* At the same time the northern border is sharply defined against the Bulgarian platform and in places it is overfolded towards the north.

Further to the west the folding becomes closer, and Mesozoic anticlines are more numerous. Elongated cores, evidently of pre-Permian age, are included within the Mesozoic folds. This may be seen from Toula's section on the Kom and his observations in the gorge of the Isker. The data furnished by Zlatarski[2] and Bontscheff[3] are also of importance.

Bontscheff's observations show that in the Balkans, north-east of Sophia, slates, including upper Silurian graptolite beds, and steeply overfolded to the north, are covered unconformably by Culm with characteristic plant remains, and the Culm is succeeded, also unconformably, by Verrucano and the Mesozoic series. Both the unconformities, which are characteristic of the Altaides, thus occur in precisely the same manner as they do in Asia, in the south Thian-shan, for example (p. 2); and we might therefore ask whether the older Altaides have already attained their separation from the Alpine chains at this place, or whether both are still united in the Asiatic direction. The European folding to the north-east is opposed to the latter supposition.

The north-westerly strike now becomes increasingly manifest; at Belogradchik Sarmatian beds, vertically upturned, occur on the concave border.

[1] F. Schaffer, Die geologischen Ergebnisse einer Reise in Thrakien im Herbste 1902, Sitzb. k. Akad. Wiss. Wien, 1904, CXIII, pp. 104–118, map.

[2] Zlatarski, Contributions to the geology of the gorge of the Isker, from Sophia to Roman and the surrounding district, Trud. Bulg. Naturf. Ges., 1904, II, 93 pp., map. (In the Bulgarian language.)

[3] St. Bontscheff, Geology of the West Balkans: I. The Silurian Formation in the defile of the Isker and its neighbourhood, Trud. Bulg. Naturf. Ges., 1906, III, pp. 34–65, map. (In the Bulgarian language.)

This is occasionally overthrust towards the east, as the west border is towards the west.

At the same time an independent range of Mesozoic folds runs to the north-north-west from the region between Küstendjil and the Vitosh. This is separated at first from the main range of the Balkan folds by the younger eruptive mass of the Visker, as well as by the Vitosh, but afterwards joins it at an acute angle between Pirot and Nish. After this encounter the main range continues on its course with many subordinate deflexions and reaches the Danube with a north and south strike.

Meanwhile, north-east of the volcanic mass of Zajcar, on the Timok, a series of fresh coulisses make their advance; these represent the beginning of the Carpathians of Roumania.

We now take Schafarzik as our guide, though there is but little here of importance.

The western coulisses, which according to our nomenclature might still, perhaps, be included in the Balkans, are wedged in, north of the Danube, between the ancient masses in the west (Lokva, Bogsán) and the eastern ranges which accompany them from Timok, but they do not reach the river Temes. Of the eastern ranges, the first is the most important; it is the range of the Almás (I, p. 484) and the Krassó-Szörenye mountains; it consists of crystalline schist, and forms a broad arc which extends from Timok to the north side of the Retyezát range, and perhaps even into the north part of the transverse valley of the river Alt [1]. This arc embraces, first several ancient fragments, such as the Retyezát range, then the gabbro boss of the Júcz on the Danube, and further away all the remaining arcs from the Timok and Mehadia out into the plain.

Inkey, in 1891, pointed out that some of the western coulisses occur in the valley of the Alt, but he also perceived that within the mountains (in the upper Latoritza valley, right tributary of the Lotru) a bend occurs in the strike, accompanied by an overthrust of older beds on to younger [2]. Subsequently Mrazec showed that no small part of the rocks assigned to the crystalline schists are of Carboniferous or Permo-Carboniferous age; he observed pinched-in beds, and conjectured the presence of overthrust flakes [3]. Next Murgoci described the great mountains of Roumania in the region of the Paring [4]. In 1903 Mrazec brought before the Geological

[1] F. Schafarzik, Die geologischen Verhältnisse der Umgebung von Borlova und Pojána-Mörul, Jahresb. k. ung. geol. R.-Anst., 1898, pp. 120–156, map; and Ueber die geologischen Verhältnisse der südwestlichen Umgebung von Klopotiva und Malomviz, op. cit., 1901, pp. 120–155, map, et passim.

[2] B. v. Inkey, Die Transsylvanischen Alpen vom Rothenthurmpasse bis zum Eisernen Thor, Math. u. naturw. Ber. aus Ungarn, p. 33.

[3] L. Mrazec, Über die Anthracitbildungen des Süd-Abhanges der Süd-Karpathen, Anzeig. k. Akad. Wiss. Wien, Dec. 19, 1895, pp. 278-281.

[4] G. Munteanu-Murgoci, Dare de seamā de Cerc. geol., 1898; V. Grupul sup. al

Congress at Vienna the general conclusions to which he had been led[1]; and finally Murgoci arrived at a synthesis which embraces the western half of the Carpathians of Roumania[2].

The area under consideration includes the mountains which extend from the Danube to within about 30 kilometers of the transverse valley of the Alt (fig. 48, I, p. 482), and from the valley of the Cerna and the Zsil to the southern foot of the range. It will facilitate our attempt to explain Murgoci's synthesis if we make use of symbols.

In the region just defined an ancient pre-Permian schist, II, occurs, and in autochthonous superposition a sedimentary series, *B* (chiefly Jurassic and lower Cretaceous limestone). There is also another series of ancient schists, I, and in autochthonous superposition a second sedimentary series *A* (Verrucano, traces of Lias and Oolites; with the Barrêmian stage as the last member).

Series *A* is penetrated by frequent intrusions of serpentine and other basic rocks; we will indicate this fact by the sign σ.

Altogether, therefore, there are two tectonic units or sheets, namely I + $A\sigma$ and II + *B*.

An extensive area north-west, north, and north-east of this region is covered by II. On the north side, starting from the upper Cerna, and then proceeding north of the Paring range and up to the east side, i. e. to within about 30 kilometers of the Alt, II rests upon $A\sigma$. This is also the case on the east side up to the margin of the plain. In this way an elongated oval space is enclosed. Below $A\sigma$, in the interior of this space, its autochthonous foundation I is exposed. In many places patches of II, owing to the subsequent folding of $A\sigma$, have been preserved in synclines. Thus II (and *B* also) must once have extended over the whole region; the succession from above downwards is therefore $B+$ II, $A\sigma+$ I, and *the whole area must be regarded as a window,* 110 *to* 130 *kilometers in length and more than* 30 *kilometers in breadth.*

In other words, north of the Danube, where the great squeezing-in due to torsion ceases, the coulisse II + *B*, becoming free, has completely blanketed over the coulisse I + *A*, which lies in front of it towards the south, and the latter has been exposed by erosion in a window. How far this overblanketing extends to the north-west is at present uncertain.

Cristianul. in Masiv. Parîngu, Bul. soc. ing. de mines, Bukarest, 1899, III, 28 pp., and, in particular, Les Serpentines d'Urde, Muntin. et Gauri (Massif du Paringu), Ann. Mus. Géol. Bucuresci, 1898, 69 pp., map.

[1] L. Mrazec, Sur les schistes crystallines des Carpathes méridionaux (Versant roumain), Congr. géol. intern., C. R. IX[e] Sess., Vienne, 1903, pp. 631–648, map.

[2] G. M. Murgoci, La grande nappe de charriage des Carpathes méridionaux, C. R. 3 et 31 Juillet et 4 Sept. 1905. Mrazec's map mentioned in the preceding note gives all the necessary information.

In this case we may regard σ as an accessory. The fact that it was injected beneath the thrust-plane is instructive in its bearing on the Alps[1]. The injection has produced contact metamorphosis. A later intrusion of granite, which forms the ridge of Suschita, and is associated with I, reaches a length of about 100 kilometers, with a breadth of only 8–10 kilometers.

The thrust-plane lies between the Barrêmian stage and the Cenomanian; the intrusion extends into the Barrêmian beds. The Cenomanian is preceded by so thoroughgoing an unconformity that we may speak, in accordance with Uhlig's observations in other parts of the Carpathians, of an older pre-Cenomanian structure and a younger structure; the trend-lines, however, have on the whole remained the same.

We may term this region the *window of the Paring*.

After the torsion, the bend to the great Carpathian arc follows on the east. The long gneiss range of the Cozia, which proceeds from the south side of the mountains and strikes obliquely to the east-north-east, marks the transition (I, p. 615). Reinhardt has recently investigated it[2]. To the east ancient schistose mountains follow once again.

An inbreak, already recognized by Toula, marks off Monte Leota, south of the Törzburg pass, as an eastern fragment. The inbreak itself, described by Popovici-Hatzeg and Simionescu, is a fault-trough containing down-thrown Jurassic and Cretaceous beds[3]. Monte Leota is the south-east corner-stone of the Carpathians.

The border of the south-east Carpathians. We will begin our description in the north. The town of Czernowitz stands on Sarmatian beds which are underlain by the second Mediterranean stage. These sediments are horizontally stratified and form a hilly country, which is separated on the south from the folded Flysch of the Carpathians by a somewhat narrow belt of the salt-bearing Schlier[4].

In northern Moldavia the border of the Carpathians is defined more sharply. According to Athanasiu, a Sarmatian platform extends from the east and north-east across the river Sereth to the Moldova. Then towards

[1] An enumeration of the earlier observations made by Szabo, Hussak, Roth. v. Telegd, Tietze, and Schafarzik on the occurrence of similar rocks is given by Mrazec and Murgoci in their description of the Wehrlit from M. Ursu; Bull. Soc. Sci. Bucarest, 1897, no. 3.

[2] M. Reinhardt, Der Cosia-Gneisszug in den Rumänischen Karpathen, Bull. Soc. Sci. Bucarest, 1906, XVI, 103 pp., map.

[3] M. V. Popovici-Hatzeg, Note préliminaire sur les calcaires tithoniens et néocomiens des districts de Muscel, Dimbovitza et Prahova, Bull. Soc. géol. de Fr., 1897, 3e sér., XXV, pp. 549–553; Sur l'âge des Conglomerats de Bucegi, tom. cit., pp. 669–675; and Étude géologique des environs de Campulung et de Sinaia, 8vo, Paris, 1898, 220 pp., map; J. Simionescu, Ueber die Geologie des Quellgebietes des Dimboviciora, Jahrb. k. k. geol. Reichsanst., 1898, XLVIII, pp. 9-51; Ammonites jurassiques de Bucegi, Ann. Sci. Univ. Jassy, 1905, 29 pp., et passim.

[4] K. M. Paul, Grundzüge der Geologie der Bukowina, Jahrb. k.k. geol. Reichsanst., 1876, XXVI, pp. 263–330, map.

the south-west follows the 'pre-Carpathian hilly land' of the salt-bearing Schlier, increasing rapidly in breadth, so that close to the Neamtzu brook (lat. 47° 13′ N.) it is already 20 kilometers across. The Flysch is overfolded to the east over its edge [1].

Here we enter the region which has been investigated by Mrazec and Teisseyre; it embraces the whole of the south-eastern part of the Carpathians [2].

The Sarmatian platform of the foreland is here separated by a fault from the salt-bearing beds. This fracture becomes so important that even south of Bakáu (south of the confluence of the Bystritza with the Sereth) the Flysch crops out along it at two places far outside the border of the Carpathians [3]. The salt-bearing beds lie, broadly speaking, in a syncline with many subsidiary folds, for the most part overturned.

Still further south (south of the river Trotus) the pressure from the side of the Carpathians becomes yet stronger; even the Sarmatian beds on the margin of the platform are steeply upturned. The salt-bearing beds lie closely folded between the Sarmatian border in the east and the flakes of Flysch in the west.

Still further south again, near the bend of the Carpathians, in the region of Rimnik-Sarat, the scene once more changes. Here we look towards the end of the Matchin range (Dobrudja), about 100 kilometers distant. The range of Sarmatian hills which has marked the west border of the platform disappears; a fresh Sarmatian range rises to the north-east of it. For a long distance this follows, in correspondence with the bend, a direction to the south-west. At the same time synclines of Sarmatian rest directly upon the salt-bearing beds; here then the folding is post-Sarmatian.

At the bend of the range the following facts may be observed:—

On the upper course of the Buseu a strip of Flysch becomes gradually detached from the outer margin of the main mass, and proceeds as the *spur of Valeni* in a gentle arc, following the bend of the strike until it finally breaks up into little islands of Flysch, which extend across the river Prahova. In this way a long independent tongue of salt-bearing

[1] S. Athanasiu, Morphologische Skizze der Nord-Moldauischen Karpathen, Bull. Soc. Sci. Bucarest, 1899, 48 pp., map; also Geologische Studien, Jahrb. k. k. geol. Reichsanst., 1899, XLIX, pp. 429–492.

[2] L. Mrazec et W. Teisseyre, Aperçu géologique sur les formations salifères et les gisements de sel en Roumanie, Bibl. du Moniteur des inter. Pétrolif. Roum., 4to, Bucarest, 1902, 55 pp., map; Mrazec, Das Salzvorkommen in Rumänien, Oesterr. Zeitschr. f. Berg-Hüttenw., 1903, LI, 19 pp., map; Arbeiten der mit dem Studium der Petrol-Regionen betrauten Commission (Published by the Royal Roumanian Ministry of Public Works), 4to, Bukarest, 1904, 104 pp., map (the authors are C. Alimanestianu, L. Mrazec, and V. J. Bratianu; here the younger anticlines stand out clearly).

[3] Mrazec and Teisseyre, Ueber oligocäne Klippen am Rande der Karpathen bei Bacau, Jahrb. k. k. geol. Reichsanst., 1901, LI, pp. 235–246.

deposits is delimited, forming the gulf of Slanitza. Its northern boundary is a fault; wherever salt is met with further to the west it belongs to a prolongation of the gulf of Slanitza, as though a new fault-trough had originated.

The continuation of the spur to the south-west and west-south-west is rich in petroleum, consequently many borings have been put down, and it is probable that the spur is better known, thanks to the study of these by Mrazec and Teisseyre, than any other free termination.

The axes of all the folds which occur in the spur descend beneath the surface, first towards the south-west and then towards the west-south-west. During the formation of the Miocene salt deposits, a part of the spur rose above the sea as a peninsula. The island of Cosmina is an anticline of

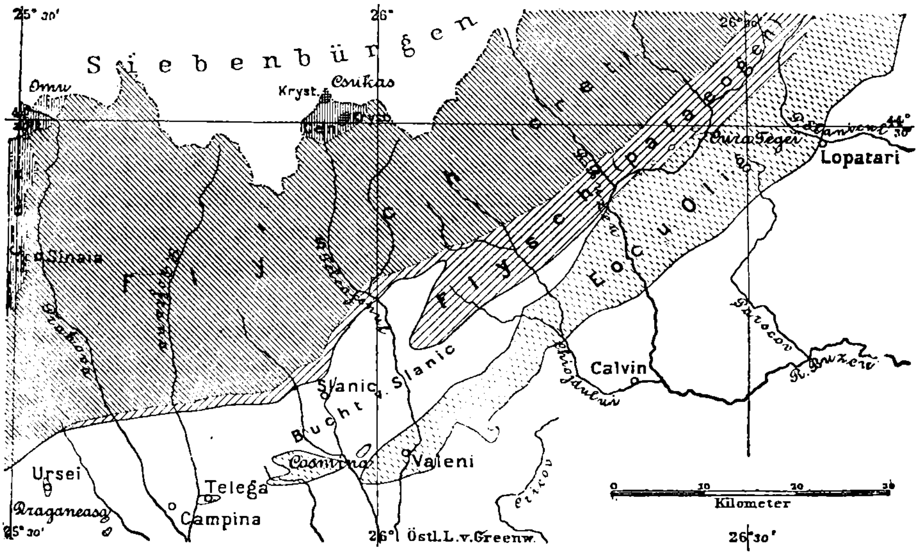


FIG. 2. *The spur of Valeni* after a sketch kindly communicated by Professor Mrazec (Eoc. u. Olig., Eocene and Oligocene; Bucht von Slanic, gulf of Slanitza).

Oligocene overfolded to the south, and overlain by Miocene salt deposits and gently folded Maeotic beds. In the valley of the Doftana post-Pontic overfolding occurs. At Moreni even the most recent Levantine beds form part of an anticline. Mrazec and Teisseyre assert that the folding extends into Quaternary times. The Loess lies undisturbed. As the folds begin to die out, i.e. towards the west-south-west, beds of increasingly recent age are included in them; the investigators term these 'plis mourants'; perhaps 'plis naissants' would be more appropriate[1]. They bear witness to the persistence and constancy of the movement.

[1] The continuation of the spur as an anticline slightly overturned to the south has been established by borings, Mrazec and Teisseyre, Communic. prel. asupra Structur Geol. a Reg. Campina-Bustenari, Acad. Bucur., 1906, XXVIII, no. 19, 20 pp., map; and

As we proceed from Bukovina towards this point the folding becomes more and more recent.

A boring sunk near the bend of the Danube in the district of Baragan (west-north-west of Tchernavoda, south of the lower Jalomitza) reached the base of the Pontic series at a depth of 178 meters, and of the Sarmatian at 318 meters; then, after four meters of variegated clay, it entered what appears to have been upper Chalk with flints and continued in this down to 783 meters. No mention is made of Eocene beds or of the Mediterranean stages.

A boring in Bucharest revealed a great thickness of stratified sand and clay containing Paludina and Unio; the first certain indication of the Sarmatian was encountered at a depth of 800 meters, and the boring terminated at a depth of 1,008 meters in beds of this stage[1].

These observations have led to renewed consideration of a view previously expressed by Cobalescu to the effect that the curvilinear cliff on the right bank of the Danube marks a fracture. Draghicénu was of opinion that this hypothetical line of fracture, supposed to extend from Galatz through Tchernavoda to Sistov, possibly even to Kalafat, 'belongs to the same system as the fracture of Slanitza'[2]. Murgoci, however, observes that near Rustchuk the Cretaceous limestone occurs on the left bank also; he denies the existence of the fracture, and ascribes the cliff to the action of the river.

In any case there is a considerable depression between the Danube and the Carpathians, and below Hirschova the whole range of Matchin certainly descends in the direction of this depression.

Recent investigations in the mountains of Matchin have been directed to stratigraphical problems[3]. A new map has been published by Pascu[4]. With regard to their structure we can only say that they are a fragment with a strike passing from west to west-north-west near the Black Sea, and becoming more and more north-west towards the interior. In the south-west, greenstone (according to Peters, diabase-pelite) is widely distributed;

Mrazec, Contribution à la géologie de Gura Ocnitzei-Moreni, Monit. Pétrol. Roum., 20 Sept., 1905, pp. 785-789; also Arbeiten der mit dem Studium der Petrol-Regionen betrauten Commission, p. 90, and in the Guide Congr. Pétrol., 1907. Mrazec observes that in the case of overthrust anticlines the salt beds frequently break through the saddles of the upper beds and are visible on the surface like 'Klippen' ('transpierced anticlines').

[1] Communication by Professor Mrazec in the Acad. Bucur., Feb. 16, 1907; Murgoci, Guide Congr. Pétrol., 1907, V, p. 227.

[2] M. M. Draghicénu, Studii as Idrologiei subterrane din Punctul de vedere al Alimentarei Oraselor, etc., 4to, Bukarest, 1895, 181 pp.; map, in particular pp. 52 and 54.

[3] K. A. Redlich, Geologische Studien in Rumänien, II, Verh. k.k. geol. Reichsanst., 1896, pp. 495–502; V. Anastasiu, Le Trias de la Dobrogea, Bull. Soc. Géol. de Fr., 1897, 3e sér., XXV, pp. 890–894. A general survey is given by F. Toula, Eine geologische Reise in der Dobrudscha, Vortr. Vereins naturw. Kenntn. Wien, 1893, XXXIII, 62 pp.

[4] R. Pascu, Stud. geol. si min. in Jud. Tulcea, Servic Minelor, 8vo, Bucar., 1904, 50 pp.

in the north-east an older series (phyllites and Verrucano at Tultcha) is also present, and, in the north-west, gneiss, which is regarded as forming the base. Between these rocks Mesozoic sediments, in bands of various length, as well as sheets of porphyry and melaphyre, extend right out into the delta. The Trias is differentiated into numerous zones. The upper Cretaceous occurs in transgression.

There can be no doubt that these mountains are a fragment of a greater complex. Their lie and their pre-Cretaceous age point to a connexion with the Crimea. Following the suggestion of Mrazec, we will call this complex, which embraces the Crimean mountains, Serpent island, and the mountains of Matchin the *Cimmerian mountains.*

They are united with the Bulgarian platform and the Crimean steppe.

In accordance with the views of previous writers we have regarded (I, p. 475) the steep submarine slope between cape Emineh and cape Staritch, by which the bottom of the Black Sea descends from −70 or 80 meters to −1,000 or 1,800 meters, as suggesting an original connexion between the Crimea and the Balkans. It does not correspond, however, with the strike; Draghicenu regards it as the border of a subsidence, and this view must be regarded as correct.

In this way an area is defined in which all the folding is older than the Neocomian. It is a fragment of Mesozoic foreland inserted between the horst of Azov and the younger folds of the Balkans and Carpathians. No other example of such an inserted fragment has yet been described. The mouths of the Danube lie within it.

There is only one structure which can be regarded as the possible continuation of the Cimmerian mountains: this is the Mesozoic ranges within the Carpathians, those, for instance, on the eastern side of the Moldavian gneiss mass and the Persány mountains in Transylvania.

Uhlig has shown that the Mesozoic zone of south Bukovina and the Moldavian mass does not possess the unilateral structure inclined to the north-east hitherto attributed to it, but that an opposed limb dipping to the south-west exists on the north-east. Consequently the zone becomes a basin; it loses its tectonic independence, and proves to be part of a larger structure. The Trias and Jurassic systems are represented here as in the Cimmerian mountains. As in the Crimea, unconformities occur within the series, and the same transgression of the upper Cretaceous is met with. The Caprotina limestone rests sometimes immediately upon crystalline schists, sometimes upon Trias[1].

The unconformity between the Trias and the Neocomian (Caprotina

[1] V. Uhlig, Vorläufiger Bericht über eine geologische Reise in das Gebiet der goldenen Bistritz, Sitzb. k. Akad. Wiss. Wien, 1889, XCVIII, pp. 728–743; and Ueber die Beziehungen der südlichen Klippenzone zu den Ost-Karpathen, op. cit., 1897, CVI, pp. 188–206, maps.

limestone), to be seen in the plateau of the Rareu in the Carpathians of Bukovina, tells the same tale as the upper Carboniferous transgression on the Variscan cores of the Alps; both mark the reappearance of the characters of the foreland.

We now come to the occurrence of Cimmerian rocks in the belt of the east Carpathians. They have been discussed by many investigators; last of all by Zuber[1].

Uhlig distinguished two zones of conglomerates and boulders in the Flysch—an inner of Carpathian origin, and an outer, the boulders of which are derived, according to a unanimous verdict, chiefly from extra-Carpathian sources.

White limestone, for the most part no doubt Jurassic, occurs along the whole course of the Carpathian border. This is associated in the west with Sudetic rocks, in the east with a curious green rock, which sometimes resembles a lustrous phyllite, and at others is of a harder and more resistant nature. Zuber regards it as a dynamically altered form of the diabase tuff which forms a broad zone in the south-west of the Matchin mountains; he has, indeed, published a series of sections, showing how these mountains descend beneath the border of the Carpathians[2].

Near Krásna, in Bukovina, Alth and Paul found on the outer margin of the Carpathians a completely isolated patch of white limestone four kilometers in length, and scarcely 200 meters in breadth; it is sometimes breccia-like, and rests on schist. The schist may possibly be part of an adjacent green agglomerate which is composed of angular fragments of a schist precisely similar to it in character[3].

Uhlig describes the rock in north Moldavia as a dark green chloritic schist. 'We discover with surprise', he says, 'that whole mountain zones are wholly composed of blocks of this rock, to the exclusion of all others. This is the case, for example, in the zone—about 10 kilometers in length, and admirably exposed—which lies between the town and the monastery of Niamtz . . .[4]'

Various theories have been advanced in explanation of this problem. Generally a 'coastal bar' has been postulated, but it has at length become

[1] R. Zuber, Neue Karpathenstudien, Jahrb. k. k. geol. Reichsanst., 1902, LII, pp. 245–258; here the earlier data are enumerated.

[2] Neminar described the rock in 1877 as green schist with many flakes of hornblende, becoming dense and massive as the hornblende increases; Paul and Tietze regarded it even at that time as quite alien, perhaps in situ at Krásna in Bukovina, Jahrb. k. k. geol. Reichsanst., 1877, XXVII, p. 123; Mrazec confirms the correspondence of the rocks of the Dobrudja.

[3] Paul, K. M., Grundzüge der Geologie der Bukowina, Jahrb. k. k. geol. Reichsanst., 1876, XXVI, p. 318.

[4] V. Uhlig, Vorläufiger Bericht über eine geologische Reise in das Gebiet der goldenen Bistritz, Sitzb. k. Akad. Wiss. Wien, 1889, XCVIII, p. 741.

abundantly clear that we have here the veritable remains of a range which belongs neither to the Carpathians nor to the Podolian horst. Zuber has expounded this view, and he terms the mountains of the Dobrudja 'a third fragment lying in front of the Carpathians.'

Indeed, the thrusting forth of intra-telluric erratics from the buried Cimmerian mountains would alone furnish an adequate explanation.

Summary. Of all the branches which make their appearance north of the horst of Azov none are continuous except the line of the Alai. This retains the rectilinear course of the Asiatic chains, and also the Asiatic movement to the south, so far as this can be inferred from the steeper dip of the southern limb in the anticlines of the coal-measures on the Donetz.

To the south of the horst of Azov, also, there is only one line, that of the Hindu-kush, which can be followed further with any degree of clearness. The Caucasus approaches with rectilinear Asiatic strike, and Asiatic folding to the south, and plunges beneath the Black Sea. Younger Tertiary folds, thrust against it from the north, divide into two groups in front of a fragment of the Cimmerian mountains.

The Cimmerian range lies up against the horst of Azov, and narrows the passage through which the younger folds advance.

The Balkans begin in the east with feeble recent folding as though approaching a free end; further west, especially on the Isker, they exhibit in enclosed ancient cores the typical unconformities of the Altaides; they surround the horst of the Danube in the region of torsion, and so pass into the Carpathians of Roumania.

After the squeezing-in produced by the torsion, the coulisses are overthrust towards the south, and the window of the Paring is formed. The arc of the Carpathians overwhelms in succession the Cimmerian mountains, the Podolian horst, the faulted-down continuations of the Variscan fore-chains (Sandomir mountains), and the Sudetes, and then at last turns to the Alps.

The story of the entrance of the Altaides into Europe is full of variety. The pre-Permian structure is certainly represented in the western Balkans. The repeated unconformities in the Mesozoic Cimmerian range may be regarded as later phases of this story. At the present day we have the strange spectacle of the *pre-Permian and Mesozoic chains* (*Cimmerian range*) *broken up and buried out of sight*, *while from both sides the free ends of the younger chains stream towards the Pontic region*; this is the case in the Carpathians, where, as we approach the spur of Valeni from the Bukovina, the folding becomes increasingly recent; it is also the case in the east Balkans, and again on the Asiatic side, in the younger bifurcate folds of the north-west Caucasus.

It seems almost as though the ancient connexion had been interrupted and were to be restored on new lines.

Variscan fractures. The Variscan arc—the first part of the European Altaides—was not a homogeneous structure even before it broke up into horsts. It included Caledonian intercalations, and it was profoundly affected by a larger pre-Cambrian body situated on its southern margin—*the Bohemian basement.* We have previously described this as an alien and unexplained fragment (II, p. 122). Since then Franz E. Suess has determined its boundaries on the Variscan side, and has named the most ancient western part *the Moldanubian mass,* and the eastern part, rich in graphite, and also of pre-Cambrian age, *the Moravian zone* [1].

The Moldanubian mass includes eastern Bavaria and western and southern Bohemia, western Moravia, the north of Upper Austria, and the north-west of Lower Austria. It crosses the Danube as a broad highland of gneiss and descends to a great depth in front of the Alps. Near Wels, in upper Austria, 17 kilometers south of the line where its southern edge becomes visible, and 26 kilometers from the foot of the Alps, middle Tertiary sediments were bored through for 1,037 meters; immediately beneath them, 722 meters below the sea level, the cordierite gneiss of Bohemia was met with, but there were no signs of the stratified series of the Alps [2].

A sudden change of strike, which occurs south of the Marienbad Spa and may be traced across the mountains towards Bavaria, marks the western boundary between this highland and the Variscan Fichtelgebirge; it has already been observed by Hochstetter. In the east, towards the Sudetes, Bukowsky has observed an equally sharp boundary in the upper March valley; but towards the middle of Bohemia the Cretaceous mantle renders the situation less clear [3].

Caledonian intercalations are known at several places. Liebe has described them in Thuringia [4]. The masses of Rocroi, Serpent, and the Hohe Venn (Massif de Stavelot) in Belgium afford an illustration on the largest scale known to us. Gosselet has shown that the horizon of the Llandovery shares their divergent strike, while the Devonian is unconformably superposed [5].

[1] Franz E. Suess, Bau und Bild Oesterreichs, pp. 39, 275, 314.

[2] R. J. Schubert, Ergebnisse der mikroskopischen Untersuchung der bei der ärar. Tiefbohrung zu Wels durchteuften Schichten, Jahrb. k. k. geol. Reichsanst., 1903, LIII, pp. 385–422.

[3] Bukowsky, Verh. k. k. geol. Reichsanst., 1890, p. 198 et passim. The lower Palaeozoic series of western Bohemia disappears not far from Prague beneath the sheet of Cretaceous. Jahn established the fact that it describes a subterranean arc, reappears on the west border of the Eisengebirge, and that near Pardubitz it has been carried up in fragments by the basalt; J. J. Jahn, Jahrb. k. k. geol. Reichsanst., 1898, XLVIII, pp. 207–230; earlier observations by Krejči suggest the same thing.

[4] K. T. Liebe, Uebersicht über den Schichtenaufbau Ost-Thüringens, Abh. geol. Specialkarte von Preussen, 1884, V, pp. 401–530, map, in particular pp. 434 and 441; also Zimmermann, Jahrb. k. preuss. geol. Landesanst., 1895, XV, p. lviii. Liebe's so-called Frankenwald system seems to be explained by the direction of the Franconian fractures.

[5] J. Gosselet, Remarques sur la discordance du Dévonien sur le Cambrien dans le massif de Stavelot, Ann. Soc. géol. Nord, 1888, XV, pp. 158–161; also op. cit., 1886, XIII,

This heterogeneous Variscan system is traversed by fractures, by far the greater number of which have been produced within the system itself, but besides these there are two groups of long fractures, which are of extraneous and independent origin. One of these groups strikes to the north or north-north-east, the other to the north-west or west-north-west.

Of the indigenous fractures we will cite only a few instances.

True strike faults occur but seldom, and appear to be restricted to the west.

The most important example of such faults is furnished by the *Saar-Nahe troughs*. Mining operations and several excellent investigations have rendered it familiar. Its history, according to Lepple, is as follows:—After the uplift of the folded Variscan range, a longitudinal trough was formed in which the upper Carboniferous and the Rothliegende coal-measures accumulated along with sediments of local origin and intrusive rocks. Then, during the deposition of the upper Rothliegende, a longitudinal anticline, the Pfälzer saddle, was formed. Next, but still before the deposition of the Bunter sandstone, the southern part of the saddle sank along a fault to a depth of about 2,000 meters. After the Bunter sandstone, and perhaps not before the early part of the Tertiary aera, further subsidences occurred to the extent of 50 or 100 meters. Thus faults with a north-east strike are known to have been formed before the upper Carboniferous and after the upper Rothliegende, as well as before and after the Bunter sandstone [1].

The trough strikes north-east to the Rhine and south-west towards France. Borings made in the department of the Meurthe-and-Moselle reached the upper Carboniferous at a depth of between 700 and 800 meters, as Nicklès, guided by the Variscan strike, had predicted [2].

p. 288, and in particular L'Ardenne, Mémoire pour servir à l'explication de la Carte géologique détaillée de la France, 4to, 1888, p. 705 et seq.; details also in A. Dumont, Mémoire sur les terrains Ardennais et Rhénan, I^{re} partie, Mém. Acad. Roy. Belg., 1846, XX, pp. 45–92; for the Condroz, G. Simoens, De l'indépendance en Belgique des chaînes calédoniennes et hercyniennes, Bull. Soc. belge Géol. Brux., 1906, Procès-Verbaux, pp. 100–102. P. Foumarier supposes that a complete overthrusting of the northern margin of the Hohe Venn has taken place later; La structure du Massif de Theux, Ann. Soc. géol. Belg. Liège, 1906, XXXIII, Mém., pp. 109–138, maps; also Tectonique de l'Ardenne, op. cit., 1907, XXXIV, Mém., pp. 15–123, maps, in particular p. 113. G. Simoens describes indications of the Caledonian disturbance west-north-west of Nivelles outside the Variscan border; Exemple de failles bordières du massif du Brabant, Bull. Soc. belge Géol. Brux., 1907, XXI, Proc.-verb. p. 71. It does not seem to be quite certain that these accidents do not belong to the Saharides, which will be described later.

[1] A. Leppla, Geologische Skizze des Saarbrücker Steinkohlengebirges, aus der Festschrift 2 zum IX. Allg. deutsch. Bergmannstage, 8vo, Berlin, 1904, 57 pp.

[2] R. Nicklès, De l'existence possible de la Houille en Meurthe-et-Moselle, 8vo, Nancy, 1902, 24 pp.; C. Cavallier, Sur la découverte de la Houille en Meurthe-et-Moselle, C. R., March 27, 1905; Nicklès, Sur la découverte de la Houille à Abaucourt (Meurthe-et-Moselle), op. cit. and July 3, 1905; also Bergeron, Laur, and others.

If we follow this direction further it does not lead us to the Central Plateau; yet the long lines of coal-seams, often bordered by faults, sometimes described as canals, sometimes as synclines, which occur in this plateau, strongly resemble those on the Saar, with which they may have characters in common. The studies by Michel Lévy, de Launay, and others on the structure of these features, and by Fayol and Grand'Eury on their contents (II, p. 244), scarcely permit us to doubt that the included beds were deposited in narrowly restricted spaces. Here, also, there are some faults which are older than the upper Carboniferous, others which are only older than the Trias, and yet others of still more recent date [1]. The long line of coal-measures extending from Savigny to Pléaux marks a Variscan fold on the north and south borders of the Central Plateau only, elsewhere it is a fracture or trough, and thus cannot be regarded as a true trend-line of the folding [2] (II, p. 115).

Another example of an indigenous fracture is afforded by the *south scarp of the Erzgebirge.* Laube has shown that it does not follow the strike, but cuts through the series of petrographical zones obliquely [3]. It terminates in the east in front of the Elbe fracture, and may therefore be younger. At the same time a Cretaceous platform descends from the summits of the Erzgebirge towards the Elbe fracture. The lignite basin at the foot of the range is traversed by parallel fractures. Between the basalts of northern Bohemia and the scarp of the Erzgebirge there is only a remote connexion. These basalts begin in Bavaria, are continued to the east across the Riesengebirge to Ostrau, and break out at isolated localities far to the south and also to the north of the Erzgebirge. They are most widely distributed, however, in the subsided region.

An example of another kind is furnished by the *fault of the Danube* between Ratisbon and Passau (I, pp. 193, 197). It lies for the whole of its course, which is slightly concave, in upper Jurassic. It can be described as a fault only in certain parts of its course; in others the beds, like a heavy carpet, sink towards the plain in a flexure. Above the line of the fault lie the well-known eruptive centres of the Ries, Höhgau, and others. The fault is younger than the upper Cretaceous and older than the lower freshwater Molasse. The extent of the subsidence is considerable. At Ochsenhausen, south of Ulm, 30 kilometers from the fault, a boring failed to reach

[1] e. g. Michel-Lévy, Roches éruptives cambriennes du Mâconnais, Bull. Soc. géol. de Fr., 1883, 3e sér., XI, p. 278; fractures of the upper Permian period.

[2] L. de Launay, Le Massif de Saint-Saulge, Bull. serv. Carte géol. France, 1896, VII, pp. 183-205, map; in particular p. 193. Bergeron has raised the question whether this long line is not a boundary line of the Armorican fractures; Bergeron, De l'extension possible des différents bassins houillers en France, Mém. Soc. Ing. Civ., 1896, 5e sér., XIII, p. 13, pl. 169.

[3] G. Laube, Geologie des böhmischen Erzgebirges, II, Arch. naturw. Landesd. Böhmen, 1887, VI, pp. 1-159 passim.

the base of the Molasse at a depth of 738 meters (141 meters beneath the sea). The existence of some connexion between this fault and the formation of the Alps has often been conjectured.

In like manner a number of arcuate faults in the eastern part of the Central Plateau have been described by M. Lévy as so many subsided anticlines running parallel to the Alps. He cites them as evidence that at this place the horst must have been less rigid.

Here it is a question of the influence of the Alps on the horst, while the influence of the horsts on the Alps, which has been conjectured by other observers, only manifests itself in the deflexions of that chain [1].

The manner in which the horsts may be *framed in* is no less various.

It often happens that a fracture remains invisible within the older rocks, and suddenly reveals itself for the first time when it emerges into the sedimentary mantle. Some characteristic rock, such as an intrusive sheet or a bed of chert, may serve to reveal many fractures which would not otherwise be recognized, and mining operations have frequently shown that the formations are broken up in a mosaic of polygonal fragments. The further observation is pushed—and its limit is reached in thin slices under the microscope—the more the broader effects disappear, and local crushing, displacement, and adaptation become all-important. Analysis then becomes a comparatively unfruitful task.

If subsidence attacks a land thus broken up, horsts originate, bounded by faults, showing extreme diversity in length and direction, all of them completely independent of the strike; sometimes they are affected by parallel planes of compression, but they never sink in flexures, such as occur on the Danube.

This independence of the marginal fractures finds an excellent illustration in Denkmann's instructive description of the Kellerwald horst which stands between Cassel and Marburg [2].

In an area about 18 kilometers square, Langdorff's map of the western Harz marks some 44 lines of disturbance, which strike approximately east-south-east; several of them, however, cut the others at an acute angle, but all run directly across the strike of the folds [3]. Here surfaces of compression are probably indicated.

[1] W. Branco, Schwabens hundert fünf und zwanzig Vulcan-Embryonen, 8vo (aus Jahresh. Ver. Naturk. Württ., 1894 and 1895), p. 15 ; M. Lévy, Environs du Mont-Blanc, Bull. serv. Carte géol. France, 1890, I, pp. 24 et seq. ; Bull. Soc. géol. de Fr., 1890, 3e sér., XVIII, p. 691.

[2] A. Denckmann, Der geologische Bau des Kellerwaldes, Jahrb. k. preuss. geol. Landesanst., 1901, neue Folge, Heft 34, 88 pp., maps.

[3] W. Langsdorff, Gang- und Schichten-Studien aus dem West-Oberharz, 8vo, Clausthal, 1885, 47 pp., map ; Geologische Karte des West-Harzes, 1 : 25,000, Clausthal, fol. ; Beiträge zur Kenntnis der Schichtfolge und Tektonik im nordwestlichen Oberharz, 8vo, op. cit., 1898, 29 pp., sections. Prinz gives a good idea of this region in a generalized sketch

On the margin of the horsts slightly longer lines sometimes occur, the origin of which is unknown. These include, for example, the marginal fractures, trending more or less north and south, of the western Morvan and the small adjacent horst of St. Saulx, which have been studied by M. Lévy. They advance through the younger sediments northwards to Auxerre and beyond, and Dollfuss was able to show that they are younger than the Calcaire de Beauce and older than the sands of the Sologne, which lie beneath the second Mediterranean stage, approximately on the horizon of the Austrian Schlier [1].

The variety of the marginal fractures cannot be exhaustively illustrated here; as a rule, anything that is concealed from view is probably part of a network of mosaic-joints which has been *made use of* and rendered visible *by the subsidence, but has not been produced by it.* Here and there an alien line makes its appearance, and may be recognized by its length and specific direction.

Faults striking north and north-north-east (*Rhine faults or African faults*). The Variscan strike to the north-east is maintained in the Vosges from Ronchamp and Belfort to the Saar. Faults with a trifling throw also occur in the broad Trias basin of the Haardt-Wald and strike obliquely from the south edge of this basin into the direction of Berg-Zabern. As they reach the Rhine valley they form the fault-trough of Langenbrücken. This group also includes the Odenwald faults (I, p. 195).

The Rhine trough has been regarded (I, p. 201) as a sunken strip of land let down between two horsts—the Vosges and the Schwarzwald. That which still remains visible is certainly only a remnant, since at Alpersbach (east-south-east of Freiburg, 994 meters) Steinmann has found fragments of Mesozoic sediments in basaltic tuff, from which it would appear that the Schwarzwald has been denuded to the extent of from 600 to 750 meters; in lower Alsatia also, according to Schumacher, borings for petroleum show that the included Tertiary beds must be at least 780 meters thick [2].

On the west the general course of the faults is no longer straight, but slightly curved. Benecke has given an admirable account of the way in

from the English maps of the coal-measures in the district between Preston, Halifax, and Manchester. The north-westerly direction is prevalent here; transverse fractures give rise to a mosaic, Bull. Soc. belge Géol. Brux., 1904, XVIII, pp. 144, 145.

[1] Dollfuss, Bull. Soc. géol. de Fr., 1904, 4e sér., IV, p. 568.

[2] G. Steinmann, Die Nagelfluth von Alpersbach im Schwarzwald, Ber. Naturf. Ges. Freiburg i. Breisgau, 1894, IV, pp. 1–32; Die Neuaufschliessung des Alpersbacher Stollens, Ber. oberrhein. geol. Ver. Marburg, 1902, 35. Versammlung, Benecke, Bücking, Schumacher und van Werveke; Geologischer Führer durch Elsass, 12mo, Berlin, 1900, p. 142. A survey of all the Rhine fractures from Bâle to Darmstadt is given in G. Regelmann's Geologische Uebersichtskarte von Württemberg und Baden, fol., 6. Aufl., 1906; also Die wichtigsten Strukturlinien Südwest-Deutschlands, Zeitschr. deutsch. geol. Ges., 1905, pp. 299–318.

which the long dissevered parts of the mountains are sometimes faulted down to great depths, and thus create a landscape distinguished by an immediate contrast between mountain and valley-plain; and how in other regions they are left suspended, as it were, in steps which now form transitional foothills. Finally, he shows how long faults may be recognized even far within the ancient mountains [1]. Near Dambach and Barr a gradual widening of the trough occurs, and is maintained through Strassburg to Wörth. The normal direction of the boundary faults is not lost, but they have no effect on the relief of the country; to the west of them a recess has been formed in the mountains—the fault region of Zabern. The marginal fractures, according to Benecke, hade steeply to the east, while in the shattered region of Zabern the faults present the most diverse inclinations. At Wörth the border resumes its former character; it becomes as broad as at Worms, and is continued somewhat more to the east in the direction of Mainz.

The stiff curves of the east border recall those of the west, and, in spite of the deviations from the rectilinear, the breadth of the trough, exclusive of the inbreak of Zabern, is fairly persistent, measuring about 32–34 kilometers throughout the whole southern region. From somewhere about Bruchsal onwards the trough bends out of the north-north-east somewhat more to the north, and with this direction it reaches Frankfort [2].

But the Rhine trough does not terminate on the Main.

Its faults are known to extend beneath the western part of the Vogelsberg basalt [3].

Its continuations to the north have been made the subject of special study by A. v. Koenen [4]. Following this observer, we recognize a part of the subsidence in the elongated Tertiary region of Ziegenhain, Fritzlar, and Cassel, which runs to the north-north-east on the other side of the Vogelsberg.

At the same time another narrower trough makes its appearance nearly east of this region, with the same direction to the north or north-north-east. It extends, according to Moesta and von Koenen, from Wichte on the Fulda (north-west of Rotenburg) across the Werra, and reaches the valley of the Leine at Witzenhausen. This valley is itself a trough. The downthrown strip extends far beyond Göttingen to Kreiensen, north of Northeim. At

[1] Benecke, loc. cit., p. 66.

[2] F. Kinkelin, Senkungen im Gebiete des Unter-Main-Thales unterhalb Frankfurt, Ber. senckenb. naturf. Ges., 1885, pp. 235–258 et passim.

[3] C. Chelius, Der Zechstein von Rabertshausen, Zeitschr. f. prakt. Geol., 1904, XII, pp. 399–402.

[4] A. von Koenen, in Jahrb. k. preuss. geol. Landesanst. for 1883, pp. 187–198, for 1884, pp. 44–55, for 1885, pp. 53–83; and in particular Ueber die Dislocationen westlich und südwestlich vom Harz und deren Zusammenhang mit denen des Harzes, op. cit. for 1893, pp. 68–82; also Otto Lang, Die Bildung des Harzgebirges, 8vo, Hamburg, 1896, p. 31, note 5, et passim.

Göttingen itself both borders are flexed upwards, and the trough is divided lengthwise down the middle by a saddle.

East of Kreiensen, as von Koenen has shown, other faults exist, running north and south as far as Hildesheim.

From Rustenberg, near the bend of the Leine, a new trough makes its appearance; it has been traced by E. Kaiser and Siegert for 60 kilometers to the north-north-east as far as Seesen, on the north-west border of the Harz; it cuts off the Harz towards the north-west. Parts of the post-Variscan mantle are let down into it, but some of the north-westerly faults of the Harz may be recognized within it, and reveal themselves in the irregularities of its border[1].

In this way the group of the Rhine faults extends from the Jura mountains for about 500 kilometers to the north-north-east or north. In the north they exhibit a tendency to veer towards the east. The trough which they enclose in the south is, as we have seen, 32 to 34 kilometers in breadth. At Mannheim the breadth is almost unchanged. The trough, in the meridional part of the Leine, measures only 7 to 8 kilometers across; that which runs to the north-west border of the Harz still less, only one to 4 or 5 kilometers.

The Rhine faults are an independent group, distinguished from the other faults of the Variscan range by their direction and the trough which they enclose. Two attempts have been made to explain them.

The first of these, following an older conception of Élie de Beaumont's, assumed a previously existent uplift, and saw in the trough a broken-in anticline. The divergent strike of the Variscan folds and the great length of the fault-lines are opposed to this view[2]. In the second explanation it was assumed that the fault-planes diverge in a downward direction—that is, that in the west they are inclined towards the west, and in the east towards the east[3]. Apart from the fact that, according to Benecke, the main fractures in the west dip steeply to the east, this theory

[1] E. Kaiser and L. Siegert, Beiträge zur Stratigraphie des Perms und zur Tektonik am West-Harzrande, Jahrb. k. Preuss. geol. Landesanst. (1905), 1906, XXVI, pp. 353-369.

[2] A. de Lapparent, Conférence sur le sens des mouvements de l'écorce terrestre, Bull. Soc. géol. de Fr., 1887, 3e sér., XV, pp. 215–238; Note sur le mode de formation des Vosges, op. cit., 1888, 3e sér., XVI, pp. 181-184; also Note sur l'histoire géologique des Vosges, op. cit., 1897, 3e sér., XXV, pp. 727–730.

[3] A. Andreae, Eine theoretische Reflexion über die Richtung der Rheinthalspalte, Verh. nat.-med. Ver. Heidelberg, 1887, neue Folge, IV, pp. 16-24; Beitrag zur Kenntniss des Rheinthalspaltensystems, tom. cit., 47–55; W. Salomon, Ueber eine eigenthümliche Grabenversenkung bei Eberbach im Odenwald, Mitth. badisch. geol. Landesanst., 1901, IV, pp. 211-252; Ueber die Stellung der Randspalten des Eberbacher und des Rheinthalgrabens, Zeitschr. deutsch. geol. Ges., 1903, LV, pp. 405–418. This work is based on the law of Schmidt-Zimmermann; practical miners have often pointed out that it is not trustworthy, e.g. H. Hoefer, Die Ausrichtung der Verwerfungen, Oesterr. Zeitschr. f. Berg- u. Hüttenw., 1881, XIX, op cit., 1886, XXXIV.

fails to recognize sufficiently the momentum with which such subsidences take place, and the fact that the movement is independent of the lie of the plane along which it occurs. This independence is so great that subsidences, as shown by the reversed dragging, may take place alternately on each side of one and the same plane, in whatever direction it may be inclined. Again, the final throw of the fault does not give the full extent of the subsidence, but only the difference in the amount of the movements on each side, so far as they have not counterbalanced each other. Such two-sided movements are known also to have occurred on the border of the Rhine trough [1].

When Oskar Fraas first looked upon the Red Sea it reminded him of the Rhine trough (I, p. 374). Reyer and von Koenen have attributed the formation of this trough to tension. Its resemblance to the fractures of East Africa is, indeed, so great that this must be accepted as the most natural explanation. Possibly it also shows to how great an extent, even as early as the middle of the Tertiary aera, this part of the Altaides had already become rigid.

The position of the Kaiserstuhl at the bottom of the trough is homologous with that of the little volcanos which occur south of lake Rudolf (volcano of Teleki, Luttur, and others) [2].

Fractures striking west-north-west or north-west (*Hercynian or Asiatic fractures; Karpinsky's lines*). Central Germany is traversed by a number of long straight fractures, which do not run quite parallel, but diverge a little from one another, striking in the south more to the west-north-west and in the north to the north-west. The south-west limb is frequently downthrown and the north-east limb thrust over the subsidence. Movements in the opposite direction, however, are not wholly wanting. Well-marked indications of the north-west direction may be traced as far as Scania. One set of these fractures lies north of the Bohemian basement; another proceeds from its west side.

These fractures produce elongated horsts, such as the Thüringer Wald and the Teutoburger Wald. They determine L. von Buch's 'Hercynian system,' which embraces all the mountains striking to the north-west; many eminent German geologists still describe these long lines as Hercynian.

Von Koenen conjectured as early as 1886 that these Hercynian

[1] Andreae, p. 52, fig. 3, subsidence of the border; Huene, Verh. naturf. Ges. Basel, 1900, XII, p. 343: 'It is a most curious circumstance that where we find this two-period displacement the motion of the fault is often reversed—the lift of the first period is the throw of the second. It is not always so ...'; Dutton, High Plateaus of Utah, p. 43.

[2] F. Graeff, Zur Geologie des Kaiserstuhlgebirges, Mitth. badisch. geol. Landesanst., 1891, II, no. 14, pp. 403–496, map; K. Gruss, Beitrag zur Kenntniss der Gesteine des Kaiserstuhlgebirges, op. cit., 1900, No. IV, 2, pp. 83–144; Steinmann and Graeff, Geologischer Führer durch Umgebung von Freiburg, 8vo, Freiburg, 1890, 141 pp., map. The Kaiserstuhl is still the centre of frequent earthquake shocks.

lines must bear some relation to Karpinsky's lines which proceed from Asia into Europe with the same direction[1] (I, p. 463: Pl. V, m, m). To this question we will now turn our attention.

We will first consider the *southern group*. Most of these faults have been previously described, and a brief enumeration will now suffice.

(*a*) The fault which proceeds from the south-east through *Deggendorf to Ratisbon* (I, pp. 138, 210). Jurassic and middle Cretaceous are overthrust from the north-east and bent in, near Voglarn, under the gneiss.

(*b*) The next line is marked within the ancient rocks by the *Great Pfahl*, and near Amberg enters the Mesozoic region (I, p. 208). Its length, measured from upper Austria to this point, is about 200 kilometers. In the interval extending from Ratisbon towards the north, and connecting this second line with the first, subsidence also occurs, and near Donaustauf, according to Brunnhuber, the Jurassic dips beneath the ancient mountains[2].

(*c*) The third line (I, pp. 193, 206; II, p. 106) begins south of Weiden and *bounds the Fichtelgebirge and the Thüringer Wald on the west.* A number of parallel lines proceed from it and form together a group of great length. Towards the west, Ammon and Thürach have observed a number of parallel faults which cut through the Franconian Alb and the Mesozoic country as far as Schweinfurt, Kissingen and beyond[3]. In front of the mountain border, near Alten-Palkstein, gneiss steps over the Rothliegende[4]. The faults proceed into the Rhone valley and extend as far as the similar lines, which have been traced by Bücking and Proescholdt along the Thüringer Wald. At Schmalkalden the Zechstein meets the Muschelkalk or Bunter sandstone along several lines, and at one place granite lies upon Bunter sandstone[5].

The Ringgau (Trias) is a horst according to Moesta, and at the same time the continuation of the Thüringer Wald[6]. Its southern border, in some places faulted into a trough, has been traced to Wollhei, west of Waldkappel;

[1] A. von Koenen, Ueber die Störungen, welche den Gebirgsbau im nordwestlichen und westlichen Deutschland bedingen, Nachr. Ges. Wiss. Göttingen, 1886, p. 197; (C. Regelmann) Tektonische Karte (Schollenkarte) Südwest-Deutschlands, herausgegeben vom Oberrhein. geol. Verein, 4 sheets, fol. 1898, is an excellent guide to the south-west, but on account of the position of the fractures it only shows a part of them; Lepsius, Geologische Karte des Deutschen Reiches, 27 sheets, 1894–1897, where they may be clearly followed.

[2] Brunnhuber, Ueber die geotektonischen Verhältnisse der Umgebung von Regensburg, Ber. naturw. Ver. Regensburg, 1894, IV, pp. 237-252; F. E. Suess, Bau und Bild, pp. 8, 215; for the continuation of the disturbances into the Mesozoic region, E. Köhler, Die Amberger Erzlagerstätten, Geogr. Jahresh., 1902, XV, pp. 11-56.

[3] Ammon and Thürach, Uebersicht der Verwerfungen in Nord-Bayern, in Gümbel, Geognostische Beschreibung des Königreiches Bayern, IV, Kassel, 1891, pp. 610–640, map.

[4] Thürach, ibid., p. 611.

[5] H. Bücking, Gebirgsstörungen südwestlich vom Thüringer Walde, Jahrb. k. preuss. geol. Landesanst. for 1884, pp. 546–555, map; op. cit. for 1886, pp. 41–44 et passim; E. Naumann, Tektonische Störungen der triadischen Schichten von Kahla, op. cit. for 1897, pp. 130–159 et passim.

[6] F. Moesta, Das Lias-Vorkommen bei Eichenberg in Hessen in Beziehung auf allge-

a new north-west line makes its appearance between the two fractures of the trough, and near Lichtenau encounters a third, which runs to the north-north-east; this is one of the Rhine faults. A little further north, at Gross Almerode, a wedge-shaped fragment is faulted down; the zone of fracture then runs more to the west-north-west; it passes beyond Cassel and then turns again suddenly to the north-north-west, reaching the western scarp of the Erzgebirge after passing through Volksmarssen. According to Stille's account it is a veritable crowd of north-westerly fractures which, with local deviations to the north-north-west, now makes its appearance near Horn, south of Detmold[1]. The southern border of the Teutoburger Wald, with its well-known overthrusts to the south-west, represents their further continuation. They terminate at a distance of about 440 kilometers from these fractures, that is from the west border of the Bavarian forest, which forms their starting-point.

A number of similar fault-lines approach from the north-west; of these we will only mention those on the south side of the Finne, which are visible as the boundaries of a long narrow band of Muschelkalk[2]. The whole plan of the country, however, as shown, for instance, on Sheet XIII of Lepsius's map, is extremely peculiar. The folds of the Harz present the Variscan strike to the north-east. At the same time a structure appears in the post-Variscan mantle, north-west of the Harz, which resembles a series of synclines striking to the north-west, as, for example, the basin of Einbeck, that of Hils, Alfeld, and others[3]. In these basins the Mesozoic stages, and sometimes the Tertiary also, appear in more or less concentric zones. Detailed investigations show us, however, that all these basins are bordered by north-westerly fractures, that they are not synclines produced by folding, but, to use von Koenen's expression, *subsidence basins.*

Fissures, which within the Harz are known as metalliferous veins, are continued outside it, and cut through the post-Variscan mantle as they proceed to the north-west. They meet first with the outrunners of the

meine Verhältnisse des Gebirgsbaues im Nordwesten des Thüringer Waldes, op. cit. for 1883, pp. 57–80, maps.

[1] H. Stille, Der Gebirgsbau des Teutoburger Waldes zwischen Altenbeken und Detmold, Jahrb. k. preuss. geol. Landesanst., 1899, pp. 1–42, map, and Ueber präcretacische Schichtenverschiebungen im älteren Mesozoischen des Egge-Gebirges, op. cit. for 1902, pp. 296–322, maps. For details of the deflexion A. Mestwerdt, Störungen am Falkenhagner Liasgraben, Festschrift für A. von Koenen, 8vo, 1907, pp. 221–230.

[2] J. H. Kloos, XI. Jahresb. Ver. Naturw. Braunschweig, 1899, pp. 114–116; E. Schutze, Tektonische Störungen der triadischen Schichten bei Eckartsberga, Sulza und Camburg, Jahrb. k. preuss. geol. Landesanst. for 1898, pp. 65–98, map.

[3] H. Dubbus, Der obere Jura auf dem Nordost-Flügel der Hilsmulde, Inaugural-Dissertation, 4to, Göttingen, 1888, 43 pp.; H. Monke, Die Liasmulde von Herford in Westphalen, Verh. Naturf. Ver. preuss. Rheinl., 1889, XXXV, 114 pp., map; M. Schmidt, Der Gebirgsbau des Einbeck-Markoldendorfer Beckens, Jahrb. k. preuss. geol. Landesanst. for 1893, 32 pp., map; also E. Harkort, Die Schaumburg-Lippe'sche Kreidemulde (Inaugural-Dissertation, Göttingen), 8vo, Stuttgart, 1903.

Rhine faults. Some local inbreaks make their appearance, such as the Kahlberg at Echte[1]; and the fault-lines then extend so far to the north-west that von Koenen succeeded in tracing one of them from the north side of the Harz through Gronau into the neighbourhood of Hameln on the Weser mountains[2]. Thus we are led to conclude that the whole of the Teutoburger Wald from Detmold to beyond Ibbenbühren, along with the Wiehern and Weser mountains, and the Süntel, has been shaped out of the post-Variscan mantle by faults and flexures. All these hills may be regarded as forming a common horst, not unlike that of the Thüringer Wald and the Ringgau, or more precisely a double horst, since the upper Carboniferous occurs at Osnabrück along two parallel lines.

(*d*) It has been shown by *borings* that only a part of the existing fractures are exposed to view. Stille states that a subterranean fault with a downthrow to the north runs from the Erzgebirge, near Paderborn and north of Münster, along the entire length of the Teutoburger Wald and parallel to it, so that the Teutoburger Wald is bordered on the south by a fault-trough. The throw is believed to amount to at least 1,000 meters[3].

The observations made by O. von Linstow are of scarcely less importance. A notable subterranean cliff runs west-north-west from the neighbourhood of Spremberg (on the Spree) as far as Wolmirstedt, on the Elbe (north of Magdeburg)—a distance of 200 kilometers. It divides the Palaeozoic formations of the south from the Trias in the north. It would appear that a sharp drop of the beds, not a fracture, runs parallel to this line, from Magdeburg to Dessau, and thus forms a horst or demi-horst. The Rothliegende and the Palaeozoic patches, once known as the coastal fringe of Magdeburg, which strongly recall the Harz, are now seen, along with the Palaeozoic exposures of Bitterfeld, Torgau, and elsewhere, to be parts of this subterranean ridge.

Another parallel fracture runs past Cöthen. The lower Tertiary areas of Egelen, Aschersleben, and elsewhere are possibly subsidence basins[4].

Borings seem to show that on the other side of the Rhine, from Aix to beyond the Meuse, the Coal-measures are traversed by a number of north-westerly faults; it is believed that they take their origin far to the east of the Rhine[5].

[1] J. Perrin Smith, Die Jurabildungen des Kalkberges bei Echte, Jahrb. k. preuss. geol. Landesanst. for 1891, pp. 1–71, map.

[2] Von Koenen, Jahrb. k. preuss. geol. Landesanst. for 1885, p. 80.

[3] Stille, Schichtenabtragung und Transgression, etc., Jahrb. k. preuss. geol. Landesanst. for 1905, XXVI, pp. 103–125.

[4] O. von Linstow, Beiträge zur Geologie von Anhalt, Festschrift für Koenen, 1907, pp. 19–64, map, in particular p. 51 et seq.; F. Klockmann, Der geologische Aufbau des sogenannten Magdeburger Uferrandes, Jahrb. k. preuss. geol. Landesanst., 1892, XI, pp. 118–256, maps.

[5] Forir, Habest, and Lohest, Ann. Soc. géol. Belg. Liége, 1902–1906, XXX, Mém., pp. 607–621, also p. 626 et seq., maps.

North-west to west-north-west fractures also traverse the islands of Rügen [1] and Bornholm. It has already been pointed out that Scania is completely broken up by them (II, p. 47, fig. 5); and that there they are of different ages. The border of the Teutoburger Wald is overthrust to the south-west; the north border of the Kyffhaus, on the other hand, to the north-east. It is a striking fact that a similar movement, restricted, however, to a comparatively narrow space, marks the northern border of the Harz. The view has often been expressed that this fracture on the north border of the Harz is a continuation of the distant fracture of the Elbe in Saxony [2].

Let us now turn our attention to this disturbance and to *the northern group of fractures* (I, p. 138; II, p. 109).

A great pencil of these lines of disturbance traverses the north-east of Bohemia and the Sudetes. The most easterly of them forms the straight, sharply-defined *slope of the Eulen range* which overlooks the Silesian plain.

The most southerly members of the group present a direction—not to the north-west, but to the north. To all appearance they proceed from the cleft between the Sudetes and the Moravian gneiss, north of Brünn (I, p.186, fig. 24), which, as recent investigations show, was already sketched out in Permian times [3]. It is in the latter part of their course that the fractures turn to the north-west. The series of fractures which make up the curvilinear outline of the south-west foot of the Sudetes, together with the just mentioned boundary fracture of the Eulen range, give to the Sudetes, regarded as a whole and including the Riesengebirge, the characters of a horst; within this horst the disposition of the Cretaceous beds indicates the presence of many other fractures running more or less parallel to the boundaries of the horst. Leppla, Frech and his colleagues, and Petraschek also, have given sketch-maps of this region. These show a horst at Landskroner and at Mense, and troughs at Neisse [4].

The scarp of the Sudetes starts, far away in the south, at Neustadt and Ziegenhals, and approaches the northern plain. Isolated bosses of the sunken

[1] W. Deecke, Der Strelasund und Rügen, Sitzb. k. preuss. Akad. Wiss. Berlin, 1906, XXXVI, pp. 618–627, and in particular N. J. f. Min., 1906, Beilage-Band XXII, pp. 114–138; E. Geinitz, Geologischer Führer durch Mecklenburg, 12mo, 1899, p. 5.

[2] e. g. O. Lang, Die Bildung des Harzgebirges, Samml. gemeinverst. wiss. Vorträge, Hefte 236-237, 8vo, Hamburg, 1896, 32 pp., maps, in particular p. 13.

[3] F. E. Suess, Bau und Bild, p. 297.

[4] A. Leppla, Geologisch-hydrographische Beschreibung des Niederschlagsgebietes der Glatzer Neisse, Abh. k. preuss. geol. Landesanst., 1900, neue Folge, Heft 32, 368 pp. and atlas, in particular p. 37; F. Frech, Ueber den Bau der schlesischen Gebirge, Hettner's Geogr. Zeitschr., 1902, VIII, pp. 553-570; W. Petraschek, Das Bruchgebiet des böhmischen Antheils der Mittelsudeten westlich des Neisse-Grabens, Zeitschr. deutsch. geol. Ges., 1904, pp. 210–222, pl. XXXV; A. Schmidt, J. Herbing, and K. Flegel, Zur Geologie des böhmisch-schlesischen Grenzgebirges (dargebracht der deutschen geologischen Gesellschaft aus Anlass ihrer Tagung in Breslau, 1904), 8vo, 158 pp., Tektonische Skizze auf

mountains rise from the depression; Cretaceous troughs enable us to trace the faults far to the north-west, and even beyond Naumburg up to Wehrau on the Queiss. Here this group of the north-westerly fractures disappears.

On the west border of the mountains, at Hronow on the Mettau, the mines show us that the Coal-measures are traversed by a great disturbance, and thrust over the margin of the Cretaceous towards the south-west[1]. From this point onwards the fractures become continuous. Near Liebenau a great flexure forms the border of the Jeschken mountains. Then follows fracture and overthrusting. At Wolfsberg, not far from Khaa, on the Saxon frontier, the border of the overthrust granite recedes in an arc: then it runs in a north-west or north-north-west direction, just east of Dresden and close to the right bank of the Elbe, up to Oberau near Meissen. This great and remarkable dislocation is called the *fracture of the Elbe* or the main fault of Lausitz.

Only two of the features which distinguish this dislocation need be mentioned here, namely, the peculiar overthrusting and a Permian disturbance below the Cretaceous at Döhlen, not far from Dresden.

The Cretaceous formation spreads over the valley of the Elbe; its most important member is the Quader sandstone (Turonian). It forms a platform sloping from the Erzgebirge towards the north-east at an angle of from less than two up to eight degrees at the most: all the table-mountains, pillars, and columns of Saxon Switzerland have been carved out of it. It is cut through by several north-westerly faults. In the west, at Windisch-Cardorf, the downthrow of the south-west limb along one of these faults amounts to 300 meters. On the left bank of the Elbe at Cosselbaude, below Dresden, a short fault occurs which, as an exception, shows a downthrow to the east[2].

The superposition of granite on Cretaceous, which occurs at Hohnstein, has from an early time excited great interest in the minds of observers. Coming from the west, we approach this spot through the valleys of the gently sloping Cretaceous platform. The castle of Hohnstein stands on almost horizontal beds of upper Quader sandstone, which are traversed by a slanting cleft, as though the upper part of the mountain had been forced obliquely upwards over the lower. The crushed Cretaceous is overlain by Jurassic, and this by the granite[3].

Pl. III; Ueber das jüngere Palaeozoicum, etc., Jahrb. k. preuss. geol. Reichsanst., 1905, LV, pp. 217–242.

[1] K. A. Weithofer, Der Schatzlar-Scwadowitzer Muldenflügel des niederschlesisch-böhmischen Steinkohlenbeckens, Jahrb. k. preuss. geol. Reichsanst., 1897, XLVII, pp. 455–478, map, in particular p. 475.

[2] K. Dalmer and R. Beck, Geologische Special-Karte des Königreiches Sachsen, Bl. 65, Wilsdruff-Potschappel, 1894, Erläuterung, pp. 54–56.

[3] R. Beck, op. cit., Bl. 84, Königstein-Hohenstein, 1893. A general survey of the sunken area is given by Beck in Tschermak, Min. petr. Mitth., 1893, XIII, pp. 290–341.

The Jurassic is continued into the north of Bohemia, but only as a band pinched into the dislocation, and it is absent throughout all the rest of Saxony and Bohemia.

The embayment in the side of the granite on the Saxon frontier was probably produced by denudation; it extends onwards for about four kilometers. Within it we see a flake of Rothliegende more than a kilometer in length, lying over the Cretaceous and below the granite. It is an intratelluric erratic which has been carried up to the surface.[1] We cannot apply the same explanation to the Jurassic; its character and distribution are not in harmony with such a view. The inverted series—Cretaceous, Jurassic, granite—indicates, in fact, overfolding to the south-west. At this place the extent of the overfolding amounts to at least four kilometers.

The expression 'backfolding' has been applied (I, p. 138) to this dislocation, but inappropriately; the term should be restricted to that process which is the reverse of forefolding (as it occurs, for instance, in the interior of the Asiatic vertex).

A little to the west of the outskirts of Dresden we reach the coal-field of *Döhlen*. It appears on the map as an ellipse of Rothliegende, 20 kilometers long and 7 kilometers broad, resting unconformably on Silurian, granite, and syenite. Its structure has been elucidated by mining operations. The ellipse is cut through by a series of faults with a north-west strike. The beds of Rothliegende dip for the most part to the north-west; the faces of the faults hade, almost without exception, steeply to the north-east. A small horst runs through this basin. The most important dislocation extends along its north border as a series of step-faults known as the Rothe Ochse. The sum of the several throws gives a subsidence of 360 meters [2].

These subsidences are produced by the local common increase in downthrow of a number of parallel strips—a sagging along fracture. The elliptical outline is due to denudation. We have thus additional examples of the same structure as that presented by the subsidence-basins north-west of the Harz, though the latter are much younger; the faults of Döhlen are older than the Cenomanian, and consequently also older than the neighbouring fracture of the Elbe, which runs parallel to them.

What kind of relation may exist between these fractures, which proceed from the Sudetes, and the long subterranean fracture of Wolmirstedt-Spremberg is not known. But it can hardly be doubted that all these lines of dislocation, possessing so many characters in common, must have a common origin independent of the Variscan folding. They are not of the same age,

[1] O. Herrmann and R. Beck, op. cit., Bl. 86, Hinterhermsdorf-Daubitz, 1897, Erläuterung, p. 34.

[2] R. Hausse, Profile durch das Steinkohlenbecken des Plauen'schen Grundes, op. cit, 1892, pl. I-III; Beck in Erläuterung zu Blatt 66, Dresden, 1893, p. 43.

but they are all later than the Permian, and the great majority are later than the Cretaceous.

They resemble the Asiatic type presented by the coal-basin on the Donetz, i.e. the continuation of the line of the Alai, in the following points: (1) their strike to west-north-west or north-west; (2) the decrease in intensity which they so frequently exhibit in this direction; (3) their rectilinear course, which may be maintained for a distance of 440 kilometers; and (4) the overthrusting, directed almost exclusively to the south-west, by which the

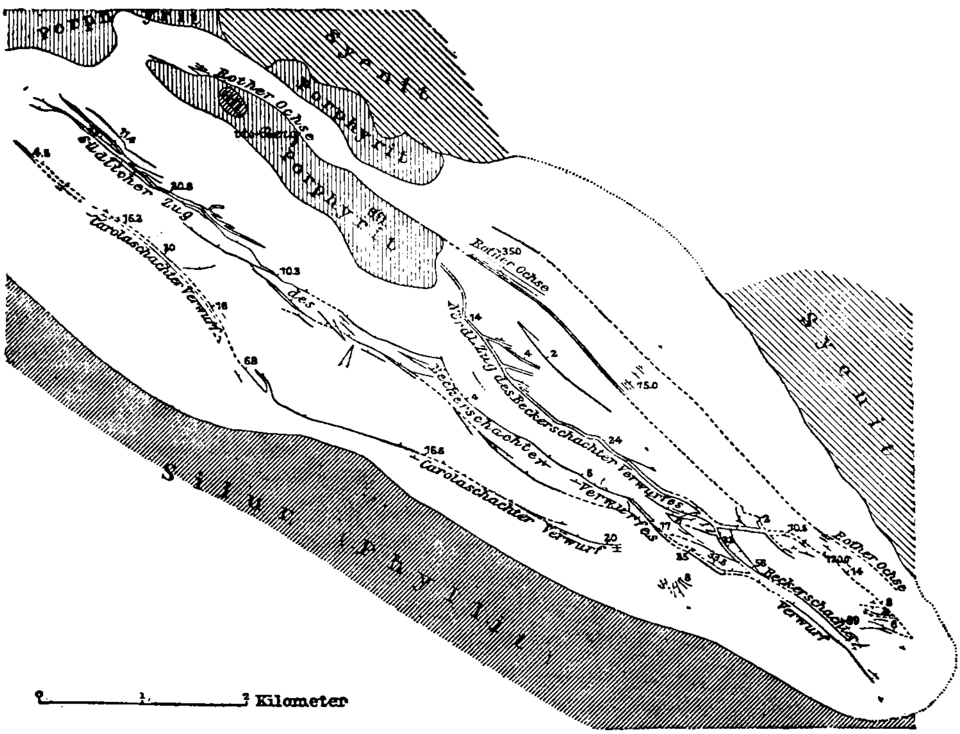


Fig. 3. *The Coal basin of Döhlen near Dresden* (after Hausse).

overthrust part may be carried to a distance of perhaps four kilometers. Concurrently with this, the south-west limb almost always sinks down.

A deviation of these lines from the Asiatic type is shown by the curved deflexion of the Elbe fractures into the clefts at Brünn.

Their characters are just as opposed to those of the European Altaides as to those of the Rhine faults, but they present this feature in common, that not a trace of them can be discovered in the Alpine region. They cannot be attributed to any movement coming suddenly from Asia, for they are of different ages. The contrast they present to folds corresponds in a striking manner with *the contrast which reveals itself in the east between the north and south sides of the horst of Azov.*

We will now only recall the manner in which the line of the Alai is continued into the coal-field on the Donetz. If we look for rectilinear horsts striking to the north-west, like that of the Thüringer Wald, with the Ringgau or the Teutoburger Wald, we shall find them again, on a very large scale, south of lake Saissan, where the Dzungarian disjunctive lines advance to the north-west, and, according to the recent observations of Obrutschew, convert the Saur, Maurak, Tarbagatai, Barlyk, Maili, and other mountain ranges into so many long horsts, which cut the strike of the folds at an acute angle[1] (III, p. 163).

The hypothesis advanced by von Koenen, that this group of dislocations corresponds with Karpinsky's lines, affords, according to existing observations, the most natural explanation. We have no grounds for connecting the fracture of the Elbe with the border of the Harz.

We shall return to these lines when discussing the Pyrenees.

[1] W. A. Obrutschew, Expedition zum Barlyk und Tarbagatai im Jahre 1905, Vorläufiger Bericht, 8vo, Tomsk, 1907, 21 pp.

CHAPTER II

ARMORICA AND THE AMERICAN ALTAIDES

The western border of the Central Plateau. Brittany. Younger folding. Extension of the London basin. Transatlantic Altaides. Relations in the pre-Carboniferous period. Stratified series in the Carboniferous system. Appălachians as far as the Mississippi. Atlantic and Pacific characters. Appalachians beyond the Mississippi. The North Atlantic Ocean.

The western border of the Central Plateau. The subsidence of the Central Plateau takes place in the west, as in the Variscan region, along marginal fractures which run in the most diverse directions. Here, also, the subsiding mantle begins with the upper Carboniferous, as in Moravia and Franconia; the Trias lies unconformably, as in certain places in west Germany, but does not begin until the Rhaetic stage, and is completely absent further north, where consequently the unconformity begins with the Lias.

Let us take the coal-fields of Decazeville as our starting-point. Great fractures approach from the east-south-east, and the Jurassic Causse du Comtal is let down along them. West of Decazeville the fault of Villefranche enters the region from the south-south-west; it is a great rectilinear marginal fracture, which cuts off the south-west of the Central Plateau for a distance of 50 kilometers. In front of it lie step-faults and repeated short folds with a different strike, which are sometimes bordered on each side by a fault, so that they possibly represent the secondary results of subsidence[1].

Further north, towards the Dordogne, fractures running to west-north-west or north-west make their appearance. Fig. 4 represents the granite platform of the Haute Corrèze as worked out by Mouret in the east. Following the margin of the granite on the west is the Faille d'Argentat which strikes to the north, and is bordered by small seams of coal. West of this fault lies the anticline of Roche-de-Vic, 80 kilometers in length, which may be regarded, perhaps, as a normal Armorican fold. The boundary faults, striking somewhat more to the west, cut across the outer zones of the Central Plateau. In front of the plateau lies the upper Carboniferous and Permian coal-field of Brive, faulted down in a trough. A fault running parallel to the boundary faults divides it from the isolated horst of Terrason which descends towards the west beneath the Mesozoic

[1] The most important of these must probably be regarded as a bent anticline lying between two bent faults. E. Fournier, Le Dôme de la Grésigne, Bull. serv. Carte géol. France, 1898, X, pp. 331–339; A. Thevenin, Etude géologique de la Bordure sud-ouest du Massif Central, op. cit., 1903, XIV, pp. 353–554, map, in particular fig. 34, p. 484.

mantle. At Meyssac, 16 kilometers south-east of Brive, the Faille du Meyssac leaves the border of the plateau and cuts off on the south the Carboniferous and Permian deposits of Brive, as well as a very small horst at Lissac and the larger one of Terrason, and then strikes away into the Mesozoic region[1].

Manês and d'Archiac early recognized the long lines of dislocation which run towards the south-east from the island of Oleron through the lower Charente. Next, Arnaud described folds in the Cretaceous between Angoulême and the Dordogne, and Fallot afterwards compared the folds of Aquitania with those of the Paris basin[2]. Then Glangeaud marked out three long anticlinal axes and two basins in a tract of country 250 kilometers in length and 50 kilometers in breadth, which extends from Oleron and Rochefort to the Lot. These lines were believed to be the outcome of the folding of the Pyrenees. It was also assumed that they are continued into the ancient horsts[3].

The only one of these lines which has been traced in the south-east up to the ancient horst is the Faille de Meyssac. In its course from the border of the Central Plateau, through a distance of 80 kilometers to the west-north-west, till it reaches the other side of the river Isle above Périgueux, this line, as Mouret has shown, is a fault with a downthrow to the south. That it has been regarded as a broken anticline is due to the fact that the horsts of Lissac and Terrason disappear along it, and with this disappearance the beds, in some localities, dip away from it on each side[4].

A fracture with a throw to the south is visible for a long distance, the strike passing from west-north-west to north-west; then follows a flexure which extends for a comparatively short distance, as may be seen from Glangeaud's detailed description; its drop decreases, and before the Drôme is reached a neutral region makes its appearance in the form of a flat saddle. Soon a flexure again sets in, but this time it is the north limb which is dropped. The so-called 'Dom' of Mareuil is a part of this flexure,

[1] G. Mouret, Bassin houiller et permien de Brive (in Études des Gîtes minéraux, publiées sous les auspices de M. le Ministre des Travaux Publics), 4to, 1891, 444 pp., maps. A comprehensive survey is given by G. Mouret in Remarques sur la géologie des terrains anciens du Plateau central de la France, Bull. Soc. géol. de Fr., 1898, 3e sér., XXVI, pp. 601–612, map, and in Aperçu sur la géologie de la partie sud-ouest du Plateau central de la France, Bull. serv. Carte géol. France, 1899, XI, pp. 51–88, maps; also in Les Régions naturelles du Département de la Corrèze, Bull. Soc. scient., hist. et archéol. de la Corrèze, Brive, 1896, XVIII, 11 pp., map.

[2] E. Fallot, Sur la disposition des assises crétacées dans l'intérieur de l'Aquitaine, C. R., Febr. 6, 1893.

[3] P. Glangeaud, Un plissement remarquable à l'ouest du Massif central de la France, C. R., June 13, 1898, map; Les plissements des terrains crétacés du bassin de l'Aquitaine, op. cit., Dec. 26, 1898; Étude sur les plissements du Crétacé du bassin de l'Aquitaine, Bull. serv. Carte géol. de Fr., 1899, XI, pp. 1–48, map.

[4] Mouret, Bassin de Brive, p. 146.

along which some upper Jurassic is exposed; and flexure or fracture continues as far as the Charente[1].

The existence of the other two anticlinal lines in north Aquitania is inferred from similar observations. The faults emerge from the ancient horsts and enter the Mesozoic covering under conditions similar to those which obtain in Bavaria, except that here they more frequently pass into flexures.

Towards the north, near Limoges, and in the neighbourhood of Confolens, the resemblance between this region and Bavaria increases, owing to the occurrence of long quartz veins, some of which are clearly associated

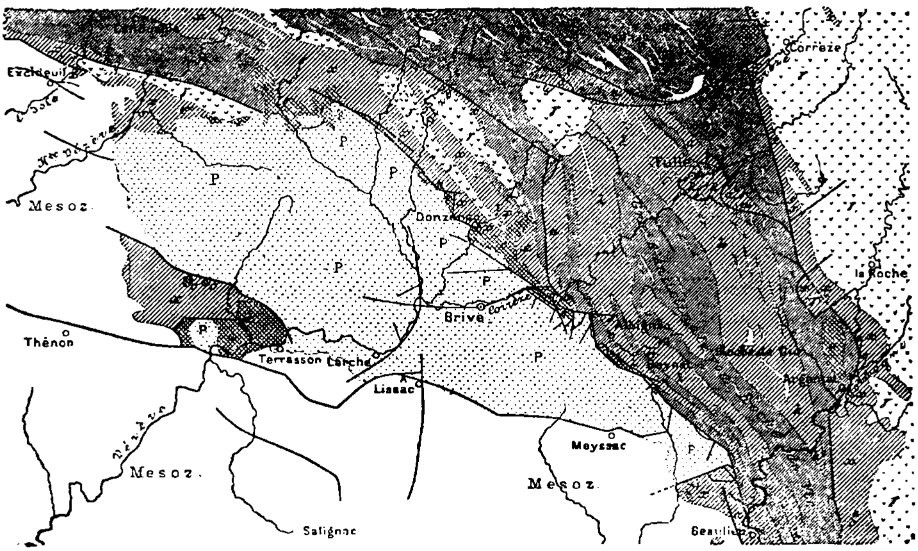


FIG. 4. *The western border of the Central Plateau near Brive* (after Mouret).
γ Granite and granulite; x gneiss and phyllite; λ leptynite; c Carboniferous sandstone and conglomerate; p Permian deposits; a the horst of Lissac.

with faults. Further east, west of the Cher, the contour of the Central Plateau, as it diverges more and more from the Armorican strike, presents

[1] For a more detailed account of these relations, cf. Glangeaud, Bull. serv. Carte géol. de France, 1899, XI, the sections in the following order from north-west to south-east: p. 8, fig. 3, section of Rochebeaucourt, flexure to the north-east; p. 6, fig. 2, Dom de Mareuil, continuation of the flexure to the north-east; p. 10, fig. 5, Verneuil, the same, but feebler; p. 10, fig. 6, neutral place on the Cole; p. 11, fig. 7, on the Beauronne, beginning of the flexure to the west; p. 12, fig. 8, Puyrina: here we already have the fracture towards the west, extending to the Central Plateau. Fig. 4, section between La Couronne and Mouthiers, is copied from Arnaud; I disregard it for the present on account of its exaggerated vertical scale. It would besides only show that a transition from flexure to fault occurs again further to the north-west. Cf. H. Arnaud, Études pratiques sur la Craie du sud-ouest; Profils géologiques des chemins de fer, Actes Soc. min. Bordeaux, 1876, 1877, 1878, 1883, 1892, etc.

in some localities, as De Launay points out, a serrated appearance, owing to the occurrence of fractures, just as may be seen on a large scale in Franconia [1].

These examples have been cited to show how difficult it may be to distinguish between faults, which emerge from horsts, and posthumous folds, when they follow nearly the same direction. The problem solves itself as soon as the directions diverge from one another.

The strait of Poitiers is completely cut through by north-westerly trending lines of dislocation; these have been mapped by Welsch. Certain parts of lines, or even entire lines, have been interpreted sometimes as faults, sometimes as folds, and attributed to the influence of the Pyrenees. In the strait itself they strike from horst to horst, and quartz veins are continued beyond the horsts, in much the same way as the Bohemian Pfahl is continued beyond the Tertiary land of Eger to reappear in the Erzgebirge [2].

Brittany. In Devonshire, the Devonian and Culm enter into the mountain structure as broad zones, but this is not the case with the Palaeozoic rocks of Brittany, for the zones they originally formed have been reduced by denudation to long pinched-in strips, often very narrow, which strike through the mountains as the trend-lines of vanished synclines (II, pp. 89, 113). We may, perhaps, infer that the chains of Brittany were once higher than those of Devonshire. In many of its features the plan of the mountain structure is more clearly exposed in this denuded area than in younger mountains of greater relief; it has been worked out by Barrois in several masterly memoirs [3].

[1] De Launay, Les dislocations du terrain primitif dans le Nord du Plateau Central, Bull. Soc. géol. de Fr., 1888, 3e sér., XVI, pp. 1045–1063; Bull. serv. Carte géol. France, 1894, IV, p. 318, and 1898, X, pp. 89, 90; also Les sources thermales de Néris et d'Évaux, Ann. des Mines, 1895, 9e sér., VII, pp. 563–623, map; Recherche, captage et aménagement des sources thermo-minérales, 8vo, Paris, 1899, p. 251 et seq. For the sheet with Limoges, Mouret, Bull. serv. Carte géol. France, 1899, XI, p. 82; cf. also Glangeaud, tom. cit., p. 44 et passim.

[2] J. Welsch, Les plissements des terrains secondaires dans les environs de Poitiers, C. R., June 13, 1892, and Bull. Soc. géol. de Fr., 1893, 3e sér., XX, pp. 440–456, map; in particular Bull. serv. Carte géol. France, 1896, IX, p. 311, and Bull. Soc. géol. de Fr., 1905, 4e sér., III, p. 941.

[3] Here we will only mention C. Barrois, Légende de la feuille de Plouguerneau et Ouessant, Ann. Soc. géol. du Nord, 1893, XXI, p. 390, on account of the important observations on the connexion between these mountain fragments, also Le Bassin du Ménez-Bélair, op. cit., 1895, XXII, pp. 181–350, maps, showing the crossing of older trend-lines by younger folds; also Feuilles de Belle-Ile et de Quiberon, Bull. serv. Carte géol. France, 1897, IX, pp. 315–318, showing the junction with the secondary folds in the south; and Des divisions géographiques de la Bretagne, Ann. de Géogr., 1897, pp. 23–64, and map (cf. II, p. 89, note 2); also sketch of the Geology of Central Brittany in Proc. Geol. Assoc., London, 1899, pp. 101–132, and 'Bretagne' in the Livret-Guide of the Eighth Geological Congress, 1900.

As we have already pointed out, there are three principal lines of dislocation. These are: (1) a long anticline of ancient gneiss, which is deflected, at its extreme western end, slightly to the west-south-west; it follows a rectilinear course from the region south of Quimper along the south coast through Vannes and Nantes on the east side of the horst (II, p. 90);

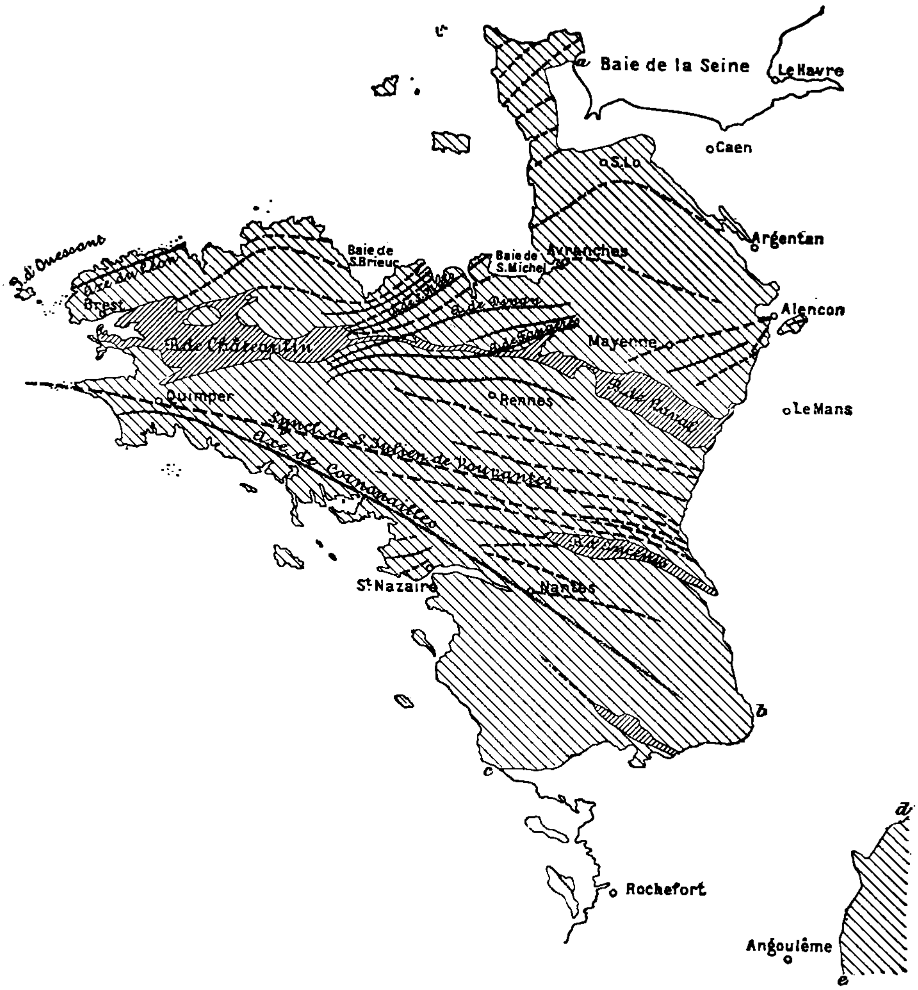


FIG. 5. *The Armorican peninsula* (after Barrois).
a, *b*, *c* border of the horst of Brittany; *d*, *e* border of the Central Plateau.

this line is the *axis of Cornouailles*; (2) a second anticlinal band of gneiss runs from the coast near the island of Ouessant along the north coast to the north-east; this is the *axis of Léon*; if it were prolonged into the sea it would meet the first line to the south-west of Ouessant; (3) between these two bands of gneiss is a long pinched-in zone of Silurian, Devonian, and Carboniferous, forming on the west the coal-basin of *Châteaulin*, on the east that of Laval; these basins are connected by a still narrower pinched-in band, the *basin of Bélair*. This pinched-in zone has been traced for a distance of 340 kilometers; and neither to the east nor to the west is its natural termination to be seen.

North of the axis of Cornouailles, the long straight syncline of Saint Julien de Vouvantes strikes from the islands off Pointe du Raz, through this promontory, and past Quimper towards the east-south-east, till it passes slightly beyond St. Barthélemy, north of Angers. This syncline, however, does not run parallel to the band of gneiss, but diverges from it more and more towards the east. Shorter anticlines and synclines insert themselves in the interval, among them the coal-basin of Ancenis; and, since they remain parallel to the syncline of Saint Julien de Vouvantes, their position

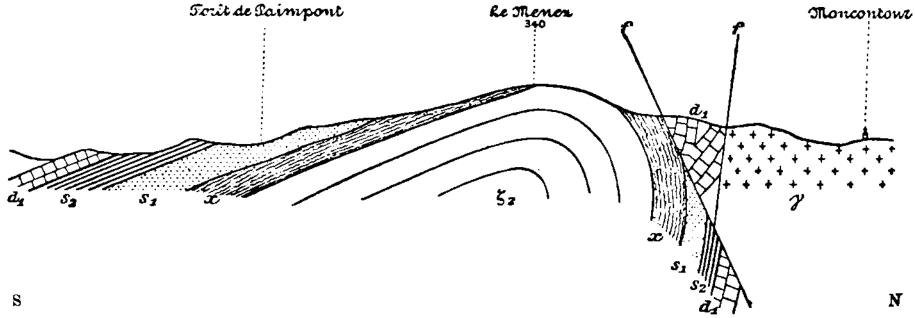


FIG. 6. *The syncline of Ménez-Bélair cut through by the anticline of Dinan* (after Barrois).

with regard to the gneiss band of the axis of Cornouailles recalls, to use Barrois's expression, the 'barbs of a feather.'

Other synclines follow towards the north in the direction of Rennes, and seem to form a gradual passage from the south-easterly direction of the axis of Cornouailles into that of the pinched-in zone of Châteaulin, Bélair, and Laval, which forms a gentle arc striking east and west or west-north-west.

In the middle of this zone we have the rare opportunity of observing how an ancient folded system is cut through by a younger. To obtain a clear conception of the facts we must start from the band of gneiss in the north-west, the axis of Léon. It is followed towards the east by other anticlines and synclines, striking eastwards in a gentle arc, and reaching the coast at the bay of St. Brieuc, or still further to the east. The margin of the basin of Châteaulin is sometimes caught in by these east-north-easterly synclines.

Still further east the pinched-in zone is actually cut across slantwise by anticlines striking to east-north-east or north-east. For instance, the syncline of Ménez-Bélair is thus cut across by the anticline of Dinan, and further east by that of Fougères. Concurrently the pinched-in zone is forced upwards in a saddle, bent in azimuth, and diminished in breadth [1].

From this Barrois concludes that the folds trending east-north-east or north-east are younger than the folding which has pinched in the long strip of Châteaulin-Bélair-Laval, and that the folding of Léon is younger than that of Cornouailles. The fact that the Palaeozoic beds are caught in by the synclines striking east-north-east shows that the Palaeozoic basin must at one time have possessed a greater breadth.

Fig. 5 marks the course of some of these younger lines. We see that as they approach the bay of Saint Malo they turn somewhat more to the north-east, and flatten out south of the bay of Saint Michel as they proceed to the east-south-east [2].

To the south a syncline with a north-east strike meets the south-west coast of the bay of Saint Michel, reappears near Avranches, then forms an arc slightly convex to the north, and turns towards the east-south-east [3].

Lecornu has described another similar arc as the 'zone bocaine'; this has its vertex south of Saint Lo [4]. Michel Lévy has given a brief account of the various lines which reach the peninsula through Jersey and Guernsey; some of them cross the Cotentin, others are heaved out in Palaeozoic synclines [5]. The northernmost extremity of the district near cape La Hague is formed, according to Bigot, of pre-Cambrian and Silurian rocks, which are affected by fractures and influenced by adjacent eruptive rocks [6].

We are thus introduced to a very peculiar structure.

The folds which make their appearance in the west, south of the axis of Léon, present, as far as the bay of St. Brieuc, a curved strike, convex towards the north. Then their course becomes concave, they turn to the north-north-east and north-east, and in the northern part of the Cotentin form the outer lines of a second and more important arc.

If we take into account the observations of Oehlert and Bigot, made near Mayenne and Alençon, then we seem to have indications of the

[1] C. Barrois, Le Bassin du Ménez-Bélair, Ann. Soc. géol. du Nord, 1895, XXII, p. 273, fig. 13; its north-east end disappears in a mass of granite. For offshoots from the basin of Laval, Oehlert, Feuille de Mayenne, Bull. serv. Carte géol. France, 1896, VIII, no. 53, pp. 57–61.

[2] C. Barrois, Feuille de Dinan; Ann. Soc. géol. du Nord, 1893, XXI, p. 39.

[3] We must thus correct the remarks made in II, p. 90, on the continuation to cape Frehel, which were based on older statements.

[4] L. Lecornu, Sur les plissements siluriens dans la région du Cotentin, Bull. serv. Carte géol. France, 1893, IV, pp. 395–414, little map.

[5] Michel Lévy, Contributions à l'étude du Granit de Flamanville, Bull. serv. Carte géol. France, 1894, V, pp. 317–357, in particular p. 318, fig. 1.

[6] A. Bigot, Feuille des Pieux, Bull. serv. Carte géol. France, 1898, X, pp. 106–109.

beginning of a third arc. The north border of the basin of Laval forms the starting-point both of a number of folded ranges, completely homologous with the anticline of Dinan, which strike between east-north-east and north-east, and of a syncline which strikes through Mayenne and Villaines into the neighbourhood of Alençon[1].

In the arc of the Sarthe, near Alençon, the anticline which approaches from the south-west divides, on the border of the ancient mountains, into two branches, one directed to the north-north-east, the other to the east-north-east[2]. In the southern part of the great basin of Coëvrons, however, which lies south of this point and reaches the border at Fresnay, the strike turns to the south-east. This is the commencement of the third arc. We see the same direction in the little remnant of the older series which crops out, north-west of Le Mans for example, from beneath the Jurassic covering.

From these observations we conclude that the very generally accepted view which regards *the arcs of a great folded system as arising in regular succession one behind the other*, and shoved, as it were, one against the other, *does not apply to this region.* The basin of Châteaulin, which even includes the Culm, is just as much the outcome of the great inter-Carboniferous movements of the Armorican folding as the saddles which cut through this basin, and in the interior of the mountains several arcs exist. Thus it would appear that the intercalation of ancient cores must be taken into account[3].

The gneiss range of Cornouailles is bordered on the east by a quartz vein 140 kilometers in length, which recalls the Great Pfahl, and marks this feature as one of great stability.

The axis of the coal-basin of Ancenis is regarded by M. Lévy as a trend-line which continues into the Central Plateau[4].

Extension of the London basin. The Armorican arc is interrupted by a gap which extends from the Mendips to Boulogne. The basin is open for the whole of this long distance, and it is precisely here that the Weald, the most important of the younger folded regions, makes its appearance. Consistently with the views of Godwin Austen and many other authorities, it was originally supposed (II, p. 92) that the overfolded Coal-measures of the Mendips were continued beneath the Mesozoic mantle, past Exeter, to the overfolded Coal-measures in the north-east of France. But the case

[1] Cf. the little map in Oehlert, Feuille de Mayenne, Bull. serv. Carte géol. France, 1896, VIII, p. 60, and p. 58 for the bend of the strike.

[2] D. P. Oehlert and A. Bigot, Note sur le massif silurien d'Hesloup, Bull. Soc. géol. de France, 1898, 3e sér., XXVI, pp. 82–103, map.

[3] A. Bigot, Le massif ancien de la Basse-Normandie, Bull. Soc. géol. de France, 1904, 4e sér., IV, pp. 909–953, map; in particular p. 944.

[4] Michel Lévy, Situation stratigraphique des régions volcaniques de l'Auvergne, Bull. Soc. géol. de Fr., 1890, 3e sér., XVIII, pp. 688–952; in particular p. 690, and pl. XXII, fig. 1.

is not so simple. A combination of earlier and later observations now enables us to perceive that to the east of the Caledonian zone of Wales movements of Armorican age have proceeded across the supposed outer border for a considerable distance to the north.

In south-west Wales, as far as Carmarthen bay, the Coal-measures are pinched in, and form an extremely narrow zone; further east, they expand into the great coal-field of Glamorganshire, broadening out widely towards the north; this is traversed by three anticlines running south-west and north-east, which bend round towards the south-west into other anticlines with an east and west strike. The anticlines running north-east and south-west were interpreted (II, p. 85) as representing a bend into the Caledonian direction; but it would now seem that they are the beginning of a sigmoidal advance of the Armorican trend-lines.

Towards the east the great coal-basin is followed by an anticline striking to the north-east, which brings up the Silurian at Usk from under the Old Red sandstone. This anticline separates the coal-field of Glamorganshire from a long syncline of Carboniferous limestone striking to the north-east, which includes towards the north the coal-basin of the Forest of Dean. In the bed of the Severn itself lies another coal-field, and beyond it, on the east side of the river, extends the longest of the Armorican branches. Much lies concealed from view beneath the Bunter sandstone; nevertheless, it is evident that the Bristol coal-field, stretching to the north-north-east, is enclosed at its northern extremity between two anticlines which meet in a fork at an acute angle, and these, conjoined from Tortworth onwards, continue further towards the north. A little cliff of upper Silurian on the south bank of the Severn marks the place where they cross the river. Then, yet further north, they crop out again in May hill, and, separating from each other, form a fork open to the north. The western branch runs to the north-west and forms, north of the coal-field of the Forest of Dean, the elongated pear-shaped anticline of Woolhope; while the other branch maintains a direct course to the north. After some interruption it forms the meridional range of the *Malvern* and *Abberley hills*, and here at last, south-west of Kidderminster, about 70 kilometers north of the end of the Bristol coal-field, and about 100 or 110 kilometers north of the foot of the Mendips, it disappears from view with a bend to the east-north-east. A meridional fault, which cuts off all the older rocks from the Permian and Bunter sandstone, borders its east side [1].

The significance of the Malverns was first made clear by the admirable work of Groom [2]. On the east side they present throughout their length

[1] J. Phillips, The Malvern Hills, compared with the Palaeozoic Districts of Abberley, &c., Mem. Geol. Surv., 1848, II, Part I, maps. The advance of the Malverns is seen very clearly on Strahan's sketch-map in Rep. Brit. Assoc., Cambridge, 1904.

[2] T. T. Groom, The geological structure of the South Malverns and of the adjacent district to the west, Quart. Journ. Geol. Soc., 1899, LV, pp. 129–169, and On the geological

from south to north a narrow Archaean band, which *is overfolded towards the west on to Cambrian and Silurian beds.* Further north the Archaean rocks disappear. In the little horst of Martley, Archaean rocks still rest upon the Cambrian. The structure of the northern part of the Abberley hills is shown in fig. 8. On the east we see the fault next the Bunter sandstone, then to the west the Silurian folds beginning to bend round to the east-north-east; next, the Old Red folded with the Silurian; and last, in a syncline of the Old Red, the south end of the Forest of Wyre coal-field. On Woodbury hill the folded Silurian is overlain unconformably by a flat-bedded patch of Permian and some upper Carboniferous; a proof that this range forms part of the Armorican system.

W. G. Clarke has shown that at the bottom of the Forest of Wyre basin, as well as in some adjacent coal-fields, the folds of the middle Coal-measures are cut off by a plain of denudation upon which the upper Coal-measures rest unconformably [1]. This plain, the so-called Symon fault, may well represent an extension of the Armorican unconformity.

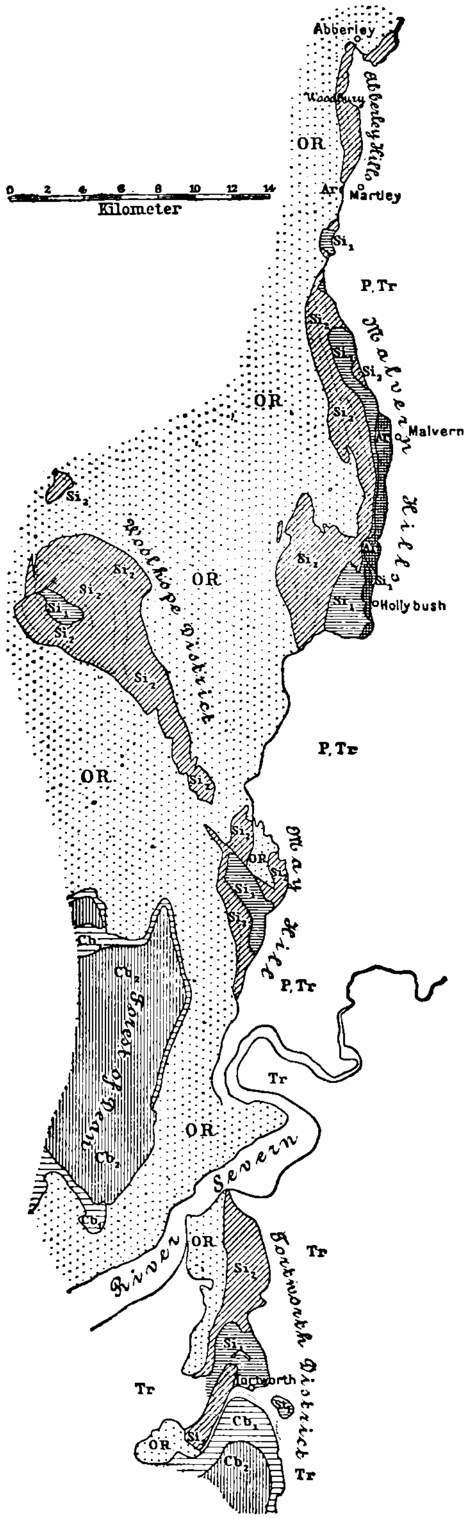
We must leave it to observers better acquainted with the district to judge whether this advance of the outer border of the Armorican system has affected the subterranean strike of the Coal-measures, which have been revealed by borings near Boulogne and the region between Dover and Canterbury.

Among posthumously-folded regions we have mentioned, as of especial importance, the Weald and the broken anticline of the Pays de Bray (II, p. 95). These led us to conclude that within the boundary of the subsidence younger folding had occurred in the ancient Armorican direction.

In the south of England the direction of these younger folds is almost east and west. Strahan's observations are, briefly, as follows: three important synclines (London, Chichester, Solent) and three anticlines (Guildford, Portsdown, Isle of Wight) are present, arranged in coulisses; the anticlines are always steeper towards the north; from the Isle of Wight onwards they proceed as two lines of disturbance, of which the first cuts through the peninsula of Purbeck, and the second runs only a little more to the north, south of Dorchester, almost to the east coast, near Lyme Regis. These disturbances may attain considerable intensity. Strahan cites an instance in which a less resistant series, normally

structure of portions of the Malvern and Abberley Hills, op. cit., 1900, LVI, pp. 138–197, maps. An overthrow observed further north, in the Isle of Man, only affects the volcanic rocks of the Carboniferous, F. W. Lamplugh, tom. cit., pp. 11–25.

[1] W. J. Clarke, The Unconformity in the Coal-Measures of the Shropshire Coal-Fields, Quart. Journ. Geol. Soc., 1901, LVII, pp. 86–95; for the more northerly regions, W. Gibson, tom. cit., p. 251 et seq. It is quite possible that the great disturbance of Orlau may be explained in the same way as the Symon Fault; the detailed investigation by R. Michael, Monatsber. deutsch. geol. Ges., 1907, no. 2, supports this view.



1,100 feet thick, is compressed in a vertical direction to 270 feet. A black flint nodule in the chalk has been crushed to powder and drawn out into a black streak like coal-dust [1].

It is more difficult to follow the trend-lines in France, where they are, to all appearance, more numerous, but in part, at least, less clearly marked. In a sketch given by Dollfus, a very general direction to the south-east is seen to predominate in the western half of the Paris basin. This is also the Armorican direction [2]. In the

[1] A. Strahan, On Overthrusts of Tertiary Date in Dorset, Quart. Journ. Geol. Soc., 1895, LI, pp. 549–562, map; The Geology of the Isle of Purbeck and Weymouth, Mem. Geol. Surv. England and Wales, 1898, 278 pp., maps; Guide to the geological model of the Isle of Purbeck, 8vo, 1906. A more comprehensive survey of the post-Carboniferous disturbances was given by Strahan in his presidential address to Section C of the British Association, 1904 (Rep. Brit. Ass. 1904, pp. 532–541, pl.). From this very instructive description it appears that a number of long fractures with a more or less Caledonian strike were formed in the west of England before the deposition of the Trias and Permian. If the comparison is to be carried further, upturning, and isolated anticlines—secondary phenomena accompanying faults—must be more clearly distinguished from folded systems; the question arises, for instance, whether the Lake District is a horst.

[2] G. F. Dollfus, Relations entre la structure géologique du Bassin de Paris et son hydrographie, Ann. de Géogr., 1900, IX, pp. 313–339 and 413–433, map, and Bull. serv. Carte géol. France (1904), 1905, XV, pp. 3–5, map, and (1905), 1906, XVI, pp. 31–35, map; also

FIG. 7. *Malvern hills* (after Phillips).
Ar = Archaean; S_1, S_2 = Cambrian and Silurian; *OR* = Old Red sandstone; Cb_1 = Carboniferous limestone; Cb_2 = coal-bearing Carboniferous; *P*, *Tr* = Permian and Bunter sandstone.

south these folds are cut through by meridional faults, which proceed from the Central Plateau. Lemoine and Rouyer thought they could recognize in the south a deflexion of the lines in the direction of the syntaxis towards the Variscan trend [1].

Many years ago some eminent observers, and among them Godwin Austen, held the opinion that the folding is repeated always and everywhere along the same lines. The first observations made by Marcel Bertrand on these younger folds, in the west of the Paris basin, referred to a region in which their trend is no doubt fairly parallel to the Armorican strike presented by the horsts. He concluded, in accordance with Godwin Austen's views, that there was continuity of folding, i. e. he believed that the folding of the horsts themselves had been renewed [2]. From the horsts, however, proceed fractures—not folds. This is shown most clearly by the changed direction of the folds in England.

The posthumous folds of the London and Paris basin stand in the same relation to the horsts surrounding them as the Alps to their frame. *They are a similar but more open structure on a smaller scale.*

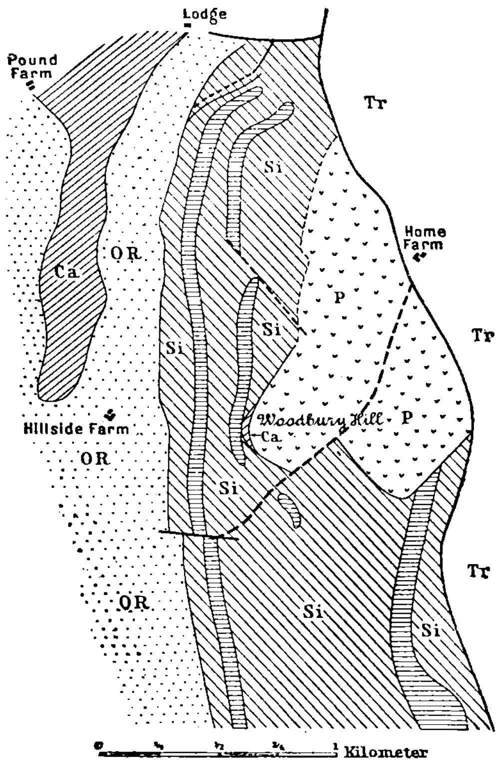


FIG. 8. *Abberley hills* (after Groom).
Si = Wenlock and Ludlow shales with bands of Aymestry limestone; *OR* = Old Red sandstone; *Ca* = Carboniferous; *p* = Haffield breccia, Permian; *Tr* = Bunter sandstone.

Here we may learn much that is instructive in its bearing on the Alps.

The eastern, Variscan border of the Paris basin shows that the Rhine mountains have been let down by strike faults into two gulfs which open

Bull. Soc. géol. de Fr., 4e sér., III, pp. 7–18; for the Pays de Bray the detailed monograph by A. de Lapparent, in the Mémoire pour servir à l'explication de la carte géologique, 4to, 1879.

[1] P. Lemoine et C. Rouyer, Sur l'allure des plis et des failles dans la Basse Bourgogne, Bull. Soc. géol. de Fr., 1905, 4e sér., IV, pp. 561–568, map.

[2] M. Bertrand, Sur la continuité du phénomène de plissement dans le Bassin de Paris, Bull. Soc. géol. de Fr., 1892, 3e sér., XX, pp. 118–165, maps; also Lignes directrices de la Géologie de la France, C. R., Jan. 29, 1894, map.

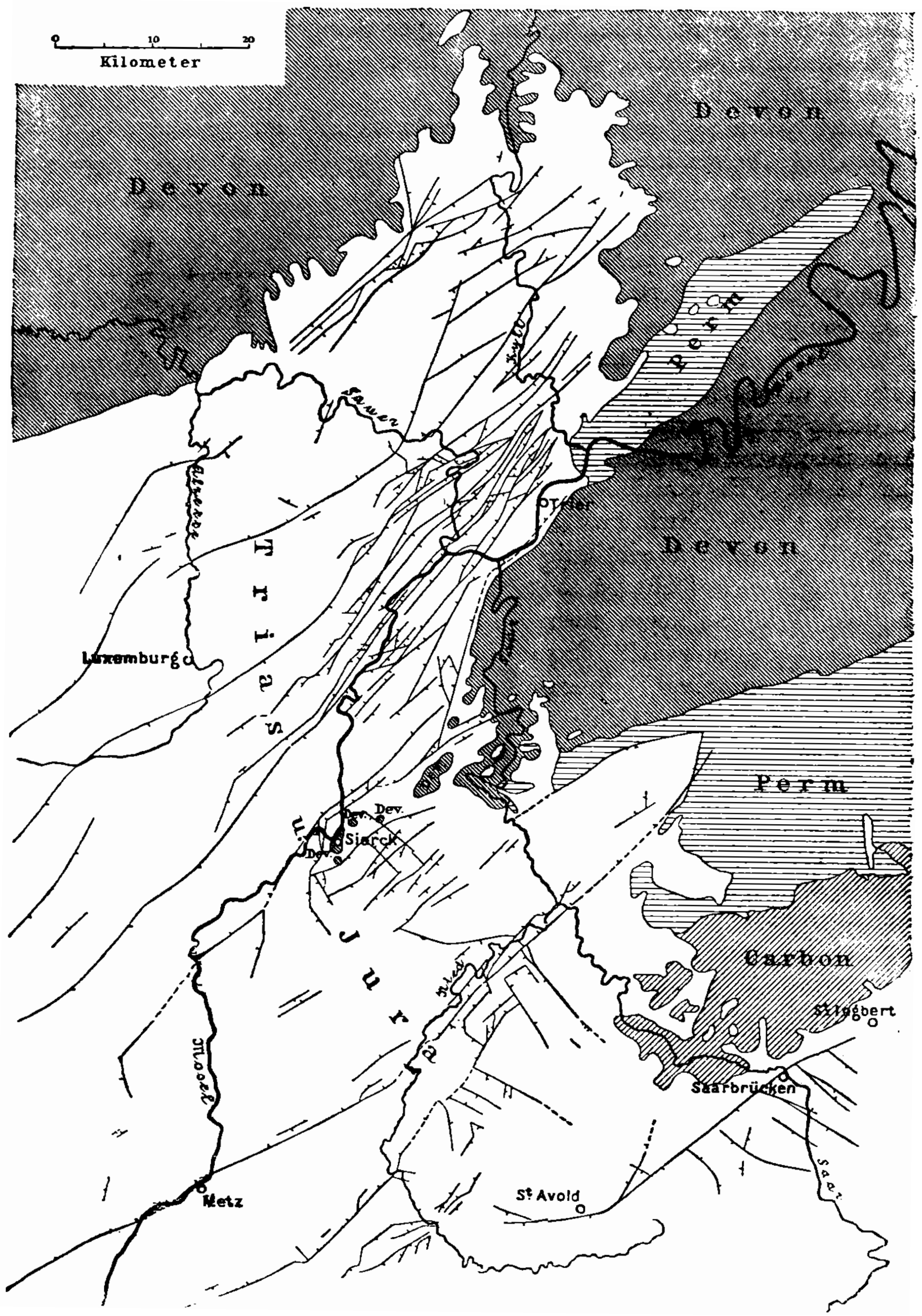


Fig. 9. *The fractures of Lorraine and Luxembourg* (after L. van Werveke).
Trias und Jura = Trias and Jurassic ; *Perm.* = Permian ; *Carbon.* = Carboniferous.

towards Luxembourg and Metz. These faults belong to the Variscan system, and run fairly parallel to the fractures of the Saar. The surveys of L. van Werveke (fig. 9) also show that by this process the two gulfs became troughs, separated by an elongated horst, which still remains visible as far as Sierck on the Mosel [1]. The resemblance of this long horst to the horsts of Lissac and Terrason shown in fig. 4, and to those of Alençon and Argentan in fig. 5, is unmistakable. The little bit of granite and Silurian south-west of Alençon (massif d'Hesloup) possesses a truly complicated structure, not at all suggestive of the axis of an independent anticline [2].

If now we picture to ourselves this posthumous folding as growing stronger towards the north, a direction so clearly expressed in the south of England, incorporating in its progress smaller horsts with itself and rising against the obstacle presented by the Malverns and their downthrown continuation to the north-east—then we have, in this incomplete range of great mountains, a scene from the development of the Alps themselves.

Transatlantic Altaides. From the southern shore of lake Maggiore to the outer border of the Jura mountains, south of Basel, the distance is 210 to 220 kilometers. If we exclude the Jura mountains and the basin of the Molasse, then the breadth from Como to the anticline of the Molasse near Lucerne amounts to 190 to 200 kilometers; from Bergamo to Bregenz is about 200 kilometers; and this includes a strip of the Dinaric system.

A line drawn straight across the Armorican arc in the meridian of 3° 30′ W. from the glaucophane rocks of the Ile de Groix to the overthrust southern border of the Glamorganshire coal-basin, west of Cardiff, measures 430 to 440 kilometers—that is, twice as much as the breadth we have just found for the Alps. Yet along this line the southern border of the Armorican system is nowhere known. The bend of the strike in the syntaxis at Valenciennes is separated from the corresponding bend in the syntactic lines south of the Cantal by a distance of scarcely less than 600 kilometers.

For the Variscan system the figures would doubtless be equally high, but owing to its more complete resolution into horsts an exact estimate is hardly possible.

A straight line starting from the outer border of the Siwaliks, south-east of Jumno, and drawn across the Tertiary foot-hills, through the continuation of the Dhauladhar and still on through Zanskár and the chains of Ladákh, close to the pass of Karákorum, as far as Shahidula, measures

[1] L. van Werveke, Uebersichtskarte der Verwerfungen des mesozoischen Gebirges in Lothringen, Luxemburg, u.s.w., in Schumacher, Steinmann, and Werveke, Erläuterung zur geologischen Uebersichtskarte des West-Deutsch-Lothringen, 1887, Pl. II; op. cit., p. 10: 'The Trias and Jurassic . . . are let down around the ancient mountains.'

[2] Oehlert et Bigot, Note sur le massif silurien d'Hesloup, Bull. Soc. géol. de Fr., 1898, 3e sér., XXVI, pp. 82–103, map.

about 500 kilometers, and thence across the Yarkand arc to the edge of the desert is about 100 kilometers more.

These figures show us how prone the eye is to underestimate the magnitudes of the past. They also show us that that part of the Armorican base which remains visible at the present day would afford room for one of the greatest folded systems of the globe. If we assume that the rias coast between Dingle bay and La Rochelle is the natural termination of this mighty structure, we do so in opposition to all observations made in other parts of the world. We must look for its termination beneath the Atlantic Ocean and on the opposite shore.

Our eyes naturally turn to the rias coast of Newfoundland and Nova Scotia.

As early as 1871, J. W. Dawson concluded, on the evidence afforded by the flora of the Carboniferous period, that a connexion extended across the Atlantic[1]. The structure of the mountains tells the same tale.

In Newfoundland the anticlines strike to the north-north-east and north-east; we have already seen that in Nova Scotia the easterly direction becomes manifest towards the ocean and that the Coal-measures rest in transgression on an older folded system (I, p. 554). It was Marcel Bertrand who, with bold hand, traced the connecting trend-lines across the ocean. He laid his results before the French Geological Society on March 21, 1887, and an important step was thus taken towards a knowledge of the plan of the northern hemisphere[2].

On the Charente, the freshwater deposits of the Weald reach the Atlantic coast, and here we must look for the continuation of the continent.

An indication is afforded in the north by the Porcupine bank. It rises to a height of −154 meters; its isobaths extend far to the south-south-west; judging from the nature of the sea-bottom, it should consist of similar rocks to those of the adjacent mainland[3]. Towards the south, depths of 4,000 meters have been sounded, but in about the latitude of the English Channel the 200 meters line lies in about long. 11° W. From this point it turns rapidly to the south-east and runs back to the great depths of the bay of Biscay.

This advance of the isobaths, which corresponds with the lie of the Scilly isles, the islands off Ouessant, and, further out to sea, Cockburn bank,

[1] J. W. Dawson, The Fossil Plants of the Devonian and upper Silurian Formations of Canada, Geol. Surv. Can., 8vo, 1871, 92 pp., and Part II, 1882, 47 pp.; in particular I, p. 82.

[2] Marcel Bertrand, La chaîne des Alpes et la formation du continent européen, Bull. Soc. géol. de Fr., 1877, 3e sér., XV, pp. 423–447; in particular map on p. 442.

[3] G. A. J. Cole and T. Crook, On Rock Specimens dredged from the Floor of the Atlantic off the Coasts of Ireland; Report on the Sea and Inland Fisheries of Ireland (for 1901) 1903, IX, Part II, App., 9 pp.

Parson's bank, &c., is the only indication—and that but slight—afforded by soundings on this side of the Atlantic of a continuation of the continent. Further out in the ocean, depths occur of over 4,000 meters.

Gwyn Jeffreys states that when laying cables in mid-ocean a rocky ridge was encountered between long. 33° 50′ and 36° 30′ W. in about lat. 51° 20′ N. Its length is about 160 kilometers, and its highest point lies at a level of −2,502 meters; thence the bottom sinks along the line of sounding, at first very rapidly (about 420 meters in a distance of 800 meters), then more gently, so that at a distance of 12·8 kilometers it lies at a level of −4,078 meters—that is, about 1,576 meters below the highest point. This ridge lies on the hypothetical trend-line of Marcel Bertrand [1].

About 880 kilometers off the coast of Newfoundland lie the Laura Ethel bank (−65 meters) and the Milne bank (−147 meters); at a distance of only 380–400 kilometers from the coast lie the Newfoundland banks within the isobath of −100 meters, and then we reach one of the most characteristic rias coasts on the globe.

Belle Isle strait cannot rightly be regarded as the boundary between the Canadian shield and the folded mountains. The outer narrower part of this strait is a fault-trough, in which flat-lying Cambrian beds are let down [2]. The broad range of hills, which forms the north-west coast of Newfoundland from the neighbourhood of the Bay of Islands (not far from lat. 49° N.) to the northern extremity of the north-west coast, is a fragment of the Canadian shield, and therefore cannot be included in the rias coast. The west coast of White bay, along with the northern and most important part of Long Range, is formed of gneiss. Yet, even after excluding this range of gneiss, the folded mountains of Newfoundland, measured across their strike, attain a breadth of more than 380 kilometers. But the other folds of the mountain chain, of which Newfoundland is a part, are cut off by the ocean along so oblique a line, and the disturbances which this chain undergoes in its further course are of so peculiar a character, that it is impossible to estimate the true breadth of the entire structure (II, p. 36).

Relations in the pre-Carboniferous period. Dawson has repeatedly pointed out that the Acadian series more closely resembles that of Europe than of many parts of America, and Walcott has described the Cambrian series of the Atlantic region of North America as a part of the European series. Ami has laid emphasis on the correspondence between the lower Silurian of Acadia and that of Britain [3].

[1] J. G. Jeffreys, Nature, Feb. 3, 1881, p. 325. The nature of the rock is not known.

[2] This is expressly stated by Hyatt in Proc. Boston Soc. Nat. Hist., 1888, XXIII, pp. 315–319.

[3] Walcott, Bull. U. S. Geol. Surv., 1891, no. 81, p. 376. H. M. Ami, Synopsis of the Geology of Canada, Proc. and Trans. Roy. Soc. Canada, 1900, 2nd ser., VI, p. 200, points out in particular the resemblance between the Skiddaw and Arenig stage, and the Hart-

Salter long ago recognized the fauna of the Tilestones in Nova Scotia, and Williams cites traces of the same fauna in the Chapman sandstone on the Aroostook river (most easterly part of the Maine). This sandstone may also include a higher horizon, at least J. M. Clarke observes that in this same district species of the Rhenish Devonian have wandered into the Chapman sandstone. All these cases bear witness to relations with Europe [1].

In Gaspé the series is continued by thick sandstone with Devonian plants. It belongs to a very extensive North Atlantic continent (II, p. 220), which probably existed, with changing contours, during the whole of the Devonian period. The remains of this continent, consisting for the most part of sandstone, are to be seen in Galicia, on the coasts of the Baltic, in Scotland, and further away in northern Russia, in the Orkneys, Shetlands, Bear island, Spitzbergen, east Greenland, Ellesmere island, and then in Acadia and the north-east of the United States. These sandstones, however, indicate a part only of its extent. Archaean hill-ranges of considerable importance must have existed to give rise to the sand. It may have included the greater part of northern Laurentia, the region of the Caledonian disturbance, and the Baltic buckler. The continent was a desert land, diversified with stretches of inland water, many of them fresh, and consequently possessing an outflow, while others were salt.

Geikie long ago attempted to define the boundaries of the Devonian lakes of Great Britain and to picture the physical conditions of the area as it existed in Devonian times. Nathorst has shown that *Archaeopteris archetypus* occurs on the Donetz and also far to the north in Ellesmere island, and similarly *Bothriodendron Kiltorkense* is found in Ireland on the one hand, and Bear island on the other [2]. Plants and fishes were carried out into the Devonian seas; *Dinicthys pustulosus*, *Dipterus flabelliformis*, and other species occur, according to Lohest, in the upper psammites of Condroz, Belgium, and in the upper Devonian of America; in both cases associated with *Spirifer disjunctus* [3].

J. W. Dawson, with great insight, arrived at true conclusions in 1871, when only a small number of facts was known. The centre of origin of

fell and Llandeilo beds of the lower Silurian of Britain, on the one hand, and Acadian beds on the other.

[1] H. S. Williams, The Palaeozoic Faunas of Maine, Bull. U. S. Geol. Surv., 1900, no. 165, pp. 21–92, in particular p. 80 et seq.; J. M. Clarke, Evidences of a Coblenzian invasion in the Devonian of East America, Festschrift für von Koenen, 8vo, Stuttgart, 1907, pp. 359–368.

[2] A. G. Nathorst, Zur Fossil-Flora der Polarländer: I, 3, Zur Ober-Devon-Flora der Bären-Insel, 4to, Svensk. Vet. Akad. Handl., 1902, XXXVI, no. 3, 60 pp., and Die Ober-Devon-Flora des Ellesmere-Landes, in Report of the 2nd Norwegian Arctic Expedition, no. 1, 8vo, Kristiania, 1904, 22 pp.

[3] Lohest, Ann. Soc. géol. Belg., 1888–1889, XVI, p. lvii.

the older sediments of the Appalachians must have lain somewhere to the north-east. In the Carboniferous epoch this centre furnished connecting links in the Atlantic region between the floras of Europe and America. In the Devonian such connecting links could only have existed far to the north-east. The most ancient flora of America must thus be sought in Newfoundland, Labrador, and Greenland, and that of Europe on the margin of the ancient Scandinavian nucleus. That the Appalachians may have formed the connexion with Europe, at least within the Devonian epoch, was, as observed above, already suggested by Dawson[1].

The flora just mentioned was termed by Dawson the Erian flora, and the corresponding deposits the Erian group, since they also occur on lake Erie, where they had been distinguished as the Erie division. To the great Devonian continent we will give the name of *Eria*.

The upper division of the Erian flora coincides with Heer's Ursa-flora, from which, as Nathorst has shown, the Culm flora of Spitzbergen must be separated as distinct[2].

In the north-eastern part of the United States we have to consider, besides the continent of Eria, three seas, each of which played an important part in the period preceding the Carboniferous; these were: the Eurasiatic-Arctic on the north-west, the Atlantic on the east, and the Mississippi sea on the south.

The first may be recognized by the middle Devonian transgression which extends from Asia past Manitoba, and even still further to the south. *Stringocephalus Burtini* has been found by Stoliczka on the south side of the Thian-shan, and by McConnell in the Ramparts of the lower Mackenzie[3]. The ancient Atlantic sea of the Cambrian and Silurian epochs has already been mentioned. The presence of the third southern sea has given rise to very complicated, but, at the same time, very instructive, relations. Within the last few years a general survey of these relations has been rendered possible by the publication of a number of special stratigraphical memoirs, such as those by Williams, Prosser, and Kindle[4],

[1] J. W. Dawson, The Fossil Plants of the Devonian and upper Silurian Formations of Canada, Geol. Surv. Can., 1871, 92 pp., I, p. 82.

[2] A. G. Nathorst, Zur Fossil-Flora der Polarländer, I, Zur palaeozoischen Flora der arktischen Zone, Svensk. Vet. Akad. Handl., 1894, XXVI, no. 4; in particular p. 74. Stur perceived that a Culm flora was present in Spitzbergen, Verh. Geol. Reichsanst., 1877, p. 80.

[3] J. F. Whiteaves, The Fossils of the Devonian Rocks of the Mackenzie River Basin, Geol. Surv., Canada; Contribution to Canadian Palaeontology, 1891, III, pp. 197–253; in particular, p. 235.

[4] H. S. Williams, The Correlation of geological Faunas, a Contribution to Devonian Palaeontology, Bull. U.S. Geol. Surv., 1903, no. 210, 147 pp.; also C. S. Prosser, The Upper Hamilton and Portage Stages of Central and East New York, Am. Journ. Sci., 1893, XLVI, pp. 212–230; E. Kindle, The Devonian Fossils and Stratigraphy of Indiana,

and by attempts at synthesis by Ulrich and Schuchert, and later by Schuchert alone[1].

In tracing the transgression which starts from the Mackenzie we observed that the Marcellus slate, Hamilton group, and Genessee slate form the middle Devonian of the State of New York. The slates above and below the Hamilton group resemble each other so closely that Williams regards the Genessee as a repetition of the Marcellus stage. The Hamilton group contains a rich marine fauna, and towards its upper part a bed with special characters, the Tully limestone, containing *Rhynconella cuboides*, sets in (II, p. 231).

It was an important step in advance when Williams showed that the European types (or Asiatic—in this case an equivalent term) are restricted to the Tully limestone, and *that the Hamilton group contains a foreign fauna*, which has since been named the *Tropidoleptus carinatus* fauna[2].

The succession is thus as follows: Slates (Marcellus); beds with a foreign fauna (Hamilton, Tropidoleptus); limestone with the European fauna (Tully limestone, *Rhynconella cuboides*); then again slates (Genessee). Above these follow beds with faunulae which possess either ill-defined characters or characters varying in a peculiar manner, but which are connected with Europe by vicarious species at least; with these are also intermingled some species of the Tropidoleptus fauna, also trunks of trees which have been floated in, and remains of great fishes (Productella fauna or Ithaca formation; Cardiola fauna or Portage stage); they extend up to the highest marine member of the American Devonian, the *Spirifer disjunctus* fauna (Chemung stage). This characteristic fossil is itself a typical European form, yet even in the midst of the Chemung stage Williams has observed an intercalation, like a colony, of the pure Tropidoleptus fauna.

Then follows the Catskill stage, i.e. the Erian sandstone with terrestrial plants and fishes.

There is thus an interdigitation of two marine faunas, and with this an interspersion in the Chemung stage of littoral forms derived from the Erian shore. The uppermost part of the marine Devonian as known in Europe does not seem to be represented. About this time the Erian sand gained the supremacy. Frech mentions a number of sand-loving bivalves from the middle Devonian of America, which may be regarded as vicarious with European forms; also five species of Avicula (Leptodesma)

25th Ann. Rep. of the Department of the Geology of India, 1900, pp. 529–758, and an abundant literature besides.

[1] E. O. Ulrich and T. Schuchert, Palaeozoic Seas and Barriers in East North America, Rep. N. York State Palaeontology, 1901, pp. 633–663; Schuchert, On the Faunal Provinces of the Middle Devonian of America and the Devonian Coral-Sub-Provinces of Russia, Am. Geol., 1903, XXXII, pp. 137–162, maps et passim.

[2] H. S. Williams, The Cuboides-Zone and its Fauna, Bull. Geol. Soc. Am., 1889, I, pp. 481–500.

which the Chemung stage possesses in common with the Famennian of Belgium[1]. These may be traces of the littoral fauna.

These observations lead to two suppositions.

The Old Red sandstone enters the anticline of the Mendips (II, p. 87), and on the west coast of Ireland its saddles advance into the sea as the spurs of the rias coast between Dingle bay and Crook bay (II, p. 83). It does not extend farther south than these Armorican folds, but the Erian fishes and plants extend as far as Thuringia, Bohemia, and the Donetz. A similar distribution is to be seen in America. The Erian sediments belong to the foreland, but they are also involved in some of the outer folds. This leads us then to suspect, in the first place, that the north border of the Altaides is continued beneath the ocean not very far from the southern border of the foreland of Eria.

The second supposition admits of more definite proof; it concerns the seas. The Eurasiatic-Arctic sea appears to have extended southwards to Iowa and Missouri. The alien Tropidoleptus (Hamilton) fauna may be traced from the east of New York State to Wisconsin, through many of the central States, and beyond the Ozark mountains to the south. To the west, in Iowa, it is not known (with the exception of *Phacops rana*). In many places a transgression already begins with the subjacent Onondaga stage; a similar transgression is also said to occur in Europe. The Onondaga (Oriskany) fauna of the central States is also cited as the fauna of *Leptocoelia* (*Anoplotheca*) *flabellites* (A. Ulrich's Icla slates), and the Hamilton (Tropidoleptus) fauna is described as the fauna of *Vitulina pustulosa* (which also occurs in the Hamilton stage of New York). Under these names both these stages are mentioned as occurring at many places in South America, the former also in the Falkland islands and Cape Colony. The Tropidoleptus stage even reaches the central Sahara.

The Hamilton stage represents the course taken by this broad southern ocean in approaching the continent of Eria over north America.

Series of strata in the Carboniferous. A long line of Coal-measures, present in Cracow and lower Silesia, on the Ruhr, in Belgium, the south of England and south Wales, corresponds to the coal-fields of the Appalachians on the other side of the ocean (II, p. 233). In the European region lower Carboniferous limestone of marine origin, and marine intercalations of the Culm, occur at the base of the Coal-measures; and then over the whole tract between the border of the Carpathians and England isolated marine intercalations occur within the Coal-measures of the Ostrau stage. These intercalations, at least in the region extending from lower Silesia to Belgium, assume characters which become increasingly littoral as they ascend in the series; they have left their last trace in isolated bivalves, and it seems

[1] F. Frech, Lethaea palaeozoica, I, 8vo, Stuttgart, 1901, p. 253; Williams, Bull. U. S. Geol. Surv., 1900, no. 165, p. 80.

probable that on the horizon of Schatzlar they have ceased to exist. Upper Carboniferous of marine origin is absent, not only in these coal-fields, but in all that part of the continent of Europe which lies to the north of them.

It seems as though the advance of the Variscan and Armorican folds had driven back the upper Carboniferous sea from Central Europe. The process recalls the way in which the Mediterranean sea was driven back from the same region by the advance of the Alps. Just as marine sediments of the third Mediterranean stage are absent north of the Alps, and we must descend into the lower Rhone valley in order to discover them, so the marine upper Carboniferous is absent north of the Variscan and Armorican arcs, and to observe it we must go to Asturias, the Carnic mountains, or Russia.

In North America the process finds still clearer expression. The marine limestone of the lower Carboniferous is widely distributed even as far as New Brunswick and Newfoundland, but no marine intercalations occur between the Coal-measures with the exception of beds containing so-called Najadites in the north-east. They begin in west Virginia and Ohio, and upper Carboniferous of distinctly marine origin is not to be seen till we proceed still further to the west and south-west, into Iowa and Illinois, Kansas and Oklahoma, Arkansas and Texas.

J. P. Smith has drawn attention to the correspondence between the upper Carboniferous fossils of Arkansas and those of Lo-ping, and describes them as indications of a Carboniferous Pacific Ocean. The waters of this ocean are known to have extended over British Columbia, Alaska, Japan, south Ussuri, and far away into the interior of Asia. According to Tschernyschew it is represented by deposits on the north border of the Parry Archipelago, and as far as cape Feilden (lat. 82° 44′ N.); hence we may conclude that marine upper Carboniferous extends around Greenland to Spitzbergen and Bear island [1].

In Europe it was only the upper Carboniferous sea which was driven back by the folding, and in the Permian the poverty-stricken fauna of the Zechstein already presents itself as the forerunner of the succeeding marine faunas; but in the north-eastern part of the United States and the adjacent part of Canada all the region lying outside the folds, that is, the land to the north-west and west, was completely separated from the sea during the long interval which elapsed between this period and the post-glacial transgression. Even the marine upper Cretaceous reaches only the inner side of the folds.

Thus any further comparison with the formations of Europe must be based on the terrestrial floras.

The distribution of the coal-bearing Carboniferous is not uniform. New-

[1] J. Perrin Smith, Marine Fossils from the Coal Measures of Arkansas, Proc. Am. Phil. Soc., 1897, XXXV, no. 152, 72 pp.; for the distribution in particular, H. Yabe, A Contribution to the Genus Fusulina, Journ. Coll. Sci. Tokyo, 1906, XXI, Art. 5, 36 pp.

foundland, Nova Scotia, and New Brunswick may be regarded as forming the first of the coal-bearing regions, and in this the series is distinguished by the variety of its development. In the second region, which includes Gaspé and Maine, and extends as far as Connecticut, it is but very poorly represented. The richest and most extensive Coal-measures occur on the west side of the Appalachians between Pennsylvania and Alabama, and even on the other side of the Mississippi, extending to Arkansas and beyond. Another region, closely connected with the preceding, comprises the rich coal-bearing series, of no great thickness, which extends to the west in horizontal beds unconformably superposed upon the Laurentian foreland—that is, over parts of Michigan, Illinois, Iowa, and Missouri.

The detailed work of the Geological Survey of Pennsylvania, the stratigraphical descriptions of J. J. Stevenson, and the phyto-palaeontological studies of David White are our most important sources of information on this system. Generally speaking, the upper Carboniferous sediments are thicker in the neighbourhood of the Appalachians, and thin out towards the west. But since their decrease in thickness is not uniform, and the lower members of the several stages thin out more rapidly than the upper, it happens that in different districts different horizons form the base, and the term 'lower Coal-measures' becomes indefinite and often misleading.

But it is not only towards the west that the lower members thin out. A map given by D. White shows that in front of the Appalachians a long depression was formed which attained its greatest depth in the south-east of west Virginia, and there the thickest deposits were formed; while towards the north-east, in south-west and central Pennsylvania, there was a ridge above which several of the lower members are absent[1]. In the following survey, therefore, we shall give preference to the neutral nomenclature afforded by local terms.

1. *The Pocono series.* Stevenson has described the conditions which immediately preceded the Carboniferous in Pennsylvania and Virginia—the great thickness of the Erian sands in the north-east, their rapid thinning out towards the south-west, the retreat of marine life before them, and the unequal surface which they left behind—and under the circumstances we may readily understand how difficult it is to classify the sediments which have been produced by the working up or rearrangement of these sands[2].

At the same time we are reminded of the masses of sand which are driven by storms at the present day out of the Sahara into the Atlantic Ocean.

[1] D. White, Deposition of the Appalachian Pottsville, Bull. Geol. Soc. Am., 1904, XV, pp. 267–282; in particular Pl. II.

[2] J. J. Stevenson, Lower Carboniferous of the Appalachian Basin, Bull. Geol. Soc. Am., 1903, XIV, pp. 15–96, in particular pp. 42 and 86; Carboniferous of the Appalachian Basin, op. cit., 1906, XVII, pp. 65–228.

Above the lower beds we can distinguish an horizon which corresponds with the European Culm. In Newfoundland it is a coarse conglomerate, and in Nova Scotia it forms Dawson's *Horton series*, which is correlated by this observer with the Tuidian of the north of England. It contains a flora with species characteristic of the Culm, such as *Cyclopteris* (*Aneimites*) *Acadica*[1]. Indications of this horizon are not absent elsewhere; in Worcester (Massachusetts) *Lepidodendron acuminatum*, Göpp. of the Silesian Culm has been met with in a bed of graphite in the mica-schist[2]. In Virginia and west Virginia the plants which Fontaine mentions as occurring in the Vespertine series must also be assigned to the Culm[3].

2. *The Mauch Chunk group.* This corresponds with the Carboniferous limestone (II, p. 233): it forms an easily recognizable marine member which may be traced from Newfoundland to the end of the Appalachians, and it is absent only in Pennsylvania and parts of Virginia.

3. *The Pottsville group* (Millstone grit) in some places lies unconformably upon the Carboniferous limestone. Near Pottsville, Pennsylvania, where there is no such unconformity, D. White mentions plants, such as Aneimites and others, which probably belong to the Culm, as occurring near the upper limit of the Mauch Chunk group. The lower Pottsville measures (lower Lykens in Pennsylvania) contain the flora of Ostrau, while in the upper Lykens the species representative of the flora of Schatzlar (lower Westphalian stage) make their appearance. To this upper group must be assigned the flora of St. John, in New Brunswick, which Dawson at one time regarded as Erian. The Millstone grit of Canada must also be assigned to this horizon. It may be traced to Alabama[4].

4. *The Alleghany group* (lower Coal-measures, Rogers). In the west, for example in Missouri and Iowa, this important stage lies in transgression upon denuded Carboniferous limestone or still older rocks. Its flora appears in the northern anthracite region (Coal-measures, C and D), the bituminous district of Pennsylvania (Cannelton), Virginia (parts of the Kanawha measures), and then further west in Illinois (Mazon Creek), Missouri (Henry

[1] J. W. Dawson, Fossil Plants, II, p. 128; H. Fletcher, Geological Nomenclature in Nova Scotia, Proc. and Trans. N. S. Inst. Sci., Halifax, 1900, X, pp. 235–244. The term 'Culm' is employed below in its usual sense; the question whether the typical Culm of England really possesses so great an age has not been considered here; a reference may suffice to E. A. Newell Arber, The Fossil Flora of the Culm-Measures of North-west Devon, Proc. Roy. Soc., 1904, LXXIV, pp. 95–99.

[2] J. Perry, Am. Journ. Sci., 1885, 3rd ser., XXIX, p. 157.

[3] W. M. Fontaine, Notes on the Vespertine Strata of Virginia and West Virginia, Am. Journ. Sci., 1877, 3rd ser., XIII, pp. 37–48 and 115–123.

[4] D. White, The stratigraphical succession of the fossil Floras of the Pottsville Formation in the South Anthracite Coalfield, Pennsylvania, U. S. Geol. Surv. Ann. Rep., 1900, XX, 2, pp. 749–918; in particular p. 911 et seq.

County)[1], Kansas (Lansing Coal-measures)[2], and the Indian Territories (Grady coal)[3]. It corresponds to the Schatzlar (Westphalian) flora of Europe, and it would appear, indeed, that it can even be correlated with the several subdivisions of this flora. Thus D. White has shown the correspondence in Henry County with Zeiller's middle and upper Westphalian, in particular with the zone de Bullygrenay of the Coal-measures of Valenciennes, while the coal *E*, of the northern anthracite region, would seem to correspond to the horizon of Geistlautern, and *G* to the Ottweil beds. The Grady coal should be the equivalent of the lower part of the Schatzlar series. We have every reason to share White's astonishment at the uniformity which prevailed in the external conditions of life during this epoch on both sides of the ocean.

5. *The Conemaugh group* (lower barren measures) and 6, the *Mononghela* (upper productive measures) represent the upper Carboniferous of Europe (Stefanian stage, Ottweil beds). A bed of Crinoidal limestone in Conemaugh may be regarded as the last trace left by the advance of the sea from the south-west. This is the period in which the sea was constricted off. In the north-east the marine intercalations terminate with the close of the Mauch Chunk stage; in the south-west they persist, chiefly as Fusulina limestone rich in Brachiopods. The flora of the Mononghela stage is known in Nova Scotia (Joggins) and also in Kansas (Le Roy shales), and the Indian Territories of the south (McAlester measures).

7. *The Dunkard group* (upper barren measures) is Permian. The coarse red New Glasgow conglomerate, which occurs in transgression in Nova Scotia, is associated with thin coal-seams, and continued along with red sandstone across Northumberland strait into the large and level Prince Edward island; it is described by Poole as Permian[4]. In Prince Edward island the sandstone, which was formerly regarded as belonging to the Trias, has yielded Ulmannia, Walchia, and other plants of the Rothliegende. In the typical Dunkard beds, which occur in south-west Pennsylvania, east Ohio, and parts of west Virginia, D. White observed among plants common to Europe and America only those of the lower Rothliegende

[1] D. White, Fossil Flora of the Lower Coal Measures of Missouri, op. cit., Monograph XXXVII, 1899, 307 pp.; in particular p. 298 et seq.

[2] G. J. Adams, G. H. Girty, and D. White, Stratigraphy and Palaeontology of the upper Carboniferous Rocks of the Kansas Section, U. S. Geol. Surv. Bull., no. 211, 1903, 123 pp.; in particular p. 110 et seq.

[3] J. A. Taff, D. White, and G. H. Girty: Geology of the McAlester coal-field by Taff, Report on fossil Plants by D. White, Report on Palaeozoic invertebrates by Girty; U. S. Geol. Surv. Ann. Rep., XIX, 3, 1899, pp. 423–593; in particular p. 457 et seq.

[4] H. S. Poole, The Pictou Coal Field, Proc. and Trans. N. S. Inst. Sci., Halifax, 1895, VIII, pp. 228–243, map. As regards the age of the sediments on Prince Edward island, see Russell and Knowlton, U. S. Geol. Surv. Bull., no. 58, pp. 25–31. They were formerly believed to be Trias.

(Kusel beds)[1]. Marine intercalations do not occur until we reach Texas. One of the most remarkable genera, Cope's Naosaurus from the red Permian of Texas, was found by A. Fritsch, though represented by a much smaller form, in the Permian gas-coal of Bohemia[2]. Handlirsch has likewise shown that the insects of the Carboniferous from the lower Lykens to the uppermost limit of the system present a striking correspondence in Europe and America, both as regards their general course of evolution and the taxonomic characters of their several subdivisions[3].

The Appalachians as far as the Mississippi. This great range reveals itself as part of the Altaides by its course and disposition; by the rias coasts, which must form a junction somewhere in the north-east; by the free ends in which it terminates in the south-west; by the contemporaneous discordance at the base of the Culm, and by the completion of its growth before the entrance of the Ottweil flora or the Permian.

The range consists of several parts or coulisses. Towards the end of the peninsula of Gaspé the strike bends completely round out of the normal south-west into an east-south-east direction; this has been demonstrated by borings for petroleum made in the Devonian[4]. The island of Anticosti belongs to the border of the Canadian shield. The same is true of the northern half of Long Range in Newfoundland. In this way the gulf of St. Lawrence is framed-in in a peculiar manner.

On the east of Long Range, Newfoundland is formed of closely-crowded folds which include rocks extending from pre-Cambrian to Carboniferous, often altered by pressure. The rias coasts in the north and south of the great island are the expression of this folding.

The Carboniferous, here including the conglomerate of the Horton stage (Culm), the marine Carboniferous limestone with associated gypsum, the Millstone grit, and the coal-bearing series, occurs in the south-west around St. George bay and Port-à-Port bay. The plants which Dawson mentions as occurring at St. George bay are for the most part well-known European types belonging to the flora of Schatzlar (*Sphenopteris Hoeninghausi, Pecopteris abbreviata, Alethopteris lonchitica* and others)[5]. These

[1] D. White, Permian Elements in the Dunkard Flora, Bull. Soc. Geol. Am., 1903, XIV, pp. 538–542.

[2] E. D. Cope, Systematic Catalogue of Vertebrates found in the Beds of the Permian Epoch in North America, Trans. Am. Phil. Soc. (1886), 1890, XVI, pp. 285–297; in particular p. 293; A. Fritsch, Fauna der Gaskohle und der Kalksteine der Permformation Böhmens, 4to, Prague, 1895, III, p. 121, and 1901, IV, p. 87.

[3] A. Handlirsch, Revision of American Palaeozoic Insects, Proc. U. S. Nat. Mus., Washington, 1906, XXIX, pp. 661–820.

[4] R. W. Ellis, The Oil Fields of Gaspé, Geol. Surv., Canada (1902-3), 1906, XV, A, pp. 310–363, map.

[5] J. W. Dawson, Carboniferous Fossils from Newfoundland, Bull. Geol. Soc. Am., 1891, II, pp. 529–540.

Carboniferous beds are continued into the interior towards the north-north-east along the east side of Long Range, and they certainly extend nearly to the northern edge end of the Grand Pond (lat. 49° N.). It may be inferred also from Murray's statements that traces of them may be recognized even much further still, in the same direction, up to Cap Rouge and Fox cape on the west coast of White bay (about lat. 51° N.) [1].

Thus it would seem that a band of coal-bearing Carboniferous lies in front of the boundary of the foreland; and, if so, White bay would correspond to the place where the Coal-measures of the Armorican belt might be expected to again emerge from the ocean.

According to Dana's view, which has been confirmed on many sides, the folds of Newfoundland proceed towards cape Breton [2]. This leads to the following conception of the facts as a whole.

The innermost range is probably represented in part by Sable island (long. 60° W., lat. 44° N.), which is said to consist of lower Carboniferous.

The first visible fragment of a continuous coulisse is formed by the lower Palaeozoic sediments which strike obliquely across Nova Scotia from St. Mary bay to Chedabucto bay in the north-east. In the south the form of the rias coast is deceptive. It might lead us to assume a strike to the south, but Bailey found that the folds strike away to the south-west and west-south-west. This misleading appearance is produced by intrusive granites, which cut through the folds, and by transverse valleys resembling fjords [3]. In the north, near Chedabucto bay, the strike turns more and more to the east-north-east (I, p. 554). Towards Fundy bay, beds containing Dictyonema are immediately overlain by the Horton series, which here already indicates the unconformable transgression of the Culm, and this is followed by a belt of horizontally stratified Trias, along with a belt of Trias trap, which forms for a long distance the south-east shore of Fundy bay. Further to the north, in cape Breton, we see, on looking northwards —that is, towards Newfoundland—folds which diverge from one another; and here, too, the first traces of Coal-measures make their appearance. The richest coal-field, that of Pictou, lies on the north-west side of Nova

[1] A. Murray and J. P. Howley, Geological Survey of Newfoundland, 8vo, London, 1881, p. 41 (as Devonian), pp. 67 and 309.

[2] J. D. Dana, Archaean Axes of East North-America, Am. Journ. Sci., 1890, XXXIX, pp. 378–383.

[3] L. W. Bailey, Report on the Geology of South-west Nova Scotia, Ann. Rep. Geol. Surv. Canada, IX, 1898, M, 151 pp., map. Something similar is to be seen in the Fox islands, Penobscot bay, Maine; they consist of an eruptive rock, the contour of which is independent of the folds striking to the south-west; G. Otis Smith, The Geology of the Fox islands, Dissertation, 8vo, Skowhegan, Maine, 1896, map; H. Fletcher, King's and Hants Counties, Ann. Rep. (1901), 1902, XIV, A, p. 210 et seq.; A. Keith, Geology of the Catoctin Belt (where the commencement of the virgation is particularly clear), Ann. Rep., XIV, 2, pp. 285–395, maps.

Scotia, where the constriction of the country begins. The Coal-measures are folded: they lie upon the Millstone grit, which belongs to the Pottsville stage. We may therefore assign them, like those of St. George bay (Newfoundland) and St. John (beyond Fundy bay), to the horizon of Schatzlar (upper Lykens). The synclines of Pictou seem, as a whole, to have been so severely denuded that, in place of a continuous band of Coal-measures, we find only isolated basins. On their north border, according to Fletcher, a dislocation brings the Coal-measures of Pictou into juxtaposition with coal-measures of the Rothliegende conglomerate, which rests unconformably on the Carboniferous.

The constriction in the south of Northumberland strait, across which the beds strike, is evidently of fundamental importance in a study of the structure of this region. It is here that we must look for the outer border of the folds of Nova Scotia; and here, on the north-east side of Chignecto bay (north-east Fundy bay), the great Joggins series, described by Dana, contains the flora of Ottweil, and lies flat—a very remarkable fact [1].

The bedding becomes flat therefore on the same horizon as in the Altaides.

The land situated further towards the north-west presents, in fact, a totally different structure. The clearest general description has been given by Poole [2].

The coast of New Brunswick, from the north coast of Chaleurs bay onwards, almost up to the eastern end of Northumberland strait, is formed of flat-lying beds only. In the north, lower Carboniferous rests unconformably upon the folds of Gaspé; at the same time it extends in a broad angulated range through Fredericton into the interior, and again reaches the sea at the Verte bay, thus enclosing a basin-like area, the north side of which forms the above-mentioned flat north coast of New Brunswick.

The whole of this area is filled by a 'grey series' of trifling thickness, containing a few insignificant coal-seams, and succeeded by the Rothliegende with Walchia and other plants. The Rothliegende is continued into Prince Edward island; the sea is here very shallow, and the island itself is only a fragment of the flat northern part of New Brunswick. It presents some gentle undulations with an east-north-east strike.

In the south the grey series lies conformably on the Ottweil beds of the Joggins series; it represents a zone of transition between the Permian and Carboniferous.

Gaspé and Maine belong to another mountain complex. New Brunswick represents to a certain extent the foreland of Newfoundland and

[1] H. Fletcher, Geol. Surv., Canada (1882–1884), 1885, H; Geology of North Cape Breton, 98 pp. For the Horton unconformity in Nova Scotia, op. cit. (1901), 1905, XIV, A, p. 214; for the Joggins unconformity, tom. cit., A, p. 208 et passim.

[2] H. S. Poole, Report on the Coal Prospects of New Brunswick, Geol. Surv., Canada (1900), 1903, XIV, MM, 17 pp., in particular p. 9 et seq.; also Bailey, op. cit., M, 26 pp.

Nova Scotia. We may assume that near the outer border of the folds an interrupted band of folded Coal-measures of the Schatzlar stage strikes from St. George bay (Newfoundland) towards Pictou (west Nova Scotia) and possibly towards St. John (New Brunswick). Culm (Horton series) and Carboniferous limestone lie unconformably in Newfoundland, Nova Scotia, and New Brunswick. This unconformity at the base of the Carboniferous is the same as that of which we cited an example from the Thian-shan (p. 2); it is repeated in the Sudetes and in Brittany. Near Joggins the Coal-measures of the Ottweil stage lie undisturbed; the Rothliegende is only traversed by gentle anticlines. With the exception of these last trifling undulations, the mountain building is thus of pre-Permian age. *This synchronism shows that the movements which gave rise to the Altaides have been propagated across the Ocean.*

The independent position of the Gaspé-Connecticut fragment has already been mentioned. A great dislocation, the 'Lawrence Champlain-fault,' forms the boundary between this fragment and the Laurentian foreland. The advance of a part of the foreland, to which the Adirondacks belong, determines the deflexion of this boundary towards the south [1].

To all appearance a fairly uniform anticline of lower Palaeozoic beds starts from Gaspé and runs fairly parallel to the boundary through the Shickshock mountains [2]. The European character of some of the faunulae of north-east Maine has already been referred to; here, also, there is a prevalent north-easterly strike, yet at several places towards the middle of Maine isolated groups of volcanic rocks (andesite, rhyolite, and others) crop out [3]. The interior of this region is little known.

As the boundary between the folded mountains and the foreland enters the interior below Quebec, the folds bend more and more to the south. The compressed rocks run past the east side of lake Champlain, then turn from New York through Vermont and Massachusetts to Connecticut: their course was traced by Walcott on a sketch-map in 1888 [4]. The most violent damming back probably occurs on lake Champlain and a little south of it. Then the several coulisses turn more and more to the south-south-west and cross the Hudson obliquely.

The ranges of gneiss, which run on both sides of Connecticut river with a north and south strike, form Dana's New Hampshire range; they also form the Green mountains. For west Massachusetts, in particular, we

[1] For the boundary see H. P. Cushing, Geology of the North Adirondack Region, New York State Museum, 1905, Bull., no. 95, pp. 271–453, maps.

[2] Ells, Geol. Surv., Canada, Ann. Rep. (1882–1884), 1885, F, p. 31; Low, tom. cit., pp. 16–20.

[3] H. S. Williams, see previous notes; H. E. Gregory, Geology of the Aroostook volcanic area of Maine, ibid., pp. 93–188, map.

[4] C. D. Walcott, The Taconic System of Emmons, and the Use of the Name Taconic in geological Nomenclature, Am. Journ. Sci., 1888, XXXV, pp. 229–327, 394-401, map.

have a number of admirable descriptions of these long ranges, exemplary studies of chains highly altered by pressure. Emerson, in his account of north-west Hampshire, describes the occurrence, in the midst of these compressed meridional ranges, of the trough of the Connecticut river, in which Trias beds have been let down to a depth of 1,600 meters [1].

The mountain waves, after they have surrounded the Adirondacks and the projecting part of the foreland, press forwards and at the same time diverge from one another, somewhat as they do in the Urals, south of the Ufa plateau (III, p. 365). Here also we may assume compulsory virgation.

The deflexion is least apparent in the eastern ranges, among which we must include the folds of the Piedmont plateau. This plateau was formerly regarded as Archaean; we may now assume that it was not folded until after the deposition of the Culm. Even in Massachusetts, plants of the Culm are said to occur, associated with graphite, in mica-schist; and to the south, in Alabama, E. Smith has met with Lepidostrobus in semi-crystalline graphitic schists [2].

The Piedmont plateau in Maryland has been described by Mathews, and in Pennsylvania by Bascom [3]. A long range of gabbro runs within the plateau, from New York through Delaware, Maryland, and south-east Pennsylvania to Virginia: it is very much ramified, and forces its way from the gneiss into the lower Silurian. Where it has undergone pressure, green hornblende and, to a lesser extent, biotite take the place of the pyroxene in this rock [4].

The deflexion is most considerable in the outer folds. It is very clearly seen in the south-west of New York State and as far as the anthracite coal-fields of north-east Pennsylvania. It produces many wonderful overthrusts, and the compulsory virgation gives rise to the broad sigmoid flexure of the Pennsylvanian coal-fields [5].

Bailey Willis has made the structure of the main range of the Appalachians the subject of studies, from which we derive the following [6]:—

[1] R. Pumpelly, J. E. Wolff, and T. Nelson Dale, Geology of the Green Mountains, Mass., U. S. Geol. Surv. Monograph, XXIII, 1894; B. K. Emerson, The Geology of East Berkshire City, Mass., op. cit., Bull., no. 159, 1899. For the region adjoining this on the south, and a little further to the east: Geology of Old Hampshire City, Mass., op. cit., Monogr., XXIX, 1898, as well as the corresponding folios of the U. S. Geol. Surv.; also W. H. Hobbs, On the geological Structure of the Mt. Washington Mass of the Taconic Range, Journ. Geol., Chicago, 1893, I, pp. 717–736, and many other detailed descriptions.

[2] E. Smith, Science, 21 Aug., 1903, pp. 244–246.

[3] E. B. Mathews, The structure of the Piedmont Plateau as shown in Maryland, Am. Journ. Sci., 1904, XVII, pp. 141–159; F. Bascom, Piedmont District of Pennsylvania, Bull. Geol. Soc. Am., 1905, XVI, pp. 289–338.

[4] Bascom, Bull. Geol. Soc. Am., 1905, XVI, p. 311 et seq.

[5] e. g. N. F. Darton, Two overthrusts in New York, Bull. Geol. Soc. Am., 1893, IV, p. 438.

[6] Bailey Willis, The Mechanics of the Appalachian Structure, U. S. Geol. Surv. Ann. Rep., XIII, 2, 1893, pp. 211–281, maps.

The folds and thrust-planes extend here for a distance of more than 720 kilometers; the several structural lines are remarkably parallel and very long; one of them attains a length of 600 kilometers. The anticlines present a steep dip on the north-west side and a gentle dip on the south-east; on their north-west side thrust-planes occur. Although considerable displacements exist, yet no rocks of greater age than the Cambrian are exposed. The thickness of the sediments, and particularly of the Devonian, decreases rather rapidly towards the south-west. Four types of structure may be distinguished: (1) open folds (in Pennsylvania and east Virginia, i. e. the region of the compulsory virgation); (2) close folds (in the so-called valley of the Appalachians, i. e., broadly speaking, a zone of older sediments preceding the pre-Cambrian zone); (3) folding and movement along thrust-planes, giving rise to imbricate flakes (south Virginia, Tennessee, Georgia); (4) folding with foliation, i. e. powerful dynamic effects (this zone is scarcely to be distinguished from the Piedmont zone).

Of particular interest are the circumstances under which the folding of the outer zones (1 and 3) passes into imbricate structure towards the south-west.

In the same section of the outer zones we may observe as many as ten of these imbricate flakes in succession. On the Coosa river, however, south of the boundary of Georgia and Alabama, the borders of the two eastern-most flakes bend round almost at right angles and step over the western flakes lying in front of them, *which retain the normal strike to the south-west with a slightly concave curve.*

From the description given by W. Hayes we may discern the following: The first thrust-plane (Rome fault) is part of a line which has been traced for a distance of 440 kilometers; the distance to which the overthrust part has been carried is 4 kilometers. At Resaca a window occurs, 3 kilometers in length, which exposes Carboniferous beneath Cambrian beds. A few patches advance beyond the edge of the flake and lie in short synclines between secondarily produced anticlines, which are common to both the flakes and more recent than the overthrusting. The extent of the over-thrust on the second thrust-plane (Cartersville fault) is at least 17 kilometers; the overthrusting has perhaps been preceded by denudation [1].

The Cahaba coal-region, which lies to the north-west, has been studied by Squire, and its neighbourhood by Eugene Smith; their results, together with Mc Calley's description of the Coosa district, show that there is a very large number of similar thrust-planes, succeeding each other, and that the extent of the dislocation is very considerable [2].

[1] C. Willard Hayes, The Overthrust Faults of the South Appalachians, Bull. Geol. Soc. Am., 1891, II, pp. 141–154, map; C. W. Hayes and M. R. Campbell, Geomorphology of the South Appalachians, Nat. Geogr. Mag., Washington, 1894, IV, pp. 63–126, maps.

[2] J. Squire, Report on the Cahaba Coal Field, with an Appendix on the Geology of the

From this point onwards the strike turns to the west-south-west, and soon all the folds disappear beneath the Cretaceous mantle of the Mississippi valley.

We have already mentioned (I, p. 557) the *Cincinnati uplift*, a long gentle anticline which we compared to the Parmas of the Ural mountains. South-east of Nashville, Tennessee, the lower Silurian Trenton limestone, which forms the basement of the low country, is exposed over a very wide

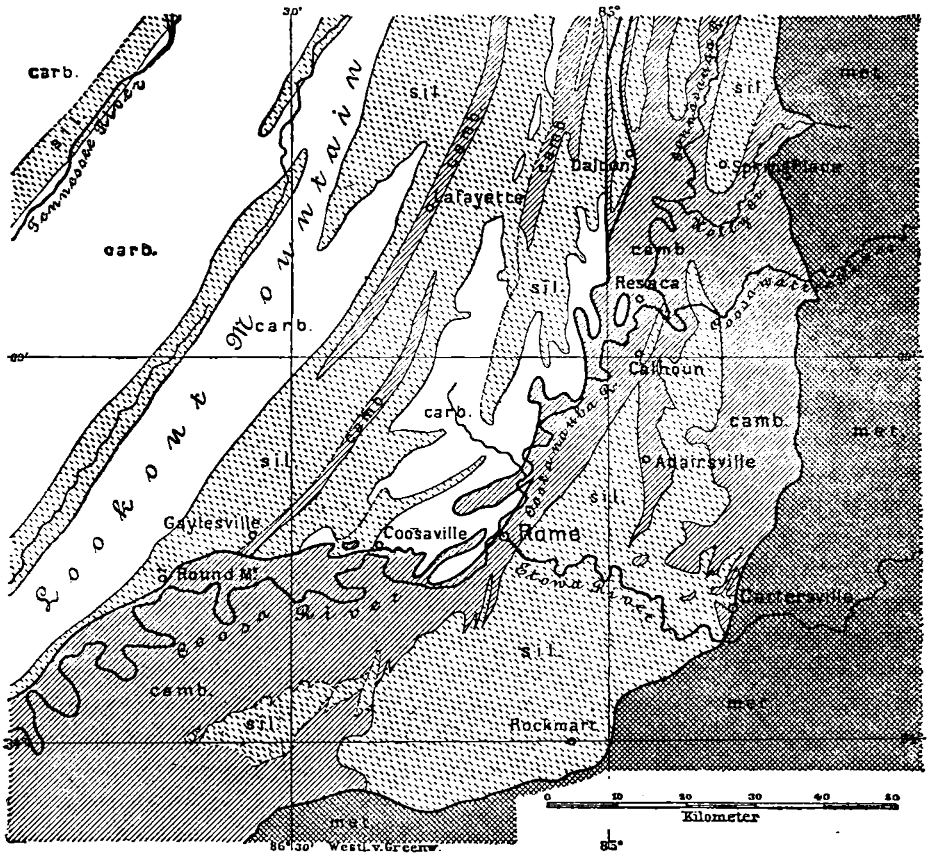


FIG. 10. *Overthrusts on the concave curve of the Appalachians* (after W. Hayes).

area. Further exposures occur towards the north-east, extending through Kentucky and up to the boundary of Ohio. The angle of dip is everywhere small. The presence of oil in the Trenton limestone has led to extensive boring, and we now know that the natural exposures afford only an

Valley Regions adjacent by E. A. Smith, Alabama Geol. Surv., 1890, map; in particular Smith, p. 139 et seq.; E. Smith, Underthrust Folds and Faults, Am. Journ. Sci., 1893, XLV, pp. 305, 306; H. McCalley, Report on the Valley Regions of Alabama, Part II, The Coosa Valley Region, Geol. Surv., Alabama, 1897; in particular p. 27 et seq.

imperfect idea of the configuration of the long subterranean ridge. The principal range runs from Nashville towards the north-east. In the north it lies in several broad saddles, which slope gradually downwards, so that between Sandusky and Toledo, even before reaching the west end of Lake Erie, they have descended to great depths. West of these saddles and parallel to them a somewhat more strongly marked subterranean anticline, the Limes or Findlay axis, runs towards Sylvania on the boundary of Michigan [1]. Finally a broad ridge runs from Cincinnati towards Indiana, and in the north of this state some brachy-anticlines crop out, which are remarkably sharp and dome-shaped [2].

Atlantic and Pacific characters. The east coast of North America may be resolved into several parts. The first includes the bare coasts of the gulf of St. Lawrence and extends as far as White bay in Newfoundland (lat. 51° N.) The second includes those parts of the Appalachians which emerge from the ocean; it extends nearly down to Martha's Vineyard (between lats. 42° and 41° N.). The third is represented by a flat-lying belt of Mesozoic and Tertiary sediments which rests unconformably against the inner side of the Appalachians. In Georgia and Alabama this belt continually recedes towards the interior and makes way for the deposits of Florida and Louisiana, which are of upper Tertiary or even more recent date.

(*a*) Near the northern end of this belt, to the west and south-west of Boston, patches of coal-bearing *Carboniferous* beds are let down by trough-faults into the rocks of the Piedmont plateau. The largest of these forms the elbow-shaped Narragansett basin; its southern part strikes meridionally through Rhode island and into the sea. The Coal-measures of this trough correspond to the upper part of the Schatzlar stage [3].

In Europe limnic transgressions of considerable extent occurred at this time affecting the previously denuded inner side of the Variscan arc, as, for example, in Bohemia (II, p. 249).

In the basin of the Saar, as in that of Narragansett, subsidence took place in a fault-trough.

(*b*) The *Newark system* is formed of extensive patches of plant-bearing beds. Basing his conclusions on Fontaine's investigations, Stur showed the correspondence of its flora with that of the German Lettenkohle, particularly

[1] E. Orton, First Annual Report of the Geol. Surv., Ohio, 3rd org., Columbus, 1890, pp. 45-54.

[2] A. J. Phinney, The Natural Gas Field of Indiana, U. S. Geol. Surv. Ann. Rep., XI, I, 1891, pp. 643–653; E. M. Kindle, The Niagara Domes of North Indiana, Am. Journ. Sci., 1903, XV, pp. 459-468.

[3] Shaler, Woodworth, and Foerste, Geology of Narragansett Basin, U. S. Geol. Surv. Monogr., XXXIII, 1899, maps. The Carboniferous of the north half of the trough is folded, but the section on p. 27 shows that the folding is a secondary effect of the subsidence; for the age see D. White, Monogr., XXXVII, p. 285.

as developed at Lunz in the eastern Alps [1]. This accords with the occurrence in the Newark beds of the crocodilian genus Belodon, which belongs to the upper Keuper of Germany. The presence of fishes (Catopterus) allied to Semionotus also points rather to the upper Keuper.

The Newark system starts from the head of Fundy bay as a long series of patches, for the greater part elongated towards the south-west; it follows approximately the strike of the Appalachians for a distance of 960 kilometers, and reaches the boundary of north and south Carolina. Davis, Darton, Russell, Hobbs, and other investigators have made it the subject of investigation, and Russell has collated all the older results [2]. The patch, 170 kilometers in length, and elongated from north to south, which contains part of the course of the Connecticut river, and reaches the sea near Newhaven, is, as we have seen, let down in a fault-trough. This is also true of the Richmond patch, rich in coal, and 50 kilometers in length; and many other patches are bounded or cut through by faults. The Newark system is associated with basic eruptive rocks, which appear sometimes as steep veins, sometimes as intrusive layers, and again as effusive mantles. The border of one of these mantles, dipping to the north-west, forms, for a breadth of 8–16 kilometers and a length of 190 kilometers, the east shore of Fundy bay and also Digby Neck, a narrow strip which bounds St. Mary bay like a lido. An intrusive flat-lying dyke, cutting through the beds obliquely, forms the Palisades on the left bank of the lower Hudson; near New York it is 260 meters in thickness. Lewis has traced a dyke through Pennsylvania for a distance of 144 kilometers; according to Williams it is continued for another 48 kilometers into Maryland [3]. In the south, where the Newark sediments are absent, these dykes may be traced even as far as Alabama, where they conform more and more to the general direction of the folding. The southernmost limit to which they are visible is given by the Cretaceous covering; it is 1,600 kilometers distant from the most northerly exposure in Fundy bay; the breadth of the zone occupied by these basic dykes and superficial sheets is estimated by Russell at about 320 kilometers.

(*c*) *Potomac zone.* The Carboniferous and Newark areas, mentioned

[1] W. M. Fontaine, The older Mesozoic Flora of Virginia, U. S. Geol. Surv. Monogr., VI, 1883; D. Stur, Die Lunzer (Lettenkohlen-)Flora in den 'Old Mesozoic beds of the Coal-Field of East Virginia', Verh. k. k. geol. Reichs., 1888, pp. 203–217; Lester Ward, Status of the Mesozoic Floras of the United States, Ann. Rep., XX, 2, 1900, pp. 211–315.

[2] I. Cook Russell, Correlation Papers. The Newark System, Bull. U. S. Geol. Surv., no. 85, 1892, 344 pp., maps; N. S. Shaler and J. B. Woodworth, Geology of the Richmond Basin, Virginia, op. cit. Ann. Rep., XIX, 2, 1899, pp. 385–519, maps; W. H. Hobbs, The Newark System of Pomperaug Valley, Connecticut, op. cit., XXI, 3, 1901, pp. 17–162, maps. The list of works referring to the Newark System given by Russell in 1892 fills no less than 199 pages.

[3] H. C. Lewis, A great Trap Dyke across south-east Pennsylvania, Proc. Am. Phil. Soc., Philadelphia, 1885, XII, pp. 438–456, map.

above, contain no marine fossils, and rest on the rocks of the Piedmont plateau. It is outside the patches that the flat-lying Atlantic belt begins. Its principal members are: the Potomac group, the Raritan formation

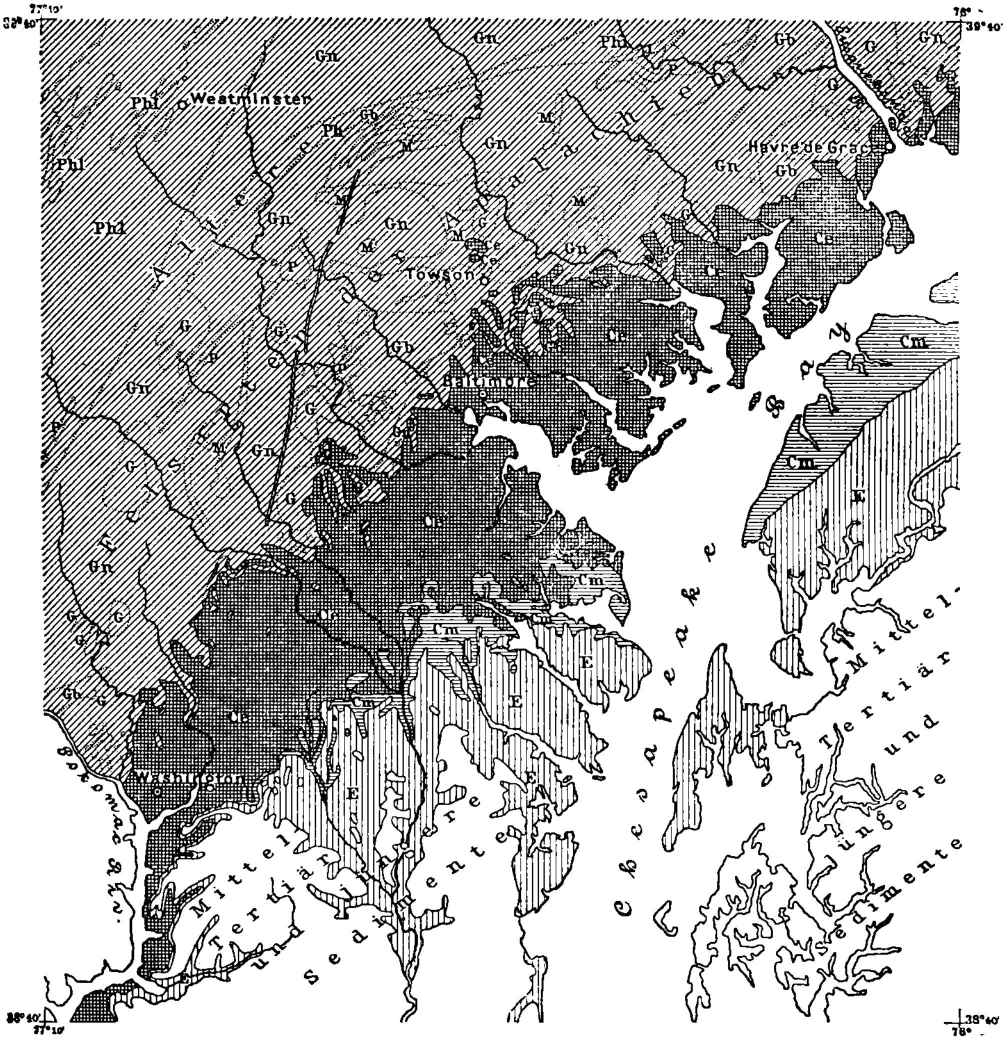


FIG. 11. *The Atlantic belt between Washington and Baltimore.*
(After the map of the Geological Survey of Maryland.)
Gn = gneiss and mica-schist; *Ph*, *Phl* = phyllite and limestone (altered Palaeozoic rocks); *M* = marble; *G* = granite; *Gb* = gabbro; *P* = peridotite and serpentine; *Ce* = lower Cretaceous = Potomac; *Cm* = marine Senonian; *E* = Eocene.

(Amboy clays), the beds representing the marine transgression of the Senonian, and the marine Tertiary beds. No doubt many displacements of the strand occurred after the deposition of this belt, but on the whole it corresponds with the existing outline of the continent, until, in the south, it recedes towards the west[1].

It consists of lower and higher members, the former (Potomac and Raritan) have only furnished terrestrial plants and a few remains of reptiles; they are often grouped together as the *Potomac zone*; the latter are purely marine.

At the boundary between the Jurassic and Cretaceous of Central Europe a negative phase occurs (II, p. 277). Even in Poland, near Thorn, close to the German frontier, Michalski has found the Cyrena marl of the Weald[2]. In the north of France, and the greater part of England, the lower Neocomian is nowhere represented by marine deposits. On the Charente and in Portugal the Weald reaches the ocean. Observations show that the boundary between the Jurassic and the Cretaceous must be drawn above the brackish-water beds of the Purbeck and below the Hastings sand and Weald, which represent the lower and part of the middle Neocomian.

The deposition of the Potomac zone began during this negative phase. In Maryland, arkose occurs at the base and is followed by clays. The lower beds contain a flora belonging to the Weald and Neocomian. Above lies the Raritan formation. After visiting the Cretaceous deposits of Portugal which Choffat and Saporta had shown to contain a combination of terrestrial floras and marine faunas, Ward came to the conclusion that the Raritan flora corresponds with the Vraconnien, i.e. it lies on the boundary between the Gault and Cenomanian[3].

The Potomac flora is known over a region extending from Philadelphia southwards through Maryland to north Virginia. It also occurs in several places much further south, as will be mentioned later. The Raritan flora extends from Martha's Vineyard to Maryland. Ward has shown that it is identical with the flora of the Tuscalosa formation in Alabama, which occurs under similar conditions.

(*d*) Overstepping this inner, non-marine belt, comes the *marine trans-*

[1] W. J. McGee, The Lafayette Formation, U. S. Geol. Surv. Ann. Rep., XII, 1, 1891, pp. 347–521, maps; N. H. Darton, Outline of the Cenozoic History of a Portion of the Middle Atlantic Slope, Journ. Geol., Chicago, 1894, II, pp. 568–587; W. B. Clarke, The Eocene Deposits of the Middle Atlantic Slope, U. S. Geol. Surv. Bull., 141, 1896, and Maryland Geol. Surv. vol. Eocene, 8vo., Baltimore, 1901, map.

[2] A. Michalski, Ueber das Vorkommen von Wealden und Neocom im nordwest. Polen, Bull. Com. géol. Russie, 1903, XXII, pp. 339–364, r.

[3] Lester Frank Ward, The Potomac Formation, U. S. Geol. Surv. Ann. Rep., XV, 1895, pp. 309–397; Some Analogies in the lower Cretaceous of Europe and America, op. cit., XVI, 1896, pp. 463–540; Status of the Mesozoic Floras of the United States, op. cit., Monogr. XLVIII, in particular p. 574 et seq.; O. C. Marsh, The Jurassic Formation on the Atlantic Coast, Am. Journ. Sci., 1896, II, pp. 433–447, and 1898, VI, pp. 105–115; W. B. Clarke and A. Bibbins, The Stratigraphy of the Potomac Group in Maryland, Journ. Geol., Chicago, 1897, V, pp. 479–506; Geology of the Potomac Group in the Middle Atlantic Slope, op. cit., 1902, XIII, pp. 187–214, map.

gression of the upper Senonian. Starting from Martha's Vineyard it runs through north and south Carolina, Georgia and Alabama, and then swerves across the strike of the Appalachians into the valley of the Mississippi (I, p. 284, fig. 37 ; II, p. 303).

Then the inner part of the belt bends to the north, crosses the mouth of the Ohio, and, north of lat. 37° N., turns to the south-south-west, thus including the valley of the Mississippi. In these regions, i. e. south-east Missouri and north-east Arkansas, we only see the continuous scarp of the older formations. It runs south-west to Little Rock (Arkansas) and beyond; then, somewhat north of lat. 34° W., a change sets in. The Tertiary girdle runs south-west across the Rio Grande to Mexico, but the inner border of the Cretaceous formation pursues a fairly rectilinear course to the west. It strikes along the south foot of the Ouachita range, nearly parallel to the Red river, through the territories of the Chocktaw and Chickasaw Indians, and Oklahoma, to the other side of the meridian of 100° W. Within this vast region, which extends as far as the cordilleras of New Mexico, rise the Cretaceous table mountains of Texas.

The investigations of R. Hill and his colleague Vaughan enable us to form a clear conception of this region[1]. Texas (688,340 square kilometers) is larger than Austria-Hungary (625,557 square kilometers), the German Empire (540,484 kilometers), or France (536,408 square kilometers). The flat-lying Cretaceous alone—if we include a strip on the other side of the Red river—occupies an area of 440,000 square kilometers. In the east it dips normally beneath the Tertiary belt. In the west it is seized by the folds of the Cordillera, and but slightly changed in character continues into Mexico. Towards the north it spreads in isolated patches over Kansas and Oklahoma. Since, however, the Neocomian flora of Potomac occurs in the Trinity sands[2], which form its lowest member, and its highest beds are correlated with the upper Senonian of Maryland, it follows that the whole of the great Cretaceous series of Texas must have been deposited during a period which corresponds with the formation of the Atlantic belt of Maryland and New Jersey, and that it is simply a broadening out and swelling up of this belt. Intercalations of Aptian occur, and of Cenomanian which attain a considerable thickness[3].

[1] R. T. Hill, Geography and Geology of the Black and Grand Prairies, Texas, U. S. Geol. Surv. Ann. Rep., XXI, 7, 1901, 666 pp., maps; Topograpical Atlas of the United States, Physical Geography of the Texas Region, fol. 1900; R. T. Hill and T. Wayland Vaughan, Geology of the Edwards Plateau and Rio Grande Plain, &c., Ann. Rep., XVIII, 2, 1898, pp. 193–321, maps; also Hill, Outlying Areas of the Comanche Series in Kansas, Oklahoma, and New Mexico, Am. Journ. Sci., 1895, L, pp. 205–234; and Vaughan, Additional Notes, &c., op. cit., 1897, LIV, pp. 43–50.

[2] R. T. Hill, U. S. Geol. Surv. Ann. Rep., XXI, 7, p. 165; W. M. Fontaine, Notes on some fossil plants from the Trinity division of the Comanche Series, Texas, Proc. U. S. Nat. Mus., Washington, 1893, XVI, pp. 261–282; L. Ward, Monogr., XLVIII, p. 326.

[3] According to Hill the *Trinity Sands* are transgressive sands and clays. They contain

The Cretaceous limestones of Texas have been broken up by erosion into table-mountains. These are: (*a*) the *Llano Estacado,* bounded in the north by the Canadian river, in the west by the Pecos; (*b*) its south-easterly continuation, the *Edwards plateau,* bounded on the south by the Balcones escarpment, and corresponding to a zone of faults which may be traced far across the Colorado river to the north-north-east; (*c*) west of the Pecos the little *Stockton plateau,* which extends up to the Cordilleras; finally (*d*) the continuous masses of the *Lampasas Cut plain,* and the *Grand prairie,* which includes the northern boundary zone on the Red river, and the *Black prairie* marked off by a long scarp. In addition, there are some isolated patches in the north and north-west, in part steeply upturned and lying at a considerable altitude; these are connected with the Cordilleras.

The denuded edges of the great plateaux *a, b,* and *d* bound a broad area situated in the middle of Texas, within which the base of the Cretaceous is exposed. In *Burnet county,* above Austin on the Colorado, ancient rocks crop out. According to Comstock's account, Archaean gneiss and

the flora of the Neocomian and marine fossils of the Aptian stage (Douvillé, Bull. Soc. géol. de Fr., 1898, 3e sér., XXVI, p. 387; Kilian, op. cit., 1902, 4e sér., II, p. 357 (*Hoplites furcatus*). Above them lie the limestone platforms, first the *Fredericksburg* division, described by Hill as the most important transgressive member, over 200 meters thick in the direction of the Rio Grande, but decreasing towards the interior. Its uppermost member, *Edwards Limestone* (Rudistes limestone), was assigned by Douvillé to the upper Gault, or rather to the lower Cenomanian, whereas G. Bohm showed its correspondence with the Schiosi limestone of the Dinarides—that is, the upper Cenomanian (Zeitschr. deutsch. geol. Ges., 1898, L, p. 331). Hill mentions *Sphenodiscus pedernalis* (according to Douvillé in Grossouvre, Craie supérieure, p. 140, certainly upper Cenomanian) and *Ostrea Munsoni,* which I regard, in agreement with Choffat, as identical with *Chondrodont Joannae* Choffat, of the Portuguese Rudistes limestone and the Schiosi beds (Hoernes, Sitzb. k. Akad. Wiss. Wien, 1902, CXI, p. 667). The *Washita* stage, which rests upon the Edwards horizon, also shows the ascent of many indigenous species, while the few European species, such as *Alectryonia carinata,* point to the Cenomanian. Above this follows the *Dakota* sandstone, Hill's *Woodbim* stage, thinning out towards the south, on the Brazos, in lat. 31° 30′ W., and towards the north opening up the transgression far and wide. The few sea-shells which occur still seem to be of Cenomanian type (De Lapparent, Traité de Géologie, 3e éd., p. 1205). They represent the stratum of the well-known dicotyledonous flora. South of the Brazos the sediments are still calcareous; a little above them in the Austin limestone follow species of the upper part of the lower Senonian (*Mortoniceras Texanum* associated, as in Europe, with *Placenticeras Syrtale*), then the upper Senonian *Navarro* beds with *Gryphaea vesicularis* and *Ostrea larva,* and finally, as the highest member, the *Arkadelphia* beds exposed beneath the Tertiary by erosion. In Colorado and further north the place of the upper limestones of Texas is taken by clayey and sandy beds resting on Dakota sandstone; they present the facies which begins with the Benton stage. Among numerous American memoirs we will only mention C. A. White, The lower Cretaceous of the south-west and its relation, &c., Am. Journ. Sci., 1889, XXXVIII, pp. 440–445; Hill, Palaeontology of the Cretaceous formation of Texas, Proc. Biol. Soc., Washington, 1893, VIII, pp. 9–40 and pp. 97–108; Hill and Vaughan, The lower Cretaceous Gryphaeas of the Texas Region, Bull. U. S. Geol. Surv., no. 151, 1898, 66 pp.; and A. Heilprin, The Geology and Palaeontology of the Cretaceous deposits of Mexico, Proc. Acad. Nat. Sci. Phil., 1890, pp. 445–469.

gneissose granite are met with, striking N. 75° W., as well as steeply upturned pre-Cambrian schists, with a predominant strike of N. 36° W.[1] Borings made on the summit of the Edwards plateau, south-west of Fredericksburg, reached the granite beneath the Cretaceous at a depth of only 55 meters (457 meters above the sea), and even at Kerville, 85 kilometers south-west of the Colorado river, it was reached at a depth of 381 meters (about 152 meters above the sea)[2].

In the valley of the Colorado this ancient mass is covered by horizontal and unconformable Potsdam sandstone (Cambrian)[3]. The Burnet mass

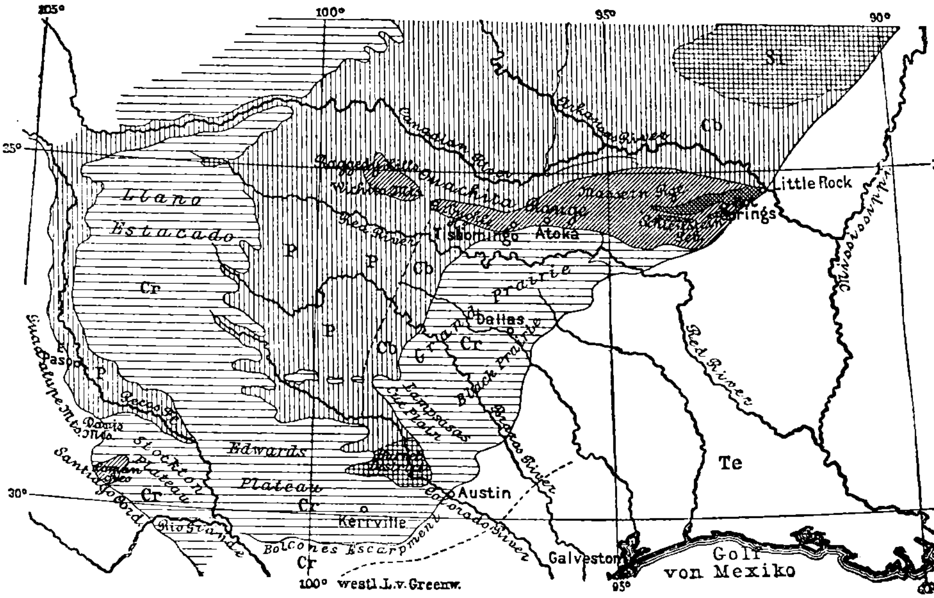


FIG. 12. *The Cretaceous platforms of Texas* (after R. Hill).

is not a continuation of the Appalachians, but a monadnock, i.e. a surviving ridge of the basement rocks, the remains of an older range, left by denudation, which, in this case, as in that of the denudation of the Canadian shield, took place before the deposition of the Potsdam sandstone.

This sandstone is followed by Silurian and then by lower Carboniferous. Upper Carboniferous surrounds a part of the ancient mass, and spreads out towards the north[4]. It lies flatly bedded along the west foot of the Lampasas Cut plain and the Grand prairie, extending from lat. 31° 30′ to

[1] T. B. Comstock, Report on the Geology and Mineral Resources of the Central Mineral Region of Texas, II, Ann. Rep. Texan Geol. Surv., 1891, pp. 553–664, map. The western half of the region is shown on Hill's beautiful geological map in Ann. Rep., XXI, 7, Pl. LXVI.

[2] Hill and Vaughan, Edwards Plateau, pp. 217, 271, 273.

[3] Walcott, Am. Journ. Sci., 1884, 3rd ser., XXVII, p. 431.

[4] Hill, U. S. Geol. Surv. Ann. Rep., XXI, 7, p. 91.

33° 30′ N.; in the Grand prairie it underlies the Cretaceous, and has been revealed by boring at a distance of as much as 64 kilometers from the border (*Cb*, fig. 12).

To the west of the Carboniferous zone we encounter beds of increasingly recent age, which all dip gently to the west. First we meet with the upper members of the Carboniferous, then red Permian sandstone and marls. At various horizons in the marls the remarkable reptiles described by Cope occur, and in one of the upper members a marine fauna, which is foreign to the east of America (*Popanoceras*, *Medlicottia* and other genera), makes its appearance [1]. Still higher, red clay with gypsum follows, the presence of Pleurophorus betraying its Permian age. The Red beds form no small part of the basins both of the upper Colorado river and the upper Red river; to this fact both rivers owe their names. The highest and most westerly beds are assigned to the Trias solely on the evidence of included pieces of fossil wood (*P*, fig. 12).

Texas thus exhibits, beneath a Cretaceous series dipping gently to the east or south-east, another and older series which is slightly inclined towards the west. The inclination, everywhere trifling, is original, and, with the exception of a few faults, there are no signs of tectonic disturbance since the deposition of the Potsdam sandstone. Tilting movements of the whole continent have been assumed, but a simpler explanation accords better with the facts.

Le Conte, Dana, and others long ago recognized that certain Pacific characters are met with on the east side of the Cordillera. Indeed Perrin Smith speaks of a Pacific sea as existing in Arkansas in Carboniferous and Permian times [2].

On the other hand, the whole of the Texan Cretaceous is inserted into the narrow Atlantic belt of the north, and this is an Atlantic formation. *The plain in the interior of Texas, between the Llano Estacado and the Grand prairie, is, as it were, a window, in which the Pacific series dipping to the west is exposed beneath the Atlantic series dipping to the east.*

The Pacific sediments are continued further towards the north, up to Oklahoma and Kansas, but characteristic Pacific fossils are afforded by the marine fauna only. In Kansas we find close below the typical Red beds the species *Callipteris conferta*, distinctive of the Permian Dunkard flora, which in west Virginia, south-west Pennsylvania, and as far as New Brunswick represents the lower Rothliegende of Europe. If this series

[1] C. A. White, The Texan Permian and its Mesozoic Types of Fossils, Bull. U. S. Geol. Surv., no. 77, 1891, 39 pp.; F. Cummins, Report on the Geology of north-west Texas, II, Ann. Rep. Tex. Geol. Surv., 1891, pp. 394–430, map. A survey of recent works on the subject is given by Prosser, Notes on the Permian Formation of Kansas, Am. Geol., 1905, XXXVI, pp. 142–161.

[2] J. Perrin Smith, Marine Fossils from the Coal-measures of Arkansas, Proc. Am. Phil. Soc., 1897, XXXV, no. 152, 72 pp.; in particular p. 18 et seq.

occurred in Germany we should describe it as the post-Variscan mantle. North of the Red river it surrounds the Ouachita mountains unconformably, thus indicating the Permian age of this range.

We must now proceed 8 to 10 degrees of latitude further north, and enter Minnesota, where, between lats. 43° and 45° N., the western border of the Canadian shield is concealed from view by glacial deposits.

In long. 96° 30′ W., on the boundary between Minnesota and south Dakota, ancient quartzite crops out on the great Sioux river beneath the glacial débris and patches of Cretaceous, and, at a more northerly locality, granite also. Even further west, at least as far as long. 98° 30′ W., borings reveal ancient quartzite or granite beneath the water-bearing Dakota sandstone[1].

Still further west, between the meridians of 103° and 104°, we reach the Black hills (I, p. 559); of these we possess recent descriptions by Ward and Darton[2]. Upon ancient granite and schists Cambrian sandstone lies unconformably, as in the Burnet mass. Carboniferous limestone follows, and then a red series with gypsum and species of Bakevellia, completely resembling the Permian of Kansas and Texas. On this rests a characteristically Pacific formation, the Jurassic sandstone with Cardioceras (Sundanee stage). Then comes unfossiliferous sandstone, succeeded by the marly shales of the Atlantosaurus beds, which have furnished the well-known gigantic reptiles, described by Marsh as Jurassic.

The deposition of the Atlantosaurus beds was followed by an interval of erosion, and valleys were excavated of such magnitude that workable Coal-measures, with the flora of the lower Potomac (Lakota stage), were laid down in them. With these begins the series of the Atlantic belt; but in this case also the contrast between the Pacific and Atlantic formations is confined to the marine deposits. We have now entered the epoch of the Weald and Neocomian, and recognize the negative phase between the Jurassic and the Cretaceous, which is quite as clearly expressed here as in the isle of Purbeck.

Here also forests of Cycads have left behind their traces. Higher up, in the Dakota sandstone, the remains of dicotyledonous plants lie buried. Then follows, here as elsewhere, the transgression of the marine upper Cretaceous.

[1] N. H. Darton, Preliminary Report on Artesian Waters of a Portion of the Dakotas, U. S. Geol. Surv. Ann. Rep., XVII, 2, pp. 603-694; in particular map C, p. 672, and Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains, U. S. Geol. Surv. Prof. Pap. no. 32, 1905, 433 pp., maps; also S. W. Beyer, The Sioux Quartzite, &c., Iowa Geol. Surv., 1896, VI, pp. 68–112, map.

[2] Lester F. Ward, The Cretaceous Formation of the Black Hills as indicated by the Fossil Plants, U. S. Geol. Surv. Ann. Rep., XIX, 2, 1899, pp. 521-712, and Wieland, in Monogr., LXVIII, p. 317 et seq.; Darton, Preliminary Description of the Geology and Water Resources of the Black Hills, &c., op. cit., Ann. Rep., XXI, 4, 1901, pp. 489-599, maps; also in Bull. Am. Geol. Soc., 1899, X, pp. 383-396, and op. cit., 1904, XV, pp. 379–448.

For the present we will proceed no farther. Our object in comparing the Atlantic belt in the east with the window in Texas, and the Lakota stage with the Potomac flora now filling erosions in the Black hills, was simply to recall once more the extraordinary extent and uniformity of the phenomena which define the limits of formations.

The Appalachians on the other side of the Mississippi. When the first Report of the Geological Survey of Arkansas appeared in 1888 it announced the existence of a range of hills, 600–700 meters high, which begins south of Little Rock, and, extending from about long. 92° to 100° W., forms the watershed between the Arkansas river (Canada) in the north and the Red river in the south. Branner named it the *Ouachita range.* Earlier maps had not given an even approximately correct idea of this range. At most they marked mount Scott, situated far to the west in Oklahoma, and already made known by earlier expeditions. The geologists who visited this range, Branner, Hill, and Griswold, were astonished at its resemblance to the Appalachians. They observed the folding directed to the north, corresponding to the bend in the Appalachians; the folded Carboniferous traversed by thrust-planes, and beside it the not-folded red Permian. On one point only was there a difference of opinion: should the Ouachita range be regarded as a continuation of the principal chain of the Appalachians, or, as its somewhat more northerly position might suggest, as a more strongly marked expression of the folds of the Cincinnati uplift? [1]

The range strikes first to the west and then turns to N. 70° W. In the east it is thickly wooded; in the west absolutely treeless, and covered with deep grass. It consists of three coulisses. The first and most extensive is the Ouachita range in the narrower sense, the *Massern range* of Hill; the second forms the *Arbuckle mountains*, which, orographically, are connected fairly closely with the first; the third, separated by an interval 40–50 kilometers wide which is occupied by horizontal red Permian beds, forms the *Wichita mountains*, to which mount Scott belongs.

The core of the eastern coulisse or the Massern range forms the *Schleifstein mountains* (Novaculite range). South of Little Rock it is cut through obliquely by the mountain border, of which it includes about 45 kilometers. Thence it runs, expanding like a wedge, for a distance of more than 160 kilometers towards the west, accompanied by numerous subsidiary folds of less importance. It consists of comparatively yielding lower Silurian rocks, accompanied by steeply upturned beds of siliceous

[1] R. T. Hill, Notes of a Reconnaissance of the Ouachita Mountain System, Am. Journ. Sci., 1891, XLII, pp. 111–124, map; L. S. Griswold, Origin of the lower Mississippi, Proc. Boston Soc. Nat. Hist., 1895, XXVI, pp. 474–479; J. C. Branner, The former Extension of the Appalachians across Mississippi, Louisiana, and Texas, Am. Journ. Sci., 1897, IV, pp. 357-371.

hornstone, which causes each of the numerous folds to stand out in sharp zig-zag lines. Griswold has given a map of the range [1].

In the north and south the Schleifstein range is bordered by a thick mantle of Carboniferous beds, and near Atoka, in the region of the Choctaw Indians, this surrounds its western end. The Carboniferous mantle also is folded, and overfolding occurs to the north. The productiveness of the Coal-measures has led to a careful investigation of the range; the north

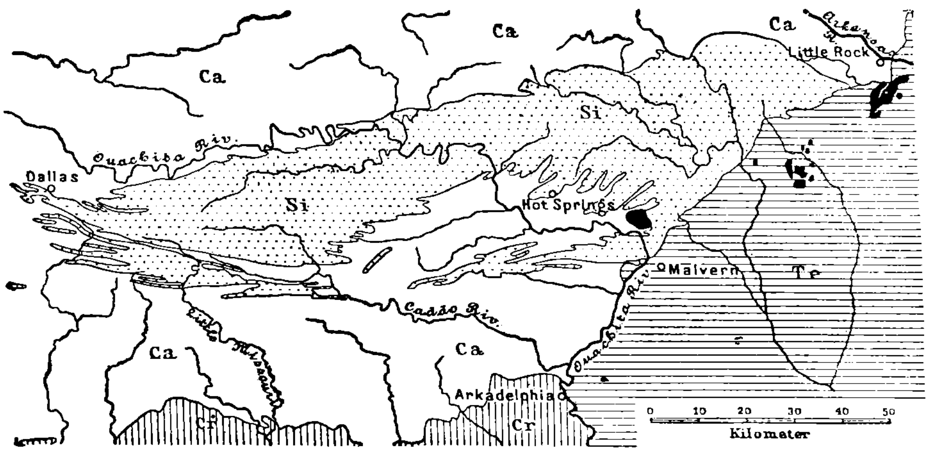


FIG. 13. *The Schleifstein range* (after Griswold).
The black patches mark ancient intrusive masses.

side has been described by Winslow, Drake, and in great detail by Taff; the south side by Ashley. The floras of Schatzlar and Ottweil have been recognized beneath marine deposits of lower and upper Carboniferous [2] (*Ca*, fig. 13).

A transverse section from north to south shows the following:—

North of the Arkansas river rise the Boston mountains, formed of

[1] L. S. Griswold, The Whetstones and Novaculites of Arkansas, Ann. Rep. Geol. Surv. Arkansas, III (1890), 1892, 443 pp., maps.

[2] A. Winslow, The geotectonic and physiographical Geology of West Arkansas, Bull. Geol. Soc. Am., 1891, II, pp. 225–242, map; N. F. Drake, A Geological Reconnaissance of the Coal Fields of the Indian Territories, Am. Philos. Soc., Philadelphia, 1897, XXXVI, pp. 326–420, maps; G. H. Ashley, Geology of the Paleozoic Area of Arkansas South of the Novaculite Region, with an introduction by J. C. Branner, tom. cit., pp. 217–318, maps. The south border also appears on Map LXVI, in Hill's Texas, U. S. Geol. Surv. Ann. Rep., XXI, 7; J. A. Taff, Geology of the McAlester-Lehigh Coal Field, Indian Territories, op. cit., 1899, XIX, 3 (accompanied by a Report on the Fossil Plants by D. White, and a Report on the Palaeozoic Invertebrate Fossils by Girty), pp. 423–593, maps; J. A. Taff and G. J. Adams, Geology of the East Choctau Coal Field, Indian Territories, op. cit., 1900, XXI, 2, pp. 257–311, maps; G. J. Adams, Stratigraphical Relations of the Red Beds to the Carboniferous and Permian in North Texas, Bull. Geol. Soc. Am., 1903, XIV, pp. 191–200, maps.

Carboniferous limestone; they are a continuation of the horizontal series of south Missouri. According to Winslow's sections they drop in a gentle flexure to the river. South of the river follow the wooded ridges of the Carboniferous, folded towards the north, next the zig-zag lines of the north border of the Schleifstein range, then its middle part of less resistent lower Silurian; on the other side of this come the zig-zag lines of the south border, then the wooded south zone of the Carboniferous, and against this, a little north of the Red river, rest the Trinity sands, which represent the beginning of the Cretaceous.

Close to the south foot of the Schleifstein range, between Hot Springs and Malvern, but still north of a secondary range of the Schleifstein crests, rises the mass of *Magnet cove*, the latest description of which we owe to Washington; it consists of a varied series of eruptive rocks becoming more basic towards the centre, which is occupied by a mass of magnetite[1].

South and south-west of Little Rock two bosses of Elaeolite-syenite rise from the Tertiary plain, and form *Fourche mountain* and *Bryant*; their richness in Bauxite has led to their investigation by Hayes[2].

The *Arbuckle mountains* are united by the Carboniferous with the Massern range. They consist, according to Taff, of several horsts bounded by strike-faults and composed of pre-Cambrian granite with a Palaeozoic border. These horsts are the remains of a range which was folded in the interval between the lower Carboniferous and the Schatzlar stage. Conglomerates are superposed unconformably, and, at the close of the upper Carboniferous (Ottweil flora), considerable folding once more occurred. The Permian and Cretaceous are undisturbed.

The total length of the range amounts to over 90 kilometers[3].

Still further to the north-west lie the *Wichita mountains*, which are also over 90 kilometers in length, and trend towards N. 70° W.[4] They consist of a great number of steep isolated ridges and bosses: Taff has counted 250. The north-westerly groups are known as the Raggedy mountains. The principal range, beginning at Fort Sill, presents only

[1] H. S. Washington, Igneous Complex of Magnet Cove, Arkansas, Bull. Geol. Soc. Am., 1900, XI, pp. 389–416, map.

[2] C. W. Hayes, Geology of the Bauxite Region of Georgia and Alabama, U. S. Geol. Surv. Ann. Rep., 1895, XVI, 3, pp. 551–597, map, and op. cit., 1901, XXI, 3, pp. 435–472, maps.

[3] R. T. Hill, Notes on a Reconnaissance of the Ouachita Mountain System, Am. Journ. Sci., 1891, XLII, p. 121; T. W. Vaughan, Geological Notes of the Wichita Mountains, Oklahoma, and the Arbuckle Hills, Indian Territories, Amer. Geol., 1899, XXIV, pp. 44–55, map; and in particular, J. A. Taff, Preliminary Report on the Geology of the Arbuckle and Wichita Mountains, U. S. Geol. Surv. Prof. Paper no. 31, 1904, 93 pp., maps.

[4] H. Foster Bain, Geology of the Wichita Mountains, Bull. Geol. Soc. Am, 1900, XI, pp. 127–144, map. With regard to the relative age of the gabbro and granite, opinions are not concordant; I have followed the observations made on the eruptive masses of the east, which have been closely studied.

pre-Cambrian granite and gabbro; the latter is the older member. Towards the north-east rises a parallel range which continues the Palaeozoic sediments of the Arbuckle mountains. Red Permian lies unconformably over isolated ridges.

In lat. 35° N., long. 99° 28′ W., 9 kilometers west of the north fork of the Red river, Taff marks the last granite boss. One of the last branches of the western Altaides here sinks beneath the arid plain, but not before the unconformities characteristic of the Altaides, and the long zone of Coal-measures, have again made their appearance in the Arbuckle mountains.

A second branch may be seen further south.

Elongated sierras run down between the Rio Grande and the Pecos. In the north their direction is north and south, then south-south-east and finally south-east. Between lat. 31° and 30° 30′ N. the Davis mountains rise near the east border to a height of 2,500 meters; they consist of recent volcanic rock and terminate on the south in a steep declivity. Then follows the Sierra Santjago; formed of Cretaceous limestone, and running south-east, it nearly reaches the Rio Grande. The river Pecos flows for a considerable distance in the red Permian clay; further south, on its west side, rises the Stockton plateau, which has already been mentioned as a continuation of the Edwards plateau. Here, a little west of the Pecos, the horizontal Cretaceous of Texas meets the folded Cretaceous of the Cordilleras.

Hill distinguishes two mountain fragments as foreign elements, the *Sierra Comanche*, and the less important *Sierra Caballos*. They lie to the east of the Cordillera, and should therefore be included in the region of the Cretaceous platforms. The Sierra Comanche, striking to the south-west, encounters in the neighbourhood of Marathon the folded Sierra Santjago which strikes to the south-east. The Sierra Comanche consists of Palaeozoic limestone and sandstone dipping to the north, on which some flat patches of Cretaceous limestone still possibly rest. The Sierra Caballos lies to the south; its beds stand vertical with a parallel strike, and probably belong to the lower Helderberg stage. Towards the south they are bordered by a belt of flat-lying Cretaceous [1].

These sierras do not belong to the great Cordillera, since they are opposed in direction and are older than the Cretaceous. Neither do they belong to the Burnet mass, in which Cambrian sediments lie horizontal. Their strike passes north of this mass and beyond it.

Robert Hill recognizes in the Sierra Comanche and the Sierra Caballos the type of the Appalachians, which here, close to the foot of the Cordillera of New Mexico, is yet once more visible. A similar correlation has been hazarded with regard to the Diablo plateau, a great area of lower Carboni-

[1] R. T. Hill, Topographical Atlas, fol., p. 4.

ferous limestone situated actually within the Cordillera and beyond the Davis mountains. But in this case the facts are less convincing, and for the present we shall regard the Sierra Comanche as the last trace of the Appalachians to be seen on the west. The point at which it meets the Mexican Cordilleras lies in lat. 30° 15′ N. and long. 103° 15′ W.

On the north, above Burnet, and in the direction of the Ozark mountains, lies a broad area in which the Palaeozoic sediments probably attain a greater thickness. Within this region the Appalachians divide into two diverging branches, and further west these great mountains die away in isolated fragments of coulisses. *These are the free ends of the longest branch of the western Altaides.*

The inter-Carboniferous movements of central Asia have travelled west as far as this point. The bend of the Altaides towards the north which

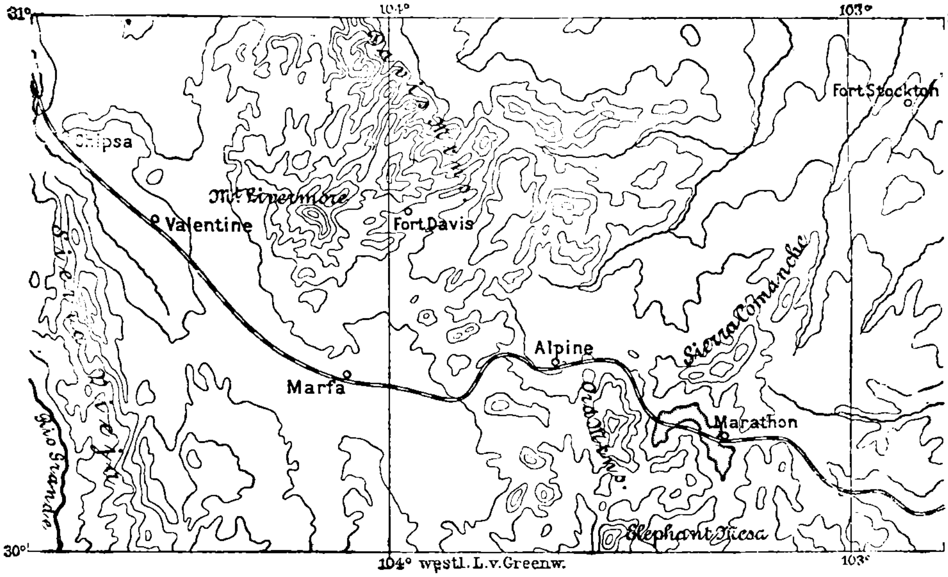


Fig. 14. *Sierra Comanche and Davis mountains* (after R. Hill).

occurs in the horst of Azov has remained of fundamental importance as far as the Cordilleras of New Mexico.

Summary. The preceding observations throw some light on the history of the *North Atlantic Ocean.*

An extensive Devonian continent, Eria, occupied the north. South and east of where it stood, a rias coast now extends between Dingle bay and la Rochelle, and the folded Armorican system sinks beneath the sea. On the west a similar rias coast is presented by Newfoundland, where the Appalachians make their advance. The Wichita mountains and the Sierra Comanche are their free ends.

The Armorican range and the Appalachians are both folded towards the north. In Europe, as the Armorican together with the Variscan folds advanced against the foreland, the Carboniferous sea was driven back; the Zechstein marks the first re-entry of the sea into the northern regions. In America, as the folds of the Appalachians approached their Laurentian foreland, they continued, from the time of the Carboniferous limestone onwards, to drive the sea of Newfoundland far towards the south. Marine sediments of Mesozoic and Tertiary age are absent on the north and west sides of the Appalachians.

If we compare the works of Stur on the Carboniferous floras of Moravia and Silesia, of Zeiller on those of northern France, of Kidstone on those of Britain, and of David White on those of North America, we find in all cases an astonishing resemblance between these floras, both in their composition and the order of their succession, whether traced upwards from the Culm to the Rothliegende or horizontally from the Weichsel to Oklahoma. This correspondence enables us to affirm that a discordance at the base of the Culm exists in Europe, and that it reappears in Newfoundland, New Brunswick, and Nova Scotia. In the whole of this region the folding had come to an end before the deposition of the Permian. This formation rests undisturbed upon some gentle anticlines which extend from New Brunswick into Prince Edward island.

There are intervening movements on the two sides of the ocean, which may also be correlated. It is clear that limnic transgressions of the Schatzlar stage stepped over already denuded parts of the inner side of the mountains, as, for example, in Bohemia, on the Saar, in the Central plateau, and at the same time on to the equivalents of the Piedmont plateau in the Narragansett basin. In the extreme east, near Ostrau, the series of coal-bearing beds terminates with the Schatzlar stage. The Devonian boss of Debnik, which rises outside the coal-region, near Cracow, is covered unconformably by the alien plant-bearing limestone of Karniovice. According to Raciborski it contains the Ottweil flora [1], which is here separated by physical changes from the flora of Schatzlar. In the extreme west we meet in the Indian territories with the Mc Alester Coal-measures, which contain the Ottweil flora; these are folded along with the rest of the coal-bearing series (Grady Coal, Schatzlar), and flat-lying beds do not occur till we reach the Permian. Further observations must decide whether this affords additional confirmation of a fact established elsewhere, that the folding persists longer in the direction of the free ends.

We now reach a more recent phase in the history of the Atlantic. South of lat. 41° N., i.e. south of the trend-line which once united America with Europe, the nature of the coast is no longer the same as that in the

[1] M. Raciborski, Permo-carboniferous Flora of the limestone of Karniowice, Rozpr. Akad. Umiej., Krakow, 1891, XXI, pp. 353–394 (in the Polish language).

north. On the inner (east) side of the Appalachians we meet with the terrestrial floras of Schatzlar (Narragansett), the Keuper (Newark), the Neocomian (Potomac), and the Vraconian (Raritan); marine deposits first make their appearance with the Senonian. With the Potomac stage a more continuous belt begins, and this has been termed the Atlantic belt.

The table-mountains of Texas are the extended continuation of this belt, although they reach greater heights, and although some marine indications occur even in the Potomac stage (Trinity sands).

The negative phase of the Weald is revealed over a wide area on both sides of the ocean, from the Weichsel to Dakota. It was followed by a positive movement. In the north of France the gradual advance of the Gault is very obvious. In Texas the first signs of it are afforded by the Trinity sands. Next the great Cenomanian transgression set in, and with it the limestone formations of the Karst of Syria, Arabia, the Sahara, Texas, and Mexico were built up. The Senonian has everywhere advanced beyond the periphery of this transgression, in the north to Disko, in the south into the Antarctic region, in the east to the Aral, and it has left its traces even on the Pacific coasts. The Senonian of Maryland represents a part of its advance.

In addition, we have the completely undisturbed position of the Cretaceous extending from Greenland down to the extreme south, and, with the exception of the Antilles, only interrupted by occasional subsidence (Balcones escarpment).

CHAPTER III

THE AFRICAN ALTAIDES

The inland sea of Africa. The Central Sahara. The Altaides of the Sahara. The Great Atlas.

The inland sea of Africa. We were unable to give more than a very fragmentary account of the Sahara in the first volume of this work (I, p. 360, fig. 41). The journey of Lenz was almost our only source of information for the whole of the vast region in the west, and as regards the east our knowledge was confined to the barest outlines; such as the existence of the Archaean rocks of Khartum, which extend towards Bardu, crop out again in Ahaggar, and are accompanied by the volcanos of Bardai and Aïr; the presence, north of this range, of the important Palaeozoic tract which extends towards Mursuk; of a great transgressive series of middle and upper Cretaceous, which reaches the Nile below and above Assuan; of a tract of Eocene within the Cretaceous, and within this again, nearer the mouths of the Nile, a Miocene region.

The maps published by Rolland in 1890 indicated with additional clearness the relations of the Cretaceous to the underlying Palaeozoic in the region south of In Salah and the Hamada el Homra, but in the western region no progress of any account had been made even at that date [1].

The most important of the many discoveries which followed later is that of a marine Tertiary series in a region lying between lats. 14° and 15° N. and long. 5° 20′ to 6° 20′ E. The Eocene was recognized simultaneously by De Lapparent and Bather, and subsequently additional fossils enabled De Lapparent to show that younger sediments also are present [2].

According to De Lapparent, the Lutetian stage of the Eocene is known to occur in the same region at Tamaské; at a neighbouring locality a Cerithium resembling *C. concinnum* of the Barton stage was found; and at a third *Ostraea longirostris*, with bones of Halitherium. Near Bututu, in the south-east corner of the region, iron sand occurs with impressions

[1] G. Rolland (Chemin de Fer Transsaharien), Géologie du Sahara Algérien, 2 vols, 4to, Paris, 1890, I, pl. IV, and p. 252.

[2] A. de Lapparent, Sur une formation marine d'âge tertiaire au Soudan français, La Géographie, 1903, VII, pp. 417–420, and Sur des nouvelles trouvailles géologiques au Soudan, op. cit., 1905, XI, pp. 1–6; also C. R. Acad. Sci. Paris, 26 déc. 1904. Specimens from this region were collected by French and English officers simultaneously in 1903; Bather recognized the presence of the Eocene at the same time as De Lapparent. P. S. Lelean, An Eocene Outcrop in Central Africa, and F. A. Bather, Eocene Echinoids from Sokoto, Geol. Mag., 1904, 5th ser., I, pp. 290–304.

suggesting *Protorotifera*, above it a bed containing plant remains, and above this the skeleton of a lumachella with impressions of a Cardita, which point, according to Douvillé, to the upper Miocene.

Here, as in the Libyan desert, a horizontal mantle, beginning with the middle or upper Cretaceous, rests unconformably on much older rocks. It extends upwards, as we now know, into the Miocene, and we may suppose that here, as in the Libyan desert (I, p. 362), the contours of the several sedimentary series become successively constricted about some particular locality on the existing sea-coast.

As regards the shore-line of the inland sea thus indicated, we may arrive at some notion of its course from a consideration of the data furnished by De Lapparent, taken in connexion with the latest general account by Chudeau [1].

The transgressive Cretaceous sea certainly extended to long. 10° 15′ E., lat. 14° 30′ N. (hill of Damergou); from long. 8° E. onwards the Cretaceous deposits are probably covered by Eocene; from lat. 14° 30′ N. by Miocene. From the south-east (Sokhoto) a bay opened into the sea. Cretaceous and Eocene reach the Niger, and in the south, between Goa and Tosaye, rest in transgressive patches upon older rocks which terminate at Tosaye (south of lat. 17° N.).

So far for the southern shore.

In the east the Eocene extends at least 400 kilometers to the north, and reaches lat. 17° 50′ N. about (Tamarlakat, 75 kilometers north of Agadés, 60 kilometers west of Aonderas). Here we are near the meridional volcanic range of Aïr, and even far to the north, in lat. 21° 15′ N. (west Tagrira and In Azua), similar sediments are mentioned, but without fossils. Doubtful traces of the Cretaceous are also known far to the east in long. 13° E., lat. 18° 40′ N. (Bilma; I, p. 363): it is possible that a connexion with the Libyan desert existed here.

To the west of Aïr the Cretaceous and Eocene waters very possibly broadened out over a wide area, yet between longs. 2° and 4° E. the ancient rocks of the Adrar are found to extend very far towards the south. Villatte followed them in long. 2° E. down to lat. 20° N.[2], and Gautier's map marks them in long. 1° E. as far as lat. 18° N. (on the Eguerrer). Nevertheless Cretaceous fossils are known to occur in long. 1° E., lat. 17° 50′ N. (Tabankort) and in long. 1° W., lat. 20° N. (Mabruk).

[1] A. de Lapparent, Sur l'extension des mers crétacées en Afrique, C. R. Acad. Sci. Paris, 6 févr. 1905, p. 349, and R. Chudeau, Le Lutétien au Soudan et au Sahara, op. cit., 15 avril 1907, pp. 811–813. Cf. also Chudeau's hypsometric map of the Sahara in Ann. de Géogr., 1908, XVII, Pl. I, and J. Chautard, Matériel pour la Géologie et la Minéralogie de l'Afrique occidentale française, I, État actuel de nos connaissances sur les formes sédimentaires de l'Afrique occidentale tropicale, 8vo, Gorée, 1906, 15 pp.

[2] N. Villatte, De Tidikelt vers Tombouctou, La Géographie, 1905, XII, pp. 209–230, map.

Let us now direct our steps due west.

Between cape Bojador and Punta Durnford, Quiroga observed a bed with *Ostraea*, *Tellina*, and other fossils, followed by 25–30 meters of quartzose sand with silicified tree-trunks, and beneath this blue marls. Towards the interior loose sands with Helix set in, and then follows a broad tract of ancient rocks accompanied by a narrow belt of Palaeozoic which extends into the Asfat, i. e. into the latitude of cape Blanco [1].

For a long distance in the south the coast is unknown. On the lower Senegal river the upper Cretaceous makes its appearance. Middle Eocene limestone was met with in a boring near St. Louis; and likewise at several localities extending to about 200 kilometers east and south-east of cape Verde [2].

In the interior of the continent lies the boundless depression of the Juf; on its west border lie the salt beds of Tichit, on its east border those of Taouden and Trasas.

Near Timbuktu, Chevalier found two species, which now live on the coast of Senegambia, *Marginella Egonen* and *Columbella mercatoria*; they occur in great numbers, but in a dwarfed state [3]. Gautier states that E. Dupuis obtained the same species to the west of lake Horo, and also that A. Dereims brought back representatives of a Pleistocene marine fauna from Mauritania, where they were found 150 kilometers from the sea and at a height of 60 meters.

Timbuktu lies at a level of 240 meters: the lowest point which Lenz met with on the east side of the Juf lies at 120–150 meters only. Gautier draws a truly instructive picture of the time, perhaps not very remote, when a great river represented by the existing Wady Messaud brought down the waters of the Great Atlas from the north-east into these depressions, a task now vainly attempted by a part of its upper course, the Wady Saura; at the time in question the lakes of Timbuktu formed part of a sheet of water, which extended eastwards to the rocky gate of Tosaye on the Niger, and southwards into the district of Massina, thus covering the bend of the Niger. The existing upper Niger discharged as an independent river into these waters [4].

[1] F. Quiroga, Apuntes de un Viaje por el Sáhara occidental, Añ. Soc. Españ. Hist. Nat., 1886, XV, pp. 495–523; Observaciones geológicas en el Sáhara occidental, op. cit., 1889, XVIII, pp. 313, 393, map, and Observaciones al mapa geológico del Sáhara de M. Rolland, op. cit., 1892, sér. 2, I (XXI), 2, pp. 29–32.

[2] Repeated accounts of it have been given by S. Meunier; the facts are collated in J. Chautard, Note sur les formes éocènes du Sénégal, Bull. Soc. géol., 1905, 4e sér., V, pp. 141–153.

[3] A. Chevalier, Sur l'existence probable d'une mer récente dans la région de Tombouctou, C. R. Acad. Sci. Paris, 15 avril 1901, pp. 926–928.

[4] E. F. Gautier, Études Sahariennes, Ann. de Géogr., 1907, XVI, pp. 46–69, and pp. 117–138, in particular p. 129 et seq., map; also A travers le Sahara français, La Géographie, 1907, XV, pp. 1–28, 103 et seq., map. The bed of marine Tertiary fossils found by

This Tertiary inland sea,—which included the lakes of Timbuktu and the Juf, and received from the south-east the waters of the existing upper Niger, and from the north-east those of the Messaud,—extended in the Miocene period to long. 6° 20′ E. (Tamaski, Bututu); if we may suppose that the case of the Libyan desert was repeated here, then we may conclude that a communication with the Ocean extended across the lower Senegal.

It is a surprising fact that the Mediterranean deposits of Austria furnish so many species of shells which are still to be found living in the Senegal, as, for instance, Adamson's Vagal (*Tellina strigosa*), Tugon (*Tugonia anatina*), three species of Dosinia, and others, although no direct communication is so far known to have existed between the Mediterranean and the Senegal. Hoernes thinks that the strait of Gibraltar was closed during the Miocene period [1].

De Lapparent supposes that the eastern Cretaceous sea communicated in the south with the existing ocean. This view is based on the fact that Bullen Newton has found middle Cretaceous Ammonites at Gongola (province of Biauchi, about lat. 11° N., long. 11° E.) [2], and also on the presence of Cretaceous and Tertiary fossils in south Cameroon. Ammonites obtained from the river Mungo are described by Solger as Turonian or lower Senonian; Oppenheim thinks that shells from an adjacent locality are probably Eocene, and some fish remains seem, according to Jaekel, to indicate upper Tertiary [3].

From various considerations—such as the extensive development of the Cretaceous deposits from this point southwards along the coast; the fact that a large part of western Cameroon is occupied by recent volcanic rock; and that on the west side of the basalts, in the direction of Old Calabar, Dusén still saw the Cretaceous cropping out from beneath them [4]—

Dereims in Mauritania is probably identical with El Hafeira in the western Adr'ar, here stated to be 300 kilometers from the sea.

[1] On the original connexion between North Africa and South Europe, Jahrb. k.k. geol. Reichs. 1863, XIII, pp. 26–30; R. Hoernes, Untersuchung der jüngeren Tertiärablagerungen des westlichen Mittelmeergebietes, Sitz. k. Akad. Wiss. Wien, 1905, CXIV, pp. 467, 637, 737, in particular p. 655; cf. also chapter V.

[2] R. Bullen Newton, A notice of some marine fossils from north Nigeria, collected by Col. Elliot and Capt. Lelain, Geogr. Journ., 1904, XXIV, pp. 522–524.

[3] A. v. Koenen, Die Fossilien der Unter-Kreide am Ufer des Mungo in Kamerun, Abh. Ges. Wiss. Göttingen, 1897–1898, new ser., I, 65 pp.; F. Solger, Die Fossilien der Mungo-Kreide in Kamerun, in E. Esch, F. Solger, M. Oppenheim, and O. Jaekel, Beitrag zur Geologie von Kamerun, 8vo, Stuttgart, 1904, pp. 83–242; P. Oppenheim, Über Tertiärfossilien wahrscheinlich eocänen Alters, von Kamerun, op. cit., pp. 243–285, and O. Jaekel, Über einen Torpeniden und andere Fischreste aus dem Tertiär von Kamerun, op. cit., pp. 289–291, and Grossouvre, Bull. Soc. géol. France, 1904, 4e sér., IV, p. 839. In the plain of South Nigeria, J. Parkinson found lignites, but no fossils, On the Post-cretaceous Stratigraphy of South Nigeria, Quart. Journ. Geol. Soc., 1907, LXIII, pp. 308–312, map.

[4] P. Dusén, Om NW. Kamerun omradets geologi, Geol. Fören. Förh., 1894, XVI, pp. 29–63, map.

we are led to ask whether the middle of the Cretaceous gulf should not be placed nearer the mouths of the Niger.

However this may be, De Lapparent's investigations show that the transgression of the middle Cretaceous probably separated a large fragment, formed of ancient rocks, from the main body of Africa. The boundary of this fragment is given approximately by the courses of the Senegal and the Niger.

The Central Sahara. The little sketch in vol. i, p. 360, fig. 41, may once more serve as our starting-point. In addition to the meridional line from Mursuk to lake Chad, explored by Barth, Vogel, Rohlfs, and Nachtigal, we are now acquainted, thanks to the successful expedition of Foureau-Lamy, with another meridional line 4 to 5 degrees further west. It extends from Temassanim to Zinder, and its connexion with lake Chad is also known [1]. North-west and west of this point lie regions in which many most valuable observations have been made. In our previous description (I, p. 356) we divided the desert into an Archaean, a Palaeozoic, and a Cretaceous-Tertiary zone, succeeding each other towards the north and north-east (Libyan desert), and this division still holds good; in the south also, as we have just shown, the zone of older rocks is succeeded by a Cretaceous-Tertiary zone (Juf-Niger-Senegal).

The boundary of the older, and in particular the crystalline, rocks is indicated on the south in a very indefinite manner owing to the denudation of the Cretaceous and the breaking up of its border into patches. It may be drawn for the present from In Azua to the west-south-west, and it meets lat. 20° in long. 1° W. On the north, this region is bounded clearly enough by a long glint of transgressive Devonian sandstone. It probably begins in the Tumno mountains (lats. 14°–15° E.), and proceeds as the south slope of the Tazili of the Asjer far to the west-north-west; then it crosses the southern slopes of the remarkable hill groups, Muydir and Ahenet, and probably disappears a little beyond long. 2° E. From this point on, the Devonian retreats far to the north.

North of the Devonian zone we encounter at places fairly well known, as, for instance, in the Wady Issawam (south-east of Temassanim), and then north of the Muydir and the Ahenet, a zone of Carboniferous which is not bounded by a glint. Further north it has been observed at several localities, as, for instance, in Gurara, and as far as the Atlas.

A second line of glint, very much cut up, is formed by the Cretaceous. It is very clearly marked at Temassanim (about long. 7° E., lat. 28° N.), in the Tinghert, and the neighbourhood of In Salah. We know that the Palaeozoic region spreads out in the east, and the Cretaceous recedes towards the Hamada el Homra.

[1] F. Foureau, Documents scientifiques de la Mission Saharienne, Mission Foureau-Lamy, 2 vols. 4to, and Atlas, Paris, 1905.

Let us retrace our steps to obtain a better acquaintance with certain details.

The Archaean zone, formed of gneiss, crystalline schists, phyllite, cipolin, and granite, is steeply folded; its prevalent north and south strike is a noteworthy feature. Patches of Devonian sandstone extend far to the north, even into the Aïr. They lie unconformably, and show how very large an area this mantle must once have covered. Quartzites are known, extending from the far west into the Fezzan; they may be recognized by their dark, often indeed black, crust, beneath which fracture reveals a pale-coloured, often white, rock. Graptolites have been found in slate at two localities, and indicate the lower part of the upper Silurian. One of these localities lies in the Tazili of the Asjer, on Foureau's route (long. 7° 8′ E., lat. 25° 50′ N.); it has been described by Foureau and Haug; the second lies remote from the first, at a place called Hassi-el-Khenig, north of the Muydir, which will be described later in greater detail; this discovery was first made known by Flamand [1].

The north and south strike, interrupted at most by local deflexions, which is observed in the Archaean basement and the beds folded in with it, dominates all the central part of the Sahara from the Tidikelt (lat. 27° N.) onwards, and neither to east, south, nor west are its boundaries to be found. The beautiful maps of Gautier and Chudeau mark this strike between long. 1° and 3° E. from lat. 22° 15′ to 19° 30′ N., and, with deviations to the south-south-west, even in lat. 18° N.; Chudeau mentions the meridional direction even at Hombori in the bend of the Niger (about lat. 15° N.) [2]. The distribution of the rocks, however, is even wider. Hubert observed the same gneisses and amphibolites, associated as in the north with included synclines of quartzite, phyllite and marble, throughout Dahomey up to the limestones (possibly Cretaceous) of the coast region.

They are known on the Niger between lats. 15° 30′ and 10° 30′ N., and their numerous short ridges of gneiss form the hill range of Atacopa. Their strike is strictly north and south to about lat. 10° N., then they bend into a south-south-west direction and so continue down to Abomay and beyond. The same structure may also be seen in a great part of Togo. On the Niger and in the district of Gurma there is an unconformable superposition of quartzite of unknown age [3]. Haug, contrasting these folds with

[1] F. Foureau, op. cit., II, p. 585; Haug, tom. cit., p. 753. The first reference occurs in Munier-Chalmas, Travaux scientifiques, 4to, Lille, 1903, p. 94 (cf. also note, p. 22); G. B. M. Flamand, Sur l'existence de schistes à graptolithes à Haci-el-Khenig, C. R. Acad. Sci., Paris, 3 avril 1905, pp. 954–957.

[2] E. F. Gautier, A travers le Sahara français, La Géographie, 1907, XV, pl. 1; Chudeau, L'Aïr et la région de Zinder, op. cit., pp. 321–336, pl. IV, and D'In Zize à In Azoua, op. cit., pp. 401–420, pl. V.

[3] H. Hubert, Esquisse préliminaire de la géologie du Dahomey, C. R. Acad. Sci. Paris, 21 oct. 1907, pp. 692–695.

the comparatively undisturbed position of the transgressive Devonian, has compared them with the Caledonian system of Europe, at the same time remarking that, as far as existing observations extend, the transgression begins with the graptolite shales [1].

The basement has indeed two characters in common with the Caledonides of Europe; the first is seen in the prolonged submeridional strike (north of Norway to the Mendips, 18 to 19 degrees of latitude, exclusive of the traces in Spitzbergen; Tidikelt to South Dahomey, 19 to 20 degrees of latitude), manifested in long, often rectilinear ranges which do not exhibit the curved trend-lines of later mountains, and scarcely seem to combine into one principal chain. The second character they have in common is their age; in Europe, pre-Devonian, in Africa, pre-upper-Silurian. The slightly earlier date of the African ranges seems to place them in the same relation to the Caledonides as the folds produced at the time of the Culm bear to those of the Altaides, which followed the same plan in late Carboniferous and pre-Permian times. In accordance with the principles of tectonic classification we have hitherto adopted, we may assign them to the submeridional, sublinear system which was completed in Europe before the deposition of the Devonian, and in Africa even before that of the upper Silurian. It may, however, be objected that the unconformity at the base of the African ranges may be much older than the graptolite shales; we shall therefore term them, following a suggestion in an instructive letter from M. Chudeau, the *Caledonides of the Sahara* or the *Saharides.*

To Haug, also, we owe the recognition of the transverse trend of the pre-Permian chains and the gradual constriction of the space from north to south in the direction of the Alpine chains. As related to Europe, Africa is only a southern continent; as related to the globe, it is an equatorial continent.

As we proceed from north to south in the eastern hemisphere we encounter first a Caledonian structure which (apart from the indications in Spitzbergen) extends from the north of Norway to the Mendips; then we cross the Altaides of France and Germany, next the Alpides and the Mediterranean Altaides extending to Tunis and Algiers, then again another belt of Altaides, which will be described directly, and finally, to the south of these, we discover the Saharides. Much further south, however, in Cape Colony, there exist the remains of another folded system turned towards the north, which recalls in many respects the Asiatic chains.

The Devonian will doubtless prove, on closer investigation, to present just as varied a development in the Sahara as in the Fezzan. Flamand has

[1] Haug, La structure géologique du Sahara central, La Géographie, 1905, XII, pp. 297–304 et passim; for the constriction see also R. Chudeau, C. R. Acad. Sci. Paris, 2 oct. 1905, p. 566.

found *Calceola sandalina* in the Gurara [1], and Gautier mentions upper Devonian with Clymenia and *Goniatites retrorsus.* Particularly noteworthy is the occurrence of American forms in South Africa, and especially Haug's discovery of the *Tropidoleptus carinatus* fauna (Hamilton stage of North America) in the desert situated to the west of the Ahenet [2].

The Carboniferous found at Igli belongs to the lower division of that system. From the Erg d'Issawan a number of species characteristic of the Carboniferous of Moscow and the Urals are cited, but so far neither Fusulina nor Schwagerina has been met with. Some doubt exists with regard to the highest stages of the upper Carboniferous.

Permian, Trias, Lias, Oolites, and Neocomian are absent from the Central Sahara. A stage represented by variegated clay and gypsum, with associated remains of fishes and Dinosaurs, occurs at the base of the Cretaceous glint below the typical Cenomanian. Haug has described it as the Ceratodus stage [3]. It has been assigned to the Albian because it occurs beneath the Cenomanian; but it contains no fossils characteristic either of the Albian or the Cenomanian, and on account of its lagoon-like characters it must be regarded as introducing the transgression, thus recalling the plant-bearing Perutz beds of Bohemia, or the phosphorite beds which occur in England, e. g. near Cambridge, beneath the transgressive upper Greensand. It corresponds to Chudeau's Tegama stage, which occurs between Zinder and Agadès in the south.

North of In Salah the Cretaceous glint changes its character. The plateau of Tademait is a platform of Turonian dolomite which ends in a steep slope towards the south-east (Jebel el Abiodh) and north-west (el Baten), and assumes in an orographical sense the rôle of the glint. The Cenomanian is but feebly represented. Beneath it lies sandstone with gypsum, concretions and fossil wood on the horizon of the Ceratodus beds; it covers a large area and is water-bearing. Still further north, in the direction of the Great Atlas, the same horizon exhibits sandstone with included tree-trunks which have been described as Neocomian.

At many points extinct *volcanos* occur; reference has already been made to mount Tarso in the Tibesti, and mount Tekinduhir in the Aïr. The latter lies at the south foot of mount Baghsem, but, although crystalline rocks are alone mentioned as occurring in this mountain and those following it towards the north, yet the basaltic sheets and the scoriae which all travellers describe on the road in the west leading to Agadès show that this is an

[1] G. B. M. Flamand, Sur la présence du dévonien *Calceola sandalina* dans le Sahara occidental, C. R. Acad. Sci. Paris, 1er juillet 1901, pp. 62–64.

[2] Haug, Sur les fossiles dévoniens de l'Ahenet occidental recueillis par M. N. Villatte, C. R. Acad. Sci. Paris, 4 déc. 1905, pp. 970–972, and Nouvelles données paléontologiques sur le Dévonien de l'Ahenet occidental (Mission de MM. Chudeau et Gautier), op. cit., 19 mars 1906, pp. 732–734.

[3] Haug in Foureau, Documents scientifiques de la Mission Saharienne, II, p. 814.

important eruptive region. Chudeau's map marks the whole chain from the Baghsem mountains onwards (Baghazam, lat. 17° 45′ to 20° N.) as a meridional series formed of Tertiary eruptive rock. Foureau speaks of the peaks of Aggatene and Diguallane in particular as volcanos. Similar centres of eruption have been pointed out by Bartholomew Barth, whose observations, together with those of Duveyrier made in the Ahaggar, and others still later, have been collated by Gentil[1]. In the Ahaggar especially the eruptive centres appear to be extremely numerous. Further west attention has often been called to the isolated In Ziza (south of the Ahenet). The volcano Tekout already described by Overweg lies below the Devonian glint of the Tazili of the Asjer; its lava flows consist of olivine tephrite. The Wady Igharghar, once the principal river of these regions, flows to the north and has carried out scoriae and lavas even into the great Erg.

Altaides of the Sahara. In 1900 Flamand reported that indications of pre-Permian (Hercynian) folding exist in the Sahara. In particular he pointed to a little chain, Aïn Kahla (or Jebel Asas), almost meridional, and to the locality El Khenig situated within the chain. This little chain emerges from the flat-lying Cretaceous between lats. 27° and 28° N., near long. 3° 14′ E., and runs south-south-east to disappear in the mass of the Muydir. It is certainly younger than the lower Carboniferous and older than the Ceratodus stage at the base of the Cenomanian[2].

Let us leave this place and seek for information much further north.

Near long. 1° 30′ W. and lat. 32° N. lie the localities of Figig and Bechar; this region has been described by Gautier and Flamand[3].

[1] L. Gentil, in Foureau, Documents, &c., II, p. 724 et seq.

[2] G. B. M. Flamand, Une Mission d'exploration scientifique au Tidikelt, Ann. de Géogr., 1900, IX, pp. 233–242, map. Flamand marks as El Khenig some 'arêtes rocheuses vives' and a little incision in the chain of Aïn Kahla (= Jebel Asas) (Ann. de Géogr., 1900, IX, p. 241), while Haci el Khenig is marked on Gautier's map far to the south-west of this point on the Wady Botha (La Géographie, 1904, X, pl. I). This place probably corresponds to the confluence of the Wady el Khenig, which descends from the Jebel Asas (taken from Flamand's map and Pelet's Atlas des Colonies françaises) along with the Wady Botha. Thus this point would lie in the midst of the Carboniferous. The folding and the discovery of Graptolites certainly correspond with its upper course, which is 60–80 kilometers distant.

[3] G. B. M. Flamand, Aperçu général sur la géologie, etc., du Bassin de l'Oued Saoura (from the Documents pour servir à l'étude du Nord-Ouest Africain), 8vo, Alger, 1897, 166 pp., map; E. F. Gautier, Rapport sur une Mission géologique et géographique dans la région du Figuig, Ann. de Géogr., 1905, XIV, pp. 144–166, map; for the region succeeding on the south, Sahara Oranais, op. cit., 1903, XII, pp. 235–259, map; also Études Sahariennes, op. cit., 1907, XVI, pp. 46–69, map, and Flamand, C. R. Acad. Sci. Paris, 16 juillet 1907, pp. 211–213; also Ficheur, Sur l'existence du terrain carbonifère dans la région d'Igli, C. R. Acad. Sci. Paris, 23 juillet 1900, p. 288; A. Thevenin, Note sur les Fossiles du Carbonifère inférieur du Djebel Bechar, Bull. Soc. géol. France, 1904, 4e sér., IV, pp. 818–822.

Jebel Grouz (1,800 meters), near Figig, is a steep east and west anticline of Lias and Oolite, which, continuing the lofty chain of Ksour to the west, forms part of the Mediterranean Atlas. A smaller Jurassic chain, the Jebel Melias, lies on its south side; the Jurassic limestone is here overturned towards the south on to the Cenomanian (i. e. over the sands of its foreland). *This locality marks the boundary between the Mediterranean Atlas and its foreland.*

From this point onwards, as Gautier remarks, we enter another world. Instead of broad stretches of sandy desert or Cenomanian, as on the whole of the south side of the Mediterranean Atlas, we now see great mountains running to the south-west.

A longitudinal valley, 130 kilometers in length and 900 meters in height, runs between these mountains to the south-west, from Figig to Bechar. Jebel Antar (1800 meters) in the north is formed of Carboniferous limestone. The valley is occupied by Cenomanian, the military station of Ben Zireg stands on steeply upturned Devonian. Jebel Bechar (1,400 meters) on the south side of the valley is a very long and broad ridge of Carboniferous limestone, which dips to the north-west; this is joined, in a manner not clearly defined, by marine middle Carboniferous, then follows green sandstone containing the upper Westphalian (Schatzlar) flora, as shown by *Neuropteris gigantea* and other species, and lastly the unconformable Cenomanian.

This range is followed by others parallel to it, in particular by the Jebel Mezarif, on the other side of the Wady Susfana, which flows in a second longitudinal valley.

This zone of parallel chains, together with the two longitudinal valleys, dates from a period of folding more recent than the lower Carboniferous and older than the Cenomanian. It differs in direction and stratigraphical sequence from the Mediterranean Atlas, although scarcely 12 or 15 kilometers of flat-lying Cenomanian beds separate the Devonian of Ben Zireg from the Jurassic limestone of the Atlas.

Although the gap between the lower Carboniferous and the Cenomanian renders it impossible to precisely determine the age of these chains, yet the French investigators are probably correct in assigning them to the pre-Permian (Hercynian) assemblage, that is to the Altaides.

Jebel Bechar is the longest and most important of the group. It bends in an arc out of the south-west into the south-south-west direction, and reaches Igli along with the Wady Susfana. Just above this place the Wady Susfana and the Wady Gir unite to form the Wady Saura, and from this point onwards the chain decreases constantly in height. Near lat. 30° N. upper Devonian advances with a somewhat divergent south-east strike to the line of the Wady Saura, and Devonian rocks with a south-south-easterly direction accompany the Wady Saura down nearly to Buda in Tuat (about lat. 28° 5′ N., long. 0° 15′ W.). Thus for four degrees of latitude the line of the Susfana and Saura marks the course of the older folding. In front of this line there lie, however, especially near lat. 29° N., repeated traces of completely denuded folds of middle and upper Devonian, which finally disappear beneath the sandstone of the great Cretaceous platform of the Tadmaït and the Turonian glint of the Baten.

Between lats. 26° 30′ and 27° N. the Wady is interrupted, and nothing is known of the substructure; further south, however, the Wady Susfana reappears as the Wady Msaud, and turns, as stated by Gautier, in contradiction to previous observers, to the south-west, i. e. towards the Juf. Then, slightly further to the east, traces of the ancient folding again make their appearance, becoming less and less distinct, until they once more become clear north of the Ahenet and the Muydir.

Here we again follow a description by Gautier[1].

Near In R'Ar (about lat. 27° N., long. 2° 15′ E.) a steep, almost meridional, anticline of Carboniferous crops out. Whether or not it is repeated in mount Ahenet is an open question. The broader folds of the eastern Ahenet and the western Muydir also demand further study. In about long. 3° 20′ E. a sharp anticline rises out of the Cretaceous. This is Flamand's Aïn Kahla or Jebel Asas; the Graptolites of el Khenig probably come from it. At first it strikes south-south-east, then follow two long hills directed almost to the south, until, after a course of about 80 kilometers, the anticline enters the most northerly part of the Muydir.

The separate course of the several folds, as well as their general disposition, indicate *a virgation which, near Figig, advances as an arc in front of the much younger folds of the Mediterranean Atlas (in lat.* 32° 15′ N.); *its branches turn out of the south-west into the south, then into the south-south-east, and finally again into the south direction. It is now known to extend nearly as far south as lat.* 26° N.

The Great Atlas. The Mediterranean Atlas belongs to the Alpine chains. It is formed to no small extent of folded Mesozoic beds; its inner side faces towards the north; it bends in an arc in the Rîf, crosses the sea in the Pillars of Hercules, and is continued in the Betic Cordillera (I, p. 221). To the south of it the maps mark radiating branches or coulisses striking to the south-west beyond Fez, and then a broad wedge-shaped strip of land, interrupted in an irregular fashion by shorter chains, which occupies the whole of the coast between cape Spartel and cape Ghir, a distance of more than 5 degrees of latitude.

[1] E. F. Gautier, Le Mouidir-Ahnet, La Géographie, 1904, X, pp. 1–18, and pp. 85–102, map. While this volume was in the press the following works have appeared: Gautier et Chudeau, Esquisse géologique du Tidikelt et du Mouidir-Ahnet, Bull. Soc. géol. France, 1907, 4e sér., VII, pp. 195–218, map; and Chudeau, Excursion géologique au Sahara et au Soudan, tom. cit., pp. 319–346.

This wedge-shaped strip is often, but incorrectly, described as the foreland of the Great Atlas; as a matter of fact the Great Atlas does not even reach cape Ghir. On the south side of this supposed foreland rises the long ridge of el Jebilet (the Little Atlas; el Jebel is the Great Atlas). This slopes away on the south to the plain of the Hauz, i. e. to the Wady Tensift, and the town of Marrakesh. Then further south the land rises rapidly until the Great Atlas is reached. Many of its peaks exceed 3,000 meters in height; and one of them attains 4,500 meters. On the south the great range descends to the Wady Sus.

North-east of the sources of the Wady Sus, still among the slopes of the Great Atlas, lie the sources of the Wady Draa. Between them rises a remarkable part of the range, which bears the Jebel Sirua and unites the Great Atlas with the Anti-Atlas situated to the south of the Wady Sus. The Wady Draa turns to the south-west, surrounds the hills of the Jebel Sirua, and thus reaches the south side of the Anti-Atlas.

Joseph Thomson found that the Jebilet is formed of ancient (metamorphic) folded rocks, which strike north-north-east transversely to the direction of the hilly ridge, and he suggested that this strike might be continued across the Wady Tensift and *through Marrakesh into the foothills of the Great Atlas.* The blunted outlines of the great ranges attracted his attention; he also succeeded in showing that the western end of the range sinks in a rapid slope and does not reach the sea. In fact we may place its termination about 60–70 kilometers inland from cape Ghir [1].

According to T. Fischer, the covering formations of the so-called foreland rest upon the same folded basement rock as that described by Thomson in the Jebilet, and this crops out even on the coast between Casabianca and Rabat. Fischer was reminded of the Variscan arc and the Spanish Meseta [2].

This comparison has been confirmed by the work of French investigators; Brives and Lemoine have made us familiar with the north of the Great Atlas; L. Gentil has crossed it four times at frequent peril of his life [3]. Many questions must still remain open, but as regards the

[1] J. Thomson, The Geology of South Morocco and the Atlas Mountains, Quart. Journ. Geol. Soc., 1899, LV, pp. 190–213.

[2] T. Fischer, Wissenschaftliche Ergebnisse einer Reise im Atlas-Vorlande von Marokko, Peterm. Mitt., Ergänzungsheft no. 133, 1900, 165 pp., maps, in particular p. 152 et seq. The appearance of Schnell's map of the Moroccan Atlas range soon after this work must also be regarded as an important step in advance, ibid. no. 103, 1892, 119 pp., map.

[3] Here we will only mention the latest and most comprehensive works on this region. A. Brives, Les terrains crétacés du Maroc occidental, Bull. Soc. géol. France, 1905, 4e sér., V, pp. 81–96, map; and Contributions à l'étude géologique de l'Atlas Marocain, tom. cit., pp. 379–398, map; also L. Gentil, Observations géologiques dans le Sud-Maroc, tom. cit., pp. 521–523; Contributions à la géologie et la géographie physique du Maroc, Ann. de Géogr., 1906, XV, pp. 133–151; and Note sur l'esquisse géologique du Haut Atlas occidental, op. cit., 1907, XVI, pp. 70–77, map; Mission de Segonzac, Exploration au Maroc,

region extending from the sea to the meridian of Demnat (long. 6° W.) we possess the following observations:—

Two systems of folds are present in Morocco. The first is of pre-Permian age and strikes N. 20° E.; further east it strikes more to the north or even north and a little east. The second is of Tertiary age with a strike to north-east or east-north-east; this forms the Mediterranean (Alpine) chains.

The difference both in the strike and the age of the folds is just as clearly marked in these two systems as it is in the Atlas of Oran and the Jebel Bechar, or in the Betic Cordillera and the Meseta.

The pre-Permian folds, as already stated, crop out on the coast between Casabianca and Rabat; they form a large part of the Jebilet, the neighbourhood of Marrakesh, and the Great Atlas. Gneiss, granite and ancient schists, Silurian (Graptolite slates and Orthoceras limestone), Devonian and lower Carboniferous are known to occur in them. The Permian, very often associated with eruptive rocks, is either invariably cut off by a dislocation, or unconformably superposed, as in the case of the cap of red sandstone resting upon ancient schist near the pass of Tizi n Teluet (Glaui)[1]. Not infrequently unconformable superposition is only mentioned in connexion with the Permian and Cretaceous, as in the Pyrenees and Bohemia.

In the west, the pass of Bibaun, through which Oskar Lenz began his famous journey, and the line of the Wady Mussa, which joins the Wady Sus between Tarudant and the sea, mark the region where the pre-Permian chain of the Great Atlas descends beneath the younger rocks.

Of the more diversified tract to the east it is much more difficult to obtain a general idea. Rohlfs has touched upon the southern part, and some light is obtained from Gentil's discoveries.

It has already been stated that the sources of the Wady Draa lie within the region of the Great Atlas, and to the north-east of those of the Wady Sus. The two Wadys are separated at their source by a broad ridge, formed of granite, gneiss and crystalline schist, which runs north-east from the Anti-Atlas into the Great Atlas. It descends to the plain of the upper Draa, and there we find, near Tikirt, horizontal chalk marl apparently surrounding its foot. Ancient rocks identical with those of this ridge form the high plateau of Aït Khzama (2,000 meters), and are known within the Great Atlas up to the summit of the pass of Tiz n Tar'rar (about 3,500 meters).

Between the Wady Draa and the Wady Sus this ancient foundation, chiefly granitic, supports the wide recent volcanic region of the *Jebel Sirua* with its ruined craters, trachytic flows, scoriae and ashes. North of this

8vo, Paris, 1906, 364 pp.; P. Lemoine, Mission dans le Maroc occidental, Rapport au Comité du Maroc, 12°, Paris, 1905, 233 pp., map.

[1] Lemoine, Mission, etc., p. 191, fig. 50.

region it also forms a great part of the district of Tameldu, and still further north the same foundation bears a vast mass of Permian eruptive rocks, including the lofty peaks of *Jebel Tamjurt* and *Jebel Likumt* (both about 4,500 meters).

To the east of this tract, as we proceed from Tikirt to the north, we come first on the already-mentioned horizontal Cretaceous of the Wady Draa, which here, as in the north, contains gypsum. In the Asif Imar' ren the road runs upwards through Cretaceous, beneath which the red Permian is visible. This younger covering persists as far as the pass in Glaui, which lies in ancient schist.

Thence the road turns towards the east, skirting the Jebel An'rmer. Richly fossiliferous lower Carboniferous now crops out, and Gentil thinks it not impossible that this may prove to continue along the south side of the range as far as the lower Carboniferous of the Jebel Bechar, i. e. *that the pre-Permian mountains surround the Mediterranean folding on the south even in the Tafilet and to the east of it.*

The great Jebel An'rmer consists, like the other high peaks, of Permian eruptive rock, here resting on the lower Carboniferous. Once more we come upon red Permian; Jurassic limestone is also mentioned. Near Aït Mdual, south of Demnat, black Graptolite slate crops out from beneath the unconformable Permian. Before reaching Demnat we are already surrounded by the Mediterranean folds with their characteristic strike to the east-north-east. These form for some distance, certainly as far as Rahat, and even beyond, the south border of the plain of Marrakesh. Possibly they border the whole north side of the Great Atlas; but there seems to be some difference of opinion on this point[1].

Between the pre-Permian outcrops of the west coast and the Jebilet several younger shorter anticlines extend through the so-called foreland to the south-west or west-south-west. The strata exposed in these anticlines were not deposited in deep water. The red Permian can only with difficulty be distinguished from the red Trias, which contains gypsum and salt, and, as in the Pyrenees, ophite also; the Jurassic, especially in the west, is either but feebly developed or entirely absent; the lower Cretaceous is present; the Cenomanian occurs in transgression, and, as in the Sahara, frequently begins with deposits of gypsum.

One of the most important of the anticlines is the *Jebel el Hadid* (the iron mountain, 666 meters, strike south-west), between the Wady Tensift and Mogador. According to Lemoine, vertical Trias is exposed along its

[1] Lemoine, Mission, etc., pp. 183–197. From the section of the Wady Reraja given here it appears as though the Cretaceous beds of the Hauz had subsided from the north border of the Great Atlas. Such a subsidence is clearly indicated by Brives et Braly, Sur la constitution géologique de la Plaine de Marrakech, Bull. Soc. géol. France, 1906, 4e sér., VI, pp. 56–66.

axis [1]. Further anticlines follow; they are less sharply defined, but reveal Trias or even Permian beneath the Cretaceous, and all decrease in height towards the sea. One of these anticlines reaches cape Tafetneh, a second, cape Ghir, and a third, Agadir n Irir.

Thus from the south-west of Europe a great branch of the Altaides, sometimes, it is true, interrupted and concealed from sight, but still clearly recognizable, extends with a strike to N. 20° E. (in the east with a north and south strike) through Casabianca, the Jebilet, Marrakesh and the Great Atlas at least as far as the Wady Sus and the sources of the Draa till it reaches the meridian of Demnat. Numerous patches of Permian and Cretaceous rest on the Great Atlas; its highest summits are of secondary and eruptive origin, in part of Permian (e. g. Likumt), and in part of much more recent age (Sirua).

The range situated further to the east is almost unknown, although it presents some lofty peaks (e. g. Jebel Uriul, 4,250 meters). Information concerning the Anti-Atlas in the south is also extremely scanty. Gentil saw it from the north-east and believed it to be a folded range. The descriptions and sketches furnished by Lenz seem to suggest that the structure of the Great Atlas finds its prolongation in the western and southern portion of this chain. At Fum-el-Hossan (lat. 28° 30′ N.) vertical beds of quartzose sandstone of unknown age occur. The lower Carboniferous was traced by Lenz down to lat. 26° at least [2]. According to Flamand the Hammada el Aricha, north of Taudeni (lat. 21° 30′ N.), also consists of lower Carboniferous [3], which there lies horizontal.

Gentil states that, according to the accounts of Dereims, sandy Devonian, folded and with a strike slightly east of north, occurs in the northern Tagant; that, according to the observations of Gérard, it also makes its appearance at Tijikja (Tagant; lat. 19° N., long. 9° 30′ W.); and further, that, according to the observations of Gruwel, it occurs beneath the dunes of the Baja del Galgo (within cape Blanco, lat. 21° N.) [4]. For the sake of completeness we may add that Dumont also met with folded schists and limestones, the latter containing Stromatopora, on the Congo, between lat. 5° 15′ and lat. 4° 45′ S. about [5].

We cannot arrive at any definite conclusions from the observations made at these points, so far remote from one another, yet it seems probable that, as a pre-Permian virgation extends far to the south in the central Sahara, so pre-Permian off-shoots may also exist in Mauritania.

[1] P. Lemoine, Sur la constitution du Djebel Hadid, C. R. Acad. Sci. Paris, 6 févr. 1905, pp. 393, 394.

[2] O. Lenz, Timbuktu, 8vo, Leipzig, 1884, II, pp. 3, 16, 21, 49 et passim.

[3] G. B. M. Flamand, Sur la présence du terrain carbonifère aux environs de Taoudeni (Sahara, SE.), C. R. Acad. Sci. Paris, 17 juin 1907, pp. 1387–1390.

[4] Gentil, Ann. de Géogr., 1907, XVI, p. 74.

[5] E. Dupont, Lettres sur le Congo, 8vo, Paris, 1889, 724 pp., map, pp. 385, 504.

CHAPTER IV

THE ALPS

I. Western Part

Situation of the Alps. Progress of investigation. Division of the Alps. Zone of mont Blanc. The Carboniferous fan and the Briançonnais. Recumbent sheets. The Glarus. The Simplon and Tessin. Ivrea. From the Dora Baltea to the Gesso. From the Gesso to the sea. The Alps in Corsica. Relations to the Apennines.

The peculiar lie of the Alpine chains follows from the facts presented by north Africa, as described in the last chapter. It will conduce to clearness if we give a collective name to these chains, the middlemost of which are the Alps themselves, and we shall therefore term them the *Alpides.*

The Alpides belong to the posthumous Altaides. They extend from the Black sea to Gibraltar. To the north of them lie the pre-Devonian Caledonides with a submeridional strike, and to the south, with a similar strike, the slightly older Saharides. Between the Caledonides and the Saharides, with a transverse strike indicating a new phase of mountain formation, lie the remains of the pre-Permian Altaides, broken up into horsts and extending in an arc from Silesia through Germany, France, Spain, and Morocco to the Jebel Bechar near Figig. The pre-Permian Altaides form the frame within which the Alpides have been built up.

A glance at the terrestrial meridian which runs through Spitzbergen and the cape of Good Hope shows that so far as it is accessible to investigation this outer frame encloses *the only area in which, from the extreme north to the extreme south, post-Permian folding has taken place on a large scale.* The mountains at the cape are at latest of Permian age. The posthumous folds of the London and Paris basin and the other posthumous Altaides attain only a trifling development. We may assert without exaggeration that almost *the whole of the contraction which has occurred since the Carboniferous epoch in a great meridional section of the globe has found expression within this frame.* This, in substance, has already been recognized by Haug.

At the same time the Alpides are not so independent of the Altaides, as the Altaides are of the Caledonides and Saharides. It is thus easier to comprehend why, in spite of the close relations existing with Asia, free ends should yet appear both at the eastern and western extremities of the

Alpides; at the western extremity they are seen in the Balearic isles, and at the eastern extremity in the east Balkans, the spur of Valeni and the most easterly and most interior fold of the Jura mountains (Gisli-fluh-Kistenberg, continued in an anticline of the Molasse)[1].

The frame, however, is open to the east and south-east. It is surmounted by the Alpides, where the Sudetes disappear beneath the Carpathians, and where the border of the Russian platform as well as the Cimmerian mountains are overwhelmed, but further south a large area lies open between the Crimea and Figig. This belongs to the Sahara and the marginal arc of the Dinarides. In that arc, as we have seen, an inter-Carboniferous basement is present, but the foldings have been continued on the same plan into the Tertiary aera, and they are directed towards the south. Here, therefore, Asiatic characters are predominant (III, p. 422).

This fragment of the peripheral Asiatic structure, although folded to the south, is, as a whole, intruded on the north-west into the frame of the Alpides, and has so deeply influenced their development that the breadth of the Alps in the meridian of Innsbruck is reduced to about 100 kilometers. Thus the contraction of the planet is expressed in this area in two ways: (1) by that collective movement of the Dinarides, which does *not* proceed from folding, and (2) by the accumulated dislocations of various kinds, to which the Alpides owe their origin. During this process a constriction of the frame has taken place from the south-east, and it is a remarkable fact that the Dinarides, unlike the Altaides, never become a passive resistent foreland, but they rather assume, as for instance in the Brenner, the character of a backland, and exert a certain amount of thrusting action.

Let us first consider the Alps themselves.

Progress of investigation. Five states, Italy, France, Switzerland, Bavaria, and Austria, claim a share in this noble mountain range. This fact, in itself, had created a certain local inequality in scientific work at a time when neither the means of communication as a whole, nor the means of access to the mountains in particular, nor again the topographical maps, were at all comparable to those of the present day.

The work has proceeded in the order prescribed by the inductive method and the nature of the subject.

First came the analytical, descriptive stage. Escher and Studer's map of Switzerland and Franz von Hauer's map of Austria may serve as monuments of this period.

These were soon supplemented by attempts at local synthesis. We may mention Escher's first sections of the so-called double fold of Glarus, Desor's attempt in 1865 to arrange the central masses of Switzerland in concentric arcs, and Lory's proposal in the following year, 1866, to attribute the struc-

[1] Mühlberg, Arch. Sci. phys. et nat. Genève, 1904, p. 37 (Ber. Schweiz. Naturf. Ges. Winterthur).

ture of the French Alps to fractures: a careful perusal of Gerlach's works, also written during this period, will discover many ideas which anticipate research of a much later date. Then by degrees, as the area taken into consideration extended its bounds, the unity of the whole Alpine system, the passive character of the central masses, the unilateral structure, the general movement to the north, and the dam-like action of the foreland were brought into relief. As early as 1877, F. Teller observed that the calc-phyllites dipped beneath the south-east side of the gneiss mountains of Oetz and Stubai, as though the calc-phyllites were inserted in a mighty fold of gneiss, inclined obliquely to the north-north-west [1].

Trend-lines were determined for the Alps; the Carpathians and the Apennines were brought into connexion with them; the Dinarides separated off. As the ground plan gradually disclosed itself, a great advance was made in the interpretation of the inner structure through Marcel Bertrand's comparison with the Belgian coalfield set forth in 1884, and the demonstration this afforded that great masses may be transported by a horizontal movement (charriage) [2]. The resemblance was recognized between Desor's first zone of the central masses of Switzerland (Mercantour, Pelvoux to mont Blanc and the Rhine) and the Variscan foreland.

This resemblance was established in 1880 by C. Schmidt [3]; in 1890 Michel Lévy went a step further and compared the structure of mont Blanc with that of the Central plateau [4]; and, in 1891, Kilian definitely asserted that these central masses are parts of the foreland [5].

Meanwhile the East became alive to the necessity of comparison with the West: the result was Noe's general map of the entire range of the Alps [6] published in 1890, and Diener's work on the west Alps, published in 1891, which led to the establishment of the zone of the Briançonnais [7].

A difference of opinion acted as a check on the works of French and Italian investigators. In Italy the lustrous schists (schistes lustrés) were regarded, in accordance with the views of Gastaldi, as Palaeozoic or pre-Palaeozoic rocks, and this hypothesis found an able advocate in Zaccagna. Lory believed them to be Mesozoic. Opinions wavered until Marcel Bertrand, in 1894, finally assigned them to the Mesozoic aera, except in

[1] F. Teller, Verh. k. k. geol. Reichsanst., 1877, p. 233.

[2] M. Bertrand, Rapports de structure des Alpes de Glaris et d'un bassin houiller du Nord, Bull. Soc. géol. France, 1884, 3e sér., XII, pp. 318–330, map.

[3] C. Schmidt, Zur Geologie der Schweizer Alpen, 8vo, Basel, 1889, 52 pp.

[4] Michel Lévy, Étude sur les roches crystallines et éruptives des environs du Mont Blanc, Bull. serv. Carte géol. France, 1890, no. 9.

[5] W. Kilian, Notes sur l'histoire et la structure des chaînes alpines de la Maurienne, etc., Bull. Soc. géol. France, 1891, 3e sér., XIX, pp. 571–661, e. g. p. 642: 'Fragments remaniés de l'ancienne chaîne hercynienne'.

[6] Franz Noe, Geologische Übersichtskarte der Alpen, 1:1,000,000, 2 sheets, Vienna, 1890.

[7] Carl Diener, Der Gebirgsbau der Westalpen, 8vo, Vienna, 1891, 243 pp., map.

so far as Tertiary formations might be involved [1]. Not long afterwards Franchi and Stella confirmed this conclusion by the discovery of Mesozoic fossils [2].

Marcel Bertrand's views on overthrusts had by this time been further developed. In the west, Kilian and Haug described recumbent sheets outside the limits of mount Mercantour and mount Pelvoux. Schardt, an early pioneer, drew instructive sections showing great horizontal movements in the neighbourhood of lake Geneva. In 1901, Lugeon was able to show that not only the Helvetian Alps which lie outside, or north and west of, the zone of mont Blanc, are overfolded for a great distance and thrown into flakes, but also that great parts of the range lying on the inside, and south and east of this zone, have been carried out over it on to the outer chains. The whole of the Chablais and the Freiburg Alps are transported masses of this kind [3].

Further east the long and laborious investigations of Heim in the region of the double fold of Glarus have led him to accept the view held by Marcel Bertrand and others, that the true explanation of this structure is afforded by a single great overfold. In the region of the upper Inn, Lugeon and Termier found that older sheets were exposed in a window beneath the sheet of the East Alps. Steinmann, who originally held another opinion, eventually arrived at the same conclusion.

Rothpletz was one of the first to maintain the existence of such overthrusts in the western part of the East Alps. At a later time, and particularly at the congress of 1903, Lugeon, Termier, and Haug attempted to show that a similar structure was presented by other parts of the East Alps. It was even maintained that the whole zone of the eastern limestone Alps, 480 kilometers in length, floated upon an alien basement.

At the same time two new groups of facts were observed at points remote from one another. The first was the result of still uncompleted studies by Becke and his colleagues on the central gneiss of the Tauern; the second followed on a knowledge of the structure of the Simplon tunnel, which afforded a basis for the discrimination of the inner zones of the West Alps.

These unexpected discoveries have stimulated the efforts of investigators, and the following attempt at a summary is made at a time when fresh results flow in without pause, and while our knowledge of the several parts of the Alps is still most unequal. Theories as to the process by which the

1 M. Bertrand, Études dans les Alpes françaises, Bull. Soc. géol. France, 1894, 3e sér., XXII, pp. 69-162, maps.

2 S. Franchi, Sull' età mesozoica della zona delle pietre verdi nelle Alpi occidentali, Boll. R. Com. geol. Ital., 1898, 3e sér., IX, pp. 325-482, map, and several later works.

3 M. Lugeon, Les grandes nappes de recouvrement des Alpes du Chablais et de la Suisse, Bull. Soc. géol. France, 1901, 4e sér., I, pp. 723-825, maps; cf. note, p. 117.

mountains were built up can only be made with a high degree of reserve, and they must be based on that broader foundation which is afforded by a comparison with other great mountain ranges. For this reason they will be left to find a place in later chapters.

Subdivision of the Alps. Disregarding the Jura mountains and the Molasse, three boundaries of different kinds enable us to subdivide the Alps into several regions, a step which will facilitate our attempt to obtain a broad and general survey.

The first of these is the sharply defined southern or *Dinaric boundary.* It runs almost in a straight line from the south side of the Bacher mountains in Styria for a long distance to the west-north-west, crosses the Brenner between Brixen and Sterzing, then turns to the south-south-west, next to the south-west and west-south-west, reaches the Adda, and finally, striking across the northern part of lake Como and the Lago Maggiore, extends in an arc west of lake Orta to the plain of Lombardy. It is a line of compression and intrusion.

The second boundary is *that between the East and West Alps.* It does not hold good for the Flysch zone. It is most clearly marked on the west side of the Rhaeticon, and is continued through Oberhalbstein into the north-east of the Disgrazia group. It marks the superposition of an upper eastern mountain complex on lower western complexes.

The third line is the least clearly marked, or, more correctly, has been most altered by later events. It separates within the western Alps *the Piedmontese from the Helvetian Alps.* Disregarding deviations to be mentioned presently, it runs from the east side of the Mercantour, close to the east side of the Pelvoux and mont Blanc, eastwards to the Rhone valley, then across val Bedretto and through Airolo to the south side of the Gotthard. This boundary is very nearly followed by a band of Oligocene, Haug's zone of the Aiguilles d'Arves, which we shall designate with Termier the *inner Flysch zone.* It first makes its appearance on the sea coast, and has been recognized by Kilian even on the east side of mont Blanc.

The separation of these branches of the Alps may be observed also on the outer border. The Jura mountains merge with the Helvetian Alps in a bend directed inwards towards Chambéry. The Helvetian (or Delphinian) Alps describe a similar bend, corresponding to the Pelvoux and directed inwards to the upper Durance, and a second bend in the direction of the Var. On the Var they terminate, while the Piedmontese Alps strike away to the sea and reappear in the north-east of Corsica.

In this subdivision the oft-mentioned zone of the Briançonnais must be assigned for the most part to the outer parts of the Piedmontese Alps.

Zone of mont Blanc. This zone of ancient rocks extends from the Mercantour across the Pelvoux, Grandes Rousses, Belle Donne and mont Blanc to the Gotthard and the mass of the Aar. The lie of the arc appears to correspond on the whole with the Variscan strike in the foreland. But closer observation shows that this correspondence exists only in the east; in the Belle Donne a considerable deviation makes its appearance; in their southern part, as in the Grandes Rousses, the dominant direction, in contrast to the general outline of the mountains, is north and south, and in the south-west part of the Mercantour the direction is east and west [1].

In addition to this divergence between the strike of the rocks and the direction of the mountains, the arrangement of the branches in an alternating series claims attention. Michel Lévy and Ritter have found that the southern branch of the Belle Donne, which follows the outer side of the Grandes Rousses, strikes obliquely through Beaufort and across the Prairion to the Aiguilles Rouges—that is, towards the north of mont Blanc. The continuation of the northern branch of the Belle Donne runs still further to the north, through Fleuret to Mégève [2]. The case is similar with regard to the oblique line of the Rhone-Furca-Urseren-Andermatt-Vorder Rhine which separates the St. Gotthard from the mass of the Aar.

These oblique lines of demarcation strike somewhat more towards the north-east than the inner side of the arc. Connexions existed not only along these lines, but also above the level of at least a part of the zone of mont Blanc. This is shown by the patch of Jurassic described by Favre on one of the peaks of the Aiguilles Rouges and the presence of Mesozoic synclines in the gneiss masses themselves. In the Grandes Rousses and the Pelvoux, Termier has distinguished older, pre-Triassic, and younger or Alpine synclines. The older are crossed by the younger at various angles which are generally acute [3]. But where Alpine folds swerve around the foot of an ancient mass, as on the south of the Mercantour, they move like a fluid on the border of a weir, and the deviation from the direction of the older folds may amount to a right angle.

The ends of the several masses resolve themselves sometimes into two or three, or even, as in the south end of mont Blanc, into six or eight separate anticlines of gneiss, between which sedimentary synclines are included. Towards the interior of the masses these synclines disappear and the mass appears to be uniform, but we are able to perceive that if the great mountain core were less profoundly eroded it would present

[1] Franchi, Boll. R. Com. geol. Ital., 1894, p. 240, gives the strike for the Italian part as still south-east; for the south-west see L. Bertrand, Bull. serv. Carte géol., 1897, IX, p. 121 et seq.

[2] Michel Lévy, Note sur la prolongation vers le sud de la chaîne des Aiguilles Rouges, Montagnes de Pormenaz et du Prairion, Bull. serv. Carte géol., 1892, no. 27, pp. 393–452, map; E. Ritter, op. cit., 1896, no. 44, pp. 144–146; La Bordure Sud-Ouest du Mont-Blanc, op. cit., 1897, no. 60, pp. 445–676, map, et passim.

[3] P. Termier, Le Massif des Grandes Rousses, Bull. serv. Carte géol., 1894, VI, no. 40, pp. 169–287, map, in particular p. 104; Sur la tectonique du Massif du Pelvoux, Bull. Soc. géol. France, 1896, 3e sér., XXIV, pp. 734–758, map.

several parallel folds much further towards its interior, resembling those which are preserved in the Pelvoux, for example. This interdigitation of the folds was described many years ago by Heim in the St. Gotthard and at the east end of the Aar mass, and afterwards by Lugeon at its south-west end. Heim terms the phenomenon 'Verfaltung' (folding pushed to an extreme [1]): in the last example the flat-folded tongues of gneiss dwindle down to a thickness of from 2 to 4 metres [2].

Too much importance has been attached to the fan-shaped structure of mont Blanc. It is true that this structure is seen in the section of Chamounix-Courmayer, but the mass of the mountains consists of crowded folds overturned to the north-west, as shown by Duparc and Mrazec, and confirmed by Ritter and other observers. We must conceive the ancient basement of mont Blanc as a basin of crystalline schists, on each side of which, on the north-west and south-east, lies a zone of fairly ancient schists, out of which rise rocks of granite and protogine [3]. Pebbles of protogine have been met with in Carboniferous conglomerate [4].

Three granitic intrusions have been described by Baltzer in the Aar mass. They belong to the group of the Variscan granites of the Erzgebirge, the Harz, and other ranges [5]. Although the members of the mont Blanc zone exhibit characters which are clearly Variscan, e. g. in the transgression of the limnic beds of middle and upper Carboniferous, yet we cannot describe them as Variscan horsts. They are resurgent parts of the basement of the Alps, which was folded together with the overlying rocks, and they consist of repeated parallel folds. They are exposed at the surface, because the longitudinal axes of the several fascicles of folds rise upwards and sink downwards together (surélévation des axes).

The Carboniferous fan and the Briançonnais. A long arc of Carboniferous and Permian sediments extends from the Rhone valley above Sion, down to the sea-coast near Savona. Running at first parallel with the inner border of the zone of mont Blanc, it crosses the Great and Little St. Bernard, extends east of Moutiers to Briancourt, is interrupted by the valley of the Guil, reappears on Italian soil, passes to the south of Santo Dalmazzo, and finally, with an almost east and west direction, reaches the

[1] That is, folded flat, hence as an English equivalent we may speak of flatfolding.—Note by Editor.

[2] A. Heim, Hochalpen zwischen Reuss und Rhein, p. 246; Lugeon, Seconde communication préliminaire sur la géologie de la région comprise entre le Sanetsch et le Kander, Eclogae Geol. Helv., 1905, VIII, pp. 421–433.

[3] L. Duparc et L. Mrazec, Recherches géologiques et pétrographiques sur le Massif du Mont-Blanc, Mém. Soc. Phys. Hist. Nat. Genève, 1898, XXXIII, pp. 1–227; in particular p. 194 et seq.

[4] M. Lévy, Bull. serv. Carte géol., 1890, no. 9, pp. 22.

[5] A. Baltzer, Die granitischen Intrusiv-Massen des Aar-Massivs, N. J. f. Min., 1903, Beil.-Band XVI, pp. 292–324, International Congress, Vienna, 1903, pp. 787–798.

sea near Savona[1]. The rocks are often altered into semi-crystalline or even gneissose schists. Plant remains, compressed anthracite seams, and graphite, bear witness to their age. The arc does not form a stratigraphical boundary. This is obvious from Kilian's observations. For the greater part of its course it possesses a fan-like structure which is most clearly expressed south of the Great St. Bernard. The west side is overturned towards the west, in the direction of mont Blanc and the Pelvoux, and the east side is overturned towards Italy. In like manner the whole of the next succeeding range is overturned on the one side as far as the older rocks of the Pelvoux, on the other, as far as the Italian plain. Earlier descriptions might easily give rise to the notion that this long fan is an independent axis of elevation. It is a zone of stowing [2].

Let us first consider its relations to the younger sediments between Briançon and the east side of mont Blanc. In our study of this region we will take Kilian's comprehensive works as our guide [3]. With regard to its southern portion we have in addition Termier's investigations north and south of the town of Briançon [4].

In this elongated, and not very broad tract, the inner Flysch zone makes its appearance. This shows that the sea still lingered here even at the time of the upper Oligocene. On the east side of the Pelvoux, Kilian encountered Flysch normally superposed on the gneiss. It also lies in transgression on folded Mesozoic beds, but is itself folded, and in the Aiguilles d'Arves, a little to the north of the Pelvoux, it reaches a height of 3,514 meters.

In the Mesozoic beds of the Swiss Alps we are accustomed to distinguish three facies, a Helvetian, a Briançonnais, and a Piedmontese facies.

The Piedmontese facies is distinguished by the preponderance of lus-

[1] M. Bertrand, Études dans les Alpes françaises, Bull. Soc. géol. France, 1894, 3e sér., XXII, pp. 69-162, maps. A summary of the whole range is given by Pellati in Giacimenti di Antracite nelle Alpi occidentali italiane, Mem. Carta geol. d'Ital., 1903, XII, tav. I.

[2] The temptation to render 'Stauung' by 'stowing' in the preceding volumes was great, it is now too strong to be resisted. The Anglo-Saxon 'stow' meant to stop, and is still sometimes used in that sense. A moving mass arrested or stowed by a dam rises up against the obstacle, and the whole effect of the dam is expressed by the term 'stowing'.—Note by Editor.

[3] W. Kilian et J. Révil, Études géologiques dans les Alpes occidentales, Contributions à la géologie des chaînes intérieures des Alpes françaises, I; Mémoire pour servir à l'explication de la carte géologique détaillée, 4to, 1904, 627 pp., maps, and a number of smaller works.

[4] P. Termier, Les Montagnes entre Briançon et Vallouise; Mémoire pour servir à l'explication de la carte géologique détaillée, 4to, 1903, 184 pp., map, and Sur la nécessité d'une nouvelle interprétation de la tectonique des Alpes Franco-italiennes, Bull. Soc. géol. France, 1907, 4e sér., VII, pp. 174–189. Compare also Franchi's observations on the 'facies mista' in Boll. R. Com. geol. Ital., 1906, p. 89 et seq., which are useful as a study of accessory characters.

trous schists, and the presence of basic green rocks. The Trias is represented by quartzites, gypsum, and marble. The lustrous schists, which belong in great part to the Lias and Oolites, also occur in the west of the Carboniferous fan, e. g. on the Col de Seigne, and the green rocks are also to be found at this and other localities. An opportunity will be afforded later of mentioning the remains of recumbent sheets situated further to the north, which have been carried from the south-east over the Briançonnais, or onwards out of the Briançonnais towards the west. It will also be necessary, before discussing the East Alps, to obtain a more definite idea of the meaning of the term 'facies'. We shall then see that the characters of the Piedmontese facies, namely, the presence of the green rocks and the marked alteration of all the rocks, are merely accessory features. They have been added later and are foreign to the original facies. Termier long ago perceived that they increase as we proceed towards the plain of Lombardy.

The town of Briançon itself lies in the Carboniferous zone. Mesozoic synclines are inserted in the fan.

As representatives of the Trias in the neighbourhood of Briançon, Termier mentions quartzite, succeeded first by greenish schist with beds of dolomite and limestone, as well as rauchwacke, gypsum, and phyllitic marble, and then by limestone, up to 300 meters in thickness, containing Gyroporella and Crinoids. The Lias presents itself as a breccia (Brèche du Télégraphe) but with a variety of development, in particular as dark platy limestone with Pentacrinus; and since the occurrence of black calcareous shales with *Avicula contorta* is mentioned, the Rhaetic stage must also be present; then comes Jurassic (Calcaire de Guillestre) often as Globigerina limestone, with Phylloceras, Aptychus, and other fossils. The whole of the upper part of this series is metamorphosed in places into platy marble (marbre en plaquettes); this, which may include the Cretaceous also, reaches a thickness of 700 meters.

This series differs from the Helvetian. Gyroporella limestone and Aptychus limestone are far more suggestive of parts of the East Alps. But in the crowded series of folds and flakes between the Carboniferous fan and the zone of mont Blanc the divergent horizons do not, as far as we can judge, appear simultaneously at a particular limit, so that series with a mixture of characters become possible.

If an example of the typical outer Helvetian series is compared with a typical series of the Briançonnais, e. g. with a recumbent segment transported from a distance, a considerable difference will be apparent, but in the broad and now compressed area across which the overriding has taken place the two series are connected by transitions.

The interpretation of the alternating series of the gneiss masses in the zone of mont Blanc now becomes apparent.

As a final result the Belle Donne disappear towards the north-east on Helvetian territory, and the Grandes Rousses, along with their associated synclines, strike away to the north side of mont Blanc, and even into its flat synclinal folds. The Mesozoic folds between the Belle Donne and the Grandes Rousses become the lofty limestone mountains of the Diablerets, Wildhorn, &c., and it seems as though the Grandes Rousses, and perhaps also a part of the Pelvoux, together with mont Blanc, had been affected by a subsequent arching up of the mountains.

We now perceive that the term 'Briançonnais' has been used sometimes in a narrower, sometimes in a wider sense. The facts so luminously presented by Kilian lead indeed to the following transverse section: 1. Outer Helvetian folds. 2. Older rocks of the Belle Donne. 3. Several fascicles of Mesozoic folds, between which mont Blanc, the little mass of Rocheray on the Arc and the Grandes Rousses, with perhaps the Pelvoux also, appear as though resting on a common anticline. 4. The inner Flysch zone (zone of the Aiguilles d'Arves). 5. Another Mesozoic zone (faisceau du Galibier, Kilian). 6. The Carboniferous fan, with infolded Mesozoic bands (so far the overfolding is to the west; beyond this point it is to the east). 7. Another Mesozoic zone (faisceau du Chaberton). 8. Lustrous schists and Piedmontese Alps.

The gneiss chains are thus encountered twice over (Belle Donne and mont Blanc). We may take as the boundary of the inner Alpine zone either the chain of mont Blanc, or the inner Flysch zone, or again the Carboniferous fan. Kilian makes his zone du Briançonnais begin with the Flysch; thus interpreted it also includes the ranges of the Galibier (5), but gives a sharper boundary between 7 and 8.

As already stated, we regard the Flysch zone (4) as the outer boundary of the inner or Piedmontese chain, although it has been subsequently broken up; but we must repeat that this boundary is not of the same nature or value as the Dinaric boundary or that of the East Alps.

The Piedmontese Alps attain a great development towards the north-east and east. As an example we may mention the series of Trias, green schists, serpentine, and Bündner schists, met with by Preiswerk between Visp and Brieg in the Rhone valley. The serpentine which invades the Trias and Bündner schists was intruded as diabase and gabbro, and has produced in places contact metamorphosis. Later injections have consolidated as wehrlite and dunite[1]. These are the representatives of the green rocks of Piedmont. The Bündner schists represent the lustrous schists.

This zone also includes the great band of Verrucano, Trias, lustrous schists and calc-mica-schists, which Heim observed near Olivone, between

[1] H. Preiswerk, Die metamorphischen Peridotite und Gabbrogesteine in dem Bündner Schiefer zwischen Visp und Brieg, Verh. naturf. Ges. Basel, 1904, XV, pp. 293–316.

the gneiss of the Adula and the south side of the Gotthard [1]. The whole breadth of the Wallis Alps as far as the Adda also belongs to this zone.

Recumbent sheets. While the synclines described above strike obliquely through the zone of mont Blanc, and may develop outside the zone into mighty limestone ranges, the situation in the south is quite different.

Between the Mercantour and the Pelvoux, the zone of mont Blanc presents a great gap, and through this, as through a gateway, the impelled mountains make their exit to the west, just as water or ice, furrowing away the ground beneath it, forces its way through a constricted passage (II, p. 343, fig. 35, and p. 344, fig. 36).

We will begin our study of this process in the south-west. For the French part of the region we will follow the accounts of Léon Bertrand [2], and for the mountains north of Mentone and Bordighera those of Franchi [3].

The Var bends in a right angle out of an east and west into a north and south direction, and reaches the sea at Nice; it receives two tributaries from the Mercantour, the Tinea coming from the north-north-west and the Vésubie from the north.

The mass of the Mercantour has turned round in its southern part towards the Col di Tenda, i.e. to the south-east, but Léon Bertrand found that its stratified border of Permian and Trias gives off a long spur which starts from the Vésubie—that is, far to the west of the Col di Tenda—and proceeds towards the south. This is an important boundary. The folds of the east and south-east side of the Mercantour engirdle its southern end, and reach this spur. Here, as far as the upper Jurassic and lower Cretaceous are concerned, the facies of the Briançonnais suddenly ends, and the Helvetian facies takes its place. The beds on the east side of the spur are overthrust and overfolded to the west, and this direction persists in the region of the lower Var as far as Nice, where the strike is east and west and the overfolding towards the south. Between Mentone and Bordighera the strike has again become more north and south, and the movement is directed towards the west.

In the region east of the spur of the Vésubie and the plain of the lower Var, the folds stowed by the Mercantour broaden out. The inner Flysch zone (zone of the Aiguilles d'Arves) then assumes so great a part that we seem to meet over considerable tracts with nothing but an extension of this zone.

West of the Vésubie we find ourselves in the midst of the outer

[1] A. Heim, Geologische Begutachtung der Greina-Bahn: Geologische Nachlese, no. 16, Vierteljahrschrift nat. Ges. Zürich, 1906, LI, pp. 378–396.

[2] L. Bertrand, Étude géologique du Nord des Alpes Maritimes, Bull. serv. Carte géol., 1897, IX, no. 56, 214 pp., maps, and Sur les grandes lignes de la géologie de la partie alpine des Alpes maritimes, Bull. Soc. géol. France, 1904, 4e sér., II, p. 638 et seq., maps.

[3] S. Franchi, Contribuzione allo studio del Titonico e del Cretaceo nelle Alpi Maritime italiane, Bol. Com. geol. Ital., 1894, XXV, pp. 31–83, map.

Helvetian (Delphinian) folds overthrust to the south, and within the bend of the Var these encounter the folds of Provence moved in the opposite direction. These we do not regard as forming part of the Alps. They surround the Hyères and the Esterel, the crystalline schists of which are still visible between Cannes and Antibes.

On the coast of Monaco traces of recent volcanic breccia have been observed [1].

And it is in this manner that the Helvetian coulisse, bent inwards, terminates on the Var and the Vésubie.

The folds of Provence, on the west bank of the lower Var, have been exposed to movements of a very late date, as shown by Zürcher's discovery near Vence (north-west of Nice), where a sheet of Trias and Jurassic has been thrust over marine Miocene, and probably over Pontic sediments also, and afterwards folded in with them, so that Trias occurs in a syncline of Miocene, and Miocene beneath an anticline of Trias. Guébhard has observed marine Pliocene at this locality, inclined at an angle of 20°, and at a height of 350 meters above the sea [2].

Let us next turn our attention to the north.

The folds advancing from the interior surround, as we have seen, the south-east end of the Mercantour. The point of contact is exposed in the tunnel of the Col di Tenda [3]. From Tenda towards Limone, on the inner side of the Mercantour, a very rapid narrowing down affects all the inner folded ranges, and persists as far as its north-western end. Here the broad portal between the Mercantour and the Pelvoux occurs, and here the inner parts of the mountains move forwards for the second time.

Broad patches of recumbent folds are to be seen here. C. Lory regarded them as islands of the Eocene epoch, Goret as horsts. Haug and Kilian recognized their true nature as early as 1892. Haug gives the distance, directly measurable, over which they have been carried as 25 kilometers. Kilian estimates the whole extent of the movement as 30 to 40 kilometers. These advancing masses probably passed over the north-west end of the Mercantour, but not over the end of mont Pelvoux. The Helvetian folds striking to the south-west are surmounted by the lower side of the inner Flysch zone, which comes from the east in great development, accompanied by basement patches of the Helvetian Trias swept away with it in

[1] They are the continuation of the more extensive outcrops of Antibes and Villeneuve, and perhaps younger than these; Issel regards them as the remains of a submarine centre of eruption, at most 5 or 6 kilometers distant: Issel, Terremoto del 1887, Suppl. al Boll. R. Com. geol. Ital., 1888, XVIII, p. 44; L. Bertrand, Bull. Soc. géol. France, 1901, 4e sér., I, p. 96.

[2] Zürcher, Bull. serv. Carte géol., 1905, XVI, p. 140; A. Guébhard, Bull. Soc. géol. France, 1904, 4e sér., IV, p. 168.

[3] L. Baldacci e S. Franchi, Studio geologico della galleria del Colle di Tenda, Boll. R Com. geol. Ital., XXXI, 1900, pp. 33–87, map.

its course. These are signs indicating that the base of the portal has been scooped out in a scape colk. Upon the Flysch rest the Mesozoic recumbent sheets of the Ubaye, which also come from the east. The whole Flysch of the Embrunais has been transported from the east[1].

On the east side of the Pelvoux the inner zones are again constricted, and at its foot the Flysch runs as a narrow belt towards Le Monêtier. On the other side of the Meige the outline of the ancient rocks recedes to the west; simultaneously the Flysch broadens out, and there rise, high upstowed, the Aiguilles d'Arves. There is no portal towards the exterior;

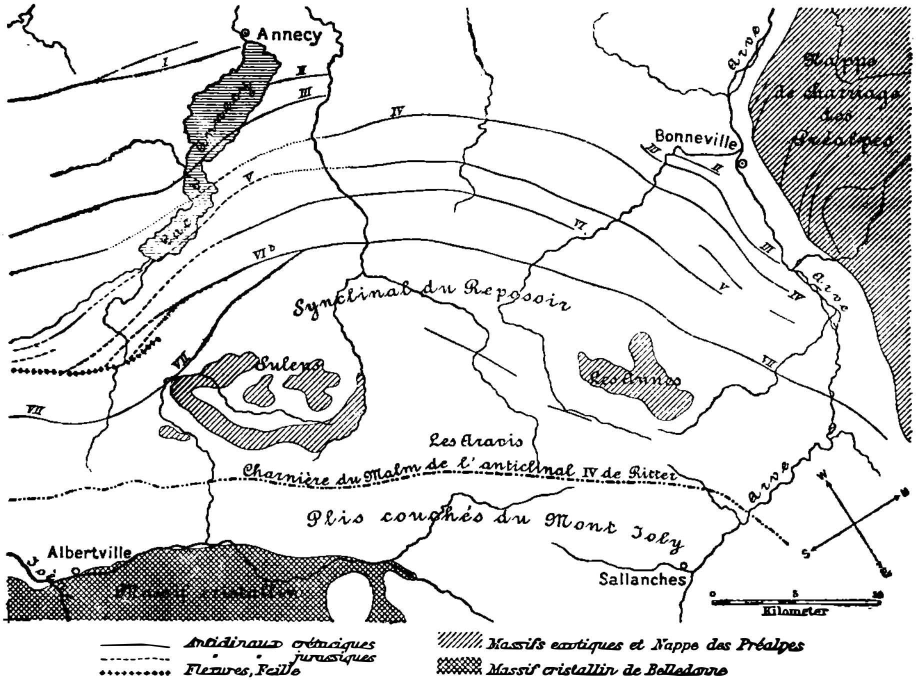


FIG. 15. *The Recumbent Folds of Sulens and les Annes* (after Lugeon).

on the contrary, the Belle Donne form a continuous rampart, and where they cast their shadow, as towards Grenoble, there are no recumbent sheets. It is not till we reach the other side of the Tarentaise that this rampart decreases in height, and beyond the mass of Beaufort and the window of Mégève (in which crystalline rock is visible beneath the sediments) an orographical gap occurs. Here the transplacements begin anew, but between them and the gap no close connexion can be perceived. A

[1] All the facts will be found in W. Kilian, Les phénomènes de charriage dans les Alpes delphinoprovençales, C. R. IXe Congrès International, 1903, pp. 455–476; and E. Haug, Les grands charriages de l'Embrunais et de l'Ubaye, tom. cit., pp. 493-506; also many older works, and in particular the survey of the two sheets Gap and Digne of the map, 1 : 80,000.

long series of fragmentary recumbent sheets now extends north of the zone of mont Blanc over the Helvetian Alps.

They begin south-east of Annecy with the little fragments of Sulens and les Annes. These are succeeded, south of the lake of Geneva, by the great sheet of the Chablais, next by that of the Freiburg Alps; then, further towards the east, by a long series of smaller examples, extending as far as Iberg, and finally by the Berglitten-Stein, near Buchs, in the Rhine valley. Renevier, Marcel Bertrand, Schardt, and other experienced observers have described these exotic masses; the problem they present has been happily solved by Lugeon[1].

The facts are not easily discerned in the external configuration of the country, since outside the zone of mont Blanc, that is in this case to the

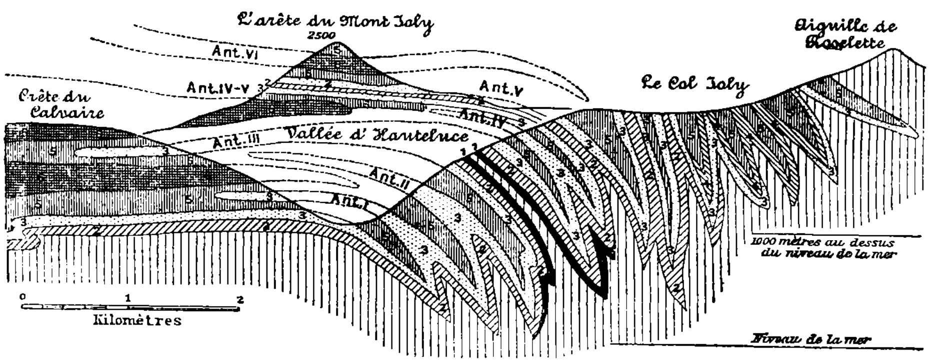


FIG. 16. *Folds of Mont Joly* (after Ritter). 1, Carboniferous; 2, Quartzite; 3, Rauchwacke; 4, Rhætic stage; 5, Lias limestone; 6, Lias shales.

north of it, and north of the gap between mont Blanc and the Finster-Aarhorn, there rises a series of lofty limestone mountains (les hautes chaînes, die Hochketten): Aravis, Dent du Midi, Morcles, Diablerets, Wildhorn, Wildstrubel, Faulhorn, and others, which are themselves thrown into great flakes, as, for instance, between Morcles and Wildstrubel, and violently overthrust to the north; while yet, in spite of their height, they form part of the Helvetian zone. The diagram (fig. 15), representing the

[1] The fundamental idea of explaining the structure of the northern part of the Swiss Alps by great overthrusts is due to Marcel Bertrand, and dates from the year 1884. In 1893 Schardt came forward in defence of the theory of great overthrusts. In 1898 he drew sections which explained the Chablais by 'two great paths of overthrusting' extending from the far south over a great part of the Alps; his map even shows a dotted northern boundary to the overthrusts, and this extends on the east to the other side of the Rhaeticon (Les régions exotiques du versant nord des Alpes Suisses, Bull. Soc. Vaud. Sci. Nat., 1898, XXXIV, pp. 113-219, map; also Eclogae Geol. Helv., 1898, V, pp. 233-253, map). In 1901 M. Lugeon published his interpretation of the facts which forms the basis of our description.

most westerly recumbent sheets, throws light on the nature of mountain formation in more ways than one; it is taken from one of the early works of Lugeon [1].

In the lower corner, on the left of fig. 15, the northern end of the Belle Donne is shown. Near Sallanches, as we have seen, the ancient rocks decrease in height to the south-west of mont Blanc and the Prarion (Aiguilles Rouges). According to the sections of Marcel Bertrand and Ritter (fig. 16), mont Joly is traversed, outside Sallanches and from the end of the Belle Donne onwards, by a number of synclines or 'roots', which rise steeply from the crystalline schists, and then bend sharply round, sometimes almost at a right angle [2].

A similar feature in mount Pelvoux has been described by Termier as 'stricture'. In the Himâlaya it has been observed, not infrequently, that the beds are more steeply upturned in the valleys than on the heights. For the present we will only point out that all recumbent sheets, however widely extended, which are derived from roots of this kind, are, in their origin, folds (synclines or anticlines), and they are generally regarded as recumbent folds. A discussion of this subject will follow on a later page, when it can be based on a larger number of facts.

The 'roots' of mont Joly are inserted in rocks which belong to the outer border of the Beaufort mass. They must be assigned to the outer end of one of the fascicles of synclines which strike through it transversely.

Beyond mont Joly, the end of one of the anticlines which have moved forwards between the 'roots' is actually seen enclosed in the malm [upper Jurassic] (fig. 15). We have now reached the peaks of Aravis, and with them the great Helvetian chains (*hautes chaînes*).

They help to form the border of a Flysch basin (syncline du Reposoir), on which rest the exotic patches of Sulens and les Annes. These have not come from mont Joly. The outer border of the Flysch basin includes the Jurassic and Cretaceous Helvetian chains of the Génevois (I to VII), which extend in concentric arcs from lake Annecy to the Arve. On the other side of the Arve lies the border of the great recumbent complex of the Chablais (Pré-Alpes), and the Helvetian arcs of the Génevois reach the Arve between this border and the patch of les Annes [3]. A short anticline strikes through the midst of the Flysch between Sulens and les Annes.

From this disposition we may fairly infer that the overthrusting of Sulens and les Annes was followed by important movements, which are probably

[1] M. Lugeon, Les Dislocations des Bauges (Savoie), Bull. serv. Carte géol., 1900, XI, no. 77, pp. 359–474, map. This region forms the subject of an abundant literature.

[2] M. Bertrand and E. Ritter, Sur la structure du Mt. Joly près S. Gervais (Haute-Savoie), C. R., 10 févr. 1896, and Ritter, La Bordure sud-est du Mont-Blanc, p. 167 et seq., p. 221, Plate I.

[3] This phenomenon is also clearly described by Haug, Bull. serv. Carte géol., 1895, VII, p. 271 et seq.

younger than that which separated the Chablais from les Annes, and in part also than that which separated les Annes and Sulens. These folds were impeded by the exotic masses which load down the Flysch basin of the Reposoir.

We now encounter one of the greatest difficulties of this problem, and it is not explained by fig. 15.

The site of the Chablais and the Freiburg Alps corresponds approximately to the gap between the Belle Donne and mont Blanc. We have seen that folds can be traced from the south side of the Belle Donne to the north side of mont Blanc. The same oblique disposition is repeated in the great chains. Lugeon states that the Morcles dip beneath the Diablerets, these beneath the Wildhorn, and this again beneath the Wildstrubel[1]. Proceeding to the north-east, we ascend as it were a tectonic ladder, passing over flakes, each of which lies higher than its predecessor.

This overthrusting of the recumbent sheets of Sulens and the others is more recent than the deposition of the Oligocene Flysch upon which they rest, but *the movements of the great chains*, mentioned above, *are still more recent*; fragments of the exotic stratified series of the recumbent sheets are folded into the synclines of the great chains. We have already pointed out that the ancient masses of the zone of mont Blanc probably suffered posthumous elevation at the time when the great chains were folded for the last time, and this diminishes to some extent the difficulty of conceiving how this now lofty zone should have been surmounted by the recumbent sheets.

We shall return to these fragments of recumbent folds when we treat of the region more to the east.

Glarus. That part of the Alps which lies between the eastern part of the Aar mass and the Säntis was regarded by Escher as formed of two great folds facing each other from north and south. This conception of *the double fold of Glarus* was a bold one, especially for that early period. Later, when the general movement of the Alps towards the north was recognized, the existence of such an opposed movement was regarded with doubt, and in 1884 Marcel Bertrand definitely expressed his belief that there is only a single fold in the Glarus, and that it comes from the south[2].

The facts are clearly displayed in the classic works of Albrecht Heim[3].

[1] M. Lugeon, Rapport Congrès géologique, 1903, p. 482. Lugeon does not think that the Wildhorn was thrust over the Wildstrubel, but that the Diablerets and Wildstrubel emerged from beneath the Wildhorn.

[2] M. Bertrand, Rapports de structure des Alpes de Glaris et du bassin houiller du Nord, Bull. Soc. géol. France, 1884, 3e sér., XII. In Vol. I (1883) I also hesitated to cite the north fold as an example of backfolding.

[3] In particular Albrecht Heim, Geologie der Hochalpen zwischen Reuss und Rhein, mit einem Anhang von petrographischen Beiträgen von C. Schmidt; Beitrag zur Geologischen Karte der Schweiz (sheet XIV), 1891, XXV, 503 pp. and 76 pp. Among other

We will follow his results as represented on a section drawn from north to south, and for that purpose we may proceed to the vorder Rhine valley above Ilanz.

The vorder Rhine valley is not the continuation of the Rhone valley; that lies south of the St. Gotthard (Airolo, Scopi), while we are now in the midst of those infolded sediments which branch off from the Rhine line above Brieg and strike across the Furca through Andermatt to Disentis. The St. Gotthard mass disappears towards the east. The rocks of the Aar mass are still visible much further east in the valley of Vättis, and near Felsberg, only six kilometers from the Rhine. If the Gotthard mass had not already been faulted down before reaching Trons, we should be standing in one of the oblique divisions of the zone of mont Blanc with its included Helvetian synclines.

From this point onwards the Verrucano attains a considerable breadth on the south side of the Aar mass. Above Ilanz it rises higher and higher above the vorder Rhine valley, till it finally reaches a height of over 3,000 meters. Broadly speaking, the slope of the Verrucano corresponds with a bedding plane rising towards the north. In the neighbourhood of the Todi, e.g. in the val Frisal, where the pre-Carboniferous rocks of the Aar mass are still visible, we perceive that this bedding plane of the Verrucano belongs to the upper limb of a syncline, which is open towards the north, and includes the pinched-in Mesozoic series. Further east the elevated border of the sheet of Verrucano is broken up into several patches, some of which extend far towards the north (Vorab, 3,025 meters; Piz Segnes, 3,102 meters; the isolated Ringelspitz, 3,206 meters, and others), and beneath these patches of Verrucano there are visible, in inverted sequence, Trias, Jurassic, Cretaceous (in places), and finally, extending down into the valley bottoms, a great thickness of Tertiary Flysch. It is this border of Verrucano, resting on the inverted series, which was formerly termed the south limb of the double-fold of Glarus.

The destructibility of the Flysch down below has caused the roof of the overfold to break off and produced this high-lying cliff of the Verrucano border; but isolated remains show that the Verrucano once extended further to the north. An indication of this kind is the Hausstock (3,156 meters), scarcely four kilometers distant from the border of the Vorab, and it is united by similar remnants (Muttlestock, Kalkstöckli) with a similar cliff of Verrucano, ragged in outline, and facing south (Kärpfstock, 2,798 meters; Ruche, 2,613 meters; Graue Hörner, 2,817 meters). This second border marks the beginning of the north limb of what was once regarded as the double-fold. It is actually the continuation of the south limb, and both,

subjects, A. Heim, Geologische Nachlese: Die vermeintliche 'Gewölbeumbiegung des Nord-Flügels der Glarner Doppelfalte' S. vom Klausenpass, eine Selbstcorrectur, Vierteljahrschrift naturf. Ges. Zürich, 1906, LI, pp. 403–431.

united, once formed a great dome which arched high over the Flysch masses of the Linththal and the Sernfthal.

The Graue Hörner just mentioned, which form part of this second cliff, lie to the north above Vättis, and as we descend to the bottom of the Calfeus valley we cross over the whole syncline; beneath the high-lying roof of Verrucano we first meet with the Jurassic, then the whole thickness of the pinched-in Flysch, and beneath this, in normal succession, the Cretaceous, Jurassic, and Trias, until the ancient schist of the Aar mass is reached at the bottom.

We now return to the north limb on the Kärpfstock.

The uppermost part of the arch lies behind us. The sheet of Verrucano begins to descend towards the north, but we can continue our walk upon it up to the shores of the Walensee, 35 kilometers distant from our starting-point on the vorder Rhine. The Jurassic, underlying the Verrucano, has been rolled out to a thin strip of white marble, and against this the crests of the Flysch folds are overturned to the north. Meanwhile, the height of the sheet of Verrucano above the sea having decreased by about 2,600 meters, concordant patches of the normal succession, Trias, Lias, and Oolites, have set in above it. Towards the west, however, in the direction of the Mürtschenstock, this series is traversed by a zone of Flysch which separates an overthrust and still higher sheet (Mürtschendecke, Arnold Heim [1]) from Jurassic and Cretaceous (Kerenzenberg). To the east near Walenstadt, the same feature is met with.

Yet another band of Flysch coming far away from the south-west draws near; it reaches the Walensee at Weesen, and dips beneath the steep cliffs of the Churfirsten. It follows a third glide-plane and bears the mighty Cretaceous formations of the Churfirsten and the closely folded Säntis (Säntisdecke). This Cretaceous differs in its development from the underlying Mürtschen sheet.

Then for the last time the most northerly folds, or even torn-off fragments of them, are heaved up and overturned against the outer band of Flysch and the Molasse. We thus reach the front of the great overfolding, 45 kilometers from the vorder Rhine valley.

Albrecht Heim recounts the serious doubts with which Escher was beset before he ventured to publish his views on the double-fold. To-day still greater generalizations force themselves upon us; the Hausstock, that key-stone which crowned the arch, and remains to demonstrate its existence, is a monument to the conscientious labours with which these two men have opened up a new road to knowledge.

The Flysch which we observed deep down, beneath the great arch, proceeds from the Linththal towards the west. It ascends beneath the

[1] Arnold Heim, Zur Kenntniss der Glarner Ueberfaltungsdecken, Zeitschr. deutsch. geol. Ges., 1905, pp. 90–118; in particular p. 94.

Clariden glacier to a considerable height, and its northern edge reaches the border of the lake of Lucerne at Flüelen. The whole of the south limb above it has been removed by erosion. Traces of Verrucano present themselves in a long band beneath the northern cliff, and from here onwards we again see the overfolding towards the north. The Jurassic wedges out near Flüelen, and all the northern chains belong to the Cretaceous, which here also is split up by bands of Flysch, indicating so many glide-planes. Here, east of the lake of Lucerne, the Cretaceous sheets assume rather the character of plunging folds, since they turn the front of their anticlines downwards.

Near Iberg, patches of the Chablais sheets rest upon the foremost bands of Flysch to the north of the Glarus overfold. On the Rhine between Buchs and Grabs, a Flysch zone is inserted between the Churfirsten and the Säntis; it is probably the same as that which separates the Säntis sheet from the Mürtschen sheet. It becomes very broad; the Berglittenstein rests upon it. Towards the east the continuations of the Churfirsten sink beneath the Falkniss.

There is no doubt that the great zone of exotic sheets rests in isolated fragments upon formations which belong to the old of Glarus.

While the Churfirsten swerve to the south-east, the Säntis proceeds in a north-easterly direction, and between Feldkirch and Dornbirn it enters the Flysch zone of the East Alps as a broad series of Cretaceous folds. Our knowledge regarding the details of the sigmoid connexion on the left side of the Rhine is chiefly due to Blumer[1].

The Simplon and Tessin. Between the zone of mont Blanc and the Dinaric boundary the rocks are altered to a high degree. Highly calcareous Mesozoic sediments are transformed into marble and lustrous schists; Permian and Carboniferous into graphitic schists; diabase, gabbro, and peridotite into green schists and amphibolite; and it is often extremely difficult to determine the boundary between the normal Carboniferous sediment and the gneiss. It is evident that there once lay, conformably beneath the Trias, a great series of argillaceous and sandy deposits belonging to the Permian and Carboniferous, and these in some places, and especially in the Carboniferous fan, may still be recognized by plant remains, &c., but in others, owing to their being the most yielding of all the rocks in the series, they have absorbed the greater part of the dynamic action and have been transformed into Casanna schists, micaceous phyllites, and talcose gneiss. Upon this series rests, still recognizable and conformable, the lower Trias, but it is difficult or impossible to discover the boundary of the underlying Carboniferous.

[1] Albrecht Heim, Das Säntisgebirge, Beitr. geol. Karte der Schweiz, 1905, new ser., XVI, 654 pp., maps, Part III; E. Blumer, Geologische Monographie des Ostendes der Säntis-Gruppe, op. cit., pp. 518–638.

For this reason the French general maps (1 : 1,000,000) mark all the great masses situated within the zone of mont Blanc, from the Simplon down to the south (monte Rosa, Dent Blanche, Gran Paradiso, &c.), not as gneiss, but as Carboniferous and Permian, thus contrasting them with mont Blanc and the Pelvoux. Granitic rocks also occur; they are regarded as Carboniferous in part. Whether the rocks have been exposed to any other influences, such as elevation of temperature, in addition to such as are mechanical, may remain an open question [1].

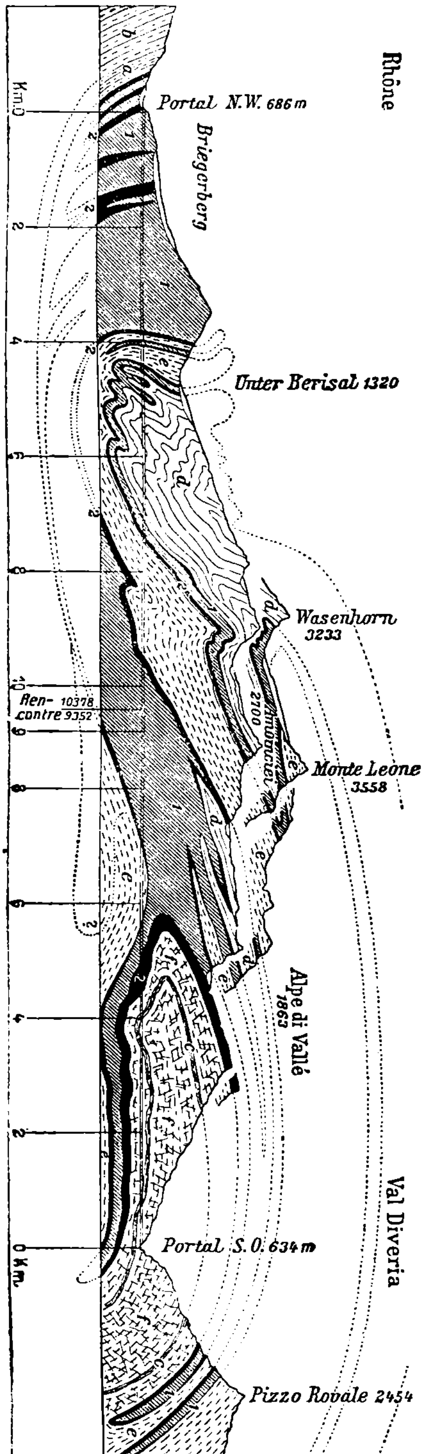
The tunnel of the *Simplon*, 19·7 kilometers in length, 705 meters above the sea at its maximum height, traverses monte Leone, 3,558 meters in height, at right angles to the strike. We might well expect important revelations from this excavation; it has not failed in them. Schardt has given a concise account of the various opinions expressed on the subject and the final result. His section of 1907 is reproduced, with his kind permission, on a reduced scale in fig. 17 [2].

Various kinds of gneiss (Antigorio, monte Leone gneiss, and others) and Mesozoic beds are present. The latter consist of Trias (gneiss-like arkoses, quartzite, gypsum, dolomite, marble) and Jurassic (lustrous schists, grey clay-slates, calc-graphite with granular limestone, garnetiferous phyllite). Traces of green schists also occur. These Mesozoic beds force their way from the north, in the form of a compressed syncline, between the gneisses through almost the whole length of the tunnel, i.e., for a distance of more than 19 kilometers, and since, at about the middle, they send off a strong branch southwards and upwards (Vallé) they completely separate the upper gneiss masses, along with the summit of monte Leone, from the lower (Antigorio) gneiss. This upper supernatant part is again divided by an intervening Mesozoic layer. Into the northern half of the long syncline the superposed gneisses penetrate from above in repeated anticlines, like the heads of so many plunging folds. From the south a thick wedge of Antigorio gneiss, 4 to 5 kilometers in length, inserts itself between the end of the long syncline and the branch of Vallé.

In other words, the Antigorio gneiss is first folded from the south into the Mesozoic, then over this folded mass the gneiss of monte Leone

[1] For opposed views we may refer to T. G. Bonney, On the Crystalline Schists and their Relations to the Mesozoic Rocks in the Lepontine Alps, Quart. Journ. Geol. Soc., 1890, XLVI, pp. 187–240, and Geol. Mag., 1901, Dec. 4, VIII, pp. 161–166; also On the Southern Origin attributed to the Northern zone in the Savoy and Swiss Alps, Quart. Journ. Geol. Soc., 1907, LXIII, pp. 294–307.

[2] Also H. Schardt, Note sur le profil géologique et la tectonique du Massif du Simplon, Eclogae geol. Helv., 1904, VIII, pp. 173–200, and Die wissenschaftlichen Ergebnisse des Simplondurchstiches, Vortr. Schweiz. naturf. Ges., Winterthur, 8vo, Winterthur, 1904, 40 pp. With admirable insight Gerlach recognized the horizontal insertion of the gneiss anticline of Antigorio as early as 1869.



has been carried up, also from the south, and monte Leone itself has been formed of two parts, that is by two similarly directed pushes. But the whole has arisen from the common folding of gneiss and Mesozoic sediments.

Other sections have been constructed from the existing observations by C. Schmidt and A. Stella. But they all have in common the deep infolding of the Mesozoic sediments, between the gneisses, and this provides a new key to the classification of the gneiss masses. We must first recall the fact that the sedimentary belt entering the tunnel from the north, that is from the Rhonevalley, is simply a part of the Mesozoic girdle which extends from Brieg towards Airolo along the south side of the St. Gotthard, and represents the tectonic continuation of the inner Flysch zone and the Briançonnais (in the restricted sense). On the south side of the St. Gotthard tunnel clearly marked backfolding sets in [1]. The movements revealed in the Simplon tunnel correspond with the forefolding of the southern, Piedmontese Alps.

[1] The basin of Tessin near Stapf (Geologisches Profil des St. Gotthard, Beilage Bericht des Bundesrathes, small folio, Bern, 1880) has been produced by this backfolding; it is of Mesozoic age, and also contains amphibolites.

FIG. 17. *The Simplon Tunnel* (reduced from a drawing kindly communicated by Herr Schardt).

1, Jurassic (lustrous schists, garnet-bearing sericite schists, calc-schists, and micaceous limestone); 2, Trias (black; dolomitic limestone, crystalline marble, gypsum, sericite schists); *a*, gneiss of the Massa (greywacke); *b*, gneiss of the Aar-mass; *c*, mica-schists in gneiss; *d*, schistose gneiss, often micaceous and hornblendic; *e*, bedded gneiss of monte Leone; *f*, massive granitoid gneiss, of Antigorio type.

We will now proceed further to the east. To the south of the line of Andermatt the St. Gotthard has disappeared and the country opens up. This is also the case south of the line of Airolo, and the inner sedimentary zones enter the vast tract covered with Bündner schist, which extends through Lugnetz, Safien, and Chur into the Prättigau. From the line of Airolo tongues of Mesozoic rock force their way southwards between the gneisses. They have been described by Heim [1].

The gneiss masses are here divided into recumbent folds, which proceed northwards; at the same time each eastern tract rests upon the next following on the west. The strike of the folds remains that of the Alps, but each part sinks along the strike towards the east. The Bündner schist approaches from the east in the Aversa-thal, and lies against or upon the gneiss of the Sureta. This lies upon a strip of Mesozoic which can be traced onwards in the valley of the Liro for a distance of 20 kilometers. This is the line of the Splügen pass. The gneiss of the Tambo mass sinks beneath this strip; and the Tambo mass itself is underlain in the west by the Mesozoic band of the Misox valley, which can also be traced for a distance of 20 kilometers. This is the line of the Bernadino pass. Beneath this band the Adula mountains dip from the west; the several gneiss masses have advanced step by step towards the north, and with the Adula the constriction of the chief syncline, i. e, the Airolo line, begins. The Mesozoic band of the Blennio valley sinks from the west beneath the Adula, and beneath this sinks the gneiss of the Molare [2]. Thus we reach val Leventina and Airolo. These gneisses, which, from Aversa and the Septim pass, advance step by step towards the north and overlap one another stage by stage towards the west, may be regarded as parts of the Piedmontese Alps. They rise out from the Bündner schists between Oberhalbstein and the line of Airolo, and form, precisely like the great Helvetian chains of the Bernese Alps, a series of tectonic steps facing towards the west.

Down to the Dora Baltea. The Carboniferous fan is shown to the west in the Swiss geological maps (sheets XVIII, XXII, XXIII), and it is accompanied as far as the Great St. Bernhard by long Mesozoic folds, which extend as far as the transverse valley of the Dora Baltea. Between the St. Bernhard and the Dinaric boundary rise some of the loftiest peaks of the Alps (monte Rosa, Grand Combin, Dent Blanche, and others). Here the long continuous strike-lines are replaced on these older maps by irregular, interrupted, and sometimes labyrinthine windings of marble and

[1] Albrecht Heim, Die Nordost-Lappen des Tessiner Massives: Geol. Nachlese, no. 17, Vierteljahrschrift naturf. Ges. Zürich, 1906, LI, pp. 397–402.

[2] Wilckens has observed Mesozoic rocks in the Zapport (uppermost Rheinwald), and conjectures that the Rheinwaldhorn is a floating mass; this would point to a deeper penetration of the Blennio intercalation, Centralbl. f. Min., 1907, pp. 341–348.

broad tracts of sedimentary schists which insert themselves between the gneisses.

As early as 1902, before the results furnished by the Simplon tunnel had been completely made known, Lugeon had attempted to analyse the structure of the region; in 1905 he succeeded in distinguishing seven successive sheets of gneiss separated by Mesozoic intercalations [1]. This bold conception was not received with unqualified approval by Italian investigators. Stella, Franchi, and Novarese raised objections, which were based chiefly on the structure of the more southerly tracts [2]. At the same time the most striking of his results, namely, the conception of the mighty mass of the Dent Blanche as the remnant of a recumbent sheet, was acknowledged on all sides as correct. The origin of this remnant will be dealt with after we have discussed the rocks of Ivrea.

The Simplon is extremely instructive, because deep-lying tectonic horizons are exposed in it. In the Tessin, i. e. towards the east, the step-like structure, inclined away from the Simplon, has already been mentioned: something similar may be seen towards the west and south-west [3].

In accordance with Schardt's description of the tunnel and Lugeon's analysis of the high mountains, we have here sheets and fragments of sheets, all derived from recumbent folds. The mass of the St. Bernhard, or at least part of it, must perhaps be excluded.

Lugeon's sheet I (gneiss of Antigorio), exposed in the south of the tunnel, is the lowest member, with the exception of a mass which crops out near Crodo, and is here regarded as the lowest gneiss visible in this region (*f*, fig. 17). It is the sheets II (Lebendun) and III (monte Leone) (*e*, fig. 17) which enter the tunnel from above as plunging sheets, burying the front of their anticlines in the long Mesozoic syncline. Their extension in space is not so great as that of the other sheets. Sheet IV (St. Bernhard) lies in the west, and extends far along the side of the Carboniferous band towards the south; as it nears the Dora Baltea it acquires a marked twist, so that the gneiss first dips in the direction of the successive

[1] M. Lugeon, Sur la coupe géologique du Massif du Simplon, C. R. Acad. Sci. Paris, March 24, 1904; Sur les grandes nappes de recouvrement de la zone du Piémont, op. cit., May 15, 1905; and Lugeon et M. Argand, Sur les homologies dans les nappes de recouvrement de la zone du Piémont, op. cit., May 29, 1905.

[2] The most important of these works are: A. Stella, Il Problema geo-tettonico dell'Ossola e del Sempione, Boll. R. Com. geol. ital., 1905, 4e sér., VI, pp. 1-41, map, and S. Franchi, Sulla tettonica della zona del Piemonte, op. cit., 1906, 4o ser., VII, pp. 118–144; H. Schardt, Die moderne Anschauung über den Bau und die Entstehung des Alpengebietes, Verh. Schweiz. naturf. Ges. St. Gallen (1906), 1907, 37 pp., map of the gneiss sheets; C. Schmidt, Bild und Bau der Schweizer Alpen, Beilage z. Jahrb. d. Schweiz. Alp.-Club, XLII, Basel, 1907, p. 44, map of the gneiss sheet, also in Führ. Deutsch. Geol. Ges. Basel, 1907, p. 47.

[3] H. Schardt, op. cit., p. 13.

sheets or towards the east, and then in the south towards the west, i.e. beneath the Carboniferous band. This feature, established by Italian geologists, marks the beginning of the fan-like structure, which becomes increasingly clear towards the south.

Sheet V (monte Rosa) rises towards the north-east and inserts itself beneath the succeeding sheets. The Dent Blanche (sheet VII) is a fragment of a sheet which advances over the broad Mesozoic region of Zermatt-Châtillon. The elongated range of the Sesia-gneiss (sheet VI) may be equally well regarded as the inrooted eastern part of VII; we shall see that it is still further subdivided.

This conception, as applied to the western parts, is due to Lugeon and Argand.

The facts we have been observing are evidence of the great general movement towards the exterior, which here, in consequence of the bend of the Alps out of the south to north direction, becomes increasingly south-east to north-west. One recumbent fold towers above another. But the fan-shaped structure has already begun to manifest itself in the St. Bernhard. A broad fragment is bent by backfolding in the direction of the Piedmontese plain, i. e. towards the east.

Ivrea and Dent Blanche. The Mesozoic sediments of the western Dinarides surround the Italian lakes. They rest, together with the Permian porphyry of val Trompia and the limnic Carboniferous of Marmo, either normally or as downthrown patches on a crust which consists first of phyllites, then of mica-schists with muscovite gneiss, and finally of biotite Strona gneiss.

Close to the western edge of the Strona gneiss an interrupted band of limestone makes its appearance, about 100 kilometers in length. It crosses the Toca near Ornavasso, where its presence is marked by marble quarries. No such band of limestone is known in any other part of the Dinarides. It presents all the characters of the Mesozoic marble ranges of the Alps. To the west of it we reach a broad band of basic rocks, which is sometimes known as the amphibolite band, sometimes as the diorite band of Ivrea. Its breadth is variable; as shown on Gerlach's map, it may amount to as much as 9 kilometers. Near Pavone, south of Ivrea, it emerges from the plain of Lombardy, and strikes in a broad arc to the north end of the lago Maggiore and even beyond it. It follows the Dinaric boundary, and an almost identical arcuate strike dominates here both the Alps and the Dinarides.

The principal features of the structure have been clearly described, first by Gerlach and later by Artini and Melzi [1]. The latter observers regarded

[1] H. Gerlach, Die Penniner Alpen, Beitr. z. geol. Karte der Schweiz, 1883, XXVII, 159 pp., and Die Bergwerke des Kantons Wallis, 79 pp. and sheet XXII of the Geol. Karte der Schweiz; E. Artini e G. Melzi, Ricerche petrografiche e geologiche sulla Valsesia, Mem. R. Ist. Lomb., 1900, XVIII, pp. 219–392, map.

the band of Ivrea as occupying a great rent in the earth's crust. As a deduction from a similar hypothesis it was interpreted as a flat-lying dyke, and it was supposed to stand in some connexion with the green rocks of the Piedmontese Alps, a conjecture which had already been put forward at an earlier date. An attempt was also made to find some causal connexion with the orographic movements. Objections have been raised to these views by Italian investigators, in particular by Franchi and Novarese [1].

According to these distinguished observers, the order in which the rocks succeed one another from east to west is first Strona gneiss, next the diorite band, and then Trias. The Strona gneiss (together with the so-called Stronalites) passes through kinzigite gneiss into the closest connexion with the diorite, from which it cannot be distinguished; it must therefore be of great age. To the north of Varallo a strip of kinzigite gneiss may even be traced right across the diorite band. On the other hand a great dislocation separates the diorite from the Trias in the west.

To arrive at a conclusion we must first consider the following observations:—

The first limestone band, namely, that of Ornavasso, mentioned above, occurs east of the diorite band. The kinzigite gneiss (gneiss with garnets, sillimanite, biotite, graphite, and in places cordierite) is probably, as in the Kinzig valley, gneiss altered by contact metamorphism. This can only have been produced by the diorite, and it remains an open question whether the diorite itself is not a mixed product due to the assimilation of gneiss by a more basic magma [2]. These facts, as well as the transverse strike of the band of kinzigite north of Varallo, show that the zone of Ivrea is not a flow, but an intrusive sill.

[1] S. Franchi, Appunti geologici sulla zona diorito-kinzigitica Ivrea-Verbano e sulle formazioni adiacenti, Boll. R. Com. geol. ital, 1905, XXXVI, pp. 270–298; V. Novarese, A proposito di un trattato di petrografia di E. Weinschenk e sul preteso rapporto fra le rocce della Zona d'Ivrea e le 'Pietre verdi' della Zona dei Calcescisti, Boll. R. Com. geol. ital., 1905, XXXVI, pp. 181–191; La Zona d'Ivrea, Boll. soc. geol. ital., XXV, 1906, pp. 176–180. For this reason additional details are cited here. The opinion in question is expressed in E. Suess, Sur la nature des charriages, C. R. Acad. Sci. Paris, Nov. 7, 1904, with which Argand's results are in accord as a whole, op. cit., Feb. 26, March 12, March 26, 1906.

[2] H. Preiswerk, Malchite und Vintlite im 'Strona-' und im 'Sesia'-gneiss, Festschrift H. Rosenbusch gewidmet, 8vo, Stuttgart, 1906, pp. 322–334; Franchi (Boll. R. Com. geol. Ital., 1906, part. uff., p. 30) cites a case in which the Strona gneiss has undergone cataclastic change, but the Sillimanite schist which belongs to the kinzigite has escaped. *Kinzigite* was the name given by H. Fischer (N. J. f. Min., 1860, p. 796, and 1861, p. 641) to the garnet gneiss of the Kinzig valley; Heberstreit determined the amount of graphite contained (Inaugural-Dissertation, Würzburg, 1877, 8vo, 74 pp.); Sauer introduced the name 'kinzigite gneiss' in the detailed geological map of Baden (Erläuterung zum Blatt Oberwolfach-Schenkenzell, 1895, p. 18). This garnet graphite gneiss has arisen by the action of granitite on a para-gneiss (H. Thurach, Beziehungen der Granitit-Gänge zum Nordracher Turmalingranat und zu dem Kinzigitgneiss, Mitth. badisch. geol. Landesanst., 1899, III, p. 637 et seq.).

Kinzigite rocks occur not seldom in these parts of the Alps; Hammer mentions them at Ulten in west Tyrol[1]. South of Bormio, the upper Adda traverses the batholite of the Serra di Morignone, the component rocks of which, according to Stache, range from tonalite to gabbro; its connexion with the Adamello mass had already been suggested by Theobald. The similar but smaller batholite of Brusio is crossed by the Poschiavino above Tirano. Stella states that rocks occur in the zone of contact which resemble the kinzigites and stronalites of Ivrea[2].

These localities lie to the north of the Dinarides. The boundary of the Dinarides follows the Judicaria line as far as Dimaro, south of Malé, and then turns to the west-south-west and finally to the west. It runs, according to Salomon's observations, north of the Tonale pass, and reaches the Adda at Stazzone below Tirano[3]. At Monte Padrio (between Oglio and Adda), a zone of marble is mentioned as marking the probable starting-point of a long band of Trias, which strikes through the Tessin valley; its traces have been followed by Theobald, Rolle, and Melzi; Rolle mentions it as still occurring in the pass of Iorio[4].

This long but interrupted band of Trias belongs to the Alps. The val Morobbia, which starts from the pass of Iorio, follows the same east and west direction; it reaches the Tessin a little south of Bellinzona, and coincides with the Dinaric boundary.

In addition to the batholites of the Serra and Brusio mentioned above, a third lies in the same line, north of Ponte; a fourth, north of lake Mezzola; and yet another of these late intrusions at Bellinzona. They all lie within the Alps, and in the east they are, perhaps, connected with dykes of various kinds (Ortlerite, Suldenite, &c.), which are known to extend far beyond the Ortler, thus showing over how large an area such processes as gave rise to them were at one time active.

At Bellinzona, Klemm, coming from the north, encountered comparatively recent granite, enclosing patches of schist, then steeply upturned sediments, amphibolite schists, and calc-silicate-hornfels, marble with garnets and

[1] W. Hammer, Jahrb. k. k. geol. Reichsanst., 1902, LII, p. 114.

[2] Stache, Verh. k. k. geol. Reichsanst., 1876, p. 357; Linck, Pegmatite des oberen Veltlin, Zeitschr. f. Naturw., Jena, 1899, XXXII, pp. 345-360; O. Hecker, Gabbro-Gesteine des oberen Veltlin, N. J. f. Min., 1902, Beilage-Band XVII, pp. 313-354; Stella, Boll. R. Com. geol. ital., 1907, Atti uff., p. 35; for these batholites, in particular, Salomon, Periadriatische Massen, p. 137 et seq.

[3] W. Salomon, Die alpino-dinarische Grenze, Verh. k. k. geol. Reichsanst., 1905, pp. 341–343; the locality may be seen on Vacek and Hammer's Kartenblatt Cles (Oesterreich. Special-Karte, Zone 20, Col. iv).

[4] The best-known locality is Dubino, near to the mouth of the Adda; Rolle, Beitr. geol. Karte der Schweiz, 1881, XXII, p. 18 et seq.; G. Melzi, Ricerche microscopiche sulle rocce del versante Valtellina della catena Orobica occidentale, Giorn. di Min., 1891, II, pp. 1-34; Ricerche geologiche e petrografiche sulla Valle di Masino, op. cit., 1893, IV, pp. 89-134, maps; Salomon, Sitzb. k. preuss. Akad. Wiss. Berlin, 1899, p. 27.

other rocks penetrated by occasional veins of pegmatite. Serpentine and peridotites are associated with the amphibolite, and Klemm regards these rocks as forming part of the zone of Ivrea. Near Arbedo (north of Bellinzona) numerous slickensides already make their appearance in this band; these increase in number towards the south, and in val Morobbia, which has already been mentioned as the boundary, the rocks of Ivrea are completely mylonitized. The normal basement of the Dinarides follows on the south [1].

Here, therefore, the dislocation lies not without, but within the zone of Ivrea, i. e. to the south of it. Hence Mattirolo concludes that it is erroneous to regard the rocks of Bellinzona, which are in fact intrusive, as the continuation of the zone of Ivrea [2]. But these dislocations are younger than the intrusion of the rocks which have been mylonitized along them.

To the west the rocks are now concealed by the broad valley of the Tessin, which extends along the strike for a distance of 12 kilometers, up to the north end of lake Maggiore, but when 8 kilometers further, on the other side of the lake, near Ascona, rocks reappear, they are again amphibolites with granitic intrusions, and these are continued without interruption into the principal band of Ivrea.

To this band we will now turn our attention. Its constitution is more various than the term diorite would imply. In the south, near Pavone and Ivrea, norite, hornblende-gabbro, and quartz-hypersthene-diorite are enumerated as the dominant rocks [3]. At Biela, within the diorite band, so called by Franchi, rocks are cited which range from granite to tonalite, from mica-diorite to rocks rich in amphibole and pyroxene [4]. It is stated that highly basic rocks, such as peridotites, collect together towards the west, while in the east diorites predominate, and this is particularly the case north of the Sesia [5]. Gerlach names seven localities along a tract

[1] G. Klemm, Bericht über Untersuchungen an den sogenannten 'Gneissen' u. s. w. der Tessiner Alpen, III, IV, Sitzb. k. Akad. Wiss. Berlin, 1906, p. 429, and 1907, pp. 251–258. It is true that these isolated batholites do not afford ground for inferring the recent intrusive character of the whole of the Tessina gneisses.

[2] Mattirolo, Boll. R. Com. geol. ital., 1907, parte uff., p. 29.

[3] Frank, R. van Horn, Petrographische Untersuchungen über die noritischen Gesteine der Umgegend von Ivrea; Tschermak (Becke), Min. Mitth., 1898, XVII, pp. 391–420, map.

[4] Franchi, Boll. R. Com. geol. ital., 1901, XXXII, Atti uff., p. 39.

[5] The most important works are by Artini e Melzi, Sulla Lherzolite di Balmuccia in Val Sesia, Rend. Acc. Linc., 1895, 5ª ser., IV b, pp. 87–92; R. W. Schaefer, Der basische Gesteinszug von Ivrea im Gebiete des Mastallone-Thales, Tschermak (Becke), Min. Mitth., 1898, XVII, pp. 495–577; C. Porro, Geognostische Skizze der Umgegend von Finero, Zeitschr. deutsch. geol. Ges., 1895, XLVII, pp. 377–422, map, and the already mentioned works of Franchi, Stella, and Novarese. Schaefer compares the diorite schists with the green schists of Wallis; he believes that all the rocks from the peridotite to the diorite were produced from a common magma, and mentions the impression made by a longitu-

25 kilometers in length at which nickel-bearing pyrrhotine is mined in peridotite[1].

The diorite band, or at least the middle part of it, is followed on the west by a profound dislocation, then by a band of Trias limestone. This is likewise of great length, and is followed on the west by the supposed Permo-Carboniferous schists of Rimella. They are known to accompany the diorite band towards the north-east, as far as the Swiss frontier, where it crosses the Cento Valli. Then towards the west we again reach the gneiss[2].

Along the dislocation itself, Franchi mentions prasinite with glaucophane, produced by the dynamic metamorphism of diorite[3]. In the south a zone of eclogite and mica-schists sets in here, and near Traversella (west of Ivrea) this is associated with a diorite containing a little quartz, which reaches the band of Trias limestone, produces contact alteration, and gives rise to ore-deposits[4].

The gneiss to the west of the Rimella schists decreases in breadth north of the Sesia, and soon terminates near the upper Mastallone. Towards the south-west, however, it widens out again and forms the great gneiss mass of the Sesia and the val di Lanzo, of which the southern wedge-shaped end, accompanied by Mesozoic calc-schists, reaches the Stura near Viu, and disappears between two vast regions of green rocks.

In the north, between the Sesia and the Toce, a *second diorite band* (Ivrea II) crops out; it presents the same characters as the principal band (kinzigite, diorite, gabbro). Gerlach marks it as striking from the other side of the Toce for more than 30 kilometers to the south-west, with a maximum breadth of 2 or 3 kilometers. To Franchi is due the merit of having shown that this second band, accompanied in its course by Rimella schists, extends still further to the south-west, thus wandering further and further away from the main band; it may be finally traced as isolated outcrops of diorite and kinzigite gneiss into the valley of Loo (above Gaby) in the Gressoney[5].

dinal Alpine fissure (as do also Artini and Melzi). According to Novarese (Boll. R. Com. geol. ital., 1905, Atti uff., p. 32) the nickel ores ascend in great veins. Smaller outcrops of peridotite are mentioned in the east of the range.

[1] G. Tschermak, Min. Mitth., 1874, p. 285; Stelzner, Zeitschr. f. Berg-, Hütt.- u. Salinenw., 1877, p. 86; Gerlach, Die Penniner Alpen, Beitr. z. geol. Karte d. Schweiz, 1883, XXVII, p. 134; J. H. L. Vogt, Zeitschr. f. prakt. Geol., 1893, p. 257.

[2] For details regarding the west border, see Franchi, Boll. R. Com. geol. ital., 1905, pp. 273 et seq.

[3] Franchi, Boll. R. Com. geol. ital., 1904, pp. 242–247.

[4] V. Novarese is inclined to regard this diorite as of middle Tertiary age, since it is not dynamically altered; L'origine dei giacimenti metalliferi di Brozzo e Traversella in Piemonte, Boll. R. Com. geol. ital., 1901, XXXII, pp. 75–93, and in Zeitschr. f. prakt. Geol., 1902, X, pp. 179–187.

[5] Franchi, Boll. R. Com. geol. ital., 1907, Atti uff., p. 30. Possibly the Vintlite of Gaby in the Gressoney, mentioned by Preiswerk, should be referred here.

In proportion as the band of Ivrea II leaves the main band the Sesia and val di Lanzo gneiss lying between them increases in breadth. Still further to the south-west we come to the town of Traversella, already mentioned, which is situated on the eclogite of the main band. These rocks now reach the great zone of Pietre verdi, which, striking south-west, passes through Chialamberto and reaches the south side of the Gran Paradiso; the rocks of these bands are so very similar that a few years ago they were not distinguished on the maps. Here, in fact, the rocks of Ivrea appear to unite with that great region of diversified basic rocks which crosses the Stura towards the south, and the French frontier towards the west. Where this region is represented by serpentine, it carries garnet-rock and magnetite; it includes the well-known mineral locality of Ala [1]. It is probable that we must also connect with the main band of Ivrea itself the many outcrops of green rocks which, following the margin of the plain of Lombardy beyond Ivrea, border the east side of the gneiss of the Sesia and the val di Lanzo, and extend up to the serpentine and peridotite mountains situated to the south of Lanzo.

Towards the west lies a large area of Mesozoic sediments and green rocks. Lugeon has named it the Châtillon-Zermatt window. It extends to the south beyond the Dora Baltea, and includes on the north the val Challant, val Tournanche, and the val de St. Barthélemy. On the north its rocks plunge below the gneiss of monte Rosa. Whether these great gneiss mountains are composed of four or six or even more sheets is a question of only secondary importance, and the greater or less frequency with which the green rocks are infolded with them depends merely on the degree of local folding.

One of these infoldings strikes from the upper Gressoney through Alagna eastwards into the immediate neighbourhood of the band Ivrea II (near Rima, upper Sermenza). Another was traced by Gerlach and Traverso from the val Anzasca to Bognanco (west of the Domo d'Ossola) [2]. If we cross the window we encounter, on the summit of the gneiss of monte Mary (monte Chatalaizena), a patch of basic rocks, and then, on the other side of a tract formed of a long strip of Trias and the gneiss band of monte Farona, we find, within reach of the Dent Blanche, a band of diorite and kinzigite, which extends through the val Pellina; it is accompanied by Trias limestone [3].

We have here the same association of Trias limestone with an igneous

[1] Cf. E. Mattirolo, Su di una carta geo-litologica della Valle di Lanzo, Boll. R. Com. geol. ital., 1905, pp. 191–211, map.

[2] Traverso, Geologia dell' Ossola, 8vo, Genoa, 1895, 275 pp., map; on p. 148 a description of the main range.

[3] Mattirolo, Boll. R. Com. geol. ital., 1902, Atti uff., p. 20 et seq.; Novarese, op. cit., 1901, p. 34, 1902, p. 32; Franchi, op. cit., 1903, p. 30, 1905, p. 293 et passim.

band as in the case of the two bands of Ivrea, and there seems to be no reason to separate the peridotite of the main band of Ivrea, for example, from the considerable masses of peridotite which occur above Gressoney, and, extending across the Breithorn towards Zermatt, separate monte Rosa from the Dent Blanche [1].

Argand points out that the basic rocks in the secondary synclines of the Dent Blanche are precisely the same as those of Ivrea, the Dent Blanche itself is a part of a great syncline, and the 'tail' (la queue) of the syncline is nothing else than the zone of Ivrea itself. To the north-west of the Dent Blanche at Évolène (val d'Hérens) Argand believes he has found the end of the recumbent fold. If we adopt this interpretation we obtain the following section from south-east to north-west: (Trias) marble zone of Ornavasso-Ivrea I—(Trias and Permian ?) zone of Rimella—Sesia gneiss—Ivrea II (probably a syncline)—gneiss—green rocks of the window of Châtillon—then a small piece of the sheet of mont Pillonet (gneiss)—again the green rocks of Châtillon with Trias—then the remains of the great sheet of the Dent Blanche—and upon this once more green rocks. Thereby these repeated layers of green rocks and Trias are regarded as so many repetitions of the band of Ivrea.

Ivrea II and the Pillonet would be connecting links.

While Argand infers from these facts that a connexion exists between the Pietre verdi and Ivrea, C. Schmidt admits that the Dent Blanche is a part of Ivrea, but he agrees with Italian geologists in regarding Ivrea itself as different from the Pietre verdi and much older; and he interprets the Dent Blanche as an encroachment of the Dinarides [2].

For my own part I am inclined to think that the marble zone of Ornavasso is a true component of the Alps. Similar zones of marble occur repeatedly in the Alps, but not in the Dinarides. Ivrea is really a part of the compressed and injected marginal cicatrice (III, p. 337), and the green rocks are continued into the Alps, but not into the Dinarides.

The Dent Blanche, along with monte Mary and monte Emilius near

[1] E. Argand, Sur la tectonique du massif de la Dent Blanche, C. R. Acad. Sci. Paris, Feb. 26, 1906; and Sur la tectonique de la zone d'Ivrée et de la zone du Strona, op. cit., March 12, 1906.

[2] C. Schmidt, Ueber die Geologie des Simplongebietes und die Tektonik der Schweizer Alpen, Eclogae geol. Helv., 1907, IX, pp. 484–584, map; also Schmidt and Preiswerk, Geologische Karte des Simplongebietes, 1:50,000, 1907. C. Schmidt distinguishes the zone of Ivrea from the Mesozoic rocks of the Pietre verdi, but thinks that they are continued on the Adda; he assigns them to the Dinarides, but admits that a genetic relation appears to exist between Ivrea and the Ophiolites of the Bünden schists, since wherever gabbro appears in the Bünden schists basic rocks also occur in the adjacent basement formations (p. 547, note); L. Milch (Ueber den Granitgneiss vom Roc noir, N. J. f. Min., 1901, I, pp. 49–88) believes that this rock is a primary eruptive hornblende granite, in places approaching quartz diorite; it has been subsequently altered by dynamic action and is probably of Carboniferous age.

Aosta, and the region extending thence to the Matterhorn and the Weisshorn (north-west of Zermatt), is thus the remnant of a sheet derived from the outermost and easternmost boundary region of the Alps, and at the same time it is the element which in a tectonic sense lies highest in all this part of the Alps.

The basic intrusions also occur to the north-east of the Simplon tunnel. As soon as they had reached the upper limit of the gneiss they discovered the places of least resistance in the Trias limestone or Jurassic calc-schists, generally the bedding planes, and spread out in them. This affords an explanation of Preiswerk's detailed descriptions of the green schists of the Simplon region. For this reason they are so often intercalated in the Mesozoic sediments one above the other; this, too, is the reason why the zone of contact of the gabbro lenses with the Jurassic calc-schists is associated in the Binnenthal with rocks which contain garnet, titanite, and zircon. The green schists have been produced by the mechanical alteration of a series of rocks, which, according to Preiswerk, ranges from gabbro and diorite to dunite and picrite [1].

In the case of the green rocks we obtain finally the following results:—

No ashes or tuffs of these rocks are certainly known, unless we regard as such the diabase tuffs which are scattered through the Flysch of Taveyannaz. Vesicular lavas or scoriae are unknown. Pebbles of the green rocks first make their appearance in the Oligocene Flysch. The green rocks form sills; ascending dykes such as occur in mont Genèvre are rare [2]. Hornfels occurs in the zone of contact, but not often; garnets, especially in the calc-schists, must be regarded as the direct products of contact alteration.

With great penetration Franchi has distinguished the piled-up folds of the Simplon type from the structures produced by the flat movements of one sheet over the other—such, for instance, as make their appearance in the Engadine. But the conception of an 'ultrapiega' or fold-fault does not explain the facts. Movements, such as that of the whole of the Dinarides towards the north, do not proceed from folding, and Termier is right in separating this movement in mass from that which produced the recumbent folds of the plunging sheets [3].

[1] H. Preiswerk, Die Grünschiefer in Jura und Trias des Simplongebietes, Beitr. geol. Karte d. Schweiz, 1907, XXVI, Part I, 42 pp.

[2] M. Bertrand, Études dans les Alpes françaises, Bull. Soc. géol. France, 1894, 3e sér., XXII, p. 160; here a comparison is suggested with the tuffs of the Wengen shales in the Dinarides. Preiswerk points to the melaphyres of south Tyrol. In like manner Kilian and Termier, Bull. Soc. géol. France, 1901, p. 394 et seq.; Cole and Gregory also mention dykes of dolerite and augite-andesite on Mt. Genèvre, Quart. Journ. Geol. Soc., 1890, XLVI, pp. 295–332.

[3] Especially in Nécessité d'une nouvelle interprétation, etc. (see note 4, p. 135), p. 188.

Even far to the west in the val Savaranche (west of the Gran Paradiso) a zone occurs which Novarese has described as consisting of quartz diorite towards the east, and of normal diorite towards the west: Rosenbusch associates it with the tonalites[1]. The zone of Ivrea evidently stands in very close relations with the tonalite zone of the east. Granite, quartz diorite, and tonalite, the gabbro-like rocks which range up to the nickel-bearing peridotite, together with serpentine and prasinite, are probably of common origin, though not perhaps contemporaneous. And this assemblage of rocks extends throughout the entire Alps, forming what is collectively designated in North America as a zone of granodiorite.

From the Dora Baltea to the Gesso. This tract is bounded on the west by the Belle Donne, the Grandes Rousses, and the Pelvoux; on the south by the Mercantour. Between the Mercantour and the Pelvoux there is a wide gap, traversed by the Guil, through which the inner Flysch zone has moved forwards in a recumbent sheet over the Helvetian Alps[2]. The Gran Paradiso is a broad dome: Lugeon regards it as the carapace of a recumbent fold[3]. It is probably due to the arching up of the same gneiss as that which forms mont Pourri on the west, the core of the Vanoise on the south-west, and the mass of Ambin (petit mont Cenis) on the south. It is in this region that the lustrous schists meet the formations of the Briançonnais. They are thrown together into piled-up folds; at the same time lateral transitions are said to occur. In particular, a vast lobe of lustrous schists extends from the val Savaranche to the Grande Sassière (east of mont Pourri), and it seems as though these piled-up folds had overridden all the gneiss masses mentioned above[4].

On the west comes the Carboniferous fan. It extends towards the south

[1] Rosenbusch, Mikroskopische Physiographie, 4th ed., 1907, II, p. 282.

[2] In addition to the works of Marcel Bertrand, Kilian, Termier and Haug mentioned above, see, in particular, Kilian, Nouvelles observations géologiques dans les Alpes Delphin. Provençales, Bull. serv. Carte géol., 1900, XI, no. 75, pp. 259–277, and Notice explicatoire de la feuille de Larche, Ann. de l'Univ. de Grenoble, 1905, XVII, pp. 1–12; Kilian and Termier, Nouveaux documents relatifs à la géologie des Alpes françaises, Bull. Soc. géol. France, 1901, 4e sér., I, pp. 385–420; and Termier, Quatre coupes à travers les Alpes franco-italiennes, op. cit., 1903, 4e sér., II, pp. 411–432. For the Italian region of the Schistes lustrés: D. Zaccagna, Sulla geologia delle Alpi occidentali, Boll. R. Com. geol. ital., 1887, XVIII, pp. 346–417, map; and Riassunto d. osserv. geologiche, op. cit., 1892, XXIII, pp. 175–244, 311–404, map, and op. cit., 1901, XXXII, p. 4 and following volumes; also besides the works already cited, S. Franchi, Ancora sull' età mesozoica della zona delle Pietre verdi nelle Alpi occidentali, op. cit., 1904, XXXV, pp. 125–178, map, and, in particular, Sulla tettonica della zona del Piemonte, op. cit., 1906, XXXVII, pp. 118–144.

[3] The different opinions are compared by G. Rovereto, Geomorfologia del Gruppo del Gran Paradiso, 75 pp. (reprinted from Boll. Club. Alp. ital., p. 1906, XXXVIII).

[4] Termier, Sur la nécessité d'une nouvelle interprétation de la tectonique des Alpes franco-italiennes, Bull. Soc. géol. France, 1907, 4e sér., VII, pp. 174–189; M. Bertrand's sketches may serve as maps to this work, op. cit., 1894, 3e sér., XXII, Pl. IV–VII.

beyond Briançon, and even beyond Argentière. In the gap of the Guil it disappears, and strangely enough it is precisely in this gap, near mont Dauphin on the Durance, that a little fragment of the Pelvoux granite, probably the remains of a flat fold, comes to light. It is not till we go further south that the fan reappears, extending from the col de Longet onwards; two comparatively small bands unite near Acceglio to form a single one composed of Permo-Carboniferous sediments, and this continues onwards along the north-east side of the Mercantour.

The fact that the fan thus becomes extinct at the place where the

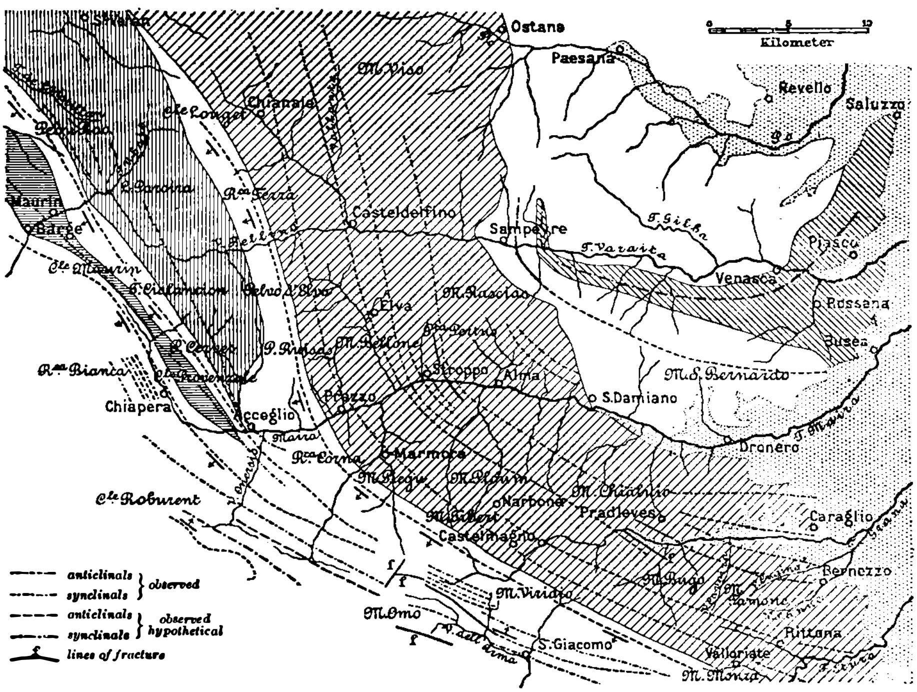


FIG. 18. *The Cottian Alps* (after Franchi). The part left white on the West represents the Fan, on the East the Dora-Maira gneiss.

resistance on the west ceases to exist shows that it is nothing else than a zone of stowing. Fig. 18, taken from a somewhat early work of Franchi's, shows in a very instructive manner the bending of the several zones and the way they die out along the strike. On French territory Kilian's map (sheet Larche) does not mark the Carboniferous (white in fig. 18) on the other side of the Tête de Cialancion, but the main boundary between the Briançonnais and the lustrous schists is certainly continued along this line. The lustrous schists extend as far as the col de Longet.

The whole of the middle zone of gneiss, approaching from the Gran

Paradiso, terminates, with the exception of a few traces in the south, in the mass of Ambin above Susa. On the east the Sesia gneiss, as we have seen, reaches the Stura through the val di Lanzo. Towards the plain it is followed, as in a belt, by green rocks, which are probably the continuation of the main band of Ivrea. Between the Sesia gneiss and that of the Dora-Maira mass (eastern part of the Cottian Alps) a gap is left. Passing mainly through this gap, but partly across the Dora-Maira mass, the green rocks enter the zone of monte Viso, contributing considerably to its breadth; monte Viso itself is a great pyramid of serpentine. The zone of monte Viso, taken as a whole, is a belt of Trias, lustrous schists, and green rocks overturned towards the east. It presents, like the whole region, a curvilinear strike, and between the Maira and the Gesso it sinks beneath the plain.

So far we have been following Franchi; we now take Stella as our guide[1].

North of the Po, near Revello, a spur of the Dora-Maira gneiss proceeds towards the plain (left white in fig. 18). A curved strip of graphite-bearing Permo-Carboniferous here borders the south side of the valley of the Po; it is probably the continuation of a similar strip, which more to the north has already reached the plain, near Pinerolo, and on the river Pellice. It is united with a second spur of gneiss, which projects between the Po and the Varaita (gneiss of Venasca). A fairly large arc of Trias, with some green rocks, surrounds its south foot, enters the plain, and, striking to the north-north-east, even reaches the neighbourhood of Saluzzo. A third spur of gneiss (mont St. Bernardo, gneiss of Dronero) succeeds. It sinks beneath the surface along the Maira. Then follow the lustrous schists and green rocks of the zone of monte Viso. This, however, splits up. One part disappears along the strike in the direction of the plain of Cuneo; another, maintaining the normal strike of the Permo-Carboniferous, passes along the Mercantour to the Ligurian Alps. All these rocks, extending from Revello to within the zone of monte Viso, are isoclinal towards the west, south-west, and south, and only in the outermost folds do they dip to the south-east.

Kilian believes that the general inclination of the Piedmontese Alps, which persists up to the Carboniferous fan, is the result of backfolding. In this case the spurs of Revello, Venasca, and Dronero are free ends of the backfolds, and have been separated off like so many coulisses.

Termier has described a section across the fan, extending from the Pelvoux down to the plain[2]. Kilian points out its want of symmetry;

[1] A. Stella, Calcari fossiliferi e scisti cristallini dei Monti del Saluzzese nel cosidetto Elissoide gneissico Dora-Maira, Boll. R. Com. geol. ital., 1899, XXX, pp. 129–160, map.

[2] In particular in his Quatre coupes à travers les Alpes franco-italiennes; also in Nécessité d'une nouvelle interprétation, etc.

the western part is steeply upturned, and gives off recumbent sheets, which enter the Helvetian region; the eastern part consists of much broader segments with a gentler slope. On the col d'Eychauda, west of the town of Briançon, and separated from the Pelvoux only by the valley of a mountain brook, the Eychauda, lies a fragment of a recumbent sheet. This, in apparent contradiction to the preceding structure, seems to have been derived from the east. Termier finds that such is in fact the case, but that it has not come from any great distance, and that it was already in place before the fan had assumed its final form [1]. Kilian suggests that all the Piedmontese folds were originally moved towards the west, and that the back-stowing is a later process, connected perhaps with the subsidence of the Lombard plain [2].

We may gather from Kilian's hypothesis how difficult are the problems presented by the Alps.

From the Gesso down to the sea. The Ligurian Alps are a fairly narrow arc-like mountain range, which runs from the Var past Genoa, and connects the Alps with the Apennines. It is composed of Alpine rocks; their strike cuts across the direction of the range. Towards the north they dip beneath an unconformable Tertiary sheet; on the south they are cut off across the strike by the sea.

We have already mentioned the encounter of Provençal, Helvetian, and Piedmontese folds along the Vésubie and the lower Var. In the Ligurian Alps we can only expect to find Piedmontese folds of the Briançonnais or Piedmontese facies. The whole coast between Nice and Albenga, along with a triangle situated in the interior, having its apex near Tenda or Limone, is formed, as we have already seen, by a vast extension of the rocks coming from the north-east side of the Mercantour, and in particular of the inner Flysch zone. The Mesozoic beds swerve round the end of the Mercantour, and become the northern border of this region. They also crop out repeatedly from beneath the Flysch. Then their folds, retaining the persistent south-east trend of the inner side of the Mercantour, stream down to the sea, almost in straight lines, or with but slight deflexions. A considerable band of Trias limestone, in particular, reaches the coast nearly north of Albenga, and similar outcrops occur as far as Bergeggi, south of Savona. As the zone becomes broader, bands of semi-crystalline, and sometimes even gneiss-like, rocks (Besimaudites) belonging to the Permian series make their appearance here and there, and beneath these, exposed at Viozene, on the watershed of the Tanaro, lies the anthracite-bearing Carboniferous. Rovereto has given a very instructive map of the trend-lines [3].

[1] This is Termier's 'Quatrième écaille' (Les Montagnes entre Briançon et Vallouise, pp. 110–127 and 167–182); in particular pp. 127 and 173.

[2] Kilian, C. R. IX^e Congrès, etc., 1903, p. 473.

[3] G. Rovereto, Carta tettonica dei Monti Liguri, in his Geomorfologia delle Valli

In this case, as in the French and the Piedmontese Alps, a long zone of Permo-Carboniferous follows on the west. The separated Permian anticlines of the Cottian Alps (fig. 18) unite in a zone of variable width, which enters the Ligurian Alps, with an east-south-easterly strike, between Demonte and San Dalmazzo, close to the border of the plain lying south-west of Cuneo[1]. Outcrops of anthracite extend for a distance of about 30 kilometers, striking across the upper tributaries of the Bormida. North of Calizzano, on the Bormida di Millesimo, Zaccagna marks a fan, like that of the French Alps[2]. This is all the more striking since, south of this point, near Calizzano itself, Issel and Rovereto have described a small independent mass of gneiss[3]. It would, therefore, seem as though the state of things in the north were completely reproduced.

The anthracite of the Bormida terminates as a continuous band near Mallare, 14 kilometers west of Savona, but traces of it are still visible beneath the Permian rocks at Quiliano, 5 kilometers only from Savona. To the north of Mallare and Quiliano, a far larger mass of gneiss crops out. Its outline, if we include a small mass of granite, is wedge-shaped. The point of the wedge lies 16 kilometers west-north-west of Savona, and on both sides of this town these ancient rocks, 12 kilometers in breadth, reach the coast. There can be little doubt that they are part of a larger mass, lying beneath the sea. Their strike, determined from intercalated sheets of amphibolite, is given by Franchi and Rovereto as N. 60° E.; the southern boundary is sharp, possibly a fracture[4].

Both masses, that of Calizzano and that of Savona, consist of rocks which do not resemble those of the Dora-Maira mass and the Piedmontese Alps, but do resemble those of the Mercantour and mont Blanc. We should term them Variscan, if the strike were not divergent. The relation of the Carboniferous to both masses is discordant. But there is this

Liguri, Atti R. Univ. Genova, 1904, XVIII, 226 pp.; also Arcaico e Paleozoico nel Savonese, Boll. Soc. geol. ital., 1895, XIV, pp. 37–75, maps, in particular Pl. II; E. Israel e S. Squinabol, Carta geologica della Liguria, 2 sheets, Genoa, 1891, and Issel e Traverso, Nota sul litorale tra Vado e Spotorno, Atti Soc. ligust., 1894, V, 20 pp. The Trias fossils and the stratified succession at Noli, not far from Spotorno, are described by Rovereto in Boll. Soc. geol. ital., 1897, XVI, p. 83, and by Tornquist in N. J. f. Min., 1900, I, p. 176.

[1] F. Sacco, I Monti di Cuneo, tra il gruppo della Besimauda e quello dell' Argentera, Atti R. Acc. Sci. Torino, 1907, XLII, pp. 61–78, map.

[2] T. Zaccagna, Studio geologico sugli terreni carboniferi della Liguria occidentale, Mem. Carta geol. ital., 1903, XII, pp. 147–161, map. A map of the region which serves as a connecting link north of the Vallone dell' Arma (cf. south-west part of fig. 18, p. 149) is also given by Franchi and Decastro, op. cit., Pl. XII, and Zaccagna in Boll. R. Com. geol. ital., 1903, XXXIV, Pl. V.

[3] A. Issel, Note spiccate, II, Valle di Pallizano, con App. di G. Rovereto, Atti Soc. lig., 1904, XV, 30 pp.

[4] S. Franchi, Nota preliminare sulla formazione gneissica e sulle roccie granitiche del massiccio cristallino ligure, Boll. R. Com. geol. ital., 1893, XXIV, pp. 43–96; Rovereto, Arcaico e Paleozoico nel Savonese, Boll. Soc. geol. ital., 1895, XIV.

difference, that the gneiss mass of Savona does not lie outside of, but within the principal zone of anthracite (on the upper Bormida), i. e. it lies to the north-east, not to the south-west of it. Carboniferous, and more especially Permian, rocks are also known at several other places. The Carboniferous of Quiliano, and all the folds to the south of the gneiss mass of Savona, are overturned towards the south [1]. At monte Moro, near Cadibona, quite close to the sharply defined southern border of the gneiss, I have observed not only limestone (probably the same as that from which de Stefani cites Dactylopora and Gyroporella), but also serpentine, and it remains to be shown by further investigation whether this southern border does not correspond to a profound dislocation, the overthrust of the Carboniferous directed to the south [2].

East of the gneiss the green rocks associate themselves in continually increasing quantities with the Permian and Trias, and at the same time the strike changes.

Approaching from monte Viso, the green rocks and the lustrous schists run to the east-south-east; in some places they make their appearance along the mountain foot; they enter the Ligurian mountains, and extend through these as far as Sestri Ponente, a little west of Genoa. Following the coast from the gneiss mass onward, we encounter, at the ruined castle of Donegale, near Cogoleto, Trias limestone vertically upturned, with a south-west strike; further on, near Avezzano, we find great sheets of schist, with a south-south-west strike; then, towards Voltri, the rocks, now associated with serpentine, pass into a north and south direction, and this is maintained as far as the Sestri Ponente. There, along the Torre Chiaravagna, the whole zone of lustrous schists and green rocks suddenly terminates against a band of Trias limestone, running north and south, and more than 20 kilometers in length; their place is taken by the great Cretaceous and Tertiary zone of the Apennines, with which green rocks, of a precisely similar character to those which have just disappeared, are associated [3]. These most easterly bands are probably the reappearance in part of those which were lost to sight west of Cuneo. Among the indications which serve to connect the two are the Radiolarian rocks which occur at Montenotte, not far from Cairo [4].

[1] C. de Stefani, L'Appennino fra il Colle dell' Altare e la Polcevera, Boll. Soc. geol. ital., 1887, VI, pp. 225-263.

[2] My own wanderings in these districts were made in 1872, with a view to ascertaining whether the continuation of the Alps lies in the Tyrrhenian subsidence, Ueber den Bau der italienischen Halbinsel, Sitzb. k. Akad. Wiss. Wien, 1872, LXV, pp. 217-221.

[3] L. Mazzuoli ed A. Issel, Nota sulla zona di coincidenza delle formazioni ofiolitiche eocenica e triasica della Liguria occidentale, Boll. R. Com. geol. ital., 1884, XV, pp. 2–23, map.

[4] C. F. Parona e G. Rovereto, Diaspri permiani di Montenotta (Lig. or.), Atti R. Acc. Sci. Torino, 1895, XXXI, pp. 167–181. These rocks are Mesozoic and associated with Pietre verdi; for this whole region see in particular Franchi, Il Trias a facies mista con calce-

If then we follow the arc of the Ligurian coast, as it cuts across the strike of the Alps, we shall observe the following: On the south-west is a region belonging to the Briançonnais and the inner Flysch zone (Aiguilles d'Arves). From Porto Maurizio onwards the strike is south-east, then east-south-east. About 5 to 15 kilometers south-west of Savona, traces of the chief band of Carboniferous should approach the sea (through Quiliano). Then follows for a distance of 12 kilometers the gneiss of Savona, with a strike of S. 60° W. On the other side of this we meet with Permian shales, Trias, green rocks, and lustrous schists. Then the strike gradually turns out of the south-west into the south, and with this direction the zone terminates at Sestri Ponente.

The Alps in Corsica. Sardinia and Corsica must be regarded as parts of a single structure. The foundations of our knowledge of *Sardinia* were laid by La Marmora. He showed that from the bay of Cagliari onwards an elongated plain of recent date, the Campidano, runs north-west up to the bay of Oristano, and cuts off a group of heights in the south-west of the island (Iglesias and Sulcis). Out of this plain, in its most northerly continuation beyond the bay of Oristano, rises the volcano of Ferro, described by Doelter, and this is followed close to the coast by a series of recent eruptive centres[1]. Then still further to the north a similar plain, of slightly less breadth, sets in, which extends to the gulf of Asinara, and in like manner cuts off a group of hills, the Nurra, situated to the west of it. On the east lies the volcanic region of Anglona. Tornquist thinks that western Sardinia is cut through by a fault-trough, which extends from the gulf of Cagliari to the gulf of Asinara[2].

Bornemann long ago observed that the Trias in the south-west of Sardinia resembles the German Trias (I, p. 305), and Tornquist recognized the same resemblance in the Nurra of the north-west. Since a different type of Trias is met with in the north-east of Corsica, on the other side of the ancient Corsardinian mass, it was suggested that this mass forms part of an extensive barrier, separating the German from the Alpine Trias[3].

sciste e pietre verdi nel versante padano delle Alpi liguri; Bull. Soc. geol. ital., 1906, XXV, pp. 128-132.

[1] C. Doelter, Der Vulcan Mt. Ferru auf Sardinien, Denkschr. k. Akad. Wiss. Wien, 1877, XXXVIII, pp. 193–214, map, and 1878, XXXIX, pp. 41–96; A. Dannenberg, Die Deckenbasalte Sardiniens, Centralbl. f. Min., 1902, pp. 331-342; G. Deprat, Les Volcans du Loudgoro et du Campo d'Ozieri, C. R. Acad. Sci. Paris, May 27, 1907, pp. 1182–1185.

[2] A. Tornquist, Ergebnisse einer Bereisung der Insel Sardinien, Sitzb. k. Akad. Wiss. Berlin, 1902, XXXV, pp. 808-829, in particular p. 828; and Deprat, Sur les rapports entre les terrains tertiaires et les roches volcaniques dans l'Aglona, C. R. Acad. Sci. Paris, Jan. 14, 1907, pp. 107–109.

[3] A. Tornquist, Die Gliederung und Fossilführung des ausseralpinen Trias auf Sardinien, Sitzb. k. Akad. Wiss. Berlin, 1904, XXXVIII, pp. 1098–1117; also E. Philippi, Centralbl. f. Min., 1901, pp. 551-557; Dom Lovisato, Rendic. R. Ist. Lomb., 1903, ser. 2, XXXVI, pp. 216-228; C. de Stefani, Rendic. R. Accad. Lincei, 1891, VII, pp. 427-431; Tornquist,

This theory has given rise to an instructive discussion. It is certain that the middle Oolites of Sardinia are different from those of the Italian mainland, and contain fossils which, in England and France, are characteristic of the Bathonian. This has been established by Fucini and Dainelli, but it appears from their works that this same stage also occurs in transgression upon the ancient mass on the other side of the Campidano[1]. In addition, Bassani has shown, from fossils found by Lorisato, that the fish fauna of Glarus (*Palaeorhynchus glarisianus* and others) occurs in the north part of the Campidano[2].

South-west and north-west Sardinia thus presents a stratified succession in which the distinctive faunistic characters are commingled. In the Iglesiente, a part of the south-west region, the series rests on pre-Cambrian, Cambrian, and Silurian rocks. The discordant superposition begins with the upper Carboniferous. Both the older substructure and the series superposed upon it have suffered a common folding, at some late period, probably one of the earlier epochs of the Tertiary aera. The strike of the folds in the Iglesiente corresponds with the general course of the western zone of Sardinia.

The region on the other side of the Campidano is regarded by Tornquist as the foreland of the folded range just mentioned. The whole of the central and eastern part of Sardinia is in fact a region which presents a precisely similar stratigraphical succession to that forming the substructure of the Iglesiente, but it has not been disturbed by the later folding. Coal of lower Permian date exists in this region, but transgressions of the several Mesozoic stages also occur, and these, beginning with the Bathonian, are not folded; thus, in the south part of the island, the ancient basement is surrounded by upper Jurassic table-mountains with a karst-like surface, as in the Causses of South France. In the Gerrei, north of the Sarrabus, there is a transgressive patch of Cretaceous also,

Die carbonische Granitbarre zwischen dem oceanischen Triasmeer und dem europäischen Triasbinnenmeer, Die Entwicklung der Trias auf Corsica, N. J. f. Min., 1905, Beil.-Band XX, pp. 466–507; K. Deninger, Die mesozoische Formation auf Sardinien, N. J. f. Min., 1907, Beil.-Bd. XXIII, pp. 435–473, map. Trachyceras, Pinacoceras, and other fossils occur on the lower Ebro (E. von Mojsîsovics, Verh. k. k. geol. Reichsanst., 1881, pp. 105–107). It certainly seems as though the Tethys had been cut off from the existing Atlantic region during a part of the Trias epoch. Whether a temporary connexion existed with Mexico is unknown; cf. The Balearic Islands, chapter V, p. 255.

[1] A. Fucini, Sopra alcuni fossili oolitici di Monte Timoleone in Sardegna, Boll. Soc. Malacol. ital., 1897, XX, pp. 150–160; G. Dainelli, Fossili batoniani della Sardegna, Boll. Soc. geol. ital., 1903, XXII, pp. 253–347; A. Tornquist, Pflanzen des mitteljurassischen Sandsteins Ost-Sardiniens, N. J. f. Min., 1904, XX, pp. 149–158. We may recall the fact that this stage is repeated in the facies of Normandy far to the east in the south-east Carpathians, Verh. k. k. Geol. Reichsanst., 1867, pp. 28–31.

[2] F. Bassani, Avanzi di *Clupea* (*Meletta*) *crenata* nelle Marne di Ales in Sardegna, Rendic. Accad. Nap., 1900, VI, pp. 156–158 and 191–194.

which seems to bear an African stamp, as in Sicily and Calabria [1]. A good description of the neighbourhood of Seui, situated south of the Gennargentu (1,793 meters), the highest point of Sardinia, has been given by Pampaloni. Anthracite, with *Cyathocarpus arborescens* and *Walchia piniformis*, rests upon the ancient formations. This is followed by sheets of Jurassic limestone, with *Ceromya concentrica*, *Modiola imbricata*, and other species, particularly such as correspond with those of the Mytilus beds of the Helvetian Alps [2].

Still further towards the north, data as to the Mesozoic transgressions are wanting. The ancient substructure, maintaining its full breadth, is continued towards Corsica; it forms the whole of this island up to an almost straight line, which runs from the mouth of the Solenzara on the east coast, towards the north-north-west, into the neighbourhood of the Isles Rousses on the north coast. On the west coast, deposits, both of marine and coal-bearing Carboniferous, are superposed on the ancient substructure [3]. The middle and west of Corsica, along with the middle and east of Sardinia, thus belong to a mighty branch of the Altaides which strikes to the south-south-east. This is the *Corsardinian branch.*

The north-east of Corsica, as far as cape Corse, consists of Alpine rocks of the same facies as the Briançonnais and the Piedmontese Alps; the strike on the coast of Liguria, and the prevalent direction to the south or south-south-east in Corsica, as well as the correspondence of the rocks, show that the mountains which reappear at cape Corse are the Piedmontese Alps.

Comparatively ancient schists, possibly Permian, occur at the base in this region; with regard to the series above the quartzite of the lower Trias, we need only remark that Rovereto found traces of Gyroporella in it [4], and Rhaetic fossils have long been known (I, p. 305). At a higher horizon lustrous schists occur, then transgressive Nummulitic beds and Flysch. Even the older map by Hollande marks isolated patches of these transgressive beds [5], and Nentien's more recent survey shows that the boundary line of the Alpine part of Corsica, from the north coast to the east coast, i. e. for a distance of about 100 kilometers, is accompanied by a similar zone of Nummulitic limestone and Flysch; at one point it is interrupted, at others it broadens out to a considerable extent [6].

[1] St. Traverso, Calcare fossilifero nel Gerrei, Sardegna, 21 pp., 8vo, Turin, 1891.

[2] L. Pampaloni, I Terreni carboniferi di Seui ed oolitici della Perdaliana in Sardegna, Rendic. R. Accad. Lincei, 1900, IX, pp. 345–349.

[3] e.g. Maury's find of *Productus semireticulatus*, near Galeria, Bull. serv. Carte géol. 1905, XVI, p. 185.

[4] G. Rovereto, Sull' età degli scisti cristallini della Corsica, Atti R. Acc. Sci. Torino, 1906, XLI, pp. 72–86.

[5] Hollande, Géologie de la Corse, Ann. sci. géol., 1877, IX, no. 2, 114 pp., map.

[6] Nentien, Étude sur la constitution géologique de la Corse, Mém. pour servir

The idea naturally suggests itself that these rocks represent the inner Flysch zone, which has here become an outer Flysch zone. Sometimes it rests directly on the granite, like the Flysch on the east side of the Pelvoux. The beds are steeply upturned, and extend along the east coast, from Port de Favone southwards to the mouth of the Solenzara and beyond. A few uncertain data seem to show that traces of them occur even as far as the gulf of Orosi, in the middle of the Sardinian coast, but we have no detailed information on this point [1].

The green rocks occur just as they do in the Alps, and with the same diversity, namely as peridotite, norite, gabbro, diabase, and in particular serpentine. According to Maury, they penetrate as far up as the Oligocene Flysch, and are overlain by the first Mediterranean stage [2].

The island of *Gorgona* has the same structure as the north-west of Corsica; Ugolino describes gneiss with a strike to N. 50° W. [3] It is the last indication of the Corsardinian branch. *Capraja* consists, according to Emmons, of andesite [4]. *Pianosa* is a platform of Pliocene. All the other islands are of much the same nature as the island of Elba; they are thus fragments of the Alpine system.

Relations with the Apennines. Elba has often been described; but it will suffice to mention Lotti's comprehensive monograph [5]. The island falls into three parts, as is clearly indicated by its outline. The eastern and middle parts consist of Alpine sediments, green rocks, and granitic intrusions. The strike is north and south. Out of this basement rises the granite dome of monte Capane, which forms the western part of the island. This granite is more recent than the green rocks. A similar recent granite also forms the island of Monte Cristo, 40 kilometers south of Elba, and the island of Giglio, situated 50 kilometers towards the south-east (with a fragment of limestone clinging to it, probably Rhaetic, such as also occurs on the island of Giannutri); it further occurs as a mighty dyke near Gavorrano (province of Grosseto), 36 kilometers east of Elba.

These are all remnants of the Piedmontese Alps.

à l'explication de la carte géol. de la France, 1897, 4to, 224 pp., map, in particular p. 205.

[1] Hollande, Géologie de la Corse, Ann. sci. géol. 1877, IX, no. 2, p. 80, note; C. de Stefani, Rendic. R. Acc. Lincei, 1891, VII, p. 465.

[2] E. Maury, Feuille de Bastia, Bull. serv. Carte géol., 1903, XIII, pp. 666-669; for the Flysch of S. Flourent, ibid., 1904, XV, pp. 273-276, and 1905, XVI, p. 181; for the age, 1907, XVII, p. 269.

[3] R. Ugolino, Appunti della costituzione di Gorgona, Atti Soc. tosc. sci. nat., Pisa, 1902, XVIII, pp. 197–213, map.

[4] H. Emmons, The petrography of the island of Capraja, Quart. Journ. Geol. Soc., 1893, XLIX, pp. 129–144, map.

[5] B. Lotti, Descrizione geologica dell' Isola d'Elba, Mem. descr. carta geol. d'Ital., 1886, II, 254 pp., map.

The Tyrrhenian subsidence is not confined within the limits of this sea, but extends far into the Apennines (I, pp. 136, 276). It includes Florence, Rome, and finally the whole of the volcanic region as far down as Vesuvius. It is not till we pass beyond this downthrown area that the Apennines become continuous.

In 1892, Stefani published a map of the trend-lines between Genoa and Florence [1]. In the same year, Lotti described the trend-lines of Tuscany starting from the Catena metallifera [2]. General summaries have been published by T. Fischer and Novarese [3].

The following main features may be recognized:—

In the north-east of Corsica the Alpine folds, closely pressed together, strike towards the south and south-south-east. In Elba and Cerboli [4] the strike is strictly north and south. In the northern region the north and south strike is continued, with many secondary deviations, from Sestri Ponente into the Cretaceous and Eocene of the Apennines. Then the lines situated to the east pass into a south-south-easterly direction, and with this strike, long anticlines, revealing older beds, reach the gulf of Spezia. The south-south-east, or nearly south-east, strike dominates as far as Florence, and then becomes due south-east on the other side of Pistoja.

In the island of Gorgona, belonging to the Apuan Alps, the strike is to south-east; near Lucca and onwards past Volterra, to south-south-east: in the Catena metallifera, more to the south; but beyond Grosseto, to south-south-east; and on the Argentario, as well as inland to the volcanic cone of Bolsena, to the south-east. On the other side of the Catena metallifera, and of the volcano, the strike of the folds, which is south-east throughout, coincides with the direction of the mountains.

A general conception of the structure can only be obtained if we take into account the whole region from the Ligurian Alps to the Corsardinian mass, and as far as the uniform outer border which the Apennines turn towards the plain of the Po and the Adriatic sea. In the north, between Genoa and the plain of Lombardy, this region is narrow, but it rapidly increases in breadth towards the south, and finally occupies the entire space between the east coast of central Corsica and the eastern outer border of the Apennines. The triangular form, partly open towards the south,

[1] C. de Stefani, Le pieghe dell' Apennino fra Genova e Firenze, Cosmos (d. G. Cora), 1892-1893, XI, pp. 129-151, map.

[2] B. Lotti, Considerazioni sintetiche sulla orografia e sulla geologia della catena metallifera in Toscana, Boll. R. Com. geol. ital., 1892, XXIII, pp. 55–71. At that time Signor Lotti was so kind as to send me a sketch of the trend-lines of Tuscany. One of these delineations may also be found in T. Fischer.

[3] T. Fischer, La Penisola Italiana: saggio di corografia scientifica; Italian translation by Novarese, Pasanisi e Rodizza, 8vo., Turin, 1902, p. 212.

[4] P. Fossen, Sulla costa geologica dell' isola di Cerboli, Boll. R. Com. geol. ital., 1885, VI, pp. 13–17.

corresponds to the divergence of the folds, which in the west strike chiefly to the south, and in the east to the south-east.

Such is the arrangement of the trend-lines, but it remains an open question whether or not they reveal the true secret of the structure. The very first spur which reaches the sea at Spezia is overfolded at its extremity towards the interior of the land, and for the whole of the range which succeeds towards the east, Steinmann assumes a disposition in recumbent sheets. Two sheets are to be distinguished here: an upper, with basic intrusive rocks, which, like those in Elba, are correlated with the green-rocks of the Alps, and a second lower-lying sheet (limestone chain of Spezia, Apuan Alps, Catena metallifera, and others), which is never broken through by the green-rocks [1].

The Ligurian Alps are a horst-like segment of the Piedmontese Alps, bounded by the Tyrrhenian subsidence on the south, on the north by the Tertiary beds, beneath which it dips. These beds form a complete series from the Oligocene to the most recent, and contribute to fill up the Lombard subsidence; they extend northwards to beyond Turin and Casale. On the west they are separated from the Alps by the plains of Cuneo and Mondovi; on the east they extend to the plain of Alessandria and Tortona.

Between Alessandria and Valenza, an anticline, or more correctly, according to Sacco's detailed description, a zone of anticlines, crops out from the plain with a west-north-westerly strike. Further away it forms three parallel anticlines, the most important of them reaching its northernmost limit at Chivasso. From this point the strike turns to the south-west so that an arc, convex to the north, results; the folding terminates at Turin. Sacco, however, has shown that the same anticlinal formation which makes its appearance between Alessandria and Valenza, is already visible further to the east on the other side of the plain of Tortona, which is here only 15 kilometers broad; in other words, *that the recent folds of Turin are the deflected continuation of the folds of the outer border of the Apennines themselves* [2].

It was not a local movement, but the younger general movements of

[1] G. Steinmann, Alpen und Apennin, Monatsber. Deutsch. Geol. Ges., 1907, LIX. pp. 177–183.

[2] F. Sacco, La Géo-tectonique de la haute Italie occidentale, Bull. Soc. belge Géol. Brux., 1890, IV, pp. 3–28, in particular p. 18 et seq.; Les Rapports géo-tectoniques entre les Alpes et les Apennines, op. cit., 1895, pp. 33–49, map, et passim: in particular his map on the scale of 100,000 to Il Bacino terziario e quaternario del Piemonte, 8vo, 1889-1890, 634 pp. Rovereto also recognizes their connexion with the Apennines, Geomorfologia, p. 44. Virgilio attempts to explain these folds by Reyer's hypothesis of gliding, and Bombicci previously attempted to explain the whole of the Apennines in this way. F. Virgilio, La Collina di Torino, 8vo, Turin, 1895, 159 pp.; also Atti R. Acc. Sci. Torino, 1895, XXX, pp. 589–606, and Boll. Soc. geol. ital., 1896, XV, pp. 36–70; also L. Bombicci-Porta, Rivendicamento della priorità, Rendic. Accad. Bologna, April 30, 1893.

the Apennines which caused this late folding to enter the region of subsidence. It is in this way that recurrent free ends are formed.

In the Apennines the green-rocks of the Alps are repeated, chiefly in Cretaceous, Eocene, and Oligocene (or upper Eocene) beds, as in Corsica. In the north they are frequent, in the south they become less and less important.

On the middle Trebbia, where they are not older than the Oligocene, Traverso distinguishes a series of igneous rocks, which has arisen from the differentiation of a common magma. The first products gave rise to lherzolite and serpentine, the second to gabbro and diabase, the most recent to granite. The granite only occurs in limited areas, generally as veins [1].

Vinassa de Regny has described the projecting bosses of lherzolite, norite, and serpentine in the Apennines of Bologna; nickel-bearing magnesite is also said to occur there [2].

In Elba, as we have observed, the granite makes its appearance in greater mass; and there, too, it represents a comparatively late product. The green-rocks are transformed, by contact with it, into alternating layers of hornblende schist and enstatite-serpentine. This granite is younger than the folding of the Apennines [3].

Here too, as in the West Alps, we recognize rocks which have solidified beneath the surface. The age of a large part admits of no doubt.

Earlier observers, Gastaldi for instance, regarded the Pietre verdi of the Apennines as identical with the Pietre verdi of the Alps [4]. And even at a later time, when the greater age of the Alpine rocks was generally accepted, a few individuals, Traverso among them, were impressed with the possibility of establishing their parallelism [5].

The twist in the curve of the Alps probably begins in the Great St. Bernhard. In the course of the bend a small part of the coulisse detaches itself, becomes free, and curves outwards towards Saluzzo. The remaining part reaches the sea as the Ligurian Alps. The meridional dislocation near Sestri Ponente (Chiaravagna) is merely the boundary of the coulisses. The Piedmontese Alps reappear in the north-east of Corsica. Elba shows the connexion between the Alps and the Apennines.

[1] St. Traverso, Le Roccie della Valle di Trebbia, 8vo, Genoa, 1896, 83 pp. Sacco is in favour of Cretaceous age, perhaps with Eocene affinities; Les formations ophitifères du Crétacé, Bull. Soc. belge Géol., 1895, XIX, Mém., pp. 247–265.

[2] P. E. Vinassa de Regny, Studii geologici sulle roccie dell' Appennino Bolognese, Boll Soc. geol. ital., 1899, XVIII, pp. 15–32.

[3] Lotti, Elba, pp. 110, 119, 179.

[4] Gastaldi, Studii geologici sulle Alpi Occidentali, Mem. R. Com. geol. ital., 1871, I, p. 32.

[5] Traverso, Roccie della Valle di Trebbia, p. 65. The whole difficulty reveals itself most clearly in the two works of Novarese, Nomenclatura e sistematica delle Roccie verdi nelle Alpi Occidentali, Boll. R. Com. geol. ital., 1895, XXVI, pp. 164–181, and S. Franchi, Notizie sopra alcuna metamorfosia di Eufotide e Diabasi nelle Alpi Occidentali, tom. cit., pp. 181–204. Kalkowsky shows that Ligurian serpentine passes under dynamic influence into nephrite, Zeitschr. deutsch. geol. Ges., 1907, LVIII, pp. 307–378.

CHAPTER V

THE EAST ALPS

Southern boundary of the East Alps. The Lepontine sheets. Selvretta. Alps on the Mur. Oetz, Ortler. Disgrazia, Bernina. Laas. Tauern. East Limestone Alps. Flysch and Lepontine belt.

THE problems presented by the Alps east of the Rhine differ in many respects from those of the west. The East Alps extend over a much greater distance. The manner in which they are connected with the Carpathians is altogether different from that in which the West Alps are connected with the Apennines, and it is unaccompanied by the great back-stowing which occurs in the latter case. The basic sills, such as that of Ivrea in the south-west, give place to intrusions of tonalite and granite, rocks which so closely recall the grano-diorites of America as to suggest that the andesites at the easternmost end of the tonalite zone (III, p. 354, fig. 17) may also form part of the intrusive girdle, and may present similar relations to it, as those existing on a larger scale between the andesites of the Cascade Range and the southern spurs of the grano-diorite of Columbia. The tuffs and breccias derived from them are interbedded with the lower Miocene, and the adjacent hot springs now existing are possibly a lingering inheritance of the past activity [1].

The ancient division of the East Alps into the Central Alps, the greywacke zone, limestone zone and sandstone (Flysch) zone, which arrests attention on the map, seems to point to simple relations; but the fact, already mentioned, that the recumbent sheets of the Chablais reach the Rhaeticon across the Glarus fold and, as we shall see directly, insert themselves in the basement of the East Alps beneath the Rhaeticon, shows that this apparent simplicity is deceptive.

On the east the Dinarides advance much further northwards than on the west. It should be borne in mind that no natural boundary exists between the Dinarides of Greece, Albania, Dalmatia, South Tyrol and Lombardy. Continuous trend-lines approach from the far south. The folds follow each other, either without interruption, or in alternating replacement. They form, in correspondence with the concave bend south of Idria, the overthrusts described by Kossmat, which precisely resemble

[1] F. Teller, Erläuterungen zu Blatt Prassberg (Oest. Special-Karte, Zone 20, Col. XII), pp. 101–158, 164.

those to be discussed later in the concave bend of the Appalachians[1]. In the Vellach valley (Carinthia) the whole of the Alpine Trias has been overturned under the influence of the Dinarides, towards the north; and south of Waidisch, 18 kilometers west of the Villach valley, the Dinarides, according to Teller, pass for a short interval far over the Alps. Dinaric upper Carboniferous rests upon Alpine Trias[2]. Here Termier's hypothesis that the Alps have been overridden by the Dinarides is visibly realized on a small scale. It must be admitted that the Alps plunge beneath the Dinarides, but it cannot be shown that the Dinaric boundary was ever situated much further to the north.

Proceeding further to the west-north-west, we find ourselves in the region of the long fractures of the Drave and Gail (I, p. 261). A movement to the north dominates the Alps near the boundary as far as the mountains of Lienz; thence the movement turns towards the south; Geyer ascribes this effect to back-stowing[3]. Pressure and denudation are then carried to such an extreme that of the Alpine Trias nothing remains but narrow roots; one of these reaches the Brenner at Mauls (I, p. 264; III, p. 341). This band also surrounds the front of the Dinarides, and, overturned towards the south, extends yet 20 kilometers further to the south-west, in the direction of Meran (I, pp. 247, 248, figs. 30, 31).

The front itself, i. e. the northernmost part of the advancing Dinarides, is accompanied by the granite zone of Brixen. Its broader central part is cut through by the Brenner road, north of Franzensfeste.

The granite lies between the Dinaric quartz-phyllite and the phyllitic gneiss of the Alps. Sander's observations show that the granite cuts through the Dinaric rocks along their strike and alters them laterally and above, after the manner of a batholite. On the other hand it follows the strike of the Alpine rocks, and is accompanied on this side by a girdle of tonalite gneiss[4]. In its relations to surrounding rocks, and particularly in

[1] F. Kossmat, Ueberschiebungen im Randgebiete des Laibacher Moores, Ber. internat. geol. Cong., 1903, pp. 505–520, map; Das Gebiet zwischen dem Karst und dem Zuge der Julianer Alpen, Jahrb. k. k. geol. Reichsanst., 1906, LVI, pp. 259–276 et passim; Palaeozoische Schiefer von Eisnern, &c., op. cit., 1904, LIV, p. 96. In the last-named work we may remark the unconformity of the upper Carboniferous in the Altaides and the continued growth of these mountains on the old plan, a phenomenon characteristic of Asiatic ranges and repeated in Carinthia.

[2] F. Teller, Erläuterungen zu Blatt Eisenkappel (Zone 20, Col. XI), pp. 18, 19; diabase and green schists, which occur at several points on the boundary, are regarded as Palaeozoic. The question is not definitely settled: V. Graber, Jahrb. k.k. geol. Reichsanst., 1897, XLVII, p. 231. Teller observed south of Villach a previously unknown intrusion of tonalite, 1 kilometer in length, representing a connecting link between the tonalite of Eisenkappel and that of the Isel valley.

[3] V. Geyer, Verh. k. k. geol. Reichsanst., 1903, p. 195.

[4] B. Sander, Geologische Beschreibung des Brixner Granits, Jahrb. k. k. geol. Reichsanst., 1906, LVI, pp. 707–744, maps.

its action on the roof, this granite recalls the zone of Ivrea. Since its consolidation it has been involved in crust movements, and these acting along inclined planes have completed the mylonitisation of the rock.

The boundary next turns into a north-north-east and south-south-west direction; it runs parallel to the Dinarides, but not quite parallel to the Alps; instructive relations now present themselves which have been described by Stache, Lepsius, and Salomon, and, in the Alpine part, by Hammer.

The strike of the Alps becomes confused in the vicinity of the boundary (here the Judicarian line), and is also dragged towards the north-north-

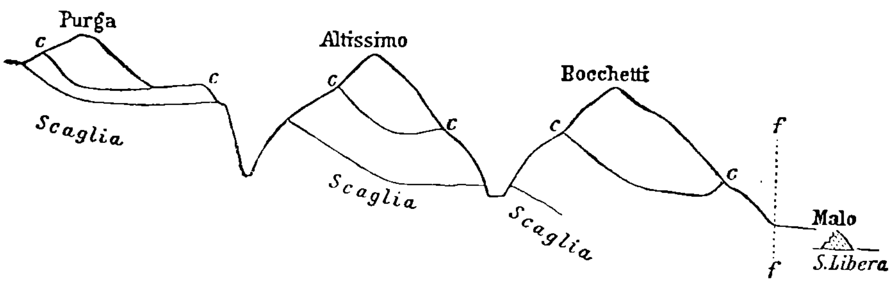


Fig. 19. *Section taken from east and west through the Vicentine Tertiary region.* The folds run at right angles to the Dinaric strike. General subsidence towards the fracture of Schio (*f, f*). *c, c* Carbonaceous bed in the Eocene; near S. Libera a downthrown patch of the Schio beds.

east. At the same time the inclination along the boundary is sometimes very steep; at some points, where there are good exposures, the Alps are seen to bend over the Dinarides. The Alpine gneiss contains peculiar, conformable, lenticular intercalations of platey olivine. They owe their form, as Hammer remarks, to the same distorting force as that which has determined the structure of the gneiss[1].

The Dinarides include a long basin of sediments which runs parallel to the Judicarian line, and presses forward, or rather has been carried forward, to within 14 kilometers of Meran, without undergoing any important dynamic metamorphism. The stratified series ranges, according to Vacek's investigations, from the Permian to the Oligocene; further south, it also includes the Schio beds[2]. At the same time the radiating lines of the Save and Etsch (III, p. 341) bear witness to the persistence of the great general

[1] W. Hammer, Olivingesteine aus dem Nonsberg, Sulzberg und Ultenthal, Zeitschr. f. Naturw., Stuttgart, 1899, vol. 72, pp. 1-48, map; Die krystallinischen Alpen des Ultenthales, Jahrb. k. k. geol. Reichsanst., 1902, LII, pp. 105-134: an instructive description of part of the boundary striking to the Tonale pass is given by G. B. Trener, op. cit., 1906, LVI, p. 410.

[2] M. Vacek, Verh. k. k. geol. Reichsanst., 1894, p. 443, and sheets Rovereto, Trient, Cles (Oest. Special-Karte, Zones 20, 21, 22, Col. IV).

movement up to very recent times. Between the Judicaria and the fault of Schio the lines of the Etsch give rise to a submeridional folding, which crosses the normal strike of the Dinarides. Within these lines lies the northern part of lake Garda.

A broad region in the southern part of the Alps swarms with dykes of porphyrite, diorite, kersantite, and other rocks. Whether they are connected with the intrusions along the boundary is not yet certainly known, but in many cases it seems probable. As a rule they are not sills, like the green-rocks, but ascending fissure dykes and possibly outrunners of the batholites of the Adda, which we have now approached [1].

Lepontine sheets. The marly facies, with abundant bivalves, distinguished by Gressly in the Jurassic, corresponds to a contemporaneous sediment in another locality which differs lithologically, being purely calcareous, and palaeontologically, since it contains a different fauna. According to the terminology of Mojsisovics, the two facies are at the same time both heteropic and heterotopic [2]. It was the unexpected appearance of heteropic formations which first led to the conclusion that the Carpathians had been carried from a great distance over the Sudetes, and the same clue led to the interpretation of the fragmentary sheets of Dauphiné.

Purely heteropic heterotopy, i. e. a difference between contemporaneous formations at places remote from one another, always implies the existence of transitions. Such formations should only be described as pure when accessory characters are absent. While Mojsisovics was careful to point out that 'chance admixtures', such for instance as volcanic ash, must not be regarded as indications of heteropy, yet it is impossible in the study of the Alps to avoid making use of such accessory characters, the occurrence of the green-rocks, for example. In such cases it is obvious that we cannot draw the same inferences as regards connecting transitions, delimitation, and so on.

The stratified rocks of the Helvetian and the East Alps form two clearly defined and fairly pure heteropic series. They are not uniform in themselves, and in the Trias and Lias of the Salzkammergut, for example, a well-marked secondary heteropy makes its appearance. Broadly speaking, they may be regarded for the present as stratigraphical units.

Between these two series lie sheets which are distinguished in places

[1] W. Hammer, Verh. k. k. geol. Reichsanst., 1906, p. 175; C. Riva describes similar rocks from the neighbourhood of the Adamello, e.g. Suldenite from the Passo della Rossola; Nuove osservazioni sulla rocce filon. del Gruppo dell' Adamello, 8vo, Milan, 1897, p. 11.

[2] E. von Mojsisovics, Die Dolomitriffe von Süd-Tirol und Venetien, 8vo, Vienna, 1879, p. 7.

by accessory characters and which have been very much altered by dynamic or other influences. In many cases their fossils, and sometimes even their original mineral constituents, are scarcely recognizable; whereas that part of the Helvetian series situated to the north of the great movements, and the east Alpine series lying high above the planes of movement, are exempt from such alterations. For the present we shall term the whole of these intervening sheets the *Lepontine* group. This name is destined to disappear as our knowledge increases. The Piedmontese facies and that of the Briançonnais are referred to this group, and we may venture to conjecture that transitional connecting links between the heteropic facies of the Helvetian and the East Alps will be found within it.

In Switzerland we meet with the following fragments of Lepontine sheets overlying the Helvetian sheet, as we proceed from west to east: Sulens, Les Annes, the larger masses of the Chablais and the Freiburg Alps, the smaller masses of Giswyl, Stanz, the Mythen, Iberg, and finally, the Berglittenstein, near Buchs, in the Rhine valley. On the other side of the Rhine, the series is continued into the Falkniss. Thence it extends along the west border of the Rhaeticon and still further south.

Investigation is sufficiently far advanced in this region to enable us to distinguish three sheets within the Lepontine series. These are:

1. The lowermost sheet, or *the sheet of the central Pre-Alps* (Nappe des Préalpes médianes, Lugeon; Klippendecke, Steinmann). This is known to extend from the Chablais to the Rhaeticon. Its most striking characters are white Tithonian limestones associated with red Senonian (couches rouges). As shown in the more complete sections, to the west of the lake of Lucerne for example, it comprises, according to Tobler and Buntorf, Trias gypsum, dolomitic limestone of the Spielgerten, the Rhaetic, and several stages of the Jurassic, Senonian, and Flysch [1].

2. *The breccia sheet (Nappe de la Brêche, Lugeon), also ranging from the Trias into the red Senonian and the Flysch.* In this sheet the Lias exhibits that peculiar breccia-like development which reappears in the roots between the zone of Mont Blanc and the Carboniferous fan [2]. Beds with *Pentacrinus tuberculatus* in the Lias breccia deserve mention on account of similar occurrences in the east.

The investigations of Steinmann and his colleagues scarcely leave room

[1] A. Tobler and A. Buxtorf, Excursions-Programm, Eclogae Geol. Helv., 1905, IX, pp. 1–53.

[2] For classification see, in addition to the works already mentioned, F. Jaccard, La région de la brèche de la Hornfluh, Bull. lab. géol. Lausanne, 1904, V, 205 pp., map; for roots extending over considerable distances into the Maurienne and Tarentaise, see Kilian and Lory, C. R. Acad. Sci. Paris, Feb. 3, 1906, et passim; this is the Brèche du Télégraphe; Kilian has shown that it is of Liassic age.

for doubt that in the Rhaeticon this sheet is covered by the next succeeding sheet, that of the green-rocks. This series was observed by Lorenz in the Falkniss [1], and the observation was confirmed by Seidlitz, who traced the series over a long distance [2]. Further south, in the Plessur range, according to Hoek, the breccia sheet gradually disappears [3].

3. *The sheet of the green-rocks* (Ophiolitic, Rhaetic, Vindelician sheet; Steinmann). This is not entirely absent in the west, but in the east it attains a much greater importance. Steinmann has devoted much attention to it. The green-rocks (gabbro, serpentine, diabase), are frequently associated with deep-sea Radiolarian chert of middle or upper Jurassic age; in addition Aptychus limestone, Cretaceous breccias, as well as red Senonian, and a peculiar form of Flysch are met with. The green-rocks are often broken up into great blocks near the overthrusts, or converted into green schists. The Aptychus limestones may be regarded as indications of comparatively deep sea.

According to Kilian and Lory, the Lepontine sheets are sometimes accompanied by very large fragments of gneiss, or granite, torn from the basement [4].

The facts seem to stand in accordance with the view that the breccia sheet has been derived from the Briançonnais, on the east side of the Mont Blanc zone, and that as a rule the higher-lying sheet has been carried furthest. This is true of the third sheet, in so far as the Piedmontese green-rocks occur in it. The oft-repeated view, supported in particular by Lugeon and Argand, that they must be connected with the outermost Dinaric boundary, that is with the limestone which runs along the zone of Ivrea, may be compared with the theory advanced on an earlier page as to the derivation of the Dent Blanche from this zone. It is possible that this

[1] T. Lorenz in Steinmann, Ber. naturf. Ges. Freiburg, 1906, XVI, p. 37, note.

[2] W. v. Seidlitz, Geologische Untersuchungen im Ost-Rhätikon: Ber. naturf. Ges. Freiburg, 1906, XVI, pp. 232–366.

[3] H. Hoek, Das zentralische Plessurgebiet; Ber. naturf. Ges. Freiburg, 1906, XVI, pp. 367–448, map. Here there appears a Klippen sheet; breccia sheet only indicated; sheet of green-rocks: then an 'intermediate fragment of Parpan' consisting of East Alpine beds from the Raibl stage upwards, and closing with radiolarian beds (but above are green-rocks), and over this the normal East Alpine series. Jaccard (Bull. lab. géol. Lausanne, 1906, VII, 15 pp.) states that in the Freiburg Alps the green boulders occur beneath the breccia sheet. According to Hoek this is also the case near Iberg (Centralbl. f. Min., 1906, pp. 461–465). It is impossible to discover whether elongated folds are present.

[4] G. Steinmann, Die geologische Bedeutung der Tiefseebildungen und der ophiolithischen Eruptiva; Ber. naturf. Ges. Freiburg, 1905, XVI, pp. 44–65. The objection, that the Ammonites were bottom-dwelling animals, does not seem to me quite convincing; cf. Jahrb. k. k. geol. Reichsanst., 1859, X, Verh., p. 5; for the frequent occurrence of Radiolaria in Aptychus limestone, H. Rust, Radiolarien des Jura, Palaeontographica, 1885, XXXI, p. 274; W. Kilian and P. Lory, C. R. des Collaborateurs, Bull. serv. carte géol. (1905), 1906, pp. 452–456.

question can never be settled by direct observation. The connexion with the south is destroyed, yet some connexion must certainly have once existed between the green-rocks. And since the remains of the sheets form a chain extending from the lake of Geneva to the Rhaeticon, the connecting rocks must once have covered a large part of Switzerland; even although a part of the sheets may have been carried further towards the exterior by later movements of the great chain.

Thus, the whole interval extending from the Piedmontese Alps up to the sheets and the Rhaeticon becomes a window, disturbed by later movements.

We now enter the East Alps.

Selvretta. The Prättigau is a green land of mountains and hills, bounded on the north by the steep walls of the Rhaeticon, and on the east by the outermost edge of the Selvretta. We have already briefly referred to this region (I, p. 139, fig. 15). The following description will show what a great advance has since been made, thanks to the labours of contemporary geologists, in our knowledge and interpretation of the facts.

Starting from the Rhone Valley, near Sion and Visp, that important trend-line which is marked in the west by the inner Flysch zone, extends across the Nufenen pass, the Bedretto Valley, Airolo and Scopi. Between the St. Gotthard and the Adula it reaches, as an open syncline or root, the mountain-land which separates the vorder Rhine from the upper Rhine. This mountain-land joins on to the Prättigau above Chur.

It is a vast region of Bündner schists, a diversified formation which here closely resembles the Flysch. Nearly all the fossils obtained from it in the Prättigau point to the lower Cretaceous.

As we approach the foot of the Rhaeticon, or the Selvretta, we come at once on to the Lepontine sheets. At Partnum, in the reëntrant angle between the slopes running to west and south, we see, even from a distance, the white walls of the Tithonian, which dip beneath the crystalline rocks of the East Alps [1]. Far away, near Arosa, on the west side of the Julier pass, in Oberhalbstein, then below Gravesalvas on the Silser See, and as far as Silva plana, or even beyond, we may trace larger or smaller parts of the Lepontine series, or at least its uppermost member, represented by a band of serpentine, and at the same time we observe the plunge of the sheets beneath the East Alps.

Starting from Partnum we will continue on our way eastwards towards the interior of the Selvretta. The mountains increase in height, many

[1] There are two divergent descriptions of this region, one by W. v. Seidlitz (see note 2, p. 153), and the other by O. Ampferer in Verh. k. k. geol. Reichsanst., 1907, pp. 192–200. Ampferer's section also marks the Tithonian, Verrucano, Fucoidal Flysch and other rocks dipping beneath the crystalline rocks of the East Alps. Tithonian and red Senonian also occur in Gargellen exposed in a window beneath gneiss.

summits exceeding 3,000 meters; ice-fields broaden out before us; we are surrounded by hornblende schist and gneiss with a nearly east-and-west strike. At last, when we have travelled from 20 to 25 kilometers and crossed the narrowest and highest part of the Selvretta, the valley of the upper Inn opens up before us, and here again, on the east of the Selvretta, as near Patnum, on the west, the Lepontine sheets crop out from beneath the gneiss.

From Ardetz downwards to below Prutz, a distance of 54 kilometers, the Inn flows in the Bündner schists. These are covered in the south part of this tract by the other Lepontine sheets. Traces of them extend to Prutz. Above them in the east lies the gneiss of the Oetzthal Alps, corresponding to the gneiss of the Selvretta on the west. Both surround a great window. Owing to the presence of the green-rocks the whole structure presents a remarkable resemblance to the window of the Paring (Aσ, p. 18)[1].

Near the frontier of Tyrol a very remarkable phenomenon occurs. The Bündner schists at the bottom of the window begin to arch up in a great anticline. The green-rocks are carried high up by the anticline; a great group of mountains, chiefly formed of Bündner schists, cut through by the cañon of Finstermünz and crowned by the green-rocks, now fills the window, and high above its margin on the summit of the Stammer Spitz (3,256 meters), Paulcke was still able to perceive, overlying the green-rocks, a patch of East Alpine Trias.

This anticline does not follow the strike of the Alps, but that of the window, as though a late and general movement of the mountains had attained expression in that part of the Alps which is least heavily burdened[2]. Theobald mentions two or three of these saddles as occurring side by side in the south. To the north also, in the Kaunser valley, near Prutz, an anticline occurs in the Bündner schists.

The window is closed on the south and north. In the south the gneiss of the Selvretta crosses the Inn, through the Piz Nuna, and continues across a great thrust-plane to the spurs of the Oetz gneiss[3]. In the north, above Landeck, the ancient rocks coming from the Arlberg join those of Oetz without any perceptible line of demarcation.

[1] The works of Steinmann, Lorenz, and Rothpletz relating to the window are enumerated in E. Suess, Ueber das Innthal bei Nauders, Sitzb. k. Akad. Wiss. Wien, 1905, CXIV, pp. 699–735. To these may be added: W. Schiller, Geologische Untersuchungen in Unter-Engadin, II, Piz Lad Gruppe; Ber. naturf. Ges. Freiburg, 1906, XVI, pp. 108–163, map; and K. Zoeppritz, Geologische Untersuchungen in Ober-Engadin zwischen Albula-Pass und Livigno, tom. cit., pp. 164–231, map; for the green-rocks see G. Steinmann, op. cit., 1905, XVI, pp. 44–65.

[2] Das Innthal bei Nauders, p. 725.

[3] W. Schiller, Lischannagruppe, Ber. naturf. Ges. Freiburg, 1904, XIV, pp. 107–180, map; and Piz Lad, op. cit., 1906, XVI, pp. 108–163, maps; A. Spitz and G. Dyrenfurth, Anzeiger k. Akad. Wiss. Wien, Nov. 7, 1907, pp. 424–427.

Proceeding towards the north we reach the broad limestone zone of the East Alps; we cross it and see before us the Flysch zone, which forms the continuation of the Helvetian zone. In the basin of the Iller, however, near Hindelang, Oberstdorf, and other localities, unexpected relations make their appearance along the boundary between the limestone zone and the Flysch. Mica-schist, diorite, and quartzite occur in such development that Gümbel had no doubt as to actual occurrence in this region of ancient crystalline schists [1]. The green-rocks are also present here, and Lorenz has observed the red Senonian (*couches rouges*) [2]. A map published by Steinmann, showing the distribution of the green-rocks, marks them on the Iller to the north, in the Rhaeticon to the west, and as far as the uppermost part of the Engadine to the south, as well as on both sides of the window [3].

All within the enclosed space, comprising Davos, Selvretta, Arlberg, and the Limestone Alps, floats upon Lepontine sheets. This is a western fragment of the East Alpine sheet. The distance from the Silser lake in the Engadine, to Oberstdorf in Bavaria, amounts to more than 120 kilometers. At Oberstdorf, the East Alpine sheet rests on the Lepontine belt, and below this the Flysch represents the Helvetian series.

Rothpletz, who has done zealous service by his constant endeavour towards enlarged conceptions, concludes that the entire north border of the East Alps must have shifted its position ('sich verlagert') during the over-thrusting [4].

In the Chablais, the Freiburg Alps, and the whole region of the Lepontine sheets so far described, we have been dealing only with sedimentary series of trifling thickness, and accompanied at most by fragments of the ancient crystalline basement; in the present case, however, the thrust-plane reaches far deeper, and whole mountains of gneiss and granite have been moved towards the north. In the north, however, the gneiss is absent from the basement, probably because the thrust-plane was directed obliquely upwards.

The Alps on the Mur. The window of the Inn is one of the great interruptions which divide up the vast sheet of the East Alps. The Tauern appears as a second and still larger window. Even in the infancy of systematic investigation, more than fifty years ago, and long before the idea of the symmetrical structure of the Alps had been abandoned, it was observed that the so-called Central chain comprised two distinct parts, the

[1] W. Gümbel, Das Auftreten krystallinischer Schiefer im Rettenschwanger Thale bei Hindelang, Geogn. Jahresh., München, 1888, I, pp. 170–172; for a petrographical description, Reiser in Tschermak, Min. Mitth., 1889, X, pp. 500–548.

[2] T. Lorenz, in Steinmann, Ber. naturf. Ges. Freiburg, 1906, XVI, p. 71.

[3] G. Steinmann, Ber. naturf. Ges. Freiburg, 1900, X, p. 258, pl. I.

[4] A. Rothpletz, Geologische Alpenforschungen, 8vo, München, I, 1900, p. 163.

lofty Tauern, formed of a mass of central gneiss with a mantle of schist, and in contrast to these, a broad region, especially extensive in Styria, which contains no central gneiss and does not present a clear, or to any extent concentric structure.

The rocks of the Tauern are repeated, however, towards the east; they are still clearly visible on the Semmering, and south-west of the Tauern we are called on to decide, not only as to the age of the marble range of Laas, but also as to a possible *sub-division* of the great East Alpine sheet. It is supposed to be divided obliquely along its whole length from south-west to north-east, as far as the Adda, *into two moieties*, more or less clearly defined.

It will be easier to form a general conception of the details enumerated if we call attention to the following fact. All the parts hitherto mentioned —the Selvretta, Arlberg, Limestone Alps, and Oetz, belong to the northern moiety, which is broadest in the west. The southern moiety attains its greatest breadth in the east: we will approach it from the Hungarian plain.—

At a considerable distance from the mountains, islands of ancient formations rise from the plain. They begin in the south, east of Gleichenberg, and are continued north-north-east to the Gunser Berg, and then north to the western shore of the Neusiedler See [1]. They are accompanied by recent eruptive rocks and a chain of carbonated springs, which likewise extend to the west side of the lake.

The rock which forms these islands is mica-schist, with a little gneiss. A long band of phyllite sometimes graphitic, calcareous mica-schist, chlorite schist, and serpentine, striking to the north, enters the Alps near Bernstein, and may be followed into the Rosalien range. K. Hofmann has found fossils near Khofidis (west of Steinamanger) which Toula recognized as Devonian [2].

The contour of the mountains does not correspond with the strike, but is produced by bay-like subsidences (I, 135, 313, 351).

Let us now turn to the mountains as they present themselves near Gratz.

We find ourselves surrounded by wooded mountains of moderate height. They are separated by broad, well-populated valleys, of a fairly gentle slope, and we might almost imagine we were in a Variscan region. Similar

[1] F. Stoliczka, Verh. k. k. geol. Reichsanst., 1862, XII, p. 114, and Jahrb. k. k. geol. Reichsanst., 1863, XIII, pp. 1–25; F. von Hauer's Uebersichtskarte der österreichischen Monarchie (1:576,000) represents the greater part of this section. Diener (Bau und Bild, pp. 410–474) has combined the observations so far made on the Mur Alps in an admirable summary.

[2] Corals and Crinoid stalks, K. Hofmann, Verh. k. k. geol. Reichsanst., 1877, p. 16; Toula, op. cit., 1878, pp. 47–52. I have observed a small boss of dark Crinoidal limestone east of Rechnitz.

mountains extend far to the west. They form the fluvial region of the Mur, and for this reason we have named them the *Mur Alps*.

Hoernes, Penecke, and Heritsch have shown that Silurian, of a very homogeneous character, is present near Gratz, and above it lies the Devonian in a rich and almost uninterrupted development, extending up to and including the Clymenia limestone. This series rests unconformably on older rocks; the lowest member (Grenzphyllite) has furnished Crinoids. The series is thrown into several broad folds, striking north-east, and cut through by faults [1]. The resemblance of this Devonian to that which occurs outside the Alps is so great that Stur inferred the existence of some connexion with the Devonian of the Sudetes [2].

In addition, a transgression of upper Cretaceous occurs in the Kainach, west of Gratz. It presents the southern (Gosau) facies, and its beds, like the preceding, are thrown into gentle folds with a north-east strike.

Further west, as the mountains grow higher, mica-schist and gneiss make their appearance; the folds become closer, and sericitic rocks and marmorized limestones are more frequent, but nevertheless we are still in the same tectonic branch of the Alps. Some rocks characteristic of the neighbourhood of Gratz, such as the green Semriach schist (Silurian, lower than the horizon of *Pentamerus pelagicus*, Barr.), are known to occur far to the west. Toula had the good fortune to find traces of still recognizable middle Devonian on the Grebenze (between Murau and Neumarkt, upper Mur valley); and from Geyer's works we may infer that the same deposits occur to the north, as far as Ober-Wölz; to the west, a little beyond Murau; and to the south, as far as the neighbourhood of Friesach [3]. This indicates a prolongation of the Devonian to within about 100 kilometers west of Gratz.

On the Stangalp, south-west of the Devonian mountains just mentioned, the Palaeozoic series is differently represented, the existence of another tectonic element being thus indicated. Mica-schist, some gneiss, and then limestone of unknown age are covered by anthracite, containing the flora of the middle or upper Carboniferous [4].

[1] K. A. Penecke, Das Grazer Devon. Jahrb. k. k. geol. Reichsanst., 1893, XLIII, pp. 567–616; F. Heritsch, Studien über die Tektonik der palaeozoischen Ablagerungen des Grazer Beckens, Mitth. naturw. Ver. für Steiermark, 1905, pp. 170–224, and Bemerkungen zur Geologie des Grazer Beckens, op. cit., 1906, pp. 96–184; Vacek, Verh. k. k. geol. Reichsanst., 1906, pp. 203–238, arrives at different conclusions.

[2] D. Stur, Geologie der Steiermark, 8vo, Gratz, 1871, p. 122 et passim.

[3] F. Toula, Die Kalke der Grebenze, N. J. f. Min., 1893, II, pp. 169–173. G. Geyer regards these limestones as Silurian, because they lie beneath the schists of Semriach; Verh. k. k. geol. Reichsanst., 1893, pp. 406–415: Toula's palaeontological arguments seem to me conclusive.

[4] V. Pichler, Die Umgebung von Turrach in Ober-Steyermark, Jahrb. k. k. Reichsanst., 1858, IX, pp. 185–228; D. Stur, op. cit., 1883, XXXIII, p. 194; F. v. Kerner, Verh. k. k. geol. Reichsanst., 1895, p. 324; W. A. Humphrey, Ueber einige Erzlagerstätten in der Umgebung der Stangalpe, Jahrb. k. k. geol. Reichsanst., 1905, LV, pp. 349–368, map.

Let us next direct our steps to the south.

The fact which first attracts our attention is the occurren[illegible]ssiliferous marine beds of the second Mediterranean stage in the Lav[illegible] valley, which they occupy as far as the west side of the Kor Alp, so that this broad valley must be of great age [1].

West of this locality and to the north of Völkermarkt and Klagenfurt we come upon patches of North Alpine Trias, let down into the ancient formations; these are parts of the long Trias band of the Drau [2]. Over the Trias lie the Gosau beds, and over these again, encroaching on the older rocks towards the north, the Eocene. This consists of variegated clay, coal accompanied by *Ostrea Roncana*, *Natica Vulcani*, &c., correlated by Oppenheim with the beds of Ai Pulli near Valdagno, and finally Nummulitic beds. The whole series is fairly well folded.

These diversified fossiliferous transgressive beds render it improbable that any other great mountain fragment, such as the Dinarides, has been thrust over the middle part of the Mur Alps, which are here more than 100 kilometers broad. They also show that the long zone of North Alpine Trias, which follows the Dinaric boundary in the north and occurs in the valley of the Gurk, 47 kilometers north of this boundary, also belongs to the Mur Alps. In the Gail valley a long dome of mica-schist and gneiss crops out between the Trias and the Dinarides; this also belongs to the Mur Alps. But the lofty mountains which rise to the north of the Trias of the Gail valley, such as the Kreuzech to the south of the Tauern, were recognized many years ago as different from the rocks of the Tauern; they are a western continuation of the Mur Alps. The subsidences of the Trias near the Lienz repeat on a large scale the subsidences on the Gurk.

This southern part of the East Alpine sheet thus comprises:—the Devonian mountains of Gratz and the whole region from the Bacher range to the Semmering, the Mur Alps, Kreuzeck, the Trias on the Drau, extending to Lienz and beyond, also the narrow range of ancient rocks between this Trias and the Dinarides. One might suppose that the Palaeozoic beds of the Mur Alps are directly connected with those on which the northern Limestone Alps are superposed, and that the Trias patches of the south with their northern facies are directly continued into the north Limestone Alps. *But this is not the case.*

Let us once more begin our survey in the east.

[1] Examples of this abundant fauna are given by H. Höfer, Das Miocän von Mühldorf, Jahrb. k. k. geol. Reichsanst., 1892, XLIII, pp. 311-324.

[2] H. Höfer, Die geologischen Verhältnisse der St. Pauler Berge, Sitzb. k. Akad. Wiss. Wien, 1894, CIII, pp. 467-487; K. A. Redlich, Geologie des Gurk- und Görtschitzthales, Jahrb. k. k. geol. Reichsanst., 1905, LV, pp. 329-348, map; for the correspondence with the north in particular, A. Bittner, Die Trias von Eberstein und Pölling, op. cit.. 1889, XXXIX, pp. 483-488.

On the *Semmering* unexpected relations already make their appearance. In the zone traversed by the railway there is a general dip to the north. Approaching from the south we first encounter crystalline rocks, and then a zone of Trias, the development of which is different from that of the adjacent Limestone Alps of the north; the Trias dips to the north beneath a zone of graphite-bearing schists and quartzite, in which Toula has discovered a Carboniferous flora; these dip in turn beneath a zone of schist of undetermined age, and this finally forms the basement of the Trias of the northern Limestone Alps. Thus two zones of Trias are present, the Trias of the Semmering and the typical East Alpine Trias of the Limestone Alps; they are separated from one another by limnic Carboniferous and various schists. Since all the beds dip to the north, the exotic Trias is inclined beneath the normal Trias of the Limestone Alps. In the exotic Trias, Toula's investigations enable us to distinguish the following:—quartzite and sericite schists with gypsum, thick light-coloured Gyroporella limestone, the Swabian facies of the Rhaetic stage, and dark limestone with abundant Pentacrinus [1].

The exotic Trias disappears towards the west, while the limnic Carboniferous, which according to Stur contains the flora of Schatzlar, still persists.

It has been shown by Stur, and in still greater detail by Vacek, that a band of graphite-bearing schists, similar to that just mentioned, and sometimes containing similar plant-remains, proceeds from the Semmering and extends towards the south-west to St. Michael, near Leoben, and thence to the north-west, through the valleys of the Liesing and the Palten to Irdning on the Enns, i.e. for a distance of 150 kilometers [2]. To the south its basement is formed of gneiss and ancient schists. The beds where they have been observed in detail are seen to dip to the north-east and north-west beneath the older zone of rocks which follows on the north [3]; but to Heritsch is due the merit of having shown that in the Sunk

[1] F. Toula, Geologische Untersuchungen in der 'Grauwackenzone' der nordöstlichen Alpen, Denkschr. k. k. Akad. Wiss. Wien, 1885, L, pp. 121–184, map; Die Semmeringkalke, N. J. f. Min., 1899, II, pp. 153–163, and Führer zum Congress, 1893, Exkursion auf dem Semmering, 50 pp., map.

[2] D. Stur, Funde von untercarbonischen Pflanzen der Schatzlar-Schichten am Nord-Rande der Centralkette, Jahrb. k. k. Reichsanst., 1883, XXXIII, pp. 189–206; H. Baron von Foullon, Ueber die petrographische Beschaffenheit, &c., tom. cit., pp. 207–252; M. Vacek in many places, and in particular in Verh. k. k. geol. Reichsanst., 1884, p. 390, 1886, p. 71, and 1893, p. 403; further in C. von John, Ueber steirische Graphite, op. cit., 1892, pp. 413–418; also R. Hoernes, Metamorphismus der obersteierischen Graphitlager, Mitth. naturw. Ver. Steiermark, 1905, pp. 90–131. The frequently mentioned Blaseneck-gneiss is shown by recent research to be sericitic quartzite with a little felspar.

[3] For example, M. Vacek, map in Verh. k. k. geol. Reichsanst., 1895, p. 299; Erzlagerstätte von Kallwang; K. A. Redlich, Berg- und Hüttenm. Jahrb. d. Montanlehranst. Leoben und Przibram, pl. I, map and sections of the Radmer coppermine.

(upper Styria) this graphite-bearing zone is overlain by the lower Carboniferous with *Productus giganteus*[1]. *The East Alpine series—Silurian, Devonian, lower Carboniferous, and Trias—rests upon the limnic middle or upper Carboniferous.* This is an important step in the analysis of the East Alps.

The lower Palaeozoic series crops out as far as eastern Tyrol at the south foot of the north Limestone Alps. It forms the basement of the north Limestone Alps which rest upon it unconformably, although to begin with they are in intimate association with Verrucano or Werfen shales. It is absent from the Semmering section and in western Tyrol. But throughout the whole tract from the Rhine to Gloggnitz, a distance of 480 kilometers, no trace of graphite or limnic Carboniferous has ever been observed beneath the Trias.

The limnic Carboniferous is everywhere distinguished from the typical East Alpine series. On the Semmering it rests upon (or at least north of) the exotic Trias; on the Brenner we again find it associated with exotic Trias; in the long band of upper Styria it is not accompanied by Mesozoic beds. In the south, beneath the Trias of the Drau range, no Palaeozoic formations whatever are to be seen, although they are so largely developed in the adjacent Carnic mountains (Dinarides).

In this way two complexes may be distinguished: I, the crystalline basement, marine Silurian—Devonian—lower Carboniferous, and the whole of the East Alpine Trias; and II, crystalline basement and limnic Carboniferous of the Schatzlar stage (according to another determination, Ottweil flora).

The distribution of I and II is very remarkable. The whole of the north is occupied by I (north Limestone Alps, and their southern lower Palaeozoic belt = the northern moiety of the East Alpine sheet). South of this follows II (Semmering, upper Styrian graphite band, Turrach, and the Brenner). South of this again follow the representatives of I (Silurian and Devonian of Gratz, extending down to the Grebenze), then the north Alpine Trias of the Drau range from the Bacher to the Brenner (= southern moiety of the East Alpine sheet).

Oetz Ortler. On the Enns, above Irdming, the belt of lower Palaeozoic is present, though but little developed; then above Schladming a narrow band of Trias limestone makes its appearance with a divergent strike to the east-north-east; this proceeds from the Limestone Alps and seems to be let down into the ancient schist. It crosses almost the whole of the schist zone; Mojsisovics named it the Mandling band.

Overlying this band of Trias, Gümbel discovered quartz sandstone with Nummulites. The band is cut through by the Enns. South of Radstatt,

[1] F. Heritsch, Anzeig. k. k. Akad. Wiss. Wien, March 21, 1907.

clay sets in, containing splinters and thin seams of lustrous coal (Glanzkohle), which dips towards the north-west beneath the high mountains; a little remnant of these coal-bearing beds, continuing the strike to the east-north-east, has been preserved, 900 meters higher up, on the Stoder Alpe (1,700 meters) which is a foothill of the neighbouring Dachstein range. It seems as though the southern border of the Limestone zone, elsewhere so continuous, is here cut through by an oblique dislocation [1].

These Tertiary outliers are quite isolated. The Eocene on the north border of the Alps is 55 to 60 kilometers distant, that of the Gurk valley almost 100 kilometers; nowhere but on the Gurk are they accompanied by coal-bearing beds, and there, as on the Enns, they rest on East Alpine, not exotic, Trias.

Close to the south foot of the Steinerne Meer (Trias), upper Silurian fossils are found in slate; then come thick limestones and dolomites in which, near Kitzbühel, Ohnesorge found upper Silurian and Devonian fossils. Here we have a continuation of the Silurian-Devonian band of north Styria. It grows narrower, the beds become steeply upturned, and finally it disappears near Schwaz, on the Inn, 24 kilometers below Innsbruck [2].

This band is bordered on the south by ancient phyllite, upon which it rests directly. Through the phyllite there runs across the Brennerstrasse a tongue of gneiss mica-schist, 14 kilometers in length, which is an eastern prolongation of the ancient range of Stubai. In this way the ancient rocks of the Mur Alps, east of the Tauern, are connected, south of Innsbruck, with those of Stubai in the west.

The large and ancient mass of Stubai and Oetz is thus older than the Silurian. It surrounds the west of the Tauern, and just as it is connected south of Innsbruck with the Mur Alps in the east, so south of Landeck it is connected with the Selvretta in the west, and thus forms the frame of the window on the Inn.

As the ancient rocks of Oetz are covered by the Limestone zone in the north, so in the south they are overlain by the Braulio range, an extensive fragment of East Alpine Mesozoic limestone. Its southernmost extremity forms the Ortler (3,902 meters). This range extends to the south-east border of the window of the Inn, and is traversed by disturbances which reveal in numerous places the phyllite basement beneath the Trias. A patch of upper Trias and Lias inclined towards the north with an east-

[1] W. v. Gümbel, Sitzb. k. bayr. Akad., München, 1889, XIX, p. 383; E. v. Mojsisovics, Verh. k. k. geol. Reichsanst., 1897, p. 215, 1898, p. 14, and 1900, p. 8; F. Trauth in Becke und Uhlig, Geotektonische Untersuchungen, Sitzb. k. k. Akad. Wiss. Wien, 1906, CXV, p. 1730.

[2] T. Ohnesorge, Verh. k. k. geol. Reichsanst., 1905, pp. 373–377; for Schwaz, Jahrb. k. k. geol. Reichsanst., 1903, LIII, p. 377: for the eastern part near Dienten, A. Till, Verh. k. k. geol. Reichsanst., 1906, pp. 323–335; a good summary with a small map is given by Diener, Bau und Bild, pp. 433 et seq.

south-east strike has been followed by Schlagintweit from the sources of the Adda into the limestone masses of the Ortler [1].

On Swiss territory, phyllite resting on Trias, was described by Theobald at several localities in the immediate neighbourhood of the Ortler, and Termier has expressed the opinion that the Ortler consists of several sheets originating in recumbent folds and thrust one over the other to the north [2]. On Monte Scorluzzo (3,094 meters), about which the Stilfser Joch Strasse describes an arc, Frech even encountered Trias limestone, in a window, beneath the phyllite. Further north the intercalations of the limestones in the ancient schists are repeated [3]. In the mighty limestone walls of the Ortler the phyllite is not to be found. The traveller along the highroad regards their foldings with amazement. Frech found that the beds were repeated five times in the Königswand (3,875 meters), and seven to eight times in the Trafoier Eiswand.

On the east, below the Königspit, Hammer found that the Trias, as well as the phyllites which join it on the south, are steeply upturned. He regards the southern border as a fault [4].

It is possible that the whole mass of the Ortler will have to be interpreted as a syncline, open towards the north, and complicated within by secondary folds and thrust-planes.

We may regard all the orographic elements mentioned above, from the phyllite of Radstatt to the Silurian and Devonian of Kitzbühel, and from the phyllite south of Innsbruck which extends to Stubai and the Ortler, as members of the northern moiety of the East Alpine sheet. This classification also applies to the formations of Oetz, as already pointed out.

[1] A. Spitz und G. Dyrenfurth, Anzeig. k. k. Akad. Wiss. Wien, Nov. 7, 1907, pp. 424–427 ; K. Zoeppritz, Geologische Untersuchungen in Ober-Engadin zwischen Albulapass und Livigno, Ber. naturf. Ges. Freiburg, 1906, XVI, pp. 164–231, map ; O. Schlagintweit, Die tektonischen Verhältnisse in den Bergen zwischen Livigno, Bormio und Münsterthal, Inaugural-Dissertation, 8vo, München, 1907, 29 pp.

[2] P. Termier, Les Nappes des Alpes orientales et la Synthèse des Alpes, Bull. Soc. géol. France, 1903, 4e sér., III, pp. 711–765, map, in particular p. 750 ; Sur les Nappes de la région de l'Ortler, C. R. Acad. Sci. Paris, Oct. 17, 1904.

[3] The infolded beds on the Hochleitenspitz described by Hammer must probably be regarded as forming a syncline open towards the north. Hammer has himself interpreted the disturbance of Kleinbrod-Uebergrimm in this way. For these occurrences see A. Rothpletz, Geologische Alpenforschungen, 1905, II, 261 pp., map, in particular p. 142 et seq. ; F. Frech, Ueber den Gebirgsbau der Tiroler Central-Alpen mit besonderer Rücksicht auf den Brenner, Wiss. Ergänz.-Hefte z. Zeitschr. d. Alpenvereines, 1905, II, 98 pp., map of the Brenner, in particular p. 70 et seq. ; P. Termier, Les Alpes entre le Brenner et la Valteline, Bull. Soc. géol. France, 1905, 4e sér., V, pp. 209–289, map, in particular p. 236 et seq., also op. cit., Compte rend. somm., pp. 159–161 ; W. Hammer, Vorläufige Mittheilungen über Neu-Aufnahme der Ortlergruppe, Verh. k.k. geol. Reichsanst., 1906, pp. 174–188.

[4] W. Hammer, Val Furva und Val Zebru, Verh. k. k. geol. Reichsanst., 1902, pp. 320–330, and op. cit., 1907, p. 234.

Disgrazia and Bernina. The western limit of the East Alpine development is clearly apparent in the Rhaeticon and at the western margin of the Selvretta. Its presence is marked by the belt of Lepontine sheets which dips beneath the East Alpine gneiss, and in particular by a strip of green-rocks, which increases in breadth as it proceeds through Oberhalbstein towards the south.

Close to the limit rise the limestone mountains of Splügen; Diener interprets them as the most westerly representatives of the East Alpine development. Piz Curvér, the eastern limestone mountain, is the last of a chain of limestone mountains (Weissberg and others) running to the east-south-east, in which dolomite, traces of Rhaetic, Belemnites in red limestone, and other indications, point to the East Alps. Towards the west, however, i. e. in the direction of Avers, they present steep bassett edges, are inclined towards the east, unite with the green-rocks of Oberhalbstein and dip together with these beneath the East Alpine sheet (Piz d'Err, Cima da Flix and other peaks). Concerning the Weissberg, Theobald writes that 'the limestone becomes marble towards the east, while towards the west, in the same mountain and in the same beds, little or no alteration occurs'[1]. Further away, in the direction of the Septimer pass, we find in fact only sheets and strips of white marble within the green-rocks.

The gneiss chains of Tessin, as we have seen, are arranged in such a way that each of them sinks beneath the succeeding chain on the east, and is separated from it by a Mesozoic intercalation. Suretta-Stella has been mentioned as the most easterly, and the sedimentary strip from Avers to the Septimer pass has been described as resting upon it in the east. But this sinks again towards the east beneath the East Alpine sheet, which now occupies *a similar position to that of the gneiss chains of Tessin.*

The Weissberg cannot therefore be part of the typical East Alpine sheet (Braulio). It dips along with the green-rocks beneath this sheet, and is in fact Lepontine. Possibly its sediments may be correlated with the Briançonnais, which resembles the East Alps in so many respects.

On the other side of the Septimer pass the boundaries become more irregular. Green-rocks and a sedimentary zone then run plainly southwards to the Piz Tremoggia, underlying the gneisses and granites of the Bernina in the Val di Fex, and separating them from the ancient rocks to the west. Diener has described this belt in detail. To the south, in the Val Malenco, the green-rocks are widely extended. The summit of Monte

[1] G. Theobald, Beitrag z. geologischen Karte der Schweiz, 1866, III, p. 157. Theobald writes Weisshorn; on sheet XX of his map we find a representation of the region now about to be discussed. Theobald, who was an admirable observer, was so far influenced by the conceptions of his time that he has interpreted almost every pinched-in band of Trias as part of a concentric syncline. The text gives the facts observed.

della Disgrazia itself (3,676 meters) consists, according to Melzi, not of granite but serpentine [1]; and although these Pietre verdi recall in so striking a manner the Piedmontese Alps, yet at the same time the gneiss of the Disgrazia displays a particular resemblance to that of the Gran Paradiso [2].

The belt of the Val di Fex is not the only one; the green-rocks advance in particular towards the Val Bregaglia, where on the south slope of the Marcio they are also accompanied by gypsum, a certain indication of Trias. We will now, however, turn to the east.

From Pontresina onwards we observe, on the east side of the Bernina, Trias and Lias forming a series of wedged-in synclines. One of these strikes along the south side of the Piz Languard; a second, the Piz Alv, runs in an arc, slightly twisted north of the pass, across the road; a third, striking north and south, lies east of Poschiavo. Between them lie smaller fragments, chiefly of gypsum. Here we have the profoundly denuded remains of a system of folds. On the Piz Alv, Diener distinguished quartzite, lower Trias (?), Main dolomite, Rhaetic beds, and Lias [3]. At other places porphyry makes its appearance beneath the quartzite. A few beds show the beginning of marmorization. Green-rocks are not known in this series.

As early as 1884, Diener observed the close resemblance of the dark Pentacrinus beds to those of the Semmering. It is still doubtful whether this group must be assigned to the Splügen mountains and the Briançonnais or whether it already belongs to the East Alpine cover itself.

South of Poschiavo a change occurs. Serpentine and several bands of Trias crop out; according to Brockmann, the latter are five in number. The strike, hitherto mainly north and south, becomes north-west and due west; the dip is to the north-east, that is beneath the Bernina. On the south a band strikes westwards across the Piz Canciano to the Disgrazia [4]; another, more to the north, runs towards the north-west, and according to older observations green-rocks strike from this locality beneath the southern glaciers of the Bernina towards the Piz Tremoggia. Thus the lake of Silva Plana, Val Fex, Piz Tremoggia and Poschiavo would form the south-western boundary between the East Alpine sheet and the region

[1] G. Melzi, loc. cit., Giorn. di Min., 1893, IV, p. 103.

[2] A. Bolla, Il Gneiss centrale nella Valtellina, Rendic. Acc. Lincei, 1891, VII b, pp. 101–105.

[3] C. Diener, Die Kalkfalte des Piz Alv in Graubünden, Jahrb. k. k. geol. Reichsanst., 1884, XXXIV, pp. 313–320.

[4] C. Tarnuzzer, Die Asbestlager der Alp Quadrata bei Poschiavo. Jahresber. naturf. Ges. Graubünden, 1902, XLV, 14 pp., map; H. Brockmann-Jarosch, Die Flora des Puschlav, 8vo, Leipzig, 1907, pp. 9–13. Brockmann's investigations show that indications exist for prolongation both of Piz Alv and Sassalbo still further towards the south, and the east and west strike, west of Poschiavo, appears in still clearer contrast. I am indebted to Herr Tarnuzzer for some valuable suggestions.

of the green-rocks. Where we shall place the Piz Alv remains an open question.

South of this line, as far as the Dinaric boundary, i. e. down to the Adda, we meet with an east-and-west strike; at Sondrio green-rocks still occur. This southern fragment is a continuation of the Disgrazia.

Coming from the Piz Languard we find a prevailing dip to the north-east and north throughout the Bernina, and also to the south of it in the continuation of the Disgrazia mentioned above; it cannot be certainly determined whether or not this persists down to the Dinaric boundary.

On the other side of the Etsch similar bands of marble lie high up in the Texel mountains, but on the river gneiss prevails. Stache assumed the existence of a fault, but we have no recent observations on this point. On the east, however, Hammer's investigations reveal the connexion. The gneisses which, as we have stated, cross the Etsch at its elbow and strike on into the Passeyr, reach the Brennerstrasse; on their northern margin stands the ruin of Sprechenstein. East of the Brennerstrasse they constantly increase in breadth. Becke and Löwl mark them there as ancient mica-schist and schistose gneiss.

This zone of ancient rocks follows the tonalite belt and the Dinaric boundary; on the north, starting from the Plattenspitz, north-east of Meran, it is accompanied by the ridge of Trias limestone, which crosses the Brennerstrasse near Mauls, and has been mentioned above as the western continuation of the Trias of Lienz, the Drave, and the Gurk. It may be traced with certainty from the Bacher range up to the Plattenspitz, i. e. for a distance of 335 kilometers (III, 341).

Thus we see that the ancient rocks coming from the Kreuzeck are continued towards the south-west across the Brenner (Sprechenstein), Passeyr, the bend of the Etsch, Ulten and Hasenohr, always following the boundary of the Dinarides; and again that it is the Trias of the Drave range, which reaches the neighbourhood of Meran as a long, wedged-in band. These elements belong to the southern moiety of the East Alps. Between them and the northern moiety (Ortler, Oetz, and other summits) extends the marble of Laas.

At the Kreuzeck we again reach the Mur Alps. All the beds now dip towards the south and are present in great thickness east of the Kreuzeck.

At the lake of Millstatt garnet-mica-schist and gneiss bend round towards the north; they dip towards the east[1]. Their relation to the limnic Carboniferous of the Königsstuhl has not been determined, and towards the north-east, i. e. in the direction of the Schladming gneiss-mass, the structure becomes extremely complicated, and is by no means fully

[1] G. Geyer, Verh. k. k. geol. Reichsanst., 1892, pp. 319–327, and 1893, pp. 49–60.

explained[1]. A zone of Trias and Jurassic surrounds the north-east of the Tauern. From Tweng onwards up to just below the Seekar-Spitz (Radstätter Tauern), a distance of 11 kilometers, we may trace step by step the easterly dip of the Trias beneath the older rocks, and the summit of the Seekar Spitz itself consists of gneiss resting on Trias[2].

Here the lie of the Trias is extremely complicated. On the north, towards Radstatt, Uhlig observed a recumbent sheet of sericitic quartzite belonging to the Permian or lower Trias; Trias limestone and Jurassic occur beneath this, in some places exposed in windows, while in others they overlie it. These occurrences continue south of Radstatt to within 3 kilometers of the normal basement of the Mandling range (East Alpine with patches of Eocene), and as towards the east they dip beneath the ancient rocks, so towards the north they dip beneath the Trias of the East Alps[3].

So far, therefore, our examination shows that the Tauern are surrounded on the west (Stubai) and north (Pinzgau, Radstatt) by the northern moiety of the East Alps, and on the south (Sprechenstein, Kreuzeck) and east (Mur Alps) by the southern moiety, and that they dip, in those places where the lie of the beds has already been described (Kreuzeck on the south, Tweng in the north-east, Radstatt on the north), beneath the frame.

Laas. From the accounts at my disposal, I have not been able to discover at what point between Poschiavo and Sondalo the boundary of the East Alpine segment may lie. South of Bormio on the Adda, which flows from north to south above Sondalo, lies the batholite of Ceppina (Serra di Morignone), to which we have already referred. At the same time thick intercalations of marble make their appearance in the schist. The dip to north-east and north has disappeared, and far and wide a strike to east-north-east and then to north-east prevails, with a dip to south and south-east. Stache, and in particular Hammer, have made us familiar with this range as far as the bend of the Etsch near Meran (Marlinger Joch)[4].

[1] An example of the difficulties encountered is given by Vacek's little map in Verh. k. k. geol. Reichsanst., 1901, p. 372.

[2] E. Frech has published a view of the Gurpetschegg near Tweng in Sitzb. k. preuss. Akad. Wiss. Berlin, 1896, p. 1274, and in Koken, Geologische und palaeontologische Abhandlungen, 1901, IX, p. 30.

[3] F. Becke and V. Uhlig, Erster Bericht über petrographische und geotektonische Untersuchungen im Hochalmmassiv und in den Radstätter Tauern, Sitzb. k. Akad. Wiss. Wien, 1906, CXV, pp. 1695–1739, in particular p. 1731.

[4] G. Stache, Verh. k. k. geol. Reichsanst., 1876, pp. 314–318, 1877, pp. 205-207, 1880, pp. 127-131; Jahrb. k. k. geol. Reichsanst., 1877, XXVII, p. 143 et seq. W. Hammer, Die krystallinischen Alpen des Ultenthales, Jahrb. k. k. geol. Reichsanst., 1902, LII, pp. 105-133, and 1904, LIV, pp. 541-576; Geologische Aufnahme des Blattes Bormio-Tonale, op. cit., 1905, LV, pp. 1-26, map, and Geologische Beschreibung der Laaser Gruppe, op. cit., 1906, LVI, pp. 497-538, map.

Towards the Dinarides, as we have mentioned above, inclusions of platey olivine occur in gneiss; and gneiss and ancient phyllites form a series of saddles and basins, which towards the north-east are more closely pressed one against the other, in correspondence with the compression of all the inner zones of the Alps, which begins at the head of the Dinarides. It is these ancient rocks, and in particular pegmatite-bearing gneisses, which strike, near the bend of the Etsch, across the river into the Passeyr.

Proceeding towards the north-west, across the strike, we find that the quartz-phyllite predominates. It forms a wide syncline upon the heights (Hasenohr, 3,257 meters) and then sinks on the west, maintaining a great breadth, towards the south: this is the upper limb of a syncline overturned towards the north (or north-north-west); and beneath it Hammer's beds of Laas crop out. These consist of mica-schist and staurolite mica-schist, and the marble of Laas is intercalated in them. This marble does not reach the Ortler towards the west, but the staurolite mica-schist extends as isolated patches into the neighbourhood of Sulden. Similarly the intercalations of marble in phyllite, south of Bormio, and the marble of Monte Sobretto, are not directly connected with Laas; yet they may well be of equal age.

In the marble of the Laas band the stems of Crinoids have been found, thus showing that the marble is an altered normal sediment, and that no other agencies are involved in the marmorization of a Jurassic or Cretaceous limestone than in the marmorization of a Silurian limestone. Two kinds of injections occur, one predominantly pegmatitic, usually in steeply ascending dykes, the other basic in sills. The latter form bands of amphibolite welded with the marble, and Weinschenk thinks that they may have been produced from a gabbro-like rock [1].

Here and there, in the zone of transition between marble and schist, Hammer has observed quartzites. We may therefore regard the marble of Laas as having been originally a crinoidal limestone, associated with quartzite and sill-like injections of a rock allied to gabbro.

Stache regards the marble as very ancient; Hammer assigns it to the pre-Cambrian; Termier has expressed his belief (1905) that it is of Mesozoic age. In Switzerland a complete change of opinion has taken place during the last twenty years as to the age of the numerous marble bands of the Alps; with good reason they are regarded almost without exception as Mesozoic [2]. Here we have the additional fact that Mojsisovics has discovered a bed of gypsum in the ancient phyllite—at an isolated

[1] E. Weinschenk, Die Tiroler Marmorlager, Zeitschr. f. prakt. Geol., 1903, XI, pp. 131–147. A precisely similar result was arrived at by Julien, for example, in New York: Genesis of the Amphibole Schists and Serpentines of Manhattan Island, New York, Bull. Geol. Soc. Am., 1903, XIV, pp. 421-494.

[2] For example, C. Schmidt, Eclogae Geol. Helv., 1907, XIX, p. 505.

locality it is true—beneath the north slope of the Marteller Vertainen, outside and to the east of the Ortler region. Hammer has confirmed this observation and has found, not far from the same place, a lenticular mass of serpentine, conformably intercalated in quartz phyllite. It occurs on the inner Pederspitz. Hammer's description of the gypsum hardly leaves room for doubt that in this case Trias is kneaded in with the quartz phyllite [1].

Thus the observations so far made tend to show that the marble band of Laas is the completely marmorized representative of the Lepontine Trias, visible beneath the East Alpine (Ortler) segment, together with its greenrocks, which here take the form of amphibolite.

The marble cliff of Laas (Jenewand) is, according to Hammer, a syncline open towards the north, and in part overfolded; upon it, completely fitting together with it, rests an anticline folded in the same direction.

The east-north-easterly extremity of the marble beds of Laas reaches the Etsch; to the west of them a narrow zone of phyllite gneiss sets in.—

The *Tauern* are a well-defined range which affords a marked feature to the landscape by the height of its peaks, and the great extent of its snowfields. It describes an arc, slightly convex to the north, which extends for a distance of 165 kilometers, from the Lieser on the east to the Tribulaun range, a little west of the Brennerstrasse. Its breadth on the east is 45 kilometers, but diminishes towards the west; on the Brennerstrasse, where the Dinarides advance, it hardly amounts to half so much.

F. von Hauer, Stache, Peters, Stur, and many other observers have recognized more or less clearly the independence of the Tauern. They distinguished the central gneiss in the middle of the range and a mantle of schist sloping away from it on all sides. Thus this group of mountains came to be regarded as the type of an axis of elevation; their structure, as well as that of the ancient schist and gneiss mountains which slope away from them to north and south, and of the Dinarides which dip to the south, have furnished the principal argument in support of the supposed symmetrical structure of the Alps.

The important, but not yet completed, investigations of Becke show that the so-called central gneiss is an intrusive rock, with variable characters, which stands about midway between tonalite and the older granite of other parts of the Alps. Its varieties are thus described sometimes as granite, sometimes as tonalite gneiss, and sometimes even as tonalite.

Five cores of this gneiss have been distinguished; of these the western (Gross-Venediger 3,660 meters) and the eastern (Hochalm-Spitz 3,350 meters) are the most extensive. The covering of schist forces its way between the

[1] E. v. Mojsisovics, Mitth. Alpenvereins, 1866, II, p. 377; W. Hammer, Laaser Gruppe, p. 518 et seq. Hammer found that the bed of gypsum is 100 meters long, 30 meters thick; it is highly crystalline, and rests conformably beneath quartz-phyllite; he believes the gypsum to be primary and syngenetic.

cores; it forms, as Stur was already aware, the Gross Glockner (3,798 meters), the highest summit of the Tauern[1].

Outside the schist mantle, the Tauern are surrounded by a belt of Trias, Lias, and Oolites, and this, though interrupted in places, separates them from the East Alps. On the whole it is narrow towards the west, as in the Tribulaun range (Great Tribulaun, 3,102 meters), but towards the north-east it becomes broader, as in the Radstätter Tauern (Weisseck, 2,709 meters), and attains orographic importance.

The Tauern, as we have already mentioned, were once regarded as the type of an axis of elevation; yet it is precisely these mountains, and in particular their western part along with the south-western region as far as the Adda, which form the subject of the works of Termier, distinguished by their broad generalizations, and by the endeavour to prove that this part of the Alps consists of several sheets lying one over the other[2].

In the forefront of this question stands one decisive fact: *the Trias of the frame of the Tauern is not the Trias of the adjacent limestone zone of the East Alps.* It is the Trias of the Semmering. Toula had long ago pointed this out in the case of the Radstätter Tauern, and Uhlig sought its equivalent in the zone of the Briançonnais[3]. Termier was astonished at the resemblance of the Trias of the Semmering to that of the Vanoise[4]; in the Tauern its correspondence with the western type is increased by the appearance of serpentine in the Trias. In accordance with its position this Trias must be placed in the Lepontine group of sheets which lie above the Helvetian and below the East Alpine sheets.

The Tauern are a mass which emerges, with a Lepontine frame, from beneath the East Alps.

The sketch on p. 130 shows a small anticline of Flysch which has arisen between the two areas weighted down by the sheets of Annes and

[1] F. Becke, F. Berwerth, and U. Grubenmann, provisional reports in Anzeig. k. k. Akad. Wiss. Wien, 1895, pp. 45–49, 1896, pp. 15–22, 1897, pp. 8–14, 1898, pp. 12–19, 1899, pp. 5–10; F. Löwl, Der Granatspitz-Kern, Jahrb. k. k. geol. Reichsanst., 1895, XLV, pp. 615–640, map; F. Becke and F. Löwl, Westlicher und mittlerer Abschnitt der Hohen Tauern, in Führer z. internat. Congress, 1903, VIII and IX, 48 and 27 pp.; Becke (in Becke und Uhlig, Erster Bericht, &c.), Sitzb. k. k. Akad. Wiss. Wien, 1906, CXV, pp. 1693–1719 et passim.

[2] P. Termier, Les Nappes des Alpes orientales et la Synthèse des Alpes, Bull. Soc. géol. France, 1903, 3e sér., III, pp. 711–765, map; Les Alpes entre le Brenner et la Valteline, op. cit., 1905, 4e sér., V, pp. 209–289, map; La Synthèse géologique des Alpes, Conference, Liège, 1906, 29 pp.

[3] V. Uhlig, Erster Bericht über petrographische und geotektonische Untersuchungen im Hochalmmassiv und in den Radstätter Tauern; Sitzb. k. k. Akad. Wiss. Wien, 1906, CXV, p. 1732.

[4] P. Termier, Sur quelques analogies de facies géologique entre la zone centrale des Alpes orientales et la zone interne des Alpes occidentales; C. R. Acad. Sci. Paris, Nov. 16, 1903, p. 807.

Sulens. An illustration on an incomparably larger scale is afforded by the anticline of Bündner schists which rises from the window of the Inn and carries the green-rocks and a fragment of the East Alpine sheet up to a height of more than 3,000 meters above the sea. In the present case also we may assume that the Selvretta in the west and the Oetz in the east restrained the folding by their weight, so that it could only take place in the window, and there only in a north-north-easterly direction.

The window in the Tauern is too large to have been produced by erosion, but a frame is present, and as soon as the Mesozoic girdle reaches this, the girdle becomes a foreland, yet at the same time a *supernatant foreland.*

In the west we have the gneiss of the Oetz and the Stubai. According to Teller's accounts, a band of isolated outcrops of marble approaches from the high mountains of Gurgl, far away in the south-west, and strikes close to the southern margin of the Oetz gneiss towards the north-east, to the zinc mine of Schneeberg. It marks the boundary between the gneiss and the phyllite which follows on the south. Some distance away the gneiss stands vertical, then it dips more gently in the direction of the phyllite boundary, which it finally overlies [1]. Nearer to the Schneeberg garnet-bearing mica-schist takes the place of the phyllite. In the Schneeberg the mica-schist is followed along this boundary by a zone rich in amphibolite, then comes quartzite, highly calcareous schists, and finally the dolomite of the Karlweissen, containing Crinoids and dipping to the north-west at an angle of 60°–80° beneath the gneiss [2].

This locality lies 10 kilometers west of the Telfer Weissen, the most southerly extremity of the *Tribulaun* range, which is about 30 kilometers long, runs north and south, and forms the western frame of the Tauern. In addition to the earlier works of Stache and Teller we have now at our disposal the investigations of Frech [3].

The relations of the Schneeberg to the Telfer Weissen and the Gschleyer Wand which is connected with it are of some importance. This connexion is indicated by a small outcrop of dolomite, dipping to the north, which was discovered by Frech on the Geringer Alpe. Our conception of the Telfer Weissen differs from that of Frech. It presents the same succession of rocks as the Schneeberg, but in the reverse order. The gneiss lies below, then follows the Trias, and above this the mica-schist. At the same time the strike turns out of the east towards the

[1] F. Teller, Verh. k. k. geol. Reichsanst., 1878, p. 66.

[2] A. v. Elterlein, Beitrag zur Kenntniss der Erzlagerstätte des Schneebergs bei Mayrn, Jahrb. k. k. geol. Reichsanst., 1891, XLI, pp. 289–348, map; E. Weinschenk, Die Erzlagerstätte des Schneebergs in Tirol, Zeitschr. f. prakt. Geol., 1903, XI, pp. 231–237; a detailed description also in Frech, op. cit. (see next note). Crinoids were also found in the neighbouring Moarer Weissen.

[3] F. Frech, Ueber den Gebirgsbau der Tiroler Centralalpen, Wiss. Ergänz.-Hefte d. deutsch-österr. Alpenvereins, Innsbruck, 1905, II. Bd., 98 pp., with map of the Brenner.

north. A screw-twist is produced. *It seems as though we had reached here the end of the supernatant foreland, that is the corner of the gneiss sheet of the Stubai*, and as if the Trias and mica-schist were about to step over its edge [1].

The whole of the Tribulaun range from the Tauern onwards is thrust up on to the border of the Stubai gneiss. This is the way in which Rothpletz interprets it [2]. It consists not of the denuded remains of a transgressive sheet of Trias, but of the overthrust belt. For this reason there are no denuded remains to be found anywhere else in the Stubai. Nowhere along the whole of the western edge is the superposition of the Trias on the gneiss normal: its lower members are absent. The total height of the limestone cliffs above the gneiss amounts in the west to 1,100 or 1,200 meters, but the beds are repeated by folding. Over these repetitions, which include infolded micaceous limestone and pyritous schist, said to be Rhaetic, Frech found on the peak of the Kesselspitz (2,722 meters) a small patch of Lias with Arietites.

The lofty cliffs of the west give a false idea of the thickness of the formation. The transverse section of the Trias is in fact that of a wedge, and so considerable is the decrease in thickness towards the east (as may be seen in the transverse valleys of the Tribulaun) that along the Brennerstrasse, 8 kilometers east of the Hohe Tribulaun there is in places only a narrow belt of dolomite, often concealed by débris and now accompanied by the lower members, quartzite and serpentine, which are absent in the west. At the same time the gneiss of Stubai disappears in the transverse valleys. In the north, owing to the denudation of the Trias, it is still seen as far as the Brennerstrasse, near Matrei, but it does not enter the interior of the Tauern.

In the south, along the Gschleyer Wand, the mica-schist of the Schneeberg rests on Trias; to the north of it, however, ascending the wedge from the east, lies a vast mass of schist containing upper Carboniferous plant-remains [3]. According to Frech, infoldings of upper Carboniferous occur in the Trias.

In the north, from about Matrei onwards, the Trias and upper Carboniferous, which engirdle the Tauern, again bend in their strike almost at a

[1] F. Frech separates the Gschleyer Wand (with the Telfer Weisse) along with the dolomite of Pflersch from the Tribulaun group, and regards it as a fold overturned to the south; Termier believes that it is a part of the Tribulaun group, he also thinks that it is possibly connected towards the south with the range of Sprechenstein (Ratschings), Bull. Soc. géol. France, 1905, p. 231.

[2] A. Rothpletz, Geologische Alpenforschungen, II, p. 208 et seq.

[3] It was discovered by Pichler; F. v. Kerner, Die Carbonflora des Steinacher Joches, Jahrb. k. k. geol. Reichsanst., 1897, XLVII, pp. 365-386, Verh. k. k. geol. Reichsanst., 1906, pp. 130, 131. Walking over this part in 1865, when the railway was in course of construction, I was shown graphite from the Jodok tunnel.

right angle, just as in the south they made a bend about the Telfer Weisse. The strike is now east and west, and the foreland consists no longer of Stubai gneiss but of the ancient phyllite of the Pinzgau, which cannot easily be distinguished from the upper Carboniferous, here present over a wide area. According to Franz E. Suess the Trias is folded into the Carboniferous, and at the same time, especially on the Tarnthaler Köpfe (2,891 meters), is markedly overfolded towards the north, although lower down there is a steep northerly dip. This apparent contradiction indicates a knee-like bend of the beds against the foreland. Rothpletz mentions Rhaetic fossils in the neighbourhood.

The synclines on the heights open towards the north: the dolomite cliffs face towards the north, as in the Tribulaun range they face towards the west: in both cases they are turned away from the Hohe Tauern [1].

The Tarnthaler Köpfe form the beginning of a band of isolated Trias outcrops, in one of them, near Krimml, Diener has found Diplopora. Löwl and Diener's sections of this part show steeply upturned beds in the valleys, and higher up a knee-like bend as before to the north [2].

Between these two points a gentle dip towards the north predominates, as observed by Becke, near Mayrhofen; possibly a greater thickness of material has been removed here by denudation. Further east, near Lind, Trias with serpentine again makes its appearance; and finally we reach the already mentioned *Radstätter Tauern.*

These mountains have been described by Vacek and Frech; a more recent and different interpretation has been given by Uhlig, whose account we will follow [3]. Upon sericitic quartzite rests dolomite with Diplopora, dark Rhaetic pyritous shales with shelly limestone made up of bivalves, Lithodendron limestone, and then as much as 200 meters of Jurassic limestone and Belemnites. Three sheets are present dipping towards the north (in Tweng towards the east). Their bassett edges face towards the south

[1] Franz E. Suess, Das Gebiet der Triasfalten im Nordosten der Brennerlinie, Jahrb. k. k. geol. Reichsanst., 1894, XLIV, pp. 589-670, map; Rothpletz has also found Rhaetic fossils in this region.

[2] C. Diener, Einige Bemerkungen über die stratigraphische Stellung der Krimmler Schichten und über den Tauerngraben in Oberpinzgau, Jahrb. k. k. geol. Reichsanst., 1900, L, pp. 383-394, section on p. 385; also Löwl, op. cit., 1894, XLIV, p. 519, and Führer z. internat. Congress, 1903, IX, p. 11.

[3] F. Frech, Ueber den Gebirgsbau der Radstätter Tauern, Sitzb. k. preuss. Akad. Wiss. Berlin, 1896, pp. 1255-1277, and Geologie der Radstätter Tauern, Geologischer und palaeozoischer Anhang, edited by Koken, 1901, new ser., V, pp. 1-66, map; V. Uhlig (in Becke and Uhlig, Erster Bericht, &c.), Sitzb. k. k. Akad. Wiss. Wien, 1906, CXV, pp. 1719-1737. From the older works: M. Vacek, Beitrag zur Geologie der Radstätter Tauern, Jahrb. k. k. geol. Reichsanst., 1884, XXXIV, pp. 609-634; in connexion with this, Verh. k. k. geol. Reichsanst., 1893, p. 386 et seq. No small part of the Trias is converted into calc-mica-schist; Pentacrinus occurs in this schist. I have found most of the fossils near the Mittereck-Alpe; cf. Anzeig. k. k. Akad. Wiss. Wien, Nov. 20, 1890.

and south-west. The calc-phyllite of the inner part of the Tauern follows them in a similar tectonic attitude as though it were a fourth sheet and the lowest. We have already seen that these sheets approach to within 3 kilometers of the East Alps and sink beneath them. Here there is no over-bending against the foreland.

Nor is there any such over-bending on the south side of the Tauern. Let us begin our study in the south-west of this region.

In the Texel range, which slopes away to the Etsch above Meran, Teller has discovered another band of limestone and marble. It makes its appearance in the hollow below the peak of the Texel (3,320 meters); the Loder (3,268 meters) and the Hohe Weiss (3,282 meters) belong to it. Striking to the north-east, it describes an arc slightly convex to the north-west, extends through the Pfeldersthal across the Weisse Wand to the valley of Ratschings, where it is revealed in a series of marble quarries, and finally, after a very broken course of 34 kilometers, reaches the Brennerstrasse [1].

Its continuation probably includes the fragment which Termier observed below Thuins near Sterzing, and in its further extension, a little to the north of the gneiss of the Sprechenstein, limestone occurs associated with serpentine. Here begins a zone of Trias which extends beyond Windisch-Matrei to the east; this zone, at first interrupted but afterwards continuous, forms the southern boundary of the western half of the Tauern. It has been described in detail by Löwl, who mentions quartzite, dolomite, calc-mica-schist, lustrous schist, gypsum and serpentine as entering into its composition. In the parts best known the beds are steeply inclined [2].

Further east, where the southern boundary of the Tauern begins to strike to the south-east, very little is known about it. Granigg's surveys in the Möll valley seem, however, to suggest that Trias accompanied by serpentine strikes out of the heart of the Hohe Tauern itself and proceeds along the south side of the Hochalmkern to the border, and near Dollach the border is apparently formed by it [3].

We have now concluded our study of the border of the Tauern, and may turn our attention once more to the Brennerstrasse; starting from the tonalite on the Dinaric border we will proceed towards the north. First we cross the granite of Brixen; then a zone of gneiss and gneiss-phyllite. It proceeds from Passeyr and extends to the Mur Alps. Accompanying it is a band of Trias which extends to the mountains of Lienz; this

[1] F. Teller, Verh. k. k. geol. Reichsanst., 1877, pp. 231–235, 1878, pp. 64–66 and pp. 392–396.

[2] Löwl in several places; in particular Führer z. internat. Congress, 1903, IX, pp. 20, 21.

[3] B. Granigg, Geologische und petrographische Untersuchungen im Ober-Möllthal, Jahrb. k. k. geol. Reichsanst., 1906, LVI, pp. 367–404, map.

presents the East Alpine facies. Thus far, that is up to the Sprechenstein, we may regard the region as a part of the southern development of the East Alps.

Proceeding from the Texel range through Ratschings, a band of marble, perhaps altered Trias, sets in north of the Sprechenstein. If this were continued it would become the belt of Trias which runs from the Brenner to Windisch-Matrei as the south border of the Tauern.

Five kilometers further north lies the south end of the Tribulaun range. Here a fresh band of marble sets in, crossing the Schneeberg. It appears to unite in the Telfer Weissen with the Tribulaun range. This range turns towards the north and forms along the Brennerstrasse the west border of the Tauern, which is thrust out over the Stubai gneiss towards the west.

Near Matrei the Mesozoic belt turns out of the north and south into an east-and-west direction, and extends as the northern border to the Radstätter Tauern.

Beyond Matrei, on the other side of a band of Carboniferous (?) schist, we reach the ancient quartz phyllites of the Pinzgau and the tongue of gneiss and mica-schist which strikes hither from Stubai. These strike to the Mur Alps; near Innsbruck they form the normal base of the East Alpine limestone zone and belong with the Mur Alps to the northern moiety of the East Alps[1].

Termier believed that the window of the Tauern was completely closed on all sides. The description given above suggests the existence of a small opening on the south-west. Two bands of marble, one of which runs towards Gurgl in Oetz, and the other to the Texel range, point to a possible continuation of the window towards the south-west. In fact Teller assigns this space between the gneiss of the Passeyr in the south-west and that of Oetz in the north-west to the calc-phyllite; but the work of Teller, though extremely valuable, belongs to a period in which the questions at present under discussion had not yet arisen; whether such a prolongation of the window exists or not can only be decided by a fresh investigation. All the questions which remained unanswered in the case of the marble of Laas thus confront us once more.

Whatever may prove to be the truth regarding the prolongation to the south-west, the most important tectonic problem has been solved by the structure of the frame of the Tauern, and Termier's views have been confirmed.

We shall devote only a brief space to that part of this region which is

[1] Frech (Tiroler Centralalpen, p. 20) mentions a patch of Trias embedded in ancient phyllite on the railway near Amras; I have visited the locality and do not agree with the doubts raised by this statement. Judging from its position, the patch must be regarded as East Alpine.

framed in by the Trias, i. e. the calc-phyllite and the central gneiss, since much difference of opinion exists as to the calc-phyllite, and the central gneiss is the special study of Becke, whose work is not yet published.

When we see the Bündner schist sink beneath the gneiss of Oetz in the window of the Inn, as at Nauders or in the Kaunser Thal near Prutz, we naturally ask whether it does not reappear anywhere in the east. Indeed Stache, who devoted many years of his laborious life to a study of the Alpine schists, observed as early as 1873 that the calc-schists between Nauders and the Kaunser Thal have 'very close equivalents' in the Ziller valley, and particularly on the Brenner between Steinach, and Gries and Gossensass [1]. Termier ventured to assert that they reappear in the schist mantle of the Tauern. This would correspond with the way they lie, and also with an observation of Uhlig's in the Radstätter Tauern, where, beneath three Trias sheets inclined to the north, beds of calc-phyllite occur, occupying a position which is precisely that which would be taken by an additional sheet. But in this range, so highly altered by pressure, no direct proof is to be found: in the beds which form its border a large part of the indubitable, fossiliferous Trias is converted into platey marble, seamed with mica flakes and streaky calc-mica-schists. Becke and Löwl distinguish two members in this schist mantle, an older and a younger, but the age of each is based on conjectures which vary as greatly as in the case of the 'calcaire phylliteux' of Vanoise [2].

Apart from the original structure of the granitic or more or less tonalitic cores (the so-called central gneiss), and whatever their age may be, it is certain that the more important of them were exposed to a considerable subsequent pressure which was directed perpendicularly to the strike of the Alps. This is clearly shown by the digitations of the Venetian core, which run to the south-west and north-east [3]. These digitations are identical with the flat folds at the extremities of Mont Blanc and the Aarhorn. They must be regarded as so many anticlines, separated by synclines, of which the Grein lobe is the best known. These synclines are places of especially intense dynamic alteration. They show that here, as in the Swiss mountains just mentioned, the existing configuration has been determined not so much by original dome formation as by simultaneous arching up, under lateral pressure, of the axes of several parallel folds (*surélévation des axes*); as a consequence, the synclines as a rule die away towards the middle of the arch.

The cores, just as in the case of Mont Blanc, are of intrusive origin, but they have been brought passively into their existing position.

[1] G. Stache, Verh. k. k. geol. Reichsanst., 1873, pp. 222, 223.

[2] For example, the discussion in Bull. Soc. géol. France, 1906, 4e sér., VI, p. 431.

[3] F. Becke and Löwl, Geologische Uebersichtskarte des West-Abschnittes der Hohen Tauern, Führer z. internat. Congress, 1903, VIII and IX.

The Tauern thus represent a window between the northern and southern moieties of the East Alps. Whilst the central gneiss—long previously a consolidated rock—was being passively forced upwards into this window, by a lateral force acting from south and south-east, it carried along with it a belt of Trias and Jurassic; this it forced outwards over the frame towards the west and north-west, and thus gave rise to overfolding. Where it is not overfolded, the frame itself bends from the Tauern towards the exterior.

It might perhaps be suggested as a simpler explanation that the East Alpine sheet once arched over the Tauern as a great dome and was removed from the summit by denudation; but the forcing outwards of the Lepontine belt is opposed to this view, so that we are led to assume a subsequent folding-up, very much as in the Mont Blanc zone (p. 119), but in the present case restricted by the frame. The Carpathians lead to similar results.

The Trias of the Semmering, as opposed to that of the East Alps, has been termed an exotic Trias. In the Tauern, where the relations are clearer and displayed on a much larger scale, *the Trias may more justly be termed indigenous than the East Alpine Trias itself.*

The lower horizons—limnic Carboniferous, which can scarcely be distinguished from the semicrystalline or crystalline schists, quartzite in lower Trias, and green-rocks—are indications of the Piedmontese type; Gyroporella, dolomite and Lithodendron limestone are common to the Briançonnais and the East Alps; the Pentacrinus beds recall the Briançonnais. The Rhaetic and Arietites beds and the Jurassic with Belemnites may be assigned just as well to the Briançonnais as to the East Alps.

The East Limestone Alps. These form a long parallelogram of remarkably uniform breadth which extends from the Rhine to Vienna, a distance of 480 kilometers. On the extreme west, in Vorarlberg, its breadth is only from 12 to 15 kilometers, but as we proceed to the east, it already amounts to 45 kilometers just before reaching Füssen in Bavaria, in the meridian of Innsbruck to 40, of Salzburg to 43, of Gmunden to 48, of the Schneeberg near Vienna, where the bend towards the Carpathians is very obvious, to 37 kilometers. The constriction of the inner zones of the Alps on the Brenner nowhere affects the breadth of the Limestone zone.

This zone consists almost exclusively of Mesozoic sediments. Since the East Alpine sheet forms that part of the Alps which is tectonically the highest, these supernatant beds have been carried forwards without, as a rule, suffering any alteration from pressure, and such alteration as does occur is restricted to the neighbourhood of friction surfaces along dislocations, as for example in the Salz-Gebirge. The dynamic effect of heavy superposed masses is absent. Nevertheless there are folds, overthrusts, recumbent sheets and allied heteropy of the most varied nature.

Two features of a peculiar kind make their appearance in this part of the Alps.

The first is the rectilinear boundary both in the north and south. In the north this is due to a dislocation along the Flysch, and indeed, for long intervals, to an overthrust. In the south it is marked by lofty limestone cliffs which resemble a true scarp.

The highest summits occur in this part of the Alps, and the sediments are purely pelagic. We see no natural boundary, no trace of a shore, and on the southern mountains as far as the Gurk there are with trifling exceptions (the Mandling range or the Gaisberg in East Tyrol) no forelying or transgressive patches. Along the southern boundary a not inconsiderable portion of the sediments rest unconformably and autochthonously upon rocks extending from the Silurian to the lower Carboniferous; the other portion rests on still older rocks. The dislocations within the Limestone zone appear to be quite independent of the two boundary lines, especially of the northern one, and of greater age; they are frequently cut through by the boundaries.

The second peculiarity consists in this, that the basement of the Werfen shales, i.e. the base of the Trias, is nowhere visible, except at the southern extremity. It seems as though all the dislocations occurring within the Limestone zone must come to an end within the Werfen shales and the salt-formations, which also belong to the lower Trias; this may be due perhaps to a horizontal *dragging away of the base* or some other cause. In like manner the basement of the anhydrite group of the Trias is nowhere visible within the whole breadth of the Jura mountains. Buxtorf concludes that the sedimentary sheet of the Jura has been detached from its basement, and that it is a 'sheared-off' sheet (Abscherungs-Decke)[1]. The tangential movements in the Limestone zone are much more considerable than in the Jura mountains, but this feature of their structure is the same.

The movements have occurred at different times. At certain places, as for instance in East Tyrol and especially in the neighbourhood of the northern boundary, unconformable marine transgressions show that parts of the structure are of pre-Cenomanian age, as in the Carpathians. In other places the Gosau deposits begin with conglomerate, and lignite measures containing fresh-water gasteropods and land reptiles; they extend over different stages of the Trias and are violently disturbed by the younger movements.

[1] A. Buxtorf, Zur Tektonik des Kettenjura, Ber. XXX. Versamml. Oberrhein. geol. Ver. zu Lindau, 1907, 10 pp.; Geologische Beschreibung des Weissenstein-Tunnels, Beitr. geol. Karte d. Schweiz, 1907, new ser., XXI, 125 pp., map, in particular p. 103.

The movements are also, however, of very various kinds. Owing to this diversity and the still defective state of our knowledge, we can only add to what has already been said with regard to the *imbricate structure* of Lower Austria (I, p. 112) by giving a few more examples, and we are not in a position to attempt a general summary.

We must first return to the *dragging away of the base* mentioned above. The mobile salt clay, in the Salzkammergut, for instance, has had a profound effect on the Limestone Alps, which load it down, and it has itself been affected in turn. By the force of the movements long streaks of pure rock-salt have been separated from the clay, and a structure has been produced which Kohler explains by borrowing Becke's account of the formation of crystalline schists [1]. By the same movements alien patches have been dragged along. The Lias, which was encountered at a depth of 125 meters in the salt-boring at Berchtesgaden, must owe its position to a thrust-plane. It is an erratic fragment, like the boulders of Tithonian, which occur at Hallstadt in the midst of the salt-formations, at a depth of 260 meters below the surface [2]. These transported fragments, like the streaks of pure salt, point to the dragging away of the base of the stratified succession [3].

It is not so easy to explain the fact that, in spite of the apparently horizontal dragging away, intrusive rocks still occur.

The isolated occurrences of these fragments have not as yet received sufficient attention. They lie in the Werfen shales and the salt-formations, or in the Gosau beds, which so often rest directly on the Werfen shales and are pinched in with them in the dislocations. On the south side of the Wolfgang See, between the sheet of the Osterhorn and that of the Schafberg, gabbro with serpentine crops out, and on the other shore, not far from St. Gilgen, boulders of tonalite, as big as houses, lie in the region of the Gosau beds which belong to the same boundary. At several localities gabbro and diabase occur as boulders in the salt-formation. In the salt mine of Hallstatt diabase porphyrite occurs; as early as 1879 Hauer described it as exposed for a distance of 49 meters, and in places so thoroughly broken up into breccia that no boundary can be drawn between

[1] E. Kohler, Ueber die sogenannten Steinsalzzüge des Salzstockes von Berchtesgaden, Geogn. Jahresh. München, 1903, XVI, pp. 105–124. These occurrences are very different from the salt masses of Roumania, which project from the Miocene clays as rigid bodies and control the folding. It is possible that here, on the border of the mountains, the loading down was less. Wieliczka exhibits a transition from folding to milling out.

[2] A. R. Schmidt, Ueber den Aufschluss des Salzlagers zu Hallstatt, Oestr. Zeitschr. f. Berg- u. Hüttenw., 1873, XXI, pp. 81, 82.

[3] Aigner's general sections show clearly the peculiar succession of strata, according to which the salt-formations of Hallstein and Berchtesgaden form a recumbent fold. Der Salzbergbau in den östlichen Alpen, Jahrb. f. Berg- u. Hüttenw., 1892, XL, pp. 202–380, in particular p. 211, Pl. III.

it and the salt-formation [1]. Mojsisovics thinks that fragments of eruptive rocks occur in almost all the exposures of the saliferous beds [2].

These fragments recall the southern parts of the Alps. They are the remains of intrusions crushed by tectonic movements and probably transported from afar, together with the surrounding rock. They are never accompanied by Archaean basement fragments and must not be confused with the Lepontine outcrops on the north border of the Limestone Alps. The occurrences on the Wolfgang See are particularly remarkable in this connexion.

To these occurrences in the autochthonous but dragged-away base of the limestone, a complete contrast is presented by the rare but very clearly marked phenomenon of *peak folding.*

On the east of the Achen See (East Tyrol), rises the Sonnwend mountain. It is formed of a stratified series which extends from the Main dolomite to the Cretaceous, and the lower beds, of great thickness, are thrown into broad gentle folds. Wähner, however, as the result of studies extending over many years, has succeeded in showing that violent folding occurs in the upper parts of the mountain, a discovery to which he was led by the glaring contrast in the nature of the rocks (red Lias, Radiolarian beds, and hornstein breccia folded in with white reef-limestone). Flakes, or flat folds, lie one above the other as many as four times, or even oftener. On the Sonnwend Joch the continuous anticlinal arches are preserved in such a pack of flat folds. They can only have arisen by detachment from the thick underlying dolomite. Wähner's descriptions recall the simile applied by Termier to another locality—that of the gale, sweeping over the summits of the forest [3].

Recumbent sheets also occur.

Rothpletz long ago distinguished two sheets in the Bavarian part of the Limestone zone.

Ampferer gives an instructive description from North Tyrol of the passage of long, east-and-west folds into an equally long sheet thrust towards the north (Hindelang-Vomp slab). The slab terminates on the north in high cliffs of Trias limestone. Below them a younger series crops out, which ranges up to the Jurassic. This forms the roof of an arch

[1] Most of the facts will be found in C. v. John, Ueber Eruptivgesteine aus dem Salzkammergute, Jahrb. k. k. geol. Reichsanst., 1899, XLIX, pp. 247–258; rocks resembling glaucophane and green schists are also mentioned. Under these circumstances it is doubtful whether the Wehrlite of the Traun terrace at Gmünden has really been transported from the Bohemian mass. Even far to the east at Würflach (not far from Wiener Neustadt) a serpentine mass occurs in the Werfen shales.

[2] E. v. Mojsisovics, Erläuterung zur Special-Karte, Zone 15, Col. IX (Ischl and Hallstatt), 1905, p. 7.

[3] F. Wähner, Das Sonnwendgebirge im unteren Innthal, I, 4to, Leipzig and Vienna, 1903, 356 pp., map; for the underlying beds of the Sonnwendjoch, see, in particular, Pl. I; also Ampferer, Verh. k. k. geol. Reichsanst., 1902, p. 108.

(Stanser Joch), which was once surmounted by the slab; on its further (northern) side the slab has left behind patches, which are 8 to 10 kilometers distant from its existing edge [1].

We have stated that the slab (Hinterau-Vomp) surmounted the arch (Stanser Joch), but it is not impossible that the arching up of the Joch is later than the over-thrusting, i. e. that the relation of the high Swiss chains (Morcles, Diablerets, and others) to the recumbent sheets of the Chablais and elsewhere is repeated here [2].

Two sheets at least play a very important part in the structure of the Salzkammergut. The situation has not yet been explained in detail, but in these fossiliferous regions the heteropy is particularly instructive.

In the Alps two extreme types of marine sediment may be observed, that of the lagoon—the salt and gypsum facies (in the lower Trias), and that of the deep sea—Radiolarian rocks (chiefly, no doubt, Jurassic), and the Aptychus limestones, which range up into the Neocomian. The great masses of limestone and dolomite between these two extremes correspond to more moderate but still considerable depths.

In all formations, and in parts of the earth most remote from one another, we encounter stratified limestones; and from what is known regarding the partings (II, p. 264), it would appear that the stratification is very often, and perhaps always, effected by terrigenous intercalations. This, however, throws no light on the origin of the fine stratification or lamination, apart from the terrigenous supply, displayed by the Radiolarian rocks; and hence arises another question: whether this supply is rhythmically controlled.

A photograph of the Dent de Mezdi (2,888 meters; Dinarides) shows 235 bedding-planes, one above the other; and neither in the ragged peaks nor at the bottom of the picture does the series terminate. We are acquainted also with stratified dolomites (II, p. 263, note 3). Most East Alpine limestones are stratified, and the compact reef-limestone (in the Tithonian, for instance), is an exception.

According to the observations of Sollas and his colleagues in Funafuti the dolomites may be regarded as formed by subsequent submarine alteration of the limestone [3]. The limestone itself is of organic origin, and has,

[1] O. Ampferer and W. Hammer, Geologische Beschreibung des Süd-Theiles des Karwendelgebirges, Jahrb. k. k. geol. Reichsanst., 1898, XLVIII, pp. 289–374, map; O. Ampferer, Geologische Beschreibung des Nord-Theiles, &c., op. cit., 1903, LIII, pp. 169–252, with tectonic stereogram by Hammer, and, in particular, Verh. k. k. geol. Reichsanst., 1906, p. 272; also A. Rothpletz, Alpenforschungen, II, pp. 187–204.

[2] This is also indicated by Ampferer; at the same time he describes the recumbent sheets with caution and reserve. The evidence of the basement patches (Rappenspitz) removes all doubt; cf. A. Rothpletz, Geologische Alpenforschungen, II, p. 202, fig. 86.

[3] The Atoll of Funafuti (published by the Royal Society), London, 1904, 4to, and Atlas; in particular Judd, p. 373 et seq.

no doubt, been produced chiefly by foraminifera; the calcareous algae and the corals play only a secondary part. The terrigenous supply occurs not only in partings, but also as a colouring admixture, which may either be inorganic (red and yellow) or organic (black). The terrigenous origin of the red and yellow element (chiefly iron) is not so certain as that of the black, but Funafuti has shown us that even on atolls remarkable bituminous deposits may occur.

Too great importance has been assigned to nodules of manganese; they may have been produced, as in the Tertiary deposits of Russia, by Fucoids.

In the Salzkammergut it is plainly evident that pure white limestones and dolomites predominate in the southern part of the Limestone Alps, and that towards the north the terrigenous element increases in the form of partings, and the limestones acquire a more variegated coloration. This change is carried so far that Mojsisovics was led to conclude that the thick light-coloured limestones, classed together as the Dachstein-kalk, correspond to at least seven palaeontological zones of the Trias and six of the Lias [1]. According to this view these zones are only intercalations in a common pelagic formation; Diener arrived at a similar conclusion with regard to the relations of the Trias to the Lias in the Himálaya [2].

At the same time it must be observed that in many great limestone-formations perfectly white sediments occur devoid of the terrigenous element, and these are distinguished by an unusual abundance of organic remains (perhaps owing to the trifling amount of sediment). Examples of these white sediments are afforded by the Permian beds of the Tibetan recumbent sheets, the Gasteropod-bearing limestones of the Marmolata in the Dinarides (Trias), and the Brachiopod beds of the Hierlatz stage (upper Lias), and of Vils and Windischgarsten (Kelloway stage) in the East Alps.

A lithological and a faunal facies must be distinguished. In most cases, it is true, the sediment and the fauna change simultaneously, and it is this holisopy which facilitates the delimitation of the stages in nature. The holisopy may be repeated at places extremely remote from one another; G. Boehm has shown that vicarious isopy occurs in several stages of the Jurassic, between Europe and the Sunda Islands. Diener has recognized the pure holisopy of several stages of the Trias, and especially of the very characteristic red Lias (beds of Adnet) in the north-east Limestone Alps and the Tibetan sheet, and he justly points out how striking is the contrast presented by the heterotypy of the adjacent sediments in the Alps [3].

[1] E. v. Mojsisovics, Ueber den chronologischen Umfang des Dachsteinkalkes, Sitzb. k. Akad. Wiss. Wien, 1896, CV, pp. 5–40, in particular p. 34. One of the most serious attempts to distinguish regions characterized by different facies in the East Alpine Trias has been made by Böse, Zeitschr. deutsch. geol. Ges., 1898, pp. 695–761.

[2] C. Diener, Beitrag zur Kenntniss der mittel- und obertriadischen Faunen von Spiti, Zeitschr. deutsch. geol. Ges., 1906, CXV, pp. 757–778, in particular p. 773.

[3] C. Diener, op. cit., 1907, CXVI, p. 608 et seq.

With the view of giving an example we will now proceed from the Dachstein mountains into the Salzkammergut, i. e. from south to north.

In the *Dachstein mountains* indications of a clearly terrigenous intercalation (Cardita beds) of trifling thickness, and often scarcely discoverable, rest upon the Wetterstein limestone which is about 1,000 meters thick; upon this follows about 1,000 meters of dolomite and stratified Dachstein limestone, containing towards the summit some intercalated reddish beds, then in irregular superposition the white crinoidal and Brachiopod limestone of the Hierlatz stage (zone of *Ammonites oxynotus*) without terrigenous indications.

To the north follows the not very broad zone of the Hallstatt Salt-formation, which is of completely different composition. North of this zone rises the *Hohe Kallenberg*; it repeats the facies of the Dachstein. Along the upper boundary of the thick Wetterstein limestone follows, as in the Dachstein, the dark, and in this place oolitic, band of the Cardita beds which, in the mountains situated still further to the north-east, contains the fauna of Raibl; it is accompanied by a thin layer of grey sandstone, which swells out towards the north-east and furnishes the terrestrial flora of Lunz (lower Keuper, Newark system of the eastern United States). The higher cliffs of the Kallenberg consist of dolomite and stratified Dachstein limestone.

North-west of the Kallenberg lies the broad and regularly stratified mass of the *Osterhorn*. Here we see feeble, argillaceous partings, with terrestrial plants and fishes, intercalated between the bedding planes of the Dachstein limestone; they increase in importance towards the summit, pass into dark limestone beds with a littoral Rhaetic fauna, until finally the light Dachstein limestone disappears, and the Rhaetic stage entirely fills its place (II, p. 269). Then follows, not the light Trias of the Hierlatz stage, but dark limestone with Psiloceras, and the whole series of the brown, yellow, red, and grey Lias up to the iron-bearing beds with *Stephanoceras Sauzei*; and last comes the upper Jurassic.

The argillaceous terrigenous element, and the bright colours of the limestones clearly indicate an unmistakable approach to the facies of the foreland. For this reason the argillaceous partings with *Avicula contorta* and the Raibl beds with *Myophoria Kiefersteini* afforded, many years ago, the first annectant threads with the facies of the foreland. Wähner has gathered the details together in the case of the Lias, and has shown that the sediment may be so thin in places that a stage, that of *Schlotheimia marmorea*, for example, is only represented by a frequently interrupted crust of brown iron ore[1].

[1] F. Wähner, Zur heteropischen Differenzierung der alpinen Lias, Verh. k. k. geol. Reichsanst., 1886, pp. 168, 190; in addition detailed palaeontological treatises in Mojsisovics and Neumayr, Beiträge zur Palaeontologie, &c., 1882 and later; also Pompecki, Palaeozoische Beziehungen zwischen den untersten Liaszonen der Alpen und Schwabens, Vortrag im Ver. f. vaterl. Naturk. Württemberg, 1892, pp. xlii-liv.

Three successive and important parts of the range—the Dachstein, Kallenberg, and Osterhorn—have now been cited; they are to some extent comparable and present distinct connecting links, although not indeed complete isopy. East of the Kallenberg, on the right side of the Traun valley, the completely divergent facies of Hallstatt prevails along the Raschberg. Little is to be seen of the pelagic limestones and dolomites of the Kallenberg, which are at least 1,300 meters thick. The characteristic members are the Salt-deposits and the typical Hallstatt beds. Mojsisovics has marked them along two elongated bands (Berchtesgaden to Hallstatt, St. Wolfgang nearly as far as Lietzen)[1]. The second band bounds on the north the mass of the Osterhorn, on this boundary lie the above-mentioned occurrences of gabbro and tonalite on the Wolfgang See, and north of the lake lies the Schafberg, the rocks of which are intensely folded and present a facies altogether different from that of the Osterhorn, particularly in the case of the Lias.

Thus, two facies at least occur in the Salzkammergut, that of the Dachstein, Kallenberg, and Osterhorn, and that of Hallstatt, Raschberg, and Wolfgang. Of the first, that of the Osterhorn would correspond to the development which is often described as the Bajuvarian, but this, according to Rothpletz, separates into at least two sheets in Bavaria itself. The second, or Hallstatt sheet, if it lay on the western border of the Alps, would probably be correlated, owing to traces of intrusions, with the sheet of green-rocks, that is the uppermost horizon of the Lepontine group. It certainly lies lower than this group[2].

This example illustrates the difficulties with which we are confronted.

The Flysch and the Lepontine belt[3]. If we enter the East Alps from

[1] E. v. Mojsisovics in Diener, Bau und Bild Oesterreichs, p. 387, fig. 2, and Erläuterung zur geologischen Special-Karte, Zone 15, Col. IX, 1 : 75,000, 1905. This gives detailed information on the stratigraphical series.

[2] That the Salzkammergut is divided into three regions, characterized by different facies, was asserted by Mojsisovics as early as 1879 in his Dolomitriffe von Südtirol, 8vo, p. 87; in the south and north the pelagic Dachstein facies prevails, and between these the Osterhorn facies. For the disposition of the Hallstätter facies, Bittner's description of the Lamm district is important, Verh. k. k. geol. Reichsanst., 1884, pp. 79, 99, 358; Rothpletz, Geologische Alpenforschungen, II, p. 183, shows the presence of pelagic beside Bunter facies, separated only by a dislocation in the Eldernbach near Vils; Böse describes Dachstein limestone above Jurassic Aptychus limestone on the Hohe Göll. Haug, Les Nappes de charriage des Alpes calcaires septentrionales, 1re et 2e parties, Bull. Soc. géol. France, 1906, 4e sér., VI, pp. 359–422, contains an attempt at a general survey. Four sheets are distinguished in this important work, namely the Bavarian sheet (B), the Salt sheet (S), the Hallstatt sheet (H), and the Dachstein sheet (D); of these (D) corresponds to the pelagic, (B) to the Bunter (Osterhorn), (S) and (H) to the Hallstatt facies. Diener raises the objection that, according to Haug, (S) and (H) should be intermediate between (B) and (D), whereas in fact (B) and (D) lie nearer one another; Peterm. Mitth., 1907. Haug's publication is not yet complete.

[3] Most of the localities mentioned in the west may be seen on Gümbel's Geologische Karte von Bayern, sheets I–IV.

the north we encounter, south of the Molasse, the Flysch zone—almost exclusively Cretaceous and lower Tertiary—then a Lepontine belt which is particularly well-marked in the east, and not till we pass to the other side of this belt do we reach the Trias of the Limestone zone. At the same time the folds of the Limestone zone are overlain from east to west in unconformable transgression by Cretaceous patches of two kinds, one of the Flysch and the other of the Gosau facies.

Let us return to the northern shore of the Walen See in Switzerland. Arnold Heim observes that the Mattstock, formed of Cretaceous limestone, rears itself up squeezed into the nagelflue of the Molasse. Wherever Eocene Flysch lies between, it is crushed, and the Mattstock itself is a fragment of a sheet [1]. Gulmen, Stock, and Goggeien are similar crushed limestone rocks, and all of them, along with the Churfirsten and the Säntis, are parts of a sheet without roots [2]. They are continued towards the east-north-east across the Rhine. At the same time there are signs of diminished pressure, and with this one Flysch zone makes its appearance to the north and another to the south of the broad range of Cretaceous limestone which runs through Vorarlberg. Vacek, many years ago, gave a detailed description of its several folds, and of its stratified series, which resembles that of the Säntis [3].

The Cretaceous range and the two Flysch bands reach the Iller. Here a great transverse dislocation sets in towards the north; the northern Flysch band disappears; the Cretaceous range, much diminished in breadth, comes in again on the Grünten, north of Sonthofen, and now forms the outer border of the Flysch zone; the southern Flysch zone is continued further.

The Grünten still belongs to the Cretaceous facies of the Säntis, the characteristic members of which are here Gault-Greensand, Seewen limestone, and the Senonian Seewen marl. This Säntis facies runs as a narrow belt along the north border of the Flysch. Traces of it are known even in the vicinity of the Isar, and Gümbel marks them still further to the east. We regard this belt, like the Säntis itself, as the border of a sheet, sometimes completely crushed, which crops out from the south from beneath the Flysch zone.

At the same time the Cenomanian occurs in transgression over parts of the Limestone zone in long bands of fine grained sandstone with *Orbitulina*

[1] Arnold Heim, Die Brandung der Alpen am Nagelfluhgebirge, and Die Erscheinungen der Längszerreissung und Abquetschung am Nordschweizer Alpenrande, Vierteljahrschr. Naturf. Ges. Zürich, 1906, LI, pp. 441-472, map.

[2] Albrecht Heim, Das Säntisgebirge, Beitrag geol. Karte d. Schweiz, new ser., XVI, 4to, 1905, 654 pp., atlas, passim; in particular Arnold Heim, op. cit., p. 450, and E. Blumer, op. cit., map on p. 599.

[3] F. Freiherr v. Richthofen, Die Kalkalpen von Vorarlberg und Nord-Tirol, Jahrb. k. k. Reichsanst., 1859, X, pp. 72-137, and 1861-1865, XII, pp. 87-206; M. Vacek, Ueber die Vorarlberger Kreide, op. cit., 1879, XXIX, pp. 659-758.

concava. A particularly long band of this kind lies close to the north border of the Limestone zone, only separated in places from the Flysch by a narrow band of Trias. It probably begins at Hindelang, and attains its greatest degree of continuity in the Ammergau and thence onwards east of the Isar, and probably yet further towards the east. In this band we observe, above the transgressive Cenomanian, the first remains of the Gosau beds with their completely southern character, the Hippurites and corals. Söhle justly emphasizes the difference between this facies and that of the Säntis [1].

The Gosau beds of the East Alps comprise several members extending into the Senonian; as to their order there is still some difference of opinion [2]. But all observers are agreed that the Inoceramus marl with *Pachydiscus Neubergicus* is the highest member. Grossouvre places it in the Campanian [3].

This uppermost member corresponds in many of its characters with the Bavarian Flysch. Inoceramus has been found in the Flysch; *Pachydiscus Neubergicus* is common to the Flysch and the Inoceramus marls of the Gosau. But the species of Inoceramus, as far as comparison has been made, are different from those of the Gosau [4]. The thickness of the Flysch is also incomparably greater. The lower and typical members of the Gosau with their corals, Rudistes, Actaeonellas, Omphalias and other forms, have never yet been found in the Flysch zone [5].

The Bavarian Flysch is overlain by marly shales, greyish-green in colour, and towards their upper part variegated or red. *In these beds a fauna makes its appearance which contains an obvious admixture of northern, extra-Alpine, upper Senonian forms; and they include, in common with the Flysch, the Fucoids and the great thin-shelled Inoceramus (Inoceramus Salisburgensis).* Here, and indeed, according to Reis, chiefly in the upper horizons, *Belemnitella mucronata* occurs in abundance, and at the same time *Gryphaea vesicularis, Ostraea ungulata, O. curvirostris,* and other well-known upper Cretaceous species. Above these, still other stages

[1] U. Söhle, Geologische Aufnahme des Labergebirges near Ober-Ammergau, Geogn. Jahresh. München, 18(96)97, IX, pp. 1–66, map, and Das Ammer-Gebirge, op. cit., 18(98)99, XI, pp. 39–87, map.

[2] In particular there seems to me good reason for doubt as to the high position assigned to the coal of Grünbach.

[3] A. de Grossouvre, Recherches sur la Craie Supérieure (Mémoire pour servir à l'explication de la Carte géologique), II, 4to, Paris, 1901; La Craie dans les Alpes orientales, pp. 597–646.

[4] W. Petrascheck, Ueber Inoceramen an dem Gosau und dem Flysch der Nordalpen, Jahrb. k. k. geol. Reichsanst., 1906, LVI, pp. 155–168. We must also mention the great *Inoceramus Salisburgensis* from North Africa.

[5] The sphaerulite found at Liebenstein in Bavaria belongs to the zone of the Säntis facies. Rothpletz, Geologische Alpenforschungen, II, pp. 215–219.

(Pattenau, Gerhartsreuter, Hachau beds) are distinguished, which are of trifling thickness, and have little importance for the questions treated here[1].

In the Pattenau beds we still find associated together *Belemnitella mucronata* of the white chalk, and *Inoceramus Salisburgensis* of the Flysch, and *Pachydiscus Neubergicus* of the uppermost Gosau beds.

The whole breadth of the Flysch zone is overfolded to the north as far as Salzburg and far beyond it.

There is a universal dip to the south. On the north border the Nierenthal beds, and still higher beds of the Cretaceous, crop out from beneath the Flysch, and from beneath these the Eocene. The investigations of J. Böhm, and particularly the studies which Reis has made of the structure of the Eocene iron-ores, show that the Eocene and the highest part of the Cretaceous are repeated by thrust-planes dipping to the south and broken up into scales or flakes at the base of the Flysch, which is here very thick[2]. Again in the beautiful section of Mattsee (Upper Austria) we see Flysch resting upon Nierenthal beds with Belemnitella and these upon Eocene.

On the south border of the Flysch zone the case is different. While in the north the uppermost Cretaceous and the Eocene are sometimes exposed over broad, irregular surfaces, as for instance south of Teisendorf, or the Eocene at least remains visible in an easily recognizable belt, as to the north of Salzburg; in the south, on the other hand, the southern dip carries the Flysch straight under the Trias, or under a zone of Aptychus limestone, which lies in front of the Trias, and in striking independence of it; only rarely indeed are Eocene and Nierenthal beds visible at all on the south boundary. A pinched-in patch of these beds does, however, occur in the Gschliefgraben near Gmunden; according to Fugger's description it dips to the south beneath the Trias, so that the Eocene dips beneath the Trias[3]. This circumstance shows that the Flysch zone must be regarded in fact as an independent formation concealed in part by the Limestone zone which comes up from the south.

A series of Tertiary patches, lying transversely across the strike of the Limestone range, extends along the north-west slopes of the Untersberg beyond Salzburg towards Reichenhall, proceeds south-west to near Reit im Winkel, and thence onwards through north-east Tyrol in an almost unbroken band into the Innthal; it continues in this valley still further towards the south-west into the neighbourhood of Wörgl, and according to

[1] J. Böhm, Die Kreidebildungen des Fürberg's und Sulzberg's bei Siegsdorf in Ober-Bayern, Palaeontographica, 1891–92, XXXVIII, pp. 1–106, map; O. Reis, Erläuterung zu der geologischen Karte der Vorderalpenzone zwischen Bergen und Teisendorf, Geogn. Jahresh., 18(95)96, VIII, pp. 1–155, map; Fauna der Hachauer Schichten, op. cit., 18(96)97, IX, pp. 67–104.

[2] O. Reis, Zur Geologie der Eisenoolithe führenden Eocänschichten am Kressenberg in Bayern, Geogn. Jahresh., 18(97)98, X, pp. 24–49, Pl. I, fig. 1.

[3] E. Fugger, Jahrb. k. k. geol. Reichsanst., 1904, LIII, p. 338.

certain statements even further up the river. It includes the lignite formations of Häring, and belongs to the Vicentine series of Laverda and Gomberto [1]. It bears a southern stamp.

In the region occupied by these patches some remains of Cenomanian are also preserved, and in the Innthal below Kufstein Schlosser has discovered the Nierenthal beds; here, too, they contain the great flat *Inoceramus Salisburgensis* of the Flysch which, while separated from the Gosau beds, is thus present in the Limestone Alps [2].

According to Gümbel's account we must conclude that these patches are the remains of beds which were deposited unconformably on the Limestone mountains, and were then, at least near Reit im Winkel, let down in more or less trough-like faults. Gümbel justly infers *that the later dislocations of the high mountains were movements in mass*, and not isolated foldings; this would explain the fact that the Molasse mountains lying in front of the great range were laterally compressed, while in these patches no signs of lateral pressure can be perceived [3]. The Limestone zone was carried forwards as a whole after it was folded, and this part of the folding was older than the Cenomanian, but the general movement was more recent than some stages of the Tertiary.

Having gained this information, and particularly the fact that the Cenomanian transgression extends unconformably over part of the Limestone Alps, and that the upper Senonian, including the Nierenthal beds, may follow it, let us turn our attention to the east.

Here, too, even up to the most easterly extremity of the Limestone zone, the same transgression is known, characterized in the same way by *Orbitulina concava*, and again followed, by the Senonian up to the Inoceramus marls. These facts have been admirably set forth by Geyer in a study of the lower Enns valley [4]. But we must not conclude that the southern boundary of the Flysch is marked only by overfoldings of such limited extent. It is a boundary of the first order, and from the Rhine to the

[1] O. Reis, Die Korallen der Reiter Schichten, Geol. Jahresh., 1889, II, pp. 91-162; K. Deninger, Molluskenfauna von Reit im Winkel und Reichenhall, op. cit., 1901, XIV, pp. 221–245; J. Dreger, Gastropoden von Häring, Ann. k. k. naturhist. Hofmus. Wien, 1892, VII, pp. 11-34; and Lamellibranchae von Häring, Jahrb. k. k. geol. Reichsanst., 1903, LIII, pp. 253–284 (p. 262, bore-holes in the Muschelkalk filled with Tertiary marls, therefore hardly overthrust segments). According to older statements an Eocene stage also seemed to be represented at Reichenhall; cf. T. Fuchs, Verh. k. k. geol. Reichsanst., 1874, p. 132. Remnants of a Cenomanian basement occur in places, e. g. M. Schlosser, op. cit., 1893, p. 195. For the south-western localities, Leusch, Kaisergebirge, Zeitschr. d. Ferdinandeum, Innsbruck, 1907, 3rd ser., LI, pp. 53–137, map.

[2] M. Schlosser, Centralblatt f. Min., &c., 1904, p. 657.

[3] C. W. v. Gümbel, Die geologische Stellung der Tertiärschichten von Reit im Winkel, Geogn. Jahresh. München, 1889, II, pp. 163-175, in particular p. 169.

[4] G. Geyer, Ueber die Gosaubildungen des unteren Ennsthales und ihre Beziehungen zum Kreideflysch, Verh. k. k. geol. Reichsanst., 1907, pp. 55-76.

Danube separates the Flysch zone from the Limestone zone as an independent tectonic element. It is, as Bittner says, 'one of the most sharply marked features in the structure of the north-east Alps.[1]'

The line stands out very clearly on the map. Sometimes the Limestone lies more nearly horizontal on the Flysch, at others it is more steeply inclined. The Flysch is in part Cretaceous, and in part lower Tertiary. The strike of its folds is independent of the direction of its boundary, as has been shown by Paul in particular[2]. The transgression shows us that some very important movements occurred before the Cenomanian and others much later, as was also the case in the window of the Paring, for example, and over a large part of the Carpathians.

It is along this dislocation also that the Lepontine belt crops out. In Bavaria it is only represented by the basement patches in the region of Oberstdorf and Ritterschwang. Besides the great boulders of Archaean, we find diabase porphyry, and limestone with chert, as well as other rocks. The great block of granite, 10 meters in length, on the summit of the Bolgen is also assigned to this belt. Above the Flysch zone isolated masses of Aptychus limestone are to be seen; Rothpletz suggests that they are remnants of fragments let down from above[3].

In the east the traces of the Lepontine belt are more considerable.

As early as 1853, when the Alpine Brachiopods formed the subject of investigation, the necessity was recognized of separating from the Kössen beds a particular group, the Gresten beds, characterized by their black colour and by particular species (*Spirifer Haueri*, *Rhynchonella austriaca* and others). A little later F. von Hauer described the fauna of the Lias and explained its connexion with the so-called Alpine coal. Subsequently when Lipold was entrusted with the investigation of this Alpine coal, and Stur at the same time made a study of its flora, it was seen that two series of lignite beds occur in the Alps of Lower Austria, namely that containing the flora of Lunz (lower Keuper) and that containing the flora of Gresten (Rhaetic and Lias). It was also shown that the black marine Lias of Gresten, along with the lignite series of the same locality, both of which present a facies different from that of all other Alpine exposures, *occur only on the boundary between the Limestone and the Flysch*[4].

[1] A. Bittner, Die Grenze zwischen der Flyschzone und den Kalkalpen bei Wien, Jahrb. geol. Reichsanst., 1900, L, pp. 51–58, in particular p. 57.

[2] C. M. Paul, Der Wiener Wald, Jahrb. k. k. geol. Reichsanst., 1898, XLVIII, pp. 53–178, map, e. g. p. 171.

[3] Similar views in Tornquist, Sitzb. k.-preuss. Akad. Wiss., Berlin, 1907, pp. 591–599. Flat overthrusting of Main dolomite upon Flysch in Rothpletz, Alpenforschungen, II, e. g. p. 14, fig. 6.

[4] Ueber die Brachiopoden der Kössener Schichten, Sitzb. k. Akad. Wiss. Wien, 1853, X, p. 286, Denkschr. k. Akad. Wiss. Wien, 1854, VII, 36 pp.; F. v. Hauer, Jahrb. k. k. geol. Reichsanst., 1853, IV, p. 739; M. L. Lipold, op. cit., 1865, XV, p. 30 et seq.

Observations now multiplied rapidly; the beds of Gresten, for example, were discovered in the Balkans, and the same facies of the Lias appears to extend to Persia, but nowhere within the East Alps are they known outside the above boundary. Finally Trauth united all the outcrops of these and the accompanying strata which extend from the Gschliefgraben near Gmunden as far as Vienna in a single 'East Alpine Klippenzone'[1].

This zone presents a mixed series. It contains representatives of the foreland and of the East Alpine sheet, as well as traces of Lepontine and, as Uhlig long ago pointed out, also of Carpathian character. The best-known of these outcrops lies near St. Veit in the city of Vienna itself. Many descriptions of it exist, the latest is by E. v. Hochstetter[2]. The visible part of the series begins with the Swabian (litoral) facies of the Rhaetic stage, presenting a development which may be compared with that of the foreland. Then follow the Gresten beds, the spotted marls of the upper Lias (hitherto without fossils), many subdivisions of the middle Jurassic (very different from that of the neighbouring limestone zone), and red Jurassic Radiolarian chert with Aptychus; in the region occupied by this chert loose blocks of a Brocken tuff were found (plagioclase basalt, according to Pelikan). Then follows white platey limestone with *Aptychus Didayi.*

The association of litoral (Rhaetic) and of abyssal (Radiolarian) beds in this series is remarkable. Every attempt to minimize the importance of these facts is frustrated by the circumstance that here, outside the existing north border of the Limestone zone, sediments occur which indicate a sea 4,000 to 5,000 meters deep.

At other localities some additional horizons occur, as, for instance, the Tithonian limestone near Waidhofen.

The Limestone zone here represents the East Alpine series: the Flysch, the Helvetian; the Gresten zone lies between the two. It must thus be placed for the present in the Lepontine group, as has been suggested by Trauth[3]. The tectonic horizon is very near to that on which patches of Archaean rocks crop out in Western Bavaria (Oberstdorf and other places),

[1] F. Trauth, Ueber die Grestener Schichten der österreichischen Voralpen, Anz. k. Akad. Wiss. Wien, 1906, pp. 308–310.

[2] W. Ritter v. Hochstetter, Die Klippe von St. Veit bei Wien, Jahrb. k. k. geol. Reichsanst., 1897, XLVII, pp. 95–156; F. Trauth, Neuer Aufschluss im Klippengebirge von St. Veit, Verh. k. k. geol. Reichsanst., 1907, pp. 241–245.

[3] Paul believed that the Neocomian of St. Veit adhered normally to the lowest members of the Flysch; in that case the Gresten series would form part of the Flysch zone. The fact that the strike of the Flysch, as Paul himself shows, frequently diverges from the boundary line, while that of the Gresten series follows it, does not favour this hypothesis (Paul, Jahrb. k. k. geol. Reichsanst., 1898, XLVIII, p. 137), but the question must remain open. Haug compares the series with the Pré-Alpes, Bull. Soc. géol. France, 1906, 4e sér., VI, p. 366.

and here as there the same phenomenon occurs, beginning at lake Traun. A hill, near Weyer, Leopold von Buch's monument, about 150 meters long and 40 meters high, formed of granite blocks all of the same kind, has frequently been regarded as standing in place, a belief shared by Gümbel with regard to similar occurrences in Bavaria. Geyer has described it as a litoral fragment of the Gresten formation [1]. The structure of the Flysch, north of this locality, would be hard to understand if the foreland cropped out here. Further these Lepontine patches cannot be compared with the isolated granite boss of the Waschberg near Stockerau, which does in fact belong to the foreland, but lies outside the Flysch zone [2].

This very remarkable part of the outer border of the Flysch, situated north-north-west of Vienna, already begins there its course to the Carpathians, but unfortunately it is very imperfectly exposed. Abel has described Tithonian from it. This on account of its position on the outer border cannot be assigned to the Gresten zone [3]. Marl with *Belemnitella mucronata* occurs and represents the Nierenthal beds of Bavaria. The Vacentine type, which prevails in the older Tertiary along the whole north border of the East Alps, also makes its appearance. In the Carpathians of Moravia the occurrence of *Rhynconella polymorpha* Maas shows a correspondence with the stage of Spilecco; the beds with *Echinolampus conoideus* of Mattsee (Upper Austria) represent the Gichelina; north of Stockerau we meet with the Priabona stage and the corals of Gomberto.—

We will now pass the facts in review.

In the Gosau beds, within the Limestone Alps, the southern facies predominates up to the lower limit of the Inoceramus marls (Campanian), as it does in the south of France, Transylvania, Armenia, and elsewhere. These southern representatives are never encountered in the Flysch zone.

In the Flysch zone very thick deposits occur which contain, in common with the Inoceramus marls of Gosau, *Pachydiscus Neubergicus* and some other Ammonites, but they are distinguished by other species of Inoceramus (in particular *Inoceramus Salisburgensis*). Towards the summit they are associated with the Nierenthal beds, in which a northern influence makes its appearance.

[1] G. Geyer, Ueber die Granitklippe mit dem L. v. Buch-Denkmal im Pechgraben bei Weyer, Verh. k. k. geol. Reichsanst., 1904, pp. 363–390; also Hochstetter and Toula, op. cit., 1870, p. 91, and Toula, 1905, p. 89; Mojsisovics, op. cit., 1893, p. 14. In the Flysch boulders occur resembling those of the foreland, along with quite alien rocks, e. g. augite porphyry; Berwerth, Min. petr. Mitth. Wien, 1907, p. 12 (also in Becke, Min. petr. Mitth., 1907).

[2] This is Sudetic granite surrounded by horizontal beds of an Eocene or lower Oligocene litoral conglomerate, the only visible sign of a shore in the neighbourhood of the East Alps; Stur, Geologische Karte der Umgebung Wien's, 6 sheets, fol., 1891.

[3] O. Abel, Verh. k. geol. Reichsanst., 1897, pp. 343–362, and 1899, pp. 284–287, 374–381, et passim.

Near Salzburg this series approaches close to the typical Rudistes beds of the Gosau [1]. In north-east Tyrol a patch of it rests upon transgressive Cenomanian, and both lie unconformably upon the folded Limestone zone: a thrust-plane separates this part of the Limestone zone from the Flysch zone.

The accumulations of *Belemnitella mucronata* which distinguish the upper Senonian of Central Europe have never been met with in the Limestone zone [2]. They are again seen on the outer border of the Flysch up to Mattsee and Stockerau [3].

Precisely similar relations are presented by the Flysch zone of the Carpathians. The lower Cretaceous bears a predominant southern stamp, though the northern influence already sets in with the Exogyras of the Cenomanian [4]. Wisniowski mentions *Actinocamax verus* as a representative of the lower Senonian, also the occurrence of *Pachydiscus Neubergicus* and *Inoceramus Salisburgensis*, that is the typical representatives of the Nierenthal beds of Bavaria [5].

In Bavaria the beds overlying these contain a very large number of species which correspond with those of Maestricht. With the Eocene, the southern Vicentine type makes its appearance, particularly in Austria.

We may therefore conclude that in the Flysch zone of the East Alps and the Carpathians a southern influence prevailed up to the Cenomanian, from that time to the close of the Cretaceous a northern influence prevailed, and after that a southern influence which continued up to and into Mediterranean times. These phases coincide with the positive movement of the middle and upper Cretaceous, and with the negative movement at the close of the latter. In other words:—*The general transgression that occurred during upper and middle Cretaceous times introduced northern elements into the Alpine sediments, which, with this exception, are characterized throughout by southern and Mediterranean types.*

In like manner the southern lower Cretaceous of Roumania and the

[1] E. Fugger, Führer z. internat. Congress, 1903, No. 4, Salzburg und Umgebung, also Die Gaisberggruppe, Jahrb. k. geol. Reichsanst., 1906, LVI, pp. 213–258, and, in particular, Erläuterung z. Specialkarte, Zone 14, Col. VIII, Salzburg.

[2] The occurrence of the rare species *Belemnitella Hoeferi*, Schlönb. in the Gosau beds of the New World, or of a rare Belemnitella in the Scaglia of the Brianza (Dinarides), does not affect this view. A different explanation is held by M. Grossouvre, who has done valuable work on the homotaxis of the Gosau. Sur les couches de Gosau, considérées dans leurs rapports avec la théorie du charriage, Bull. Soc. géol. France, 1904, 4e sér., IV, pp. 765–776.

[3] O. Abel, Verh. k. k. geol. Reichsanst., 1897, p. 361.

[4] V. Uhlig, Tatra-Gebirge, Denkschr. k. Akad. Wiss. Wien, 1897, LXIV, p. 684 et passim.

[5] T. Wisniowski, Inoceramus-Schichten in den Karpathen, Anz. Akad. Wiss. Krakau, 1905, pp. 352–359, and Fauna der Spasser Schichten, op. cit., 1906, pp. 240–254.

Crimean steppe is overlain by northern Senonian, and this by southern Nummulitic limestone.

Finally there are certain facts of general significance which cannot be passed without mention. These are: the very great thickness of the Flysch, the complete absence of Cretaceous ingressions and transgressions from the great longitudinal valleys on the south border of the Limestone zone, and the occurrence of isolated patches of limestone, chiefly no doubt Neocomian, within the Austrian Flysch, and at one locality the association of serpentine with this limestone [1].

[1] O. Abel, Jahrb. k. k. geol. Reichsanst., 1903, LIII, p. 108.

CHAPTER VI

POSTHUMOUS ALTAIDES

1. The Alps. Their continuation to the north-east and east. Their continuation to the south and south-west. 2. The folds of Provence. 3. The Pyrenees.

After the Eastern Altaides had been built up, and the Altaides had been converted into horsts, mountain ranges arose in the areas faulted down between the horsts, and it is these which we designate 'posthumous Altaides'. All these posthumous chains have undergone folding in Tertiary or even later times. All, with the exception of the Mediterranean Atlas, form part of Europe.

The most important member is the Alpine system, or the Alpides. In studying these mountains on the basis of the two preceding chapters we shall first consider the Alps themselves and particularly their subdivision into sheets. Following their continuation to the north-east we shall discuss the part played by overthrust sheets in the structure of the Carpathians. In the south-west the very peculiar relations of Calabria to Sicily, and of Sicily to Tunis, will have to be considered. The divergent development of the Trias in different parts of the western Mediterranean will throw some additional light on that part of the Tethys.

The second member of the Altaides comprises the folds of Provence, the Pyrenees and the mountains of northern Spain. In this case the chief points which call for mention are the relation of a fragment of the Altaides—the mass of Mouthoumet, situated in the bend of the Provençal folds—to the Pyrenees, the large part played by the Altaides in the composition of the Pyrenees, and their movement towards the south, as well as many unusual features which occur in the structure of these mountains.

There are also posthumous Altaides in the London and Paris basin, and in western Portugal, but these have already been dealt with, and will not be discussed again.

1. The Alps.

The East Alpine sheet. From what has already preceded it will be seen how great are the gaps in our knowledge of the Alps, and how recent are the attempts to explain the problems they present, especially on the east, in the light of modern discoveries. Under these circumstances the most valuable service which can be rendered by a synthetic research is to point out the problems which most press for solution.

We must never lose sight of the different nature and value of the three principal boundaries: namely, first, the Dinaric boundary, of profound significance as a line along which a foreign element approaches the Alps; next, the line through the Rhaetikon, Oberhalbstein, and Piz Tremoggia, important as forming the western boundary of the superposed East Alpine sheet; and finally the inner Flysch zone, instructive in itself, but not entering so deeply into the structure. The East Alpine sheet is divided into two halves along its length. The Semmering, the graphite zone of north Styria, and the Tauern are anomalous elements which mark the division. In all likelihood the marble ranges of Schneeberg and Ratschings, and the probable continuation of the latter to Laas and south of the Ortler, will one day prove to be the continuation of the Mesozoic limestones of the Tauern, and thus prolong the separation towards the south-west; but at present the proof of this is lacking.

Its *southern half*, where it emerges from the Hungarian plain on the east, is very broad. It includes the greater part of the basin of the Mur above Gratz, the Palaeozoic mountains of Gratz, and the mountains formerly known as the Central Alps of Styria. In the south this half of the sheet is adjoined by a long strip of Mesozoic accompanying the Dinaric boundary, which to the east in the Karawanken, and to the west in the mountains of Lienz, is violently folded, and includes the Drau range. Large elongated parts of it are let down in troughs. In the Gurk valley these Mesozoic sediments accompanied by upper Cretaceous and Eocene encroach in a flat transgression far to the north over the ancient rocks of the Mur Alps. They present the character of the northern Limestone Alps.

Throughout the west they are separated from the Dinarides by a strip of gneiss and mica-schist. On the Brenner, over the narrow zone between Sprechenstein and the granite of Brixen, this strip and a pinched-in band of Trias alone represent the southern half of the East Alps. They surround the head of the Dinarides, and the older rocks may be followed west of the Judicaria line into the region north of the Tonale pass.

The southern and western part of this great piece of the Alps appears to have stood passive under the influence of the advancing Dinarides. In the Kreuzeck group there is the added influence of the Tauern. The Mur Alps present in no small degree, both as regards their scenery and the manner in which they emerge from the broad plain, the characters of an older autochthonous region. It is here that doubts as to the sheet-like structure of the Alps find their greatest justification. It is possible that with the progress of discovery we shall be able to eliminate here a foreign fragment from the Alps.

Throughout this region, from Hungary to the Brenner, there is a complete absence of glaciers.

The northern half of the East Alps differs from the southern in many respects. It consists in the south of a strip of ancient rocks, which is regarded as a continuation of the Mur Alps. It adjoins on the west the ancient quartz phyllite of the Pinzgau, crosses the Brenner south of Innsbruck, and west of the pass attains a great breadth, forming the Stubai, Oetz, and Selvretta. The same rocks bear in the south the whole of the Mesozoic Braulio range, together with the Ortler.

In the north, throughout North Styria, the ancient rocks are overlain by a zone of Silurian, Devonian, and Carboniferous limestone, which disappears in East Tyrol. Resting upon this, and in the west directly upon the ancient older rocks, is the East Alpine Limestone zone. Towards the north it is thrust over on to the Flysch zone or bounded by a steep dislocation.

The Limestone zone exhibits all the characters of a 'supernatant' segment. Along the whole western boundary, from Poschiavo to lake Sils, and through Oberhalbstein, on the Rhaeticon and as far as the Falkniss, the mountains of the west dip beneath the East Alps. Their relation to the Flysch has already been mentioned. On the east, where the northern part of the East Alps is but narrow, it proceeds towards the Carpathians, but on the south border it again presents itself as supernatant, since all the foreign separative elements, such as the Semmering, the graphitic range of North Styria, the eastern part of the Tauern, and the marble zone of the Schneeberg, dip beneath this border towards the north-west. North-west and west of the Tauern, overthrusts of the foreign elements towards the west and north occur under peculiar conditions. Many indications combine to show that the mass of the Ortler is a syncline open towards the north.

The inclination of the Flysch, directed almost exclusively to the south, gives to all the sheets of the northern East Alps, and in particular the northern Limestone zone, the form of a basin. At the same time the Limestone zone is broken up into several sheets overthrust towards the north. The contours of many of these appear to be determined by the outline of the Bohemian mass and the encroachment of the Carpathian strike; all of them have been moved upon the Werfen shales and the salt beds, without working down into the deeper substratum. One set of movements is older than the Cenomanian, the other is younger.

At the lowest level affected by these movements, and particularly in the Salzkammergut, intrusive rocks occur. They also make their appearance, perhaps as kneaded-in rather than intruded rocks, in the Cretaceous, which rests unconformably on the Werfen shales.

The scenery also of the northern Alps is extremely different from that of the southern. No comparison can be made between the great snowfields of west Tyrol, or the group of the Piz Buin in the Selvretta, and the mountains of Central Styria with their soft outlines and green mantle of vegetation: the Mesozoic region of the south gives rise in the Ortler to the highest mountain of Germany. The Limestone zone bears all its highest peaks, such as the Scesaplana, the Zugspitz and the Dachstein, on its steep southern slope.—

The *Lepontine group* includes all those sheets which occupy a lower tectonic position than the East Alpine, and a higher tectonic position than the Helvetian sheet. They are distinguished, as a consequence of their position, by considerable dynamic alteration, and in many parts by basic injections—the Pietre verdi. In this group, Trias and Jurassic sediments are frequently converted into sericitic quartzite and white marble.

The Lepontine sheets extend on the south to the plain of Lombardy and the Dinaric boundary; on the east they dip beneath the East Alpine sheet; on the north and west we shall find the line of the inner Flysch zone useful as a means of distinguishing the various members of the Lepontine group; it will afford assistance in the correlation of the Corsican fragment of the Alps. The Lepontine sheets, however, in so far as they do not proceed directly from this line, overlap, in a long series of recumbent patches, not only the line itself but even the outer border of the Helvetian sheet which lies in front of it.

As a consequence involved in the general structure of the Alps, this group of sheets appears on the *west* as a broad open range or in *the form of recumbent sheets*, on *the east on the other hand it is revealed in great windows.*

(a) *The sheet of the Dent Blanche* is a Lepontine sheet resting on Lepontine rocks. It has its origin in the zone of Ivrea, which is strongly injected with basic rock and accompanied on both sides by Mesozoic marble; it owes its separation from this zone to erosion. It extends from Monte Emilius, south of Aosta, to the Turtman glacier, north of Zermatt.

(b) *The Piedmontese Alps* form so large a part of the whole of the high mountain region that we might be inclined to include them, as a sub-division, in a group of a higher order. It is the difficult questions which arise as to the origin of their representatives in the north and east that have prevented the application of the name Piedmontese to the Lepontine group as a whole.

The Piedmontese Alps include all the mountains from the border of the plain of Lombardy to the compressed fascicles of sedimentary folds on the inner side of the Mercantour, the Pelvoux, Mont Blanc, the Rhone valley as far up as Sion, the val Bedretto, Airolo, and the Luckmanier pass. This vast region is characterized by great masses of gneiss, by a high degree of dynamic alteration in the sediments, and, more especially in the south, by the importance of the basic injections. A great arc of Carboniferous, extending from the Rhone valley a long way to the south, borders the west of this region and points to the unity of the movement as a whole. Traces of it occur in the Ligurian Alps, even in the vicinity of the sea. Within this part of the Alps the recurvation towards the Apennines is effected.

Thus, the Piedmontese Alps include the range of the Pietre Verdi of Monte Viso, the possibly autochthonous gneisses of the Dora Maira range and the Gran Paradiso; further, the elongated zone of the Great Saint Bernard, in which the recurvation begins; Monte Rosa and, with it, all the folds of gneiss characterized by Mesozoic intercalations as far as the Simplon; all the gneiss zones dipping towards the east as far as the Limestone mountains of Splügen and the green-rocks of Oberhalbstein; further, the region in the south, extending up to the Dinaric boundary on the Adda (except where a narrow East Alpine belt is inserted in front of it); and then, finally, the Disgrazia and the lower half of the Poschiavino valley.

(c) *The recumbent folds*, which proceed from the Piedmontese Alps over Helvetian territory, and attain a considerable extension as they advance to the south and north of the Mercantour. The part played by the Flysch in the Dauphiné shows that in that region they originate in the inner Flysch zone. In the north the largest recumbent folds lie in the Chablais and the Freiburg Alps. Their fragmentary remains extend through Giswyl, the Stanzer Horn, and the Mythen, near Schwyz, the Berglittenstein in the Rhine valley, to the Falkniss beyond the Rhine, and, with this, the Lepontine rocks, which underlie the whole of the western boundary of the northern half of the East Alps.

The Piedmontese Alps make their appearance to the north of the Carboniferous zone with a change of character; green-rocks only appear at isolated spots, and the Mesozoic series presents a certain resemblance to that of the East Alps. The facies is the Briançonnais. It forms compressed fascicles of folds, and some of these are inserted obliquely between the alternately arranged gneiss-cores of the Mont Blanc zone. At the same time there seems to be some approach to the Helvetian facies. The close resemblance of the sediments has attracted attention to the val Ferret, on the east side of Mont Blanc, as a region of roots. The extension of these sediments far beyond the Rhine, and the constant occurrence of green-rocks in the topmost fold, lead us to suppose that the little patches preserved here and there are the remnants of a once colossal structure, composed of crowded recumbent folds, which is now destroyed and for ever withdrawn from our eyes.

It must be added that the basement, that is, the Helvetian region, together with a part of the gneiss-cores of the Mont Blanc zone, have undergone still later movements.

(d) In the East Alps the place of the Lepontine sheets is taken by the *Lepontine windows*.

On the upper Inn, the Lepontine sediments are visible, for a distance of 54 kilometers, beneath the East Alpine gneiss-masses of the Selvretta on the west, and of Oetz on the east. From the midst of the window, which is elongated towards the north-north-east, rises the anticline of the Stammerspitz.

It seems probable, although we have no direct proof, that we must assign to the Lepontine formations a chain of marble outcrops which makes its appearance south of the Ortler, and then, with frequent interruptions, runs past Laas and the Texel range towards Ratschings on the Brenner. A second and similar chain of marble comes from Gurgl in Oetz, and, crossing the Schneeberg, reaches a point on the Brenner not very far from the first chain. Existing observations, so far as they go, lead us to conclude that these two marble zones unite in the Mesozoic frame of the window of the Tauern, the length of which is 165 kilometers. This frame is Lepontine; the Tribulaun range forms part of it. It presents limnic Carboniferous, Trias, Lias, and Jurassic. Towards the interior lie the schist mantle and the central gneiss of the Tauern. They have been exposed to tangential pressure, and part at least of the schist mantle is Trias. The larger cores of the central gneiss are folded flat, along with the schist mantle, at their ends.

The Lepontine frame of the Tauern dips beneath the East Alpine rocks which surround it, or is steeply upturned; to the north-west and west it is folded outwards over the frame of the window.

On the east of the Tauern, south of Schladming lies a region as yet scarcely understood, and then comes a band extending through North Styria for 150 kilometers, which is formed of limnic, upper, or middle Carboniferous, and dips towards the north beneath the northern half of the East Alpine sheet. This long band leads to the Semmering where, along with the limnic Carboniferous, the Mesozoic rocks of the Tauern reappear. These also are inclined to the north.

Here many questions await solution. The existing state of observation shows, however, that the marble band of Laas and Ratschings, the window of the Tauern, the Carboniferous band of North Styria, and the Semmering are features which represent in the better-known regions a lower-lying member of the mountains. There are long stretches along which the boundary between these and the East Alpine rocks is not yet marked on the map, and the position of the limnic Carboniferous with regard to the Lepontine Trias is not clear.

These features are described as exotic because they occupy less space than the East Alpine sheet, *but they have actually a better claim than this sheet to be regarded as indigenous and autochthonous.*

(e) *The Lepontine belt.* Between the northern border of the East Alpine sheet and the Flysch elements of an anomalous character crop out. They begin as basement patches on the Iller in western Bavaria. On the east, in upper and lower Austria, the basement patches are associated with an independent succession of strata which is elsewhere unknown in the Alps. Its characteristic sub-divisions are a black Lias (Gresten beds), accompanied by lignite seams, and a middle Jurassic series which most nearly recalls that of Switzerland. In the upper Jurassic, red Radiolarian shales with Aptychus also occur. This succession extends into the suburbs of Vienna and is continued into the Pienines (Carpathians).

The Helvetian sheet forms the outer border of the Alps from the Var to the Carpathians. Although the very general inclination of the beds towards the interior of the range, and the division into subordinate sheets, which is particularly clear in the east of Switzerland, indicate the force of the general movement, yet there are some signs, at least in the west, which point to a trifling amount of horizontal displacement. In many of its characters the facies resembles that of the foreland.

The zone of Mont Blanc, which is orographically the most prominent part, may be regarded as the remains of the foreland, lying in an obliquely arranged series. It includes the great gneiss-cores which extend from the Mercantour across the Pelvoux, Belle Donne, Mont Blanc, the Aiguilles Rouges, the mass of the Aar, and the St. Gotthard. It terminates on the Rhine; to the south the little gneiss masses of Liguria may perhaps be referred to it.

Between these alternating cores, and at one time extending in part beyond them, Helvetian sediments unite with those of the Briançonnais. These sediments, chiefly limestones, which advance to the outer border of the Mont Blanc zone, gave rise, by their folding and piling up, to the high chains of the Bernese Alps, such as the Dents du Midi, Wildstrubel, Faulhorn, and others. They reveal a movement which is later than the transport of the Lepontine sheets.

In eastern Switzerland the Helvetian zone includes the overfold of the Glarus, together with the Churfirsten and Säntis. Here too, however, an oblique arrangement occurs, which does not completely correspond with the principal strike of the Alps, for while, just east of the Rhine, the limestone range of the Säntis is accompanied by Flysch on the north and south, the northern range disappears in Bavaria. Traces of the Säntis range accompany the north border of the mountains to beyond the Isar, and only the Flysch that lies south of the Säntis reaches the Danube, as the Austrian Flysch zone, near Vienna. This part of the mountains is chiefly formed of the uppermost part of the Cretaceous, with northern characters, and lower Tertiary, with southern characters.

The Gosau beds rest in transgression upon the Limestone zone. They have a well-marked southern character. Their uppermost member, the Inoceramus marl, approximates by its Ammonites to an horizon of the Flysch. The Cenomanian with Orbitulina is also common to both zones; it often rests in transgression on the folded Trias of the Limestone zone; in

East Tyrol, Flysch-Cretaceous of northern type and lower Tertiary of southern type transgress over parts of the Limestone zone. But the typical Gosau beds of southern character have never so far been encountered in the Flysch zone.

General observations. As a conclusion to this brief survey of the Alps some disconnected observations of a general nature may find a place.

1. The series Silurian, Devonian, lower Carboniferous is only represented on that part of the Alps which is tectonically the highest, namely the East Alps, where it occurs both in the northern and southern moieties. It is not known either in the Lepontine or the Helvetian mountains; in place of it the fossiliferous series everywhere begins with limnic Carboniferous (flora of Schatzlar, or according to some observers of Ottweil). This is the case on the Semmering, in northern Styria and the Tauern, in the great Carboniferous fan which extends along the west side of the Great St. Bernhard to the Ligurian Alps, also in the Helvetian region on the Tödi and elsewhere. All these parts of the Alps thus bear a close resemblance to the Altaides. No marine representative of the upper Carboniferous or Permian occurs anywhere in the Alps. This is the more remarkable since such deposits are very evidently present just beyond the boundary, in the Carnic mountains, the independent basement of the Dinarides. There in the east, Silurian, Devonian, and lower Carboniferous are followed by the typical unconformity at the base of the Ottweil stage, which is accompanied by marine beds; but in the western part of the Dinarides, as in Lombardy, fossiliferous deposits again begin with limnic middle or upper Carboniferous (Manno).

2. The pre-Permian gneisses and granites of the Alps have assumed a great variety of tectonic forms. There are some profoundly denuded which completely resemble autochthonous masses (South Styria, Bacher mountains, Sau Alps and Kor Alps; or, occurring as the lowest member in the midst of violently disturbed mountains, may be regarded as autochthonous (Dora Maira); or again, may be either autochthonous or a very deep-lying vault (Gran Paradiso). Others have offered resistance to the lateral pressure and are divided into parallel anticlines, which betray their presence by indentation (flat-folding) at the ends where they run with the strike (Mont Blanc, mass of the Aar, core of the Hochalm in the Tauern). Yet others are the cores of anticlines (gneiss of Antigorio and Monte Leone on the Simplon). The Dent Blanche again, is to be regarded as a flat recumbent fold. Finally, we have great sheets completely severed from their original basement by a thrust-plane. Such is the Selvretta. It is phenomena of this kind which, as we shall see later, play an important part in the Tatra mountains and the eastern Pyrenees. The great height to which the overthrust masses have been carried up and their mode of occurrence may even lead us to inquire whether the chief features in the relief may not be older than the overthrusts.

While the progress of investigation shows more and more that the sheets of Switzerland are elongated recumbent folds, yet no sign of such folding or of a plunging sheet have so far been recognized in the East Alps.

3. The Bohemian mass and the pre-Permian foreland disappear in face of the Alps. The only explanation possible is that their continuation lies beneath the Alps. The gneiss of Stockerau, which lies just outside the border of the Flysch, the character of many Lepontine basement patches on the south border of the eastern Flysch zone, and the character of the Mont Blanc zone all speak in favour of this explanation. On the south side of the Alps, opposite the Dinarides, precisely the same question arises, and the only answer is that the continuation of the Alps lies beneath the Carnic range and the Dinarides. The Carnic basement, however, seems to disappear rapidly, towards the west and south-west, at the base of the Dinarides; it is absent in the window of Recoaro (III, p. 352), and also from the pre-Permian gneiss of the Cima d'Asta; but at none of these localities are traces of Alpine formations visible beneath the Dinarides.

At the head of the Dinarides, on the Brenner road, the strike of the Alpine ranges follows the outline of this head, and of the intercalated granite of Brixen, as though these ranges had been moved irresistibly forwards, but the effect of this thrusting can hardly have extended far beyond Sprechenstein. As we have already pointed out, the tonalite girdle indicates that the Dinarides never extended very far to the north beyond their present limits, and this is confirmed by all the other evidence; but we cannot conclude from this that wide-reaching subterranean overthrusts do not exist.

Extension of the Alps to the North-north-east (*I, pp.* 187, 216).

The Limestone Alps disappear on the Baden line of hot springs. The inner zones of the Alps and with them, to all appearance, the Lepontine Limestone zone of the Semmering, strike away, like the Flysch, to the north-east; but they soon lose themselves in the Rosalien range. This range is now no longer bordered by a continuous crystalline zone, but by a series of isolated cores. The Flysch zone in the north of the Carpathians, which extends with great uniformity over diversified foreland, lies opposite an extremely irregular boundary in the south, the irregularities of which would be yet more striking if it were not for the apparent continuity established by flows of trachyte and accumulations of ash. The irregularity is more especially connected with the upper basin of the Theiss, which encroaches from the south so far into the Carpathians, that these mountains are represented almost wholly by the Flysch zone.

A little to the west of this line of division lies the eastern end of the *mountains of upper Hungary*, which extend for 140 kilometers from west to east between the rivers Gran and Hernad. The towns of Neusohl and Kaschau mark the two extremities of the range. It is the only fragment of the eastern Carpathians which is comparable in its extent with a part of the crystalline inner zone. As regards its structure we are almost wholly restricted to older observations, in particular to those of Stur; such facts as are known have been collated by Uhlig. It will suffice to mention that a Palaeozoic range, in which Carboniferous is represented, runs with a north-easterly strike and cuts off that part of the crystalline rocks situated east of Dobschau; that the whole of the north border of the mountains is accompanied by Trias and Jurassic in their Alpine development; that these with strikingly flat bedding (Murány plateau) penetrate deep into the region of the ancient rock, and are present with equally flat bedding in the south (Bük range) [1].

To the north and west of the mountains of upper Hungary rise isolated cores of gneiss and granite, generally extending along the strike, accompanied by Trias and Jurassic, and surrounded by Tertiary beds. The Leitha mountains and the Little Carpathians are the first of these. They are succeeded by the Inowec (left bank of the river Waag), the Tribec (left bank of the Neutra), the Sucha and Mala Magura, the Zjar (the water-shed between the rivers Neutra and Dunajec), and other heights. The most considerable of these isolated masses is the *Hohe Tatra*, north of the mountains of upper Hungary. It is elongated from east to west, 50 kilometers in length, about 15 kilometers in breadth, and some of its summits exceed 2,600 meters. This is the highest part of the Carpathians.

The history of the tectonic interpretation of the Tatra resembles that of the fold of Glarus; both are the result of the comparative method. First of all, the actual facts were established with all the precision possible. So exact was the description that a geologist personally unfamiliar with the country was able to suggest new ideas and new transverse sections. The first observer then confirmed the new theory from the abundance of his local knowledge.

The first phase of this process is illustrated by Uhlig's monograph, which represents the Hohe Tatra as a block of gneiss and ancient granite, bearing on the upper parts of its northern side an incomplete series, known as the *high Tatrian* series. This is of Alpine character, with some indications of sublitoral origin; and it is folded towards the north. On the lower parts of the northern slope, the high Tatrian series is adjoined by a second and much more complete succession of Alpine sediments, the *sub-Tatrian* series. Its folds dip steeply to the north.

The same contrast between the less complete high Tatrian and the more complete sub-Tatrian series was observed by Uhlig in other isolated

[1] V. Uhlig, Bau und Bild, pp. 690–708.

mountain masses. The conclusion he drew was that each of these masses is an ancient island, that the high Tatrian series was its natural covering, that the sub-Tatrian series was formed at greater depths in the sea, and, further, that the sub-Tatrian folds dipping to the north on the northern side of the Tatra had been forced up against this mountain from north to south [1].

So complete was the work accomplished in the first phase, that in the second phase M. Lugeon, without having seen the Carpathians, and basing his conclusions on observations made in the Western Alps, ventured on the bold assertion that the sub-Tatrian folds, inclined to the north on the northern side of the Tatra, had not been urged against it from the north, but were carried from the south, over the mass of the Tatra, as an independent sheet. Thus, the islands become windows, and a uniform movement to the north dominates the whole range [2].

This view was adopted by Limanowski, who, however, added the statement that a Flysch sheet of Dinaric origin had crossed the Tatra from the south, along with the Klippen lying in front of it in the north [3].

Finally, the third phase is distinguished by Uhlig's later descriptions, which cover the greater part of the Carpathians. Here Lugeon's theory as to the overthrusting of the sub-Tatrian sheet is adopted; the claim of Dinaric influence in this region is dismissed, but traces of the Dinaric facies as revealed by Loczy's and Arthaber's studies are admitted to exist in a more southerly region, the Mittelgebirge of Hungary. Lugeon left the position of the gneiss and granite mass of the Tatra an open question; Uhlig regards it as supernatant [4].

Taking these results as our basis, we will now start from the south side of the Tatra, and, gradually extending our field of view, attempt to give a general survey of the Carpathian region.

The *Niedere Tatra*, a range of hills striking east and west, which is regarded as a western part of the range of upper Hungary, is bordered on

[1] V. Uhlig, Geologie des Tatra-Gebirges, Denkschr. k. Akad. Wiss. Wien, 1897, LXIV, pp. 643-684, and 1899, LXVIII, pp. 43-130, maps; in the west, Beitrag zur Geologie des Tatra-Kriwan Gebirges, op. cit., 1902, LXXII, pp. 519-561, map.

[2] M. Lugeon, Analogie entre les Carpathes et les Alpes, C. R. Acad. Sci. Paris, Nov. 17, 1902, and Les Nappes de recouvrement de la Tatra et l'origine des Klippes des Carpathes, Bull. Lab. Géol. Univ. Lausanne, 1903, no. 4, 51 pp.

[3] M. Limanowski, Sur la découverte d'un lambeau de recouvrement subtatrien dans la région hauttatrienne de Gladkie (M. Tatra), Bull. Intern. Acad. Sci. Cracovie, Mar. 7, 1904, pp. 197-199 (also in the Polish language); Blick auf den Bau der Karpathen, Kosmos (Lemberg), 1905, XXX, pp. 253-340 (Polish); Sur la genèse des Klippes des Carpathes, Bull. Soc. géol. France, 1906, 4e sér., VI, pp. 151-164.

[4] V. Uhlig, Ueber die Tektonik der Karpathen, Sitzb. k. Akad. Wiss. Wien, 1907, CXVI, pp. 871-981, map; for Dinaric traces in the Hungarian Mittelgebirge, G. von Arthaber, Die Alpine Trias des mediterranen Gebietes (Frech, Lethaea Geognostica, II, I), 8vo. Stuttgart, 1906, pp. 432-434.

its north side by the sub-Tatrian series; this is followed by sub-Tatrian Flysch, which forms the broad plain, covered far and wide with glacier débris and extending up to the south foot of the Hohe Tatra.

The south slope and all the summits of the Hohe Tatra are formed of crystalline rocks. On the north side these are covered at considerable heights by the high Tatrian series. They share a common folding towards the north. Upper Cretaceous marl occurs wedged in.

These rocks are, in fact, overridden from the south by the sub-Tatrian sheet, which, inclined to the north, now forms the lower parts of the northern slope. Precisely similar relations are repeated in many others of the isolated mountain cores, so that the sub-Tatrian series forms a sheet widely extended over the inner parts of the western Carpathians, interrupted and broken through by the frequent outcropping of the high Tatrian sheet, which is tectonically lower, but as a rule orographically higher. For this reason Uhlig compares the high Tatrian sheet with that of the Tauern, and the sub-Tatrian sheet with the East Alpine sheet in the Alps.

North of the Tatra we cross lower Tertiary of moderate breadth, dipping to the south, and reach that remarkable series of Klippen which forms the *Pienine zone.* It appears in the landscape as a chain of rocky fantastic isolated hills, which emerge in long stretches from the verdant land of Flysch or Cretaceous soil. Coming from Moravia it surrounds the west Carpathians in a broad arc, rises from the midst of the trachytes north of the Theiss, and extends far into the east Carpathians. Its length amounts to at least 560 kilometers. In the south-west it probably extends into the city of Vienna and into the Alps [1].

The stratified succession ranges from Trias dolomite through an extremely diversified series into the Neocomian; but throughout this central region the beds, instead of forming regular sheets one over the other, are disposed in numerous flakes, from 10 kilometers and more, down to a few meters in length, generally elongated in the direction of the strike, and probably also arranged in groups; two different facies of the Jurassic seem to occur side by side. One of these includes many stages and is rich in fossils; the other consists of shales with *Posidonia alpina* and cherty limestone with Radiolaria, as well as Aptychus and Tithonian fossils in some places, and in others Neocomian fossils.

These flakes are enclosed in upper Cretaceous beds of sandy marl, over which the movement took place. Vast and general it must have been, and Europe can offer few landscapes more surprising than this chain of rugged rocks, extending to right and to left far beyond the range of vision, and

[1] A catalogue of the abundant literature on this subject is to be found in V. Uhlig, Der pieninische Klippenzug, Jahrb. k. k. geol. Reichsanst., 1890, XL, pp. 559–824; for the more recent theory in particular, Tektonik der Karpathen, p. 913.

facing the traveller who approaches the Hohe Tatra from the north like a gigantic fence.

The general inclination in the Klippen is towards the south, i.e., towards the high mountains. Lugeon regarded them, in Uhlig's words, as a 'surging frontal region', and left it an open question whether they were connected with the sheets of the Tatra or were the advancing heads of one or more independent sheets. Uhlig holds the latter view. Consequently his transverse section shows the Pienine (fossiliferous Jurassic and Neocomian) and sub-Pienine (chert) sheet cropping out from beneath the Hohe Tatra, and thus the mountain itself becomes a supernatant fragment.

Throughout the region of the Alps the black Gresten beds, with their characteristic Brachiopods, are confined to the narrow belt between the Limestone zone and the Flysch. In the Carpathians, traces of these beds are found on various tectonic horizons. They are associated with Jurassic Radiolarian rocks only in the Pienine zone, and this fact, along with their similar disposition, justifies Uhlig's correlation of the Carpathian Klippen with the outcrops of St. Veit in Vienna.

The broad Flysch zone makes its appearance here outside the Pienine, just as it does outside the East Alps. The work of the Imperial Geological Institute of Vienna, and that of the local geologists in Galicia, have provided us with a mass of observations. But the vast extent and densely wooded character of the region, the rarity of fossils, and the similarity of the sediments rendered it impossible to arrive at any general conception of the structure till after laborious investigation and many fluctuations of opinion. Here again we follow Uhlig [1].

Two zones may be distinguished, formed in part of sediments of the same age, but with a different facies; both dip towards the south. The inner zone is Uhlig's *Beskidian zone*, the Magura sandstone is its most important member. Proceeding towards the north we cross Tertiary beds, beneath these upper Cretaceous and then lower Cretaceous, which rest on Tertiary beds of the outer zone. The lower Cretaceous does not occur over any considerable area except in the north-west, chiefly in Silesia. It is traversed by sills of Teschenite, which are, however, older than the overthrust, and are not exposed on the thrust-plane itself. Along with the lower Cretaceous great boulders of its Jurassic basement also occur; here too we must refer the rocks of Stramberg. The Jurassic is different from that of the Tatra and the Pienine: many characters appear here which recall the foreland. To this zone we must also assign loose fragments of Carboniferous, blocks of granite and gneiss and, with them, the oft-mentioned gigantic Carboniferous fragment of Hustopetsch [2].

[1] V. Uhlig, Tektonik der Karpathen, pp. 877 et seq.
[2] D. Stur, Jahrb. k. k. geol. Reichsanst., 1891, XLI, pp. 1–10.

The northern margin of this lower Cretaceous exposure is the northern margin of the Beskidian zone. Owing to its superposition on the Tertiary of the outer zone it is broken up into patches by erosion, and close to its edge the coal-bearing Carboniferous has been reached by borings made through the outer zone [1] (I, p. 187). In Moravia the Beskidian zone comes into contact by its foothills with the offshoots of the Flysch zone of lower Austria, and it may be regarded as the direct continuation of the Helvetian Alps towards Roumania.

Outside of this zone lies Uhlig's *sub-Beskidian zone*. Upper Cretaceous and lower Tertiary occur, but the characteristic beds are the menelite shales. Here, beside numerous blocks of Tithonian beds, the previously-mentioned basement patches crop out, along with other remains of the Variscan, Russian, and Cimmerian foreland. The numerous borings for petroleum, often sunk to a depth of 900 or 1,000 meters, give full information as to the lie of the beds; in fact, we could hardly find in the whole of Europe a clearer description of an outer border, undisturbed by a foreland, than that given by Grzybowski and Miaczynski of the ozokerite district of Boryslav [2]. A mass of upper Cretaceous, dipping to the south, has been carried along a thrust-plane, with a maximum inclination of 45° to the south, over a packet of middle (and perhaps lower) Tertiary beds, which dips in folds steeply to the south and ascends along a second gentler thrust-plane on to the thick Oligocene beds of Dobrotov (sandstone and shales) and the overlying Miocene saliferous clay.

Three flakes are thus present, of which that situated towards the north is the lowest-lying, though formed of the youngest beds. The convergence of the thrust-planes shows that the middle flake must terminate downwards and towards the south in a wedge-like form; as a consequence of the pressure exerted on the foremost and most northerly flake a broad anticline of saliferous clay and Dobrotov beds has been formed within it. A boring through the Dobrotov beds did not reach their base at a depth of 1,000 meters. They dip beneath the higher flakes, and the anticline they form is not followed by a syncline (cf. Chap. IV).

These results are in complete accord with those obtained from a study of the anticline of the Swiss Molasse. That anticline also is the result of a general lateral pressure coming from the high ranges, and again, according to Arnold Heim's observations and in opposition to older views, no syncline

[1] I have visited such a locality near Paskau, south of Mähringen-Ostrau. A large, thinly wooded ridge of lower Cretaceous stands out, and only a few hundred paces from its slope, covered with teschenite débris, lies the borehole. Petraschek states that the coal-bearing Carboniferous was reached after boring through a thickness of 400 meters of (Tertiary) beds, Verh. k. k. geol. Reichsanst., 1906, p. 362.

[2] Geologischer Atlas Galiziens, published by the Physiographical commission of the Academy of Cracow. Text to sheet Drohobycz by W. Szajnocha, J. Grzybowski, and P. Miaczyński, 1906; in particular the sections by Grzybowski and Miaczyński on sheet 6.

follows the anticline towards the mountains, but the south limb of the anticline (as far as it is possible to judge) passes straight beneath the first Alpine chains [1].

Uhlig supposes that the movements in the Carpathians were directed obliquely from below; he mentions laminated sheets, the splitting up of gently ascending thrust-planes, and the absence of roots. All these statements agree with the facts revealed by the borings in Boryslav.

The Carpathians, like the Alps, are built up of sheets; but, as in the Alps, and especially the Tauern, many facts seem to indicate that a secondary folding up of the several masses, such as Tatra, Tatra-Krivan, and others must have taken place.

The Helvetian sheet extends from the Alps into the region of the Carpathians, the middle and upper Cretaceous alike indicate a northern influence, and this extends even into the Tatra; typical Gosau beds do not make their appearance till we proceed further towards the south.

The Lepontine group undergoes modifications, in particular by the introduction of a new member, the Pienine, which is already visible in the East Alps. In respect to its tectonic position, the high Tatrian zone resembles the beds of the Tauern.

The same is true of the sub-Tatrian zone and the East Alpine sheet. Each of these is the highest tectonic member in its own region. There are also a number of accessory characters by which they are united; thus, in the eastern parts of the East Alps several smaller outcrops of augite melaphyre occur; these are repeated in the little Carpathians and more to the east.

The diversity of the East Alpine sheet itself demands further study. But we already perceive that, in spite of such striking and remote isopy, several sheets undergo alteration in the region between the West Alps and the Carpathians, and that when we come to subdivide the Lepontine group it will be necessary to avoid limits of too strict a nature.

The trend-line of the East Carpathians is clearly marked by the curve of its outer border and by the strike of the long gneiss-mass of Moldavia. There is abundant evidence to show that the structure of this mass resembles that of the East Carpathians, but we will not enter into further details here, since so many have already been given in Chapter I, as, for instance, the occurrence of increasingly younger folds on the outer border, the window of the Paring, the torsion, the pre-Permian patches within the Balkans, and the open recent folding of the eastern Balkan which recalls a free end.

[1] Arnold Heim, Brandung der Alpen am Nagelfluh-Gebirge, Vierteljahrsschr. nat. Ges. Zürich, 1906, LI, pp. 441 et seq.

Continuation of the Alps towards the south and south-west.

(I, p. 219.)

The existence of subsidences in Tuscany, and at the same time the original continuity of the Tyrrhenian islands off its coast, was long ago discovered by the insight of Italian observers such as Brocchi, and particularly Savi and Cocchi. In their time this view was based chiefly on the occurrence of the Pliocene. In 1872 a conjecture was hazarded that the whole of the Tyrrhenian sea was a subsidence, and that within it lay the tectonic continuation of the Alps [1]. At a later time the seismic phenomena in Calabria were regarded as indicating a continuation of the process of subsidence (I, p. 232, fig. 26).

Many facts have already been mentioned with regard to the region in question, for instance, the reappearance of the Piedmontese Alps in north-east Corsica, the north-and-south strike in Elba, and Steinmann's theory of a great overthrust. At Spezia the meridional direction of Genoa is already replaced by the general south-easterly direction of the Apennines. This is also the prevalent direction in the intensely folded Apuan Alps. Lotti has shown that their south-easterly continuation, Monte Pisano, 4 kilometers in breadth, consists of a flat anticline of Lias, over the whole breadth of which there rests, with the same curvature, a sheet of upper Trias, Rhaetic, Lias, Oolites, and Neocomian, so that throughout the mountain Trias is found resting on Lias [2]. Lotti has also shown that the green rocks of Monte Argentario belong to the Trias, as De Stefani had previously affirmed, and that the rocks of the Apuan Alps, of the Montagnuola of Siena, of Monte Argentario, and the island of Giglio show indeed complete correspondence [3].

Thus, a range of rocks of Alpine character occupies the whole breadth of the sea from Corsica to Orbetello. It is, nevertheless, separated from the main range of the Apennines by the ancient rocks which make their appearance in the so-called Catena metallifera, near Gavorrano, Campiglia, and other localities.

In the east of the Apennines the normal direction to the south-east is not always maintained. Between Spoleto and Rieti a north-and-south strike prevails, with overfolding towards the east. Near Spoleto, according to Lotti's statements, a platform of lower Lias, about 250 meters thick, 7 kilometers long, and 5 kilometers broad, rests on the Senonian Scaglia [4].

[1] Ueber den Bau der italienischen Halbinsel, Sitzb. k. Akad. Wiss. Wien, 1872, LXV, pp. 217–221.

[2] R. Lotti, Boll. R. Com. geol. ital., 1905, XXXVI, p. 50.

[3] R. Lotti, Sulla età delle roccie ofiolitiche del Capo Argentario, Boll. R. Com. geol. ital., 1905, XXXVI, pp. 177–181.

[4] R. Lotti, Di un caso di ricuoprimento presso Spoleto, Boll. R. Com. geol. ital., 1905, XXXVI, pp. 42 et seq., 1906, XXXVII, pp. 34 et seq. and 280 et seq.

This meridional strike in Umbria, and certain features in the structure of Tunis led Haug to draw trend-lines from the Sabine mountains obliquely across the Tyrrhenian sea towards Cape Bon and Biserta, thereby excluding the Basilicata, Calabria, and Sicily [1]. Although the meridional direction can be traced towards the south, almost down to Tivoli, yet it can only be regarded as exceptional, for normal south-easterly chains occur both on the west and on the east, and further south the Monti Lepini strike to the south-east across Haug's hypothetical trend-lines.

It is possible that the older rocks of the Catena Metallifera have not been without some effect in producing the deflexion in the Sabine range. They do not behave, however, as an obstructing foreland, for the easterly-lying Umbrian chains are folded towards the east, and Lotti even believes that the Catena Metallifera affords evidence of a strike which was originally more meridional, and has since been affected by the general strike to the south-east [2].

Let us now proceed a good way further south.

On the west side of the gulf of Tarento the lower course of the river Crati broadens out into the wide plain of Sybaris. It thus separates the bold Trias range of Lagonegro, together with the Cretaceous and Eocene zone, which lies in front of it on the east, from the crystalline mountains of Calabria. The river Sinni cuts through the Cretaceous and Eocene zone. Not very far from Latronico it receives the Frida rivulet, and here Viola has found in the midst of the folded formations a considerable exposure of crystalline schist, including amphibolites. A distance of at least 50 kilometers separates this locality from the crystalline rocks of the Sila [3].

Between the locality just mentioned and the Tyrrhenian sea rise the Trias mountains of Lagonegro. The lower Trias is absent. According to De Lorenzo the range is closely folded, and in part overturned to the east; possibly it is dammed back by the crystalline rocks of the Frida. The strike is north and south. Lias rests unconformably against the Main dolomite. The Cretaceous and Eocene extend in a second unconformity over the whole structure. De Lorenzo points out that the upper beds do not present the north-and-south strike of the Trias, but the normal south-east strike of the Apennines, so that a twofold strike exists here.

Baldacci and Viola have published an instructive account of the manner in which these Trias limestones and dolomites, according to their estimate

[1] E. Haug, Sur quelques points théorétiques relatifs à la géologie de la Tunisie, Assoc. Franç. pour l'Avancement des Sciences, Congrès de Saint-Étienne, 1897, pp. 366–376.

[2] R. Lotti, Considerazioni sintetiche sulla orografia e sulla geologia della Catena metallifera, Boll. R. Com. geol. ital., 1892, XXIII, pp. 55–71.

[3] C. Viola, Comunicazione preliminare sopra un terreno cristallino in Basilicata, Boll. R. Com. geol. ital., 1892, XXIII, pp. 244–246.

some 3,000 meters thick, are inserted into the structure of the Apennines. The Trias runs to the north through Paterno, Padula, and Marsiconuovo, then through the province of Potenza, diverging only a little to the north-north-west, and reaches the mountains of San Fele, not far from the outer border of the Apennines, south of Monte Vulture. Towards the north the direction becomes north-west, then turns almost due west, and the Trias reaches the proximal end of the peninsula of Sorrento, north of Salerno, and in the direction of Amalfi, the innermost part of the gulf also. A curvilinear trend-line is thus revealed, which runs approximately from Castrovillari on the Crati towards San Fele and thence to Salerno. Baldacci and Viola speak of it as the *Tyrrhenian semicircle* [1].

The most northerly part has been described by De Lorenzo. Long before this is reached, and while still within the region of the north-westerly strike, the south side of the Trias is affected by great longitudinal dislocations, which throw down the inner side of the arc in step faults, while its outer surface is inclined towards Monte Vulture, i. e. towards the north-east. Within the folded Eocene Flysch rises the volcano; the Flysch is affected by the step faults. Similar step faults appear to accompany the whole western half of the Semicircle on its southern side, and have been recognized in particular to the north of Salerno and in the peninsula of Sorrento. Rovereto disputes their presence in Capri (and in part also in the peninsula) and suggests another structure—in the case of Capri, successive overthrust sheets [2].

[1] Of the numerous works on this subject we will only mention: for the north, F. Bassani, Sui fossili e sull' età degli schisti bituminosi di Monte Pettine, Mem. Soc. Ital. Sci. (Napoli), 1892, XL, 27 pp., and Fossili nella Dolomite triasica del dintorno di Mercato San Severino, Atti Accad. Nap., 1893, 2ª ser., V, no. 9, 15 pp.; Bassani e de Lorenzo, Per la geologia della peninsula di Sorrento, Atti R. Acc. Lincei, Rendic., 1893, 5ª ser., II, pp. 202, 203; A. Galdieri, Osservazioni geologiche sui Monti Picentini, op. cit., 1907, 5ª ser., V, pp. 529–534; for the south, G. de Lorenzo, Trias del Dintorno di Lagonegro, Atti R. Acc. Lincei, 1892, 2ª ser., V, no. 8, 48 pp.; I Monti mesozoici di Lagonegro, op. cit., 1894, 2ª ser., VI, no. 15, 125 pp., map; Osservazioni geologiche nell'Appennino della Basilicata meridionale, op. cit., 1895, 2ª ser., VII, no. 8, 31 pp.; and in particular Guida geologica in Boll. Soc. geol. ital., 1898, XVII, pp. 170–195, map, and Studio di geologia nell' Appennino meridionale, op. cit., 1896, 2ª ser., VIII, no. 7, 128 pp., and Geologia e geografia fisica dell' Italia meridionale, 1904, 8vo, Bari, 241 pp.; Bittner, Brachiopoden der Trias von Lagonegro, Jahrb. k. k. geol. Reichs., 1894, XLIV, pp. 583–588, and Böse and Lorenzo, Geologische Beobachtungen in der südlichen Basilicata und dem nordwestlichen Calabrien, op. cit., 1896, XLVI, pp. 235–268. For the whole region Baldacci e Viola, Sull' estensione del Trias in Basilicata e sulla tettonica generale dell'Appennino meridionale, Boll. R. Com. geol. ital., 1894, pp. 372–390; E. Cortese, Descrizione geologica della Calabria, Mem. descr. Carta geol. Italia, 1895, IX, 310 pp., map, and G. Di-Stefani, Osservazioni geologiche nella Calabria settentrionale e nel circondario di Rossano, 1904, op. cit., appendix to vol. IX, 119 pp.; also the geological map on the scale 1:100,000.

[2] G. de Lorenzo, Studio geologico del Monte Vulture, Mem. Acc. Nap., 1900, 2ª ser., X, no. 1, 207 pp., map, in particular p. 37 et seq.; further, E. Böse, Contribuzioni alla

It is not certain whether the Trias range terminates with the Semicircle. The next trace of the Apennines, revealed beyond the volcanos of Naples, is the isolated Monte Massico in the plain of Volturno. It consists of Cretaceous limestone and beneath it lies the Main dolomite with *Gervillia exilis*[1]. The substructure of the volcanic Ponza islands is visible on the north side of Zannone, the most northerly of the group; the Main dolomite with *Gervillia exilis* again makes its appearance, and at the same time sericitic shales, which belong to the Trias, and some Eocene[2]. In the Lepini mountains Cretaceous limestone predominates; the very prominent *cape of Circe* is an isolated rock of Lias with a patch of Eocene[3].

Calabria (I, p. 219). South of the lower course of the Crati lies a land which in its outer configuration differs greatly from the Apennines. Broad valleys filled with comparatively recent marine deposits separate the hills, which thus present an appearance of great independence. The upper Crati divides the broad mass of the Sila in the east from the long and narrow mass of the Catena litorale (Monte Cocuzzo) in the west. Beyond the sources of the Crati, near Martirano and Nicastro, the east and west unite. The neck of land between the gulfs of Squillace and of Santa Eufemia separates northern from southern Calabria. In the south the elongated Serra runs to the south-south-west and unites with the Aspromonte. The valley of the Mesima cuts it off on the west from the little Vaticano mass (Monte Poro), and the strait of Messina separates the Aspromonte from its natural continuation, the Peloritan range in Sicily.

Cortese distinguishes the following sub-divisions in the crystalline series. Ancient hornblende gneiss and mica-schist form the Aspromonte and the adjacent part of the Peloritan mountains and are restricted to this region. These are followed by a thick mass of various phyllites, which towards the summit sometimes present intercalations of augen-gneiss or transitions to sericitic or talcose schist. Over these lies an extensive mass of garnet-bearing gneiss, for the most part true kinzigite, quite similar to that of Ivrea; associated with it is a garnet-bearing schist. Finally a large quantity of granite is exposed. It breaks through the lower rocks in numerous dykes and spreads out over the surface. At two localities tonalite makes its appearance and occupies a slightly larger area;

geologia della Peninsula di Sorrento, op. cit., 1896, 2ª ser., VIII, no. 8, 18 pp., and Böse and de Lorenzo, Zur Geologie der Monti Picentini bei Neapel, Zeitschr. deutsch. geol. Ges., 1896, XLVIII, pp. 202-215; G. Rovereto, L'Isola di Capri, Atti Soc. ligust. Genova, 1907, XVIII, pp. 22-25; on the other hand, de Lorenzo, Atti R. Acc. Lincei, Rendic., 1907, XVI, pp. 853-857.

[1] M. Cassetti, Osservazioni geologiche sul Mt. Massico presso Sessa Aurunca, Boll. Com. geol. ital., 1894, XXV, pp. 160-166.

[2] A. Galdieri, Osservazioni sui terreni sedimentarii di Zannone, Rendic. R. Acc. Sci. Napoli, Feb. 18, 1905, 8 pp., map.

[3] C. Viola, Il Monte Circeo, Boll. R. Com. geol. ital. 1896, XXVII, pp. 161-171, map.

diorite and dykes of porphyry occur. The granite covers almost the whole Serra and a considerable part of the Vatican mass [1]. Mention is also made of the Sila, but according to Fucini's observations the foregoing subdivision does not apply to it. The oldest rock is granite; this is covered by phyllite and some gneiss; then follows a schist which resembles the Carboniferous of Monte Pisano and the Alps [2].

In the north, where the garnet gneiss of the Catena litorale dips beneath the Trias, there lies, beneath it and above the phyllite, a green schist which has been produced from diabase. Serpentines make their appearance in several places, and in some isolated localities their resemblance to the Pietre verdi of the Alps is so striking that Lovisato regarded them as a continuation of the green-rocks of the Alps [3].

The difference between this substructure and other parts of the Apennines, though remarkable, is not more so than the difference in the distribution of the sediments.

Phyllite, kinzigite, and green schists form the greater part of the Catena litorale; this range, as we have seen above, extends as far as the Trias mountains to the north, which it reaches near Santa Agata on the Esaro. A fragment of black limestone, completely separated from these ranges, occurs on the coast near Cetraro. A much larger fragment, about 8 kilometers in length, very narrow, consisting, as it would appear, of horizontal beds, and probably over 200 meters thick, crowns the whole crest of Monte Cocuzzo (1,542 meters) and dominates the country far and wide. Other smaller patches extend southwards to Malito (west-south-west of Rogliano), 56 kilometers from Santa Agata; this limestone is characterized by the presence of Megalodon and Diplopora [4].

The great southern slope of the Trias recedes from Santa Agata towards the north-east as far as Castrovillari, and then disappears beneath the Cretaceous. In front of the slope the plain becomes broader, and 10 kilometers to the south-east of Castrovillari two isolated bosses of Trias rise out of it; for a distance of 10 kilometers along the southern border of the plain the ancient phyllites, forming the foothills of the Sila, crop out.

[1] E. Cortese, Descrizione geologica della Calabria, Mem. descr. Carta geol. Italia, p. 63 et seq.

[2] A. Fucini, Studio geologico sul circondario di Rossano, Atti Acc. Gioen. Catania, 1896, IX, No. 17, 87 pp., map; in particular p. 5 et seq. On the schist which is assigned to the kinzigite in the north-western part of the Sila: L. Busatti, Atti Soc. tosc. sci. nat. Pisa, Proc.-verb., 1891–1893, VIII, March 5, 1893, pp. 202–208.

[3] D. Lovisato, Cenni geognostici e geologici sulla Calabria settentrionale, Boll. R. Com. geol. ital., 1878, IX, p. 155 and continuations, in particular 1879, X, pp. 39 and 137; precisely the same views in Novarese, Boll. Soc. geol. ital., 1906, XXV, p. 179.

[4] G. v. Rath, Geognostisch-geographische Bemerkungen über Calabrien, Zeitschr. deutsch. geol. Ges., 1873, XXV, pp. 150–209, in particular p. 159; E. Cortese, Descrizione geologica della Calabria, Mem. descr. Carta geol. Italia, p. 219.

Here the Crati, as it makes its bend between Terranova and Spezzano-Albanese, cuts through another patch of limestone. In 1871 I visited this spot in the company of my deceased friend G. von Rath. We found Crinoids, which left us in no doubt that this patch was an outlier of the great limestone cliffs which rise in full Alpine splendour on the north side of the Crati valley. Lovisato and Fucini have expressed the same opinion. The former adds that the limestone of Terranova rests on mica schist or green schist, but is not defined from them by any sharp boundary. Repeated alternation occurs; then come beds of cippoline and other rocks. A very similar account is given by Fucini [1].

As far as existing observations extend this is the last trace of Trias on the Crati.

We have already mentioned that the granite of the Sila is regarded as older than the associated schists. These rocks are overlain, south of Rossano, on the Ionian slope, by several patches of fossiliferous Mesozoic strata. They have been described by Fucini, Greco, and di Stefano [2].

The most important of them is a long patch of Lias, 17–18 kilometers in length, resting partly on granite, partly on schist, and elongated towards the south-east. On its west border lies Longobuco. On the east it rests, according to the map (1 : 100,000), on granite at the bottom of the Trionto valley, at a height of 300 meters above the sea, and at its western border it attains a height of 1,481 meters on Monte Palepito; not far away the granite reaches a height of 1,431 meters. As it ascends the Lias exhibits folding. Taken as a whole it would seem to form a syncline open towards the east. Its lowest subdivision consists of an accumulation of boulders and pebbles, with beds of sand and traces of plants [3]. It passes upwards into lower Lias limestones; the middle Lias is but poorly represented, the upper Lias, on the other hand, is of very wide extent, and in places overlaps on to granite.

To the north, as far as the neighbourhood of the town of Rossano, a series of different and smaller, sometimes indeed very small patches, set in. At one place the remains of a bed containing *Rhynconella Clesiana* rests on ancient schist. There are three small patches of reddish limestone,

[1] G. v. Rath, op. cit., p. 167, D. Lovisato, Boll. Com. geol. ital., 1879, X, p. 33 et seq.; A. Fucini, Atti Acc. Gioen. Catania, 1896, IX, No. 17, pp. 18–21. On the map, 1:100,000, this limestone is represented as Archaean.

[2] A. Fucini, op. cit.; Greco, in particular Lias inferiore nel circondario di Rossano, 8vo, Pisa, 1893, 128 pp.; Sulla presenza della oolite inferiore nelle vicinanze di Rossano Calabro, Atti Soc. tosc. sci. nat., Proc.-verb., 1895, IX, March 3, 6 pp.; and Il Lias superiore nel circondario di Rossano Calabro, Boll. Soc. geol. ital., 1896, XV, pp. 92–121; the results are combined in Di-Stefano, Osservazioni geologiche, etc., Mem. descr. Carta geol. Italia, 1904, pp. 93-119.

[3] M. Canavari, Conglomerati arenarii e quartziti liasiche di Puntadura, Atti Soc. tosc. Pisa, Proc.-verb., 1891–1893, VIII, 15 Nov. 1891, pp. 13, 14.

likewise resting on schist and containing the fauna of the stage of San Vigilio with intermingled fragments of the basement rocks. Two small patches of Aptychus limestone (Tithonian) rest partly on this reddish limestone and partly on granite.

The middle Eocene Nummulitic beds lie on the various stages mentioned above. Following the coast they form a fairly long but interrupted zone striking to the south-east. These beds also begin with a basement conglomerate [1].

Thus we reach the following conclusions:—the Trias is absent. All the other stages are autochthonous, as is shown by the repeated basement conglomerates. Sila was a rocky shallow or island from the time of the lower Lias, but it has nevertheless been affected by folding.

There is no evidence that the Trias patches of the Catena litorale and Terranova are autochthonous.

The Eocene belt on the Ionian coast disappears, becomes visible again from Ciro onwards, and disappears again beneath the broad plain of Catrone, which extends to the gulf of Squillace and the constricted part of the peninsula. Here, near Catanzaro, in the so-called little Sila, and as far as the west coast, there is scarcely anything more striking than the diversity of the crystalline limestones which occur in intimate association with diorite, granite, or kinzigite. The penetration of eruptive rock into the stratified and intensely folded limestone or calc schist may be seen beautifully illustrated on the road from Catanzaro to Tiriolo. Strings of garnets accompany the bedding planes.

All these limestones are generally regarded as Archaean, but we continually meet with expressions of doubt. Lovisato says that he could neither assert nor deny that the upper beds belong to the Trias. Cortese admits that he had believed them to be younger, possibly Permian, and has only assigned them to the Archaean on account of their crystalline grain and intimate association with garnetiferous schist [2].

Coming from the west coast near Amantea the groups of rocks which include the crystalline limestones are surmounted by a number of scattered crags of white limestone, among them the well-known rock of Tiriolo on the summit of the pass of Catanzaro. Ellipsactineae and corals are found in their further continuation to the south, likewise Nerineae. They have been assigned to the upper Jurassic, more recently to the Cretaceous, and thus enable us to fix at least an upper limit to the age of the crystalline limestones.

[1] Di-Stefano, Osservazioni geologiche, etc., Mem. descr. Carta geol Italia, 1904, p. 114.

[2] D. Lovisato, Cenni geognostichi, etc., Boll. Com. geol. ital., 1878, IX, pp. 226, 228; E. Cortese, Descrizione geologica della Calabria, Mem. descr. Carta geol. Italia, 1895, IX, p. 223; Fucini, Studio geologico, etc., Atti Acc. Gioen. Catania, 1896, IX, No. 17, p. 20; for the minerals of the limestone in the kinzigite, V. Novarese, Calcari cristallini e calcefiri dell' Arcaico calabrese, Boll. R. Com. geol. ital., 1893, XXIV, pp. 17-43.

These younger limestones unite to form isolated and fairly long ranges, and they surround in a girdle, one evidently continuous, the east of the Aspromonte. Along with some Cenomanian of African type, and Flysch of upper Eocene and Oligocene age, they form a belt from Stilo onwards; its beds in several places dip steeply towards the Ionian sea, and are probably folded also. The white limestones of Jurassic or Cretaceous age extend nearly up to cape Spartivento, while the Flysch surrounds the whole southern part of the peninsula as far as cape d'Armi and beyond it[1].

Sicily. In considering the north-east part of the island we will follow Di Stefano and Cortese[2]. The ancient formations which strike across from Calabria are covered unconformably by the 'Strati di Ali', a series comprising quartzite, violet schist, and jasper alternating with brown limestone; cellular limestone with gypsum is also mentioned; grey, thinly stratified limestone forms the capo di Ali. The relations of this series to the next cannot be determined.

The second and more southerly series begins with a deep red conglomerate very similar in character to the Rothliegende, which, also, rests unconformably upon the ancient formations. Towards its upper part it passes through sandy marls into beds of limestone and some dolomite, which contain in abundance Gastropods characteristic of the lower Lias of Palermo. Above, dolomite occurs in rocky masses and this series may reach a thickness of 200 meters; over this follow beds with a rich marine fauna which still belongs to the lower Lias.

The middle Lias, but little developed, consists of grey Crinoidal limestone with species of the Hierlatz facies.

The upper Lias may attain a thickness of 300 meters or more; the lower part is formed of Leptaena beds, the upper of stratified limestone and fluhen marl with *Hildoceras bifrons*. The Middle Jurassic is represented by the stage of San Vigilio, and beds containing *Rhynconella Clesiana* and *Rhynconella Vigilii*; locally a bed with *Harpoceras opalinum*

[1] Erdbeben des südlichen Italien, Denkschr. k. Akad. Wiss. Wien, 1875, XXXIV, pp. 1-32; L. Burgerstein und F. Noë, Geologische Beobachtungen im südlichen Calabrien, Sitzb. k. Akad. Wiss. Wien, 1880, LXXXI, pp. 154-173, map; Bassani e de Lorenzo, Il Monte Consolino di Stilo, Atti Acc. Napoli, 1894, 2ª ser., VI, No. 8, 6 pp. Also the recent studies of Cortese and Di-Stefano mentioned above.

[2] Di-Stefano e Cortese, Guida geologica dei dintorni di Taormina, Boll. Soc. geol. ital., 1891, X, pp. 197-246. This series differs considerably from that which I have myself described (e. g. Erdbeben des südlichen Italien, p. 6, also in this work, I, p. 219) in accordance with the older views of Sicilian geologists; on these views Baldacci's more detailed Descrizione geologica dell' Isola di Sicilia (Mem. descr. Carta geol. Italia, 1886, I, 403 pp.) and the special map, 1:100,000, are based. The changed standpoint is chiefly due to Di-Stefano. The dolomite is now assigned to the lower Lias. It is true that there are still serious tectonic difficulties (Guida geologica in Boll. Soc. geol. ital., 1898, XVII, p. 46).

or *Posidonia alpina* may be met with. Then follow the Alpine Klaus beds with *Rhynconella Berchta,* various stages of the upper Jurassic up to the Tithonian and finally Cretaceous and Tertiary.

This series is generally admitted to correspond in a very striking manner with that of Rossano on the north-east side of the Sila. The intercalation of dolomite in the lower Lias forms the most important difference, but here as there the whole of the Trias is absent, except in so far as the beds of the Ali may represent some trace of it. Here as there also transgressions of the upper Lias occur, and the Tithonian encroaches in like manner upon a variety of underlying formations. Cretaceous and Tertiary also overlap on to the ancient rocks. We must point out that on the northern slope, near Castroreale above Barcelona, Seguenza discovered another fragment of the African Cenomanian with *Ostraea scyphax* lying between the lower Tertiary and gneiss.

Towards the middle of the island the Trias, divisible into numerous zones, makes its appearance from beneath the Lias, and at one locality on the river Sosio, in the south part of the province of Palermo, marine Permian also occurs. The comprehensive studies of G. G. Gemmelaro show that there is no boundary in Sicily between the Dinaric and Alpine facies. The marine Permian (Trogkofel beds, III, p. 349) is a very characteristic member of the Dinarides and approaches close to the boundary of the Alps, but has never yet been encountered in those mountains. In Sicily it appears beside the typical Hallstatt beds of the Alps, as represented, for example, by the fauna of the zone of *Trachyceras aonoides*[1].

The beds of Sosio are the oldest rock outside the Peloritan belt, but the whole island is underlain by Mesozoic beds. Trias also makes its appearance to the south-west of Aetna, and *Harpoceras opalinum* occurs in the extreme west near Trapani. The Trias strikes out from the Madonian islands along the north coast towards the west; a second branch crosses the middle of the province of Palermo and extends in a number of isolated outcrops as far as Monte San Calogero di Sciacca on the south coast. With regard to the structure there is a difference of opinion. Lugeon and Argand assume a great overthrust, extending from the north across the west of Sicily to the south coast, and they conjecture that the crystalline masses of Calabria have also been overthrust. Di-Stefano disputes the existence of such great movements. A decision can only be reached as the result of further investigations[2].

[1] G. G. Gemmelaro, La fauna dei Calcari con Fusulina della Valle del fiume Sosio, 4to, Palermo, 1887, 338 pp.; I Cefalopodi del Trias superiore della regione occidentale della Sicilia, Giorn. Soc. Sci. nat. e econom. Palermo, 1904, XXXIV, pp. 1-319; in particular note to p. 25.

[2] M. Lugeon et E. Argand, Sur de grands phénomènes de charriage en Sicile; Sur la grande nappe de recouvrement en Sicile; La racine de la nappe sicilienne et l'arc de

Indications exist which point to the existence of a down-thrown granitic country. It was long since observed that blocks of granite, syenite, porphyry, and other rocks are scattered in great numbers over the Apennines, and Capellini supposed that the subsided Tyrrhenius was their original home. In Umbria they are small where they occur in the Flysch, their head quarters are the middle Miocene. In isolated localities they are also accompanied by Trias and green-rocks, and by rocks which range up to the Eocene. A. d'Ossat concluded that the boulders on Monte Deruto (not far from Foligno) were derived from the Catena metallifera—that is, from localities 60 to 100 kilometers away, and in 1900 he suggested that they might be the remains of sheets like the foreign pebbles of the Swiss Molasse [1].

Deecke, who had become familiar with them further south, in the neighbourhood of Monte Vulture, did not doubt that they had been derived from the west. Baldacci and Viola encountered these erratics in so great a quantity to the north of the bay of Policastro, and also on the opposite side of the great Trias range of Lagonegro, that they inferred the existence of two branches of crystalline rocks proceeding from Calabria; the existence of the eastern branch seems to be confirmed by the outcrops on the Frida [2].

At Fuscaldo (north of Paolo) G. von Rath has described a conglomerate about 100 meters thick, lying beneath inclined Tertiary beds; it consists of blocks of a foreign granitite sometimes over a meter in diameter; this again recalls the Nagelflue of the Rigi [3].

Worthy of note is the instance described by Cortese of pebbles beneath the Miocene gypsum, e. g. near Gerace in east Calabria and near Garistoppa (north of Caltanisetta) in the middle of Sicily [4]. A number of similar accumulations which occur in east Calabria are doubtless only ancient and local torrent deposits. The examples we have cited are sufficient for our purpose, and lend support to the view that a great mountain range, in part granitic, at one time existed in the west of the peninsula [5].

charriage de la Calabre, C. R. Acad. Sci. Paris, 23 avr., 30 avr., 14 mai 1906; G. Di-Stefano, I pretesi grandi fenomeni di carreggiamento in Sicilia, Atti R. Acc. Lincei, Rendic., 3 e 14 marzo 1907, pp. 258–271, 375–381.

[1] A. d'Ossat, I Ciottoli esotici nel Miocene del Monte Derutta, Atti R. Acc. Lincei, Rendic., 1900, IX, pp. 384–391, X, pp. 40–44; Roccati records similar facts in the Apennines of Bologna, Boll. Soc. geol. ital., 1904, XXIII, pp. 409–418.

[2] W. Deecke, Die sogenannten 'erratischen Granite' in Apulien und der Basilicata, N. J. f. Min., 1891, II, pp. 49–61, Baldacci e Viola, Boll. R. Com. geol. ital., 1894, pp. 372–390.

[3] G. v. Rath, Geognostisch-geologische Bemerkungen über Calabrien, p. 162.

[4] Baldacci, Descrizione geologica dell' Isola di Sicilia (Mem. descr. Carta geol. Italia, 1886, I), p. 266.

[5] De Stefani, de Lorenzo, and Di-Stefano deny the presence of a subsidence in the Tyrrhenian sea, and in part also the unilateral structure of the Apennines; the last-named author writes in great detail in Mem. descr. Carta geol. Italia, 1904, App. to vol. IX, pp. 83–92. On the other hand Nicotra attempts to determine the details in connexion

Thus we seem to have evidence of the existence of two distinct elements.

The first is an Alpine range, the manifold continuation of the Alps, striking down from north-east Corsica, Elba, and the Argentario; its eastern part is the Apennines. To this the foreign granites belong, the Trias of Lagonegro and Sicily, and the Trias of the Catena litorale which takes the form of outrunners or is thrust forward in recumbent sheets.

The second element is represented by Calabria, along with the north-east of Sicily. This is not a true foreland, but seems to occupy a similar position in the Apennines, though on a grand scale, to that of the Catena metallifera, or that of the Mouthoumet mass in front of the Pyrenees, which will be described later. This element is certainly surrounded by a part of the Apennine folds.

In Sicily itself two regions may be distinguished, one in the north-east corresponding with Rossano, in which the fossiliferous series begins with autochthonous lower Lias, and a second, comprising all the rest of the island, in which the series is probably complete from the marine Permian upwards.

The Mediterranean Atlas. This range, turned towards the south, repeats the structure of the Apennines (I, p. 221). The first zone is volcanic, and lies partly on islands; the second is characterized by masses of gneiss and ancient schist, it forms peninsulas and follows the coast; to the south of it we encounter long folds of sedimentary formations which extend as far as the Sahara.

Such are the parts viewed as a whole. But if we enter into details we perceive a number of divergent and very important features. In particular the gneiss masses have already disappeared on the east before reaching Bona, and inner folded ranges strike in long gentle arcs east-north-east and north-east to the sea. Finally a complete bend is made in Tunis, whereby all the coulisses passing through Ferriana turn gradually out of the east-north-east into the north-east direction; they form series of brachyanticlines, accompanied by longitudinal fractures which strike to the north-north-east through Zagonan and reach the bay of Tunis. This is shown in particular by Pervinquière's sketch of the trend-lines of Tunis [1].

We will choose the Tell of Oran, of which we have a clear account by

with subsidence in fragments, Come siasi fatta l'Italia, Mem. Acc. Zelant., Aci Reale, 1905, 3ª ser., IV, pp. 51–72. The literature on zoological distribution which deals with this subject cannot be discussed here.

[1] L. Pervinquière, Étude géologique de la Tunisie centrale, 4to, Paris, 1903, 359 pp., maps; in particular p. 336. Baltzer also perceived that the chains strike in the direction of the gulf of Tunis; Beitrag zur Kenntniss des tunesischen Atlas, N. J. f. Min., 1893, II, p. 27 and 1895, I, p. 105.

Gentil[1], as illustrating in a particularly instructive manner the questions we are dealing with here. The Tell of Oran begins in the region of the Traras, west of the river Tafna, strikes, with frequent interruptions, towards the north-east, is separated by the Sebcha from the interior of the country, and sinks beneath the sea between the town of Oran and cape Falcon.

The Traras mountains are a mass of ancient schist elongated towards the north-east and broken through by a granite boss (granite of Nedroma). On this schist a ferruginous conglomerate rests unconformably, and upon this the thick limestone of the Lias, then other stages of the Lias up to the zone of *Hildoceras bifrons*, next shales with *Posidonia alpina*, and finally the Oxfordian. Thus far the resemblance with the series of Taormina and Rossano is unmistakeable.

In the Jebel Skouna the same series crops out from beneath basalts; further to the north-east it forms isolated hills, becomes visible beneath the lavas and breccias of the recent volcano of Tifaronin, and finally reaches the gulf of Oran in the long folds of the Sahel d'Oran.

The total length of the Tell of Oran amounts to 120 kilometers. In isolated localities we find between the Lias and the ancient schist a gypsiferous variegated marl with platey limestone. It represents the Trias. Again on the south-west side of the Traras, resting for the greater part on the granite of Nedroma, is an accumulation of blocks over 200 meters in thickness; the blocks are imbedded in dark red sandstone, and some beds of similar sandstone occur without blocks; this is the puddingstone of the Beni Menir. To the north-east of the Traras, on the other side of the river Tafna, near Kef el Goléa, Gentil encountered this red deposit of Beni Menir *beneath the gypsiferous Trias. Thus it actually represents the Rothliegende,* and must be distinguished from the basement conglomerate of the Lias. Probably the red conglomerates associated with violet shales, which occur at cape Falcon and the Löwenberg near Oran, are also of Permian age (I, p. 225). It seems likely that a further continuation of the Tell occurs in cape Ferrat.

Much further to the north-north-east, in the mountain mass of Milianah (south of Cherchel) Gentil has observed, not only the deposit of Ben Menir, the violet shales of cape Falcon, and above them the gypsiferous Trias, but porphyrites also[2]. The ancient schists are also present, and in the mountain range of Blidah, which forms the eastern continuation of the mass of Milianah, the Lias limestone rests, according to Ficheur, directly upon them[3].

[1] L. Gentil, Esquisse stratigraphique et pétrographique du Bassin de la Tafna, 8vo, Alger, 1902, 536 pp., maps.

[2] L. Gentil, op. cit., pp. 84, 97.

[3] E. Ficheur, Les Plissements au Massif de Blide, Bull. Soc. géol. France, 1896, 3e sér., XXIV, pp. 982–1041, in particular p. 985. It is certainly remarkable that organic

From these facts—the nature of the deposit of Beni Menir, the presence of the porphyrites, the discordant superposition upon ancient schist, and the covering of Trias gypsum—it is clear that in this region we again are in presence of the Rothliegende of the Great Atlas, the highest summits of which consist in part of Permian porphyrite. The ancient schists of the Tell of Oran, of Milianah and Blidah are thus, along with the granite of Nedroma, parts of the Altaides, and are incorporated with the younger folds like the zone of mont Blanc with the Alps.

This again raises the question of the significance of the violet shales and the traces of gypsum, trifling though these are, which in north-east Sicily rest directly upon the Peloritan mountains and are known as the 'beds of Ali'. How difficult it often is to establish the presence of Trias is shown by the fact that many experienced observers either barely admitted or wholly failed to recognize the existence of Trias in Algeria, even as late as the year 1890, notwithstanding the fact that it is spread out over the whole land, and even the great shotts derive their salt from it [1].

The Trias of this region consists, as we have seen, of variegated marl with gypsum, anhydrite, and salt, also of rauchwacke and platey limestone. In the latter *Myoporia vulgaris* and *Gervillia socialis* of the German Muschelkalk were found near Constantine, and M. Bertrand pointed out its complete identity with the Trias of Provence [2]. From another locality *Mytilus psilonoti* is mentioned. In central Tunis Pervinquière found *Myophoria Goldfussi* and *Ostrea Montis caprilis*. The gypsiferous marls, however, like the Trias of the Jura mountains and the Salt range of the eastern Limestone Alps, have been involved to so great an extent in mountain movement that they are frequently rolled out or mylonitized, and the Platten limestone can only be recognized as kneaded-in sherds. They also seem to possess a tendency, as the result either of the welling-up of the anhydrite, or perhaps of lateral pressure, to force their way upwards in isolated dislocations and to drag their surroundings up with them.

remains have never been found in these shales, while lower Carboniferous is known right into the south-westerly continuation of the mountains of Tlemcen, and, according to Gentil, possibly as the northern continuation of the Jebel Bechar; Gentil, C. R. Acad. Sci. Paris, 24 févr. 1908, p. 428.

[1] As, for example, A. Pomel's otherwise admirable Explication de la seconde édition de la Carte géologique provisionnelle de l'Algérie au 1:800,000, 4to, Alger, 1890, 217 pp.; appended: J. Curie et G. Flamand, Étude succincte sur les roches éruptives, 101 pp. No details are known with regard to the traces of Ammonitides and Walchia, or the trunks of conifers, which Jordan, Coquand, and other older observers mention as occurring on the coast of Oran, and especially the Löwenberg; cf. Pomel, op. cit., pp. 11–14.

[2] M. Bertrand, Bull. Soc. géol. France, 1896, 3e sér., XXIV, p. 1184; J. Blayac et L. Gentil, Le Trias dans la Région de Souk-Ahras, op. cit., 1897, 3e sér., XXV, pp. 523–548.

Perhaps this is the reason why massive salt deposits and many masses of gypsum were long regarded as eruptive [1].

In the distorted gypsiferous marls are alien blocks which may be some meters in size. Sillimanite and garnet-bearing gneisses, granulites and mica-syenites are also known to occur in sitû in the substructure, and may be transported basement patches. At the same time, however, a great variety of intrusive rocks make their appearance. Gentil, who paid particular attention to this subject, mentions ophite (chiefly diabase with ophitic structure), diorite, quartz diorite, dipyre diorite and gabbro, and believes that they are all derived from a common source. They are in every instance intrusive, almost without exception broken up by tectonic movements, and often kneaded up with the gypsiferous bed into a breccia. Since they have produced contact alteration, giving rise for example to albite, tourmaline and, in the limestone, to dipyre, they are more recent than the Trias, and according to Gentil are either Jurassic or Cretaceous [2]. The ophites have been met with from Morocco to Tunis throughout the whole of the Mediterranean Atlas.

It is scarcely necessary to point out the correspondence of these blocks with those in the saline beds of the eastern Limestone Alps, or to the connexion between diorite, quartz diorite, and gabbro in Ivrea. The sillimanite gneiss, garnet gneiss, and cordierite gneiss, which belong in Oran to the basement formations, appear to play there a part similar to that of the kinzigite in Calabria and the neighbourhood of Ivrea.—

If we travel from England to the Alps in a south-easterly direction, we start from a region in which the whole of the Trias is represented by a salt-bearing series of sandstones and clays, not easily divided into horizons. It is not till we reach the horsts on the Rhine that the Muschelkalk is intercalated and we reach the Germanic type of the Trias (II, p. 258). In the Rhaetic period a positive movement began; it persisted with oscillations during the Lias; a long way to the north, as in Skye, far beyond the region of the Trias, the Lias still maintains its marine character (II, p. 270). The whole western region of the Mediterranean, from the Var and all around as far as Tunis, is occupied, with the exception of the Balearic isles and the lower Ebro, by the Germanic development of the Trias, more or less impoverished. Traces of it have also been observed in Sardinia, where it is chiefly represented by lagoon clays with gypsum, and limestone with

[1] Termier supposes that in Tunis great overthrusts occurred over the Trias; there is some difference of opinion as to their extent; Sur les phénomènes de recouvrement du Djebel Ouenza (Constantine) et sur l'existence de nappes charriées en Tunisie, C. R. Acad. Sci. Paris, 9 juill. 1906, also in de Launay, Les richesses minérales d'Afrique, 8vo, 1903, p. 341.

[2] L. Gentil, Esquisse stratigraphique et pétrographique du Bassin de la Tafna, 8vo, Alger, 1902, p. 210 et seq., pp. 274, 275; also Curie et Flamand, Étude succincte sur les roches éruptives.

Myophoria. The positive movement, persisting since the Rhaetic age, has however led to the deposition of the Lias upon it all around the area. The gradual advance of the Trias with the Rhaetic stage, followed by that of the Lias along the west side of the Central plateau, has already been mentioned on p. 42.

It is not till we arrive at the other side of this broad margin, and the other side of the Jura mountains and the Helvetian Alps, that we reach the pure pelagic sediments of the Tethys in the Piedmontese and Eastern Alps, the Dinarides and Sicily.

With these results the remains of the Altaides in the Tell of Oran near Milianah and elsewhere, and the superposition of the Lias, are in complete accordance. But this is also true of the occurrences in north-east Sicily and the north-east Sila. *A fragment of the Altaides, or at least a broad elevated mass, is inserted in Calabria between the southern Apennines and the Dinarides.*

This enclosure of the western Mediterranean by the Germanic Trias renders completely untenable the ancient notion that in Germany the Germanic Trias was cut off from the Alpine Trias by a long range of (Vindelician) mountains.—

From the termination of the Peloritan mountains near Taormina to the emergence of the African Altaides near Figig there is no sharply marked frame, and the platform of the Sahara forms the foreland of the Mediterranean Atlas in a manner which recalls the Russian platform between the downthrown Cimmerian fragments and the first of the Sudetic remnants on the river San.

This fact affects the arrangement of the folds of the Mediterranean Atlas.

These folds are not parallel. The Tell of Oran strikes almost to the east-north-east, and its probable continuations in cape Ferrat and in the masses of Milianah and Blidah maintain the same direction into the mountains to the south of the town of Algiers. They extend to the south of the gneisses of the coast. In the much broader range which succeeds on the south no rocks are exposed, according to existing observations, of greater age than the Trias. The Cretaceous predominates. It forms broad folded ranges, separated by the depressions of the shotts. They begin in the south with a direction more nearly east and west, and proceed in a very broad arc to E. 30° N., or emerge direct from the desert with a strike of E. 30° N.

The most southerly parts of the range are often termed the Sahara Atlas; they are not, however, a continuous range, but consist of the ends of alternating coulisses, comparable in some degree with the east border of the Rocky mountains.

Near Figig the southern boundary of the Mediterranean Atlas is marked by the Jebel Melias (p. 98) overfolded towards the south. It is true that from this point onwards the range of the Ksour, and then the Jebel Amour, rise above the broad desert as a steep straight wall (I, p. 226), but near Laghouat they recede from the desert with a strike to E. 30° N. towards the interior of the mountains. Beyond Laghouat a continuous south border occurs only in places. One after another the parallel coulisses leave the desert with a strike to E. 30° N. and enter the mountains. The best known is the Jebel bou Kahil. A number of them unite within the mountains to form the mighty Jebel Aourès. The desert now extends more towards the north; and between the ends of the coulisses, fairly far to the north, lies Biskra. From this place onwards it becomes increasingly clear that the several coulisses start in a west-and-east direction before they assume the strike to E. 30° N. From the Jebel Chechan onwards the desert gradually recedes again towards the south, and in southern Tunis the east-and-west direction becomes more prominent. In particular a continuous Cretaceous anticline runs from Negrine towards Gafsa: Cretaceous chains striking east and west accompany the shott Djerid and Fedjedj, and may still be recognized in Gabès (II, p. 365) [1].

In many of the coulisses from Figig to the shott-el-Fedjedj, the gypsiferous marls, and with them the ophites, crop out beneath Cretaceous or Jurassic [2].

In fact the folding of the Mediterranean Atlas was bounded by the frame which extends as far as Figig. The Jebel Amour is the last great coulisse which emerges from the frame; all the coulisses which succeed to the east of Laghouat lie outside the Jebel Amour and are not continued towards the west. The outermost and last coulisses are those which strike due east towards Gabès. It is a group lying more towards the interior which reaches Tunis with a strike to north-north-east. Hence we perceive that the whole of the east coast of Tunis as far as Gabès is occupied by the spurs of the Atlas.

We are now confronted by a problem which cannot at present be definitely solved, partly in consequence of the vast regions covered by the sea, and partly on account of the inadequate results as yet furnished by investigation.

That the trend lines run as a whole from the Apennines to the Atlas is universally admitted. Haug, however, points out that the facies of the sediments is not the same in Africa as in Sicily, and also that the north-

[1] In connexion with the earlier description we have here made use of the more recent account by Rolland, Chemin de Fer Transsaharien, Géologie du Sahara Algérien, 4to, Paris, 1890, pp. 14–29, Pl. IV, and the map of the Geological Survey 1:800,000. Much repetition was found necessary in order to make the connexion clear. The several chains, which bear the general name of Jebel Tebaga, run from Gabes towards the west and enter the Shott-el-Djerid, forming a peninsula, Idoux, Ann. géogr., 1902, XI, p. 439.

[2] In particular P. Thomas, Recherches sur quelques roches ophitiques du Sud de la Tunisie, Bull. Soc. géol. France, 1891, 3e sér., XIX, pp. 430-472.

north-easterly direction characteristic of Tunis is opposed to that which predominates in Sicily. The difference of the facies may be explained by supposing that the overthrust sheet of Sicily, assumed by Lugeon and Argand, did not reach Africa. The difference in direction is said to be caused by a syntaxis between Sicily and Africa, with the rëentrant angle situated in the neighbourhood of the volcanic islands of Pantellaria and Linosa [1].

These hypotheses are correct as far as the facts are concerned, but the problem is scarcely so simple.

The contrast between the facies of Sicily and Africa certainly exists, but a well-marked African facies also occurs in Rossano, and both facies are met with in Sicily itself. Further, the distinction is confined to the marine Permian and the Trias. In the Lias it has already almost completely disappeared. Thus it happens that Zittel, for instance, was able to point to the existence near Constantine of the particular horizon of the 'grey limestones' of South Tyrol, which is also of frequent occurrence in the Apennines; attention may also be drawn to the remarkable resemblance of the Tithonian as met with in Jebel Ressars, near Tunis, to that of Sicily; near Constantine the great *Inoceramus Salisburgensis* (here up to 50 cm.), which in the East Alps is associated with the northern sediments, makes its appearance in the Flysch, along with *Inoceramus Crispi* and other species [2].

The strike in the northern part of Tunis would be consistent with the presence of a syntaxis, but not so the open character of the folds, and in southern Tunis even the strike is scarcely concordant. As regards the western part of Sicily it is difficult to discover any definite direction [3]. The direction of the autochthonous beds concealed by the overthrust sheet would be decisive on this point, but such beds are wholly unknown.

On the other hand the diversified form of the foreland has evidently helped to determine the structure. The more elevated position of the substructure has caused either the complete absence of Trias or its development in lagoons. On the plateau of the Sahara the folding of the Atlas becomes

[1] E. Haug, Sur les relations tectoniques et stratigraphiques de la Sicile et de la Tunisie, C. R. Acad. Sci. Paris, 14 mai 1906; also Bull. Soc. géol. France, 1906, 4e sér., VI, pp. 355, 356.

[2] K. A. Zittel, Bull. Soc. géol. France, 1896, 3e sér., XXIV, pp. 1175, 1181 et seq.

[3] In the extreme west of Sicily, near Trapani, a strike to the north-east prevails in the Trias and Jurassic, and also in the Aegaean isles, Levanzo and Marittimo (?); south of these localities, however, an east-and-west strike sets in from Corleone onwards, and this direction is maintained in Favignana, the largest of the Aegaean isles (Baldacci, G., Descrizione geologica dell' Isola di Sicilia, p. 185 et seq.). A series of shallows (Sylvia, −13 m., Hecate −7 meters, and others) appears to continue the direction to the west and a little south towards Galita; but the accounts of this island are contradictory (I, p. 221, and note 3).

gentler, spreads out and dies away, and the connexions are concealed by the sea. Above all, it is necessary to determine whether the pelagic Trias of Sicily does in fact occur only as a sheet. Further, what is the significance of the Trias on Monte Cocuzzo and near Terranova, and finally, whether the Trias of Lagonegro breaks off in the south or swerves towards the west.

At present we are able to distinguish—

1. Regions in which the substructure is unknown, and the series begins with *pelagic Permian*, followed by pelagic Trias (west and centre of Sicily as far as Monte Judica, south of Aetna).

2. Regions in which the substructure is known or unknown, and the series begins with Rothliegende or gypsiferous Trias and *Germanic Muschelkalk*, or with a basement conglomerate of the *lower Lias* (Mediterranean Atlas, north-east Sicily, north-east Sila).

3. Regions in which the marine series begins with the *middle Jurassic* and rests on extra-marine Upper Carboniferous, and this again on a known substructure (Corsardinia).

4. Regions in which a known substructure bears a series beginning with the *Cenomanian* (Sahara, Peloritan gneiss in part).

At the same time the first marine horizon in any given case (perhaps with the exception of the Muschelkalk) extends over all the preceding regions, thus the Lias of 2 also extends over 1, the Dogger of 3 over 1 and 2, the Cenomanian of 4 over 1, 2, and 3.

It is not impossible that in this arrangement some signs of the ancient isohypses may be perceived. In proportion as we succeed in increasing the area over which such comparisons can be made we may be able to render them more independent of tectonic changes.

The Betic Cordillera. There is no difference of opinion as regards the further course of the trend lines. All travellers, who of late years have visited the Rif and the surrounding regions, have remarked on the regularity of the arc described by the Mediterranean Atlas in its course to Gibraltar. The rock of Gibraltar, hitherto believed to belong to the Oolites, is now regarded as Lias [1].

With respect to the Betic Cordillera we may refer to Vol. I, p. 247. The direction of the folding force has once more completely changed; it is now directed towards the north; the foreland, represented by the Sierra Morena, lies to the north; the volcanos on the south. The comprehensive accounts of French investigators, published after the earthquake of 1884 [2], show that the lofty masses of the south, from the Sierra de Ronta to the Sierra Nevada, possess the same constitution as the Tell of Oran. These, too, are mighty ridges of ancient schist, on which here and there

[1] Bull. Soc. géol. France, 1892, 3e sér., XX, p. 9.

[2] Mission d'Andalousie. Études relatives au tremblement de terre du 25 déc. 1884, 4to, Paris, 1889, 772 pp., maps.

a patch of Rothliegende is preserved. They are thus parts of the Altaides.

On their north side the Germanic Trias broadens out and here its subdivisions appear to be most clearly distinguished; the Bunter sandstone, is present, Muschelkalk with *Gervillia socialis* and other characteristic fossils, and Keuper, represented by variegated gypsiferous clay with *Myophoria vestita*. On their south side thick dolomitic limestones make their appearance, and in the Sierra Almijera Barrois found in them some beds filled with the smaller forms of Megalodonta[1]. This fact has led to the suggestion that the great schist mountains actually mark the boundary between the pelagic and the lagoon facies of the Trias.

These investigations have also given rise to the theory that the inner zones of the Cordilleras are traversed by three great flaw-like dislocations, striking to the north-west. The first is supposed to pass through Malaga; the second through Motril and the maximum point of the seismic area, near Zafarraya; and the third from cabo di Gata towards Guadix[2].

Many instructive facts are afforded by the north side, and particularly by the so-called sub-Betic Cordillera.

Nicklès found that the folds of Jaen are continued without interruption as far as cabo de la Nao, a distance of more than 350 kilometers, and that overthrusts towards the north may be recognized over at least the half of this tract[3].

We will now attempt to follow the description given by R. Douvillé of a tract, about 60 kilometers in length, situated between Marto, Jaen, and the Sierra Sagra[4].

The country south of the Guadalquivir may be divided into a lowland and an upland. The former, which adjoins the river, is covered along its banks by a fertile belt of upper Miocene and Pliocene; this is followed towards the south by very barren stretches of folded gypsiferous Keuper, upon which rest scattered patches of lower Cretaceous. Then we come to the foot of the highland.

This side of the highland is formed by the brow of a great recumbent fold, broken up by erosion into several fragments; of these the most easterly is the largest; it is 20 kilometers in length, over 2,000 meters in height, and rises between 1,300 and 1,400 meters above the plain. The

[1] Barrois, Mission d'Andalousie, p. 84; Bertrand and Kilian, op. cit., pp. 406 and 573; the older statements of Gonzalo y Tarin with regard to the fossils of the limestone of the Sierra de Gador merit fresh investigation (Bol. Com. Mapa geol. España, 1882, IX, p. 104).

[2] Bol. Com. Mapa geol. España, 1882, IX, p. 117.

[3] R. Nicklès, Sur l'existence de phénomènes de charriage en Espagne, Bull. Soc. géol. France, 1904, 4e sér., IV, pp. 223–247 (also C. R. Acad. Sci. Paris, 24 févr. 1902).

[4] R. Douvillé, Esquisse géologique des Préalpes subbétiques, 8vo, Paris, 1906, 222 pp., maps.

rocks which form the brow of this fold are chiefly Jurassic limestone, differing in its dark colour and dearth of fossils from the light-coloured autochthonous limestone of the same system. The brow bends in an arc downwards and inwards, so that at its foot we discover the overthrown, wedged-in, and in large part crushed remains of the Cretaceous and Eocene beds, which were originally superposed on the Jurassic. These deposits once formed the roof of the fold. R. Douvillé states, however, that a surface of separation was formed in the upper limb on the horizon of the Cenomanian, probably after the great movement had ceased, and that then the middle and upper Cretaceous accomplished an independent movement over parts of the plain.

The original home of this dark Jurassic limestone is unknown, and with regard to the origin of the fold we can only say that it has been thrust from the south.

The foregoing facts are instructive, in so far as they afford a fairly simple example by which the form of the recumbent fold is placed beyond doubt. But there are other circumstances which are also important. The earlier statements as to the rather recent date of the fracture on the south side of the mountains, and of the strait of Gibraltar as well, are confirmed in detail.[1] Here also the ophitic intrusions accompany the Trias and in a few cases even extend into the upper Lias, if not further[2]. The masses of blocks associated with gypsum, belonging to the Second Mediterranean stage, which occur in Calabria and Sicily, seem to be repeated in the basin of Granada, where they form Drasche's 'Miocene block formation'.[3]

The same structure and the same succession of strata strike towards the north-east as far as the Cabo de la Nao, and even in the Sierra

[1] Mission d'Andalousie, p. 576; R. Douvillé, p. 108. According to the later accounts of M. Gentil, which have arrived while this volume is in the press, the facts are as follows: during the deposition of the upper Miocene (II Mediterranean stage) communication existed along the north side of the Betic Cordillera; during the period of the lower Pliocene (III Mediterranean stage) communication through Fez; during the upper Pliocene (IV Mediterranean stage) the straits of Gibraltar must have been already open, since the upper Pliocene does not occur above 120 meters; with this height it could not cross the mountain arc, and yet it occurs in Tetuan in the same form as on the Atlantic coast. Renseignements coloniaux supplémentaires au Bulletin du Comité de l'Afrique française, févr. 1908: Gentil, Report from Tangiers, p. 34.

[2] Mission d'Andalousie, pp. 527–532; with a diminution in the size of the felspars, diabase passes into porphyrites, and these, through the occurrence of peridotite into melaphyre (spilite), op. cit., pp. 220–223.

[3] Mission d'Andalousie, pp. 489 et seq., in particular p. 507. Drasche distinguishes the more recent Guadix formation from the Miocene accumulation of blocks (Jahrb. k. k. geol. Reichsanst., 1879, XXIX, pp. 112 et seq.); on these peculiar occurrences see also L. Siegert, Das Becken von Guadix und Baza, Zeitschr. Ges. Erdk., Berlin, 1905, pp. 528–554 and 586–614; further, W. H. Hobbs, Guadix Formation of Granada, Bull. Geol. Soc. Am., 1906, XVII, pp. 285–294.

Mariola, north of Alcoy, Nicklès came upon a great fold, overturned towards the north, which may be compared with the fold of Jaen.[1]

The doubts entertained with regard to the Balearic islands (I, p. 231) seem about to be dispelled in a somewhat unexpected manner as the result of the observations made by Hermite and Nolan.[2] *Two mountain systems are represented in this little group of islands.*

Iviza, Formentera, Majorca, and Cabrera belong to the Betic Cordillera. The whole of the north-west of Majorca in particular is formed by a fragment of a chain 80 kilometers in length and 1,571 meters in height. It is formed of flakes overdriven towards the north, exhibits the Betic strike and is evidently a continuation of the Betic structure. Lacustrine deposits with Anthracotherium are a continuation of similar beds in eastern Spain. They show that a lake extended to the island of Majorca, which in the Oligocene period formed part of the mainland.[3] Then came an invasion of the sea. Even as early as the time of *Natica crassatina* the existing south border formed part of the coast line. Horizontal beds of Miocene limestone cover a great part of the centre of the island.

In Minorca the situation is different. A fault cuts through the island from north-west (Gulf of Algairens) to south-east (Port Mahon). Its southern half is a flat platform of Miocene limestone, which lies unconformably over the fault. In the higher-lying northern half, middle Devonian limestone is the oldest rock, which, according to its fossils, corresponds approximately to the Eifelian. Nothing similar has hitherto been observed anywhere in the younger folded ranges which surround the western Mediterranean. Hermite mentions also plant-remains, possibly belonging to the Culm. According to Nolan's description these beds occur in three anticlines, the one in the middle, which is by far the most important, strikes N. 5° E.

Although Majorca throughout its breadth strikes towards Minorca yet we are precluded from assuming the continuity of these islands owing to

[1] R. Nicklès, Recherches géologiques sur les terrains secondaires et tertiaires de la province d'Alicante et du Sud de la province de Valence; Annales Hébert, 1892, I, 219 pp.; maps, in particular p. 151.

[2] H. Hermite, Études géologiques sur les îles Baléares: I. Majorque et Minorque, 8vo, Paris, 1879, 357 pp., maps; H. Nolan, Sur le Trias des Baléares, Bull. Soc. géol. France, 1887, 3e sér., XV, p. 593, and Sur les terrains triassiques et jurassiques des îles Baléares, C. R. Acad. Sci. Paris, 4 déc. 1893; Structure géologique d'ensemble de l'Archipel Baléare, Bull. Soc. géol. France, 1895, 3e sér., XXIII, pp. 76–91, maps; and Notice préliminaire sur l'île de Cabrera, op. cit., 1897, 3e sér., XXV, pp. 303–305; Nolan distinguishes in the upper Trias: 1. zone of *Trachyceras Curionii* and *Trachyceras Vilanovae*; 2. zone of *Daonella Lommeli*; 3. zone of *Hoernesia pseudosocialis* and *Monotis salinaria.* Then follows the general series of Lias and Oolites; in Majorca it is traversed by numerous dykes of melaphyre.

[3] L. M. Vidal, Note sur l'Oligocène de Majorque, Bull. Soc. géol. France, 1905, 4e sér., V, pp. 651–654.

the completely different direction of the anticlines and the occurrence of Devonian. This seems doubly strange since in Minorca the folding certainly extends far into the Mesozoic aera, and the Mesozoic sediments are similar in both islands.

On the mainland the Betic division of the Trias has been recognized as far as Alcoy and beyond; as we proceed further we meet, first in Iviza and then in Majorca, with thick Bunter sandstone, and then Muschelkalk as on the mainland, but instead of the variegated Keuper marl, thin platey limestones occur with *Daonella Lommeli* and Trachyceras. Here we have reached the limit of the Germanic facies of the Keuper, and the outliers of the pelagic Trias, as it occurs on the lower Ebro, make their appearance. Since this facies is mentioned as occurring already in Iviza it is apparent *that in this region the boundary of the facies does not coincide with the tectonic boundary.*

The Trias here, as Nolan observes, show less resemblance to that of the mainland, notwithstanding its proximity, than to that of Sicily.

The Alpides terminate, not in the Balearic isles, but to all appearance in Majorca. We must mention, however, that the indications of particularly recent folding, which elsewhere make their appearance at free terminations, do not occur in this case. The horizontal platforms of Miocene limestone rather suggest that the movements which have occurred further to the west have not extended thus far.

2. *The folds of Provence.*

The eastern parts of the folds of Provence, which have been driven towards the east and north, meet the Piedmontese and the Helvetian Alps on the Var. Mention has already been made of the comparatively late date of the Provençal folding over this tract. Concealed by recent deposits for a great distance along the Durance, indications of these folds occur still further in the north, on the other side of the fractures-area of Banon, where they run east and west as far as the neighbourhood of Sisteron, there presenting a contrast with the adjacent recumbent sheets of the Alps.

They occupy a large area, yet although built on a uniform plan, they do not form a uniform chain, but on the north and west only isolated fascicles of folds. On the south they are bounded by the sea. Towards the south-west they are connected in a peculiar manner with the outer chains of the Pyrenees.

It will be convenient to commence with a brief account of the foreland on the north-west. This is formed by the Montagne Noire and the Cevennes; the Catalonian mountains to the south of the Pyrenees exhibit a particular resemblance.

On the map the *Montagne Noire* looks like an adjunct to the south-west part of the Central Plateau. It extends from Castel Naudary to Lodêve, and slopes away southwards towards the plain of Béziers. But while the gneiss of the Rouergue (south and south-east of Rodez) strikes in the Armorican direction to the north-west and belongs to the Central Plateau, the rocks of the Montagne Noire strike N. 60° E. Bergeron, to whom we owe a great part of our knowledge of this region, has shown that three great lobes of Silurian and Devonian coming from the south-east are thrust up on to the Montagne Noire. To the east of the point at which the river Orb issues from the mountains, Silurian and Devonian extend almost horizontally for a distance of nearly 5 kilometers over the bassett edges of the folded lower Carboniferous [1].

The older rocks of the Montagne Noire are covered obliquely and unconformably by the Coal measures and Graissesac [lower zone of Stephanian]; they show that the Montagne Noire belongs to the Altaides [2].

The manner in which the Cambrian rocks and the several folded ranges of the east border of the Montagne Noire reappear on the other side of the Causses in the *Cevennes*, and particularly the way in which they dip beneath the Mesozoic sheet near Saint Afrique and re-emerge near Vigan, shows that the structure of the Montagne Noire is continued to this point. Hence its independence in respect to the Variscan system also becomes manifest [3].

The Catalonian mountains have been described by Almera and Bergeron. On the coast between cape Dagur and the mouth of the Llobregat lies a range of hills with a coincident direction and tectonic strike of N. 60° E. as in the Montagne Noire. Towards the sea this range terminates along a strike fault. Overthrusting occurs towards the north-west and the sub-divisions of the lower Palaeozoic series, which extends upwards into the lower Carboniferous, coincide with those of the Montagne Noire [4].

[1] J. Bergeron, Étude géologique du massif ancien situé au Sud du Plateau central, Ann. sc. géol., 1889, XII, pp. 1-361, map; Étude du versant méridional de la Montagne Noire, Bull. Soc. géol. France, 1898, XXVI, pp. 472–487; Note sur la base du Carbonifère dans la Montagne Noire, op. cit., 1899, XXVII, pp. 36-43; and Sur les nappes de recouvrement du versant méridional de la Montagne Noire, C. R. Acad. Sci. Paris, 8 févr. 1904, p. 394; and in particular the report of the annual meeting of the French Geological Society in Bull. Soc. géol. France, 1898, pp. 661–900, also 1899, pp. 605–790. To the east of the disturbed region belongs the frequently mentioned lower Devonian of Cabrières: C. Barrois, Sur le Calcaire à Polypiers de Cabrières (Hérault), Ann. Soc. géol. du Nord, 1886, XII, pp. 74–97; F. Frech, Die palaeozoischen Bildungen von Cabrières, Zeitschr. deutsch. geol. Ges., 1887, pp. 380–487, map, &c.

[2] The same fact is suggested by the superposition of the Stephanian and Permian beds between Albi and Castres; A. Dereims, Feuille d'Albi, Bull. serv. Carte géol., 1898, X, pp. 118-120.

[3] J. Bergeron, Feuille de Bédarieux, Bull. serv. Carte géol., 1899, X, p. 125, and Feuilles de S. Afrique et du Vigan, op. cit., 1903, XIII, p. 577 et seq.

[4] J. Bergeron, Note sur les terrains paléozoiques des environs de Barcelone et Comparaison avec ceux de la Montagne Noire, Bull. Soc. géol. France, 1898, 3e sér., XXVI,

Very thick lower Tertiary conglomerates, crowned by the monastery of Montserrat, occur on the north slopes of the Catalonian mountains. They may be regarded as an indication that the mountains still possessed, even in the Tertiary aera, a greater extension in the direction of the existing sea. Depéret observes that the conglomerates of Castel Naudary at the south end of the Montagne Noire completely resemble those of Montserrat and are of the same age. Near Montserrat they extend from the lower into the upper Eocene and the higher members are the 'Poudingue de Palassou' of the Pyrenees. Eocene, lying almost flat, surrounds the basin of the Ebro in the direction of the Meseta; it is filled by Oligocene sediments (gypsum, beds with *Cyrena semistriata* and other characteristic fossils) [1].

The Montagne Noire thus forms along with the Cevennes a branch of the Altaides striking N. 60° E. and overthrust towards the north-west; they are separated by the Pyrenees from the Catalonian mountains, which form a similar fragment.

Let us now turn our attention to the more recent folds.

To the south-east of the area, enclosed on the one side by the Alps and on the other by the Montagne Noire and the Cevennes, gneiss, mica-schist and phyllite make their appearance. Upper Carboniferous and Permian, unconformably superposed, show that here too a part of the Altaides is visible. It consists of several adjacent fragments which together occupy a space elongated towards the south-west. The first fragment is the Esterel, between Cannes and the valley of the Argens; the second, and largest, is the hill range of the Maures, situated between this point and the neighbourhood of Toulon, and continued to cape Sicié; as a third fragment we may regard the islands of Hyères. All these fragments are included under the name of the *Maures* [2]. A continuous furrow lying in Permian sediments (Dépression de Cuers) bounds the Maures towards the interior; on the other side of this furrow we reach the complicated structure of the Provençal folds.

Just here, extending from the depression of Cuers to Marseilles and the Durance, lies the scene of the classic labours of Marcel Bertrand, which have inspired so many of our modern views on the structure of the younger ranges of Europe [3].

pp. 867–875; J. Almera et Bergeron, Sur les nappes de recouvrement des environs de Barcelone, op. cit. 1905, 4e sér., IV, pp. 706–721.

[1] Depéret, C. R. Acad. Sci. Paris, 26 mars 1906, pp. 752–755.

[2] I have referred to this range at the beginning of these studies as a fragment of the foreland of the Alps, and have termed it the 'mass of Hyères'.

[3] Some of the most important are: M. Bertrand, Coupes de la chaîne de S. Baume, Bull. Soc. géol. France, 1884, 3e sér., XIII, pp. 115–130, and Nouvelles études sur la chaîne de S. Baume, op. cit., 1888, 3e sér., XVI, pp. 748–778, map; Plis couchés de la région de Draguignan, op. cit., 1889, 3e sér., XVII, pp. 234–246; Le Massif d'Allauch, Bull. serv. Carte géol., 1891, no. 24, III, pp. 283–333, map; La Basse Provence, relief et lignes

These investigations, combined with those of Zürcher and the studies of Fournier and others, which are based in part on different conceptions, show that this region is built up of recumbent folds piled one upon another. They form circumscribed masses (Massif du Beausset, de la Sainte-Baume, d'Allauch, de l'Étoile and others). It is not till we proceed to the north that they are succeeded by comparatively longer folds striking east and west [1].

This second sketch receives important confirmation from Kilian's observation that the east-and-west direction is already prevalent in the recumbent sheets of the south, in contrast to the south-westerly course of the furrow of Cuers, which forms the natural boundary of the Maures. From this it has been concluded, and probably with justice, that the Maures, notwithstanding certain Mesozoic patches which occur upon them, do not stand in such an intimate, and as it were organic, connexion with the Provençal folds as Mont Blanc, for example, with the Helvetian Alps. They present rather the characters of a fragment of foreland overwhelmed by recumbent sheets but now exposed by denudation; of a window, in fact, and the roots of the sheets may have belonged to the denuded covering, or they may lie in the Tyrrhenian subsidence [2].

The folds now advance, but in diminished strength, towards the west and north with an east-and-west strike; west of Marseilles they separate the great lagoon of Martigues from the sea, they disappear below the Rhone delta, but reach the river above Arles and still farther to the north, a fold being mentioned as crossing it near Montélimar.

In the foreland deflexion occurs. Near Alais, in the coalfield of the Gard, the Carboniferous itself is overthrust in the direction of the Cevennes. An important scarp formed by the Jurassic limestone of the Causses, the Montagne de la Seranne, which runs north-west from the Montagne Noire to the Cevennes, causes stowing on the upper Hérault and becomes

directrices, in Ann. de Géogr., 1897, VI, pp. 212-229, and 1898, VII, pp. 14-33, maps; Le Bassin crétacé de Fuveau et le Bassin houiller du Nord, Ann. d. Mines, Paris, 1898, 9e sér., XIV, pp. 5-85, maps; La grande nappe de recouvrement de la Basse Provence, Bull. serv. Carte géol., 1899, no. 68, X, pp. 397-467, maps.

[1] The drainage adit 14·5 kilometers in length beneath the mass of l'Étoile has since been completed. In the 'Lambeau charrié de Gardanne,' north of the Étoile, the outcropping Trias, as M. Bertrand foresaw, has not been encountered in the adit; the adit is cut in the Aptian. Thus the presence of the overthrusts of the north is confirmed. Beneath the Étoile itself the adit lay too high in the Jurassic for a decision to be possible. A. Boistel, Résultats géologiques du percement de la Galerie de Gardanne à la Mer, Bull. Soc. géol. France, 4e sér., V, 1905, pp. 724-740, map.

[2] Kilian, Remarques sur la tectonique de la Basse Provence, Bull. serv. Carte géol., 1906, no. 110, XVI, pp. 449-451; Vasseur and Fournier mention that from cape Sicié, where the Maures and the furrow of Cuers sink beneath the sea, there is a submarine cliff which runs south of Marseilles, while at Pointe Rouge a little south of the same town a conglomerate with Permian pebbles occurs. Both these facts are regarded as indicating a continuation of the Maures: C. R. Acad. Sci. Paris, 27 janv. 1896, map.

a boundary of the foreland. From the south the Trias and Lias have surged up towards this barrier in six successive flakes[1].

This is the beginning of a long belt of dammed-up folds on the south border of the Montagne Noire. It extends to St. Chinian and has been described by Nicklès[2].

Isolated fragments, extending from Montpellier onwards, between this belt and the sea indicate the continuation of the Provençal folds as far as the Montagne de la Clape, near Narbonne; near St. Chinian, however, circumstances occur which have an important bearing on the interpretation of the Pyrenees.

The illustration (fig. 20) is taken from a tectonic map published by de Margerie in 1890. Many additional details have been discovered since the continuity of the folds has become more apparent, but the less complicated representation given in the figure shows the various trend lines in a very clear manner[3].

The folded region of St. Chinian leaves the Montagne Noire while describing an arc. Depéret distinguishes several concentric folds. The most northerly anticline reveals beneath Trias and Infra-Lias the Eocene stage of Rognac; beneath this, Nummulitic beds extending as far as Bize, and beneath these, limestone with *Planorbis pseudoammonius*. Between this overturned fold and the Palaeozoic beds of the Montagne Noire lies one end of the basin of Minervois, which widens out rapidly towards the west, i. e. in the direction of Carcassone. Near Bize, a small dome of Eocene is separated off towards the south-south-west; it represents the free end of the first anticline.

The next anticline presents the same succession of strata as the first[4].

In the Minervois, to the west, the Eocene broadens out; north of the Aude no further folds occur; the foot of the Montagne Noire is free and lies as it were in a dead angle. North of the Pyrenees rises the Palaeozoic mass of *Mouthoumet*. It is 45 kilometers in length and attains a breadth of 15 kilometers. The stratified sequence is the same as that of the

[1] R. Nicklès, Sur les plis couchés de S. Jean-de-Buèges (Hérault), C. R. Acad. Sci. Paris, 30 janv. 1905. Here the obstacle (upper Jurassic) consists of more recent rocks than the sediments stowed by it.

[2] R. Nicklès, Bull. Soc. géol. France, 1899, 3e sér., XXVII, p. 715 et seq.; in particular pp. 719, 743, 773 et seq. to 787.

[3] E. de Margerie, Notes sur la structure des Corbières, Bull. serv. Carte géol., 1890, no. 17, II, pp. 283–318, map; also an older work by d'Archiac, Les Corbières, Mem. Soc. géol. France, 1859, 2e sér., VI, pp. 209–446, map; among recent works in particular, L. Carez, Composition et structure des Corbières et de la région adjacente des Pyrénées, Bull. Soc. géol. France, 1892, 3e sér., XX, pp. 470–506; L. Doncieux, Monographie géologique et paléontologique des Corbières orientales, Ann. Univ. Lyon, 1903, new ser. I, fasc. II, 377 pp., map; O. Mengel, Observations géologiques sur la partie sud-est des Corbières, Bull. Soc. géol. France, 1904, 4e sér., IV, pp. 256–281, map.

[4] C. Depéret, Bull. serv. Carte géol., 1896, VII, pp. 86–88, and 1899, X, pp. 515–517.

Montagne Noire. Its north border is bent over towards the north; Mesozoic folds encroach from the west. There is no doubt that this mass was affected by the folding of the Pyrenees. Nevertheless it has caused a deflexion of the Mesozoic folds. The north-east corner near Durban leaves no doubt on this point. The Provençal folds composed of Trias, Jurassic, and Cretaceous, but without Eocene, approach from the subsidence of Narbonne, bend gradually between the eastern border of Mouthoumet and cape Leucate

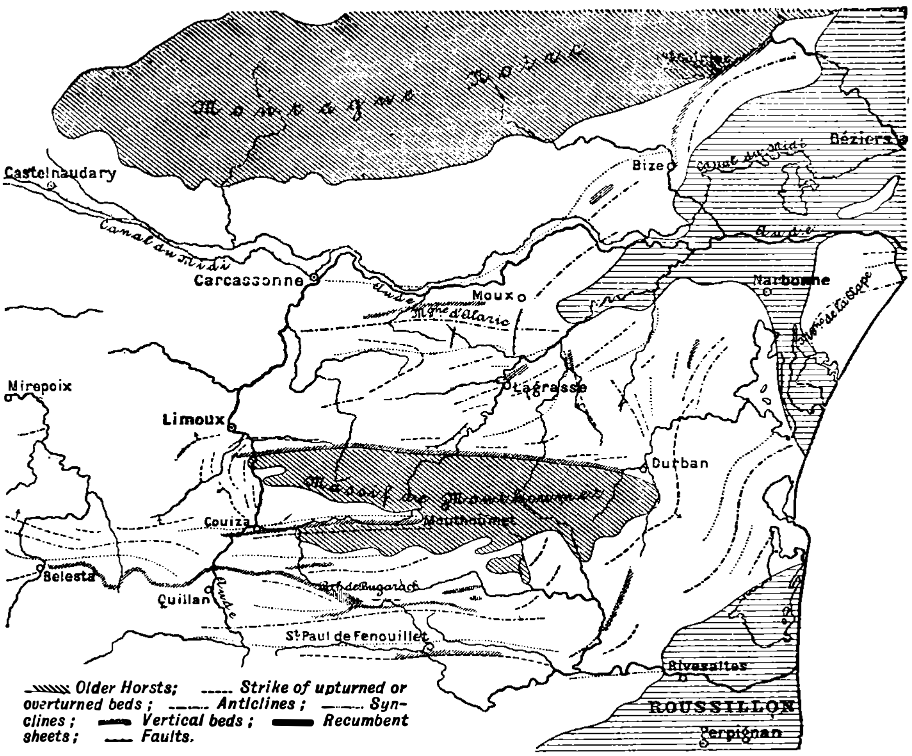


FIG. 20. The valley of the Aude. (After E. de Margerie.)

into a due east-and-west direction, as a consequence of overthrusts towards their concave side[1]; *they unite south of the Mouthoumet mass with the folds of the Pyrenees.*

Near Jonquières (8 kilometers north-west of Durban) the Trias and Jurassic disappear. All the folds west of a line joining Jonquières and Bize, i. e. the folds between Mouthoumet and the Aude, consist solely of Danian and Eocene, thus offering a marked contrast to the deflected folds of Provence. They are thrust towards the north, frequently cut through by faults, and

[1] C. Depéret, Bull. serv. Carte géol., 1906, XVI, p. 402, window of Vingrau (north-west of Rives Altes).

near Moux and Lagrasse reveal the Devonian, lying beneath the Danian; the folds die away towards the west [1].

Thus between the Montagne Noire and Mouthoumet a *connexion exists, beneath the Danian, between the Palaeozoic foreland and the core of Mouthoumet.* At the same time we have here an instructive example of *folds exhibiting two different facies* (Devonian, Danian, Eocene; and Trias, Jurassic, and Cretaceous) which have developed together side by side.

3. *The Pyrenees.*

The study of this great mountain range has made considerable progress in the last few decades. A catalogue drawn up by Carez in 1903 contains the names of more than 2,000 works of a geological nature. In this period of progress three phases may be distinguished. The first centres round the works of d'Archiac and Leymerie[2]; the second is marked by the publication of the map by Carez in 1892 [3] and the almost contemporaneous sketch of the structure as a whole by E. de Margerie and F. Schrader [4]. As regards the third period it will suffice for the present to mention the monograph by Carez (subsequent to 1903) [5], Bresson's study of the ancient formations (1903) [6], and the investigations of Léon Bertrand in the east. Important results as regards some of the principal questions were furnished by the excursion of the French Geological Society in the West Pyrenees in 1906 [7]. The writings of Mallada and other investigators, such as Stuart-Menteath, Roussel, Caralp, Seunes, Mengel, Yarza, and in particular Lacroix, contribute in many directions to the completion of our knowledge.

The substructure of the Pyrenees is formed by a series which begins with gneiss, and from the lower Silurian up to and including the Carboniferous is characterized by fossils. Bresson has shown that the same subdivisions of the Palaeozoic series may be recognized here as in the mass of Mouthoumet, the Montagne Noire and the Catalonian mountains. In this respect there is no difference between the mountains and the foreland. This ancient series is invaded by granite batholites. They are of pre-

[1] For example, E. de Margerie, Bull. serv. Carte géol., 1890, no. 17, II, pp. 283–318; A. Bresson, op. cit., 1897, IX, pp. 349–352 et passim.

[2] D'Archiac's above-mentioned work on the Corbières; A. Leymerie, Description géologique et paléontologique des Pyrénées de la Haute-Garonne, 8vo, Toulouse, 1881, and atlas, et passim.

[3] L. Carez et Vasseur, Carte géologique de la France, 1:500,000.

[4] E. de Margerie et F. Schrader, Aperçu de la structure géologique des Pyrénées, Ann. Club alp. franç. (1891), 1892, XVIII, 65 pp., map.

[5] L. Carez, La Géologie des Pyrénées françaises, Mémoire pour servir à l'explication de la Carte géologique détaillée de la France, 3 vols, 4to, 1903–1905, 1917 pp., maps.

[6] A. Bresson, Études sur les formations anciennes des Hautes et Basses Pyrénées, Bull. serv. Carte géol., XIV, 1903, pp. 45–322, map.

[7] Réunion extraordinaire dans les Pyrénées occidentales, 1906, Bull. Soc. géol. France, 4e sér., VI.

Permian age. They do not occur in the mass of Mouthoumet. The investigations of these batholites by Lacroix have an important bearing on the question as to granites when the surrounding rock is consumed [1].

The Altaides enter largely into the structure of the Pyrenees and are termed here the 'primary series'. Within the mass of Mouthoumet folds occur running to the south-west and almost east and west [2]. In the midst of the Pyrenees tracts occur in which these ancient folds are covered by transgressive red Permian and pale-coloured upper Cretaceous; it is the same succession as in Bohemia, for example, or in parts of the Great Atlas. Outside these older regions, both on the north and south, lie the younger folds. The Mesozoic series extends upwards into the Cretaceous without any sign of pelagic characters. Marine Permian fossils have been found by Caralp in one of the northern foot ranges [3]. The Trias is represented by gypsum, salt-bearing marls, and Rauchwacke.

The North. The folds of Provence advance behind the mass of Mouthoumet. When, having made a bend almost at right angles, they reappear in the west as the northern part of the Pyrenees, we see how tremendous must have been the pressure to which they were subjected from the south. Mouthoumet now assumes a position similar to that of Ufa in front of the Urals, and the Adirondacks in front of the Appalachians. The northern border of the Pyrenees breaks up towards the west in a compulsory virgation, which in the Petites Pyrénées gives rise to a north-westerly strike, divergent from that of the principal chain.

The structure of the great range running to the north-east has been made known nearly as far as Tarbes by L. Bertrand [4]. In the north an autochthonous foreland (I. Région Sous-pyrénéenne) lies here in front of the Pyrenees. To this, as a basement, Mouthoumet also belongs. It is followed by a sheet (I *a*. Nappe Pré-pyrénéenne, L. Bertrand, Zone cénomanienne, Carez) which, although separated from the foreland by a thrust-plane, still possesses its stratified succession with an important

[1] A Lacroix, Le Granite des Pyrénées et ses phénomènes de contact, I, Bull. serv. Carte géol., 1898, X, pp. 241-308, and II, op. cit., 1900, XI, pp. 50-68.

[2] L. Bertrand, Sur l'allure des plis anciens dans les Pyrénées centrales et orientales, C. R. Acad. Sci. Paris, 4 févr. 1907, pp. 289-292; L. Bertrand compares the encounter with the syntaxis in the Central Plateau.

[3] Caralp, Le Permien de l'Ariège, ses divers facies, sa faune marine, Bull. Soc. géol. France, 1903, 4e sér., III, pp. 635-650. In the north of Europe, also, a marine Permian stage, the Zechstein, is present; in the Alps, however, marine Permian is unknown, and the outcrops discovered by Caralp correspond to those of south Europe and the Dinarides; according to Haug they contain species from Sicily and the Urals.

[4] L. Bertrand, Sur les nappes de charriage Pyrénéennes et Pré-Pyrénéennes à l'Est de la Nesle, C. R. Acad. Sci. Paris, 18 nov. 1907; and Contributions à l'histoire stratigraphique et tectonique des Pyrénées orientales et centrales, Bull. serv. Carte géol., 1907, XVII, pp. 281-315.

development of transgressive Cenomanian. It is within this that we first encounter the frontal overthrusting of the Pyrenees themselves.

L. Bertrand distinguishes three sheets transported from the south, any one of which may conceal that preceding it. Large patches of the primary series (gneiss to Lower Carboniferous) form part of these sheets. In some places they rise up to a great height, at others they are ground down and milled out into narrow strips. They are separated by long pinched-in Mesozoic zones or strips.

Sheet A makes its appearance from beneath the other sheets, and is visible at intervals in the south, in autochthonous association with the primary principal chain.

Sheet B comprises the primary mass of Agly (west of Perpignan), is represented further west by a Mesozoic zone, and includes (in the west) the masses of the Trois Seigneurs, Castillon and Milhas.

South and east of the Trois Seigneurs a belt of marble with intrusions of Lherzolite makes its appearance; towards the west the Mesozoic zone becomes broader and the basic intrusions come to an end. In two erosion-windows in sheet B, situated north-east and north-west of the Trois Seigneurs, the pre-Pyrenean foreland, and in part the Cretaceous also, may be seen in the midst of the great range; rolled-out fragments of A may be recognized round about these windows, lying beneath B and upon the denuded foreland.

The highest sheet, C, consists principally of primary masses, those of S. Barthélemy, the Arize (north of the Trois Seigneurs); possibly the Barousse also must be referred to it.

These instructive results, which have been made clear to me by the kindness of M. Bertrand, who has lent me his unpublished map, recall the Alps, on account both of the overthrusting of great masses of the ancient substructure, and of the presence of marble bands and basic intrusions. The Trois Seigneurs and sheet A occupy the same position as the Hohe Tatra in the Carpathians. L. Bertrand regards the sheets as folds (*replis*) of the primary principal chain of the south, and states that the sheets are clearly bounded by Mesozoic zones in the south, while in the north they are united by a common covering formed of the marls of the Albian stage, in which the saddles of the anticlines are preserved, and play a part somewhat similar to that of the Alpine Flysch.

East of the exit of the Ariège from the mountains, rise some folds of Cretaceous and Eocene striking west-north-west; they depart further and further from the direction of the Pyrenees and soon form the fairly independent chain of the *Petites Pyrénées*. West of the middle course of the Garonne there lies a flat cone of débris easily recognizable on the map by a radiate arrangement of numerous river courses. Its summit forms the Plateau of Lannemezan. Beneath this cone the Petites Pyrénées disappear, but to the south of them, as far as the foot of the cone, we see that other zones of the Pyrenees insert themselves and form a transition. Traces of the Cenomanian occur beneath the cone. Independent bands of salt-bearing Trias with smaller occurrences of mylonitized granite make their appearance [1]. An almost continuous series of small exposures runs south of Salies in front of the Pyrenees into the neighbourhood of Lannemezan, and has been traced still farther, up to Lourdes and beyond. Further north a larger series of dislocations, striking more or less to the north-west, makes its appearance on the west side of the cone. The land is concealed, however, to a large extent, and the exposures are seldom connected; there is room therefore for difference of opinion. It will suffice to compare the plan of the lines made by Seunes in 1890 [2] with that by Carez in 1903 [3]. The studies of Seunes refer chiefly to the southern lines as far as Dax. Repeated anticlines, bent in irregular arcs, convex towards the north, are said to occur; hence the folding force has acted from the south. One line on the map is particularly conspicuous; it runs from Clarac towards the west-north-west, passes north of Oleron on the way to Peyrehorade, there changes its direction and reaches the sea near Bidart.

Carez agrees with earlier observers in his plan of the anticlines, the most northerly of which runs 28 kilometers south of Bordeaux. They are regarded as parallel to the Pyrenees (consequently not arranged in virgation), and are compared with the parallel lines trending to the north-west, which further north extend from the Central Plateau towards southern Armorica. One of the synclines, however, which strikes from Pau towards Gaas (north of Peyrehorade) is said to also possess the bend observed by Seunes.

It is certain that the dislocations may still be recognized at a quite unexpected distance from the Pyrenees; and ophites also accompany them as far as the neighbourhood of Dax.

The bend as perceived by Seunes is governed by a foreign body, which it surrounds. This is the broad and low mass of *Labourd*, formed of granite and gneiss, which is exposed south of Hasparren; some 20 kilometers away, situated on the Spanish frontier and cut through in its northern part by the Bidassoa, lies the granite mass of Aja (or Haja) 12 kilometers in length; it is a continuation of the mass of Labourd.

[1] L. Carez, Feuille de Tarbes, Bull. serv. Carte géol., 1898, X, p. 102. In the valley furrow in the direction of Tarbes, granite still crops out on the west side of the cone; for the force of the movement: P. Termier, Les Brèches de Friction dans le Granite et dans le Calcaire crystallin à Moinè-Menda, Bull. Soc. géol. France, 4e sér., IV, pp. 833–838.

[2] J. Seunes, Recherches sur les terrains secondaires et l'Éocene inférieure de la région sous-pyrénéenne du sud-est de la France, Ann. Mines, 1890, 8e sér., XVIII, pp. 209–458, map; in particular p. 412 et seq.

[3] L. Carez, La Géologie des Pyrénées françaises, I, p. 671 et seq., pl. ii. A sketch of the crossing of these lines by the Garonne (differing from the older description by Leymerie) is given by Carez in the Bull. Soc. géol. France, 1902, 4e sér., II, pl. xvii.

The situation is rendered still more remarkable by a series of rocks striking to the south-south-west, which rise from the sea a little south of Biarritz; these present a wonderful diversity in kind; and their direction corresponds approximately to that which would be followed by a similar line surrounding the mass of Labourd at a greater distance; it is also nearly parallel to the zone of Flysch which borders the gneiss of Labourd, extending along the coast to St. Sebastian and beyond [1].

Hautes Pyrénées. On the east the space allotted to this group of mountains is reduced by the encroachment of the recent subsidence of the Roussillon, which also cuts through a part of the Provençal folds, as they strike by from cape Leucate; on the south border of these folds, where the Tech emerges from the mountains, extremely complicated relations set in. Immediately to the west, however, the great range becomes continuous. Its breadth in the meridian of Andorra, from the south side of the granite of Foix to somewhere near the exit of the Segre from the mountains, amounts to about 72 kilometers. From here onwards the northern border strikes east and west towards the Mesozoic belt, while in the interior of the range a strike of W. 30° N. prevails, and the south border runs almost north-west.

In this way the breadth decreases towards the west. Near Urdos it amounts to only about 22 kilometers; a little further west, at the Pic d'Anie, it is a great deal less. From this point onwards the Basses Pyrénées take the place of the principal chain. The primary rocks, which form by far the greater part of the Hautes Pyrénées, appear in these mountains only as recumbent sheets or as pinched-in strips. Some distance away, on the other side of the plain of Mauléon, the gneiss of Labourd crops out on the north, and the structure of the mountains undergoes a change.

We have mentioned above that the relations become complicated on the Tech. According to Mengel's very instructive description, the situation on the east of this region is as follows:—

The primary rocks form a broad mass, which is called after its most northerly point the *Roc de France* (1,449 meters south of Ceret). Its boundary runs from the upper Ter towards the north-east, crosses the Spanish frontier north-east of Camprodon, runs parallel to the Tech as far as Amélie-les-Bains and beyond, and bends between Ceret and the Roc de France towards the south-east. Maintaining this direction, it passes Massarach and reaches the plain which surrounds the gulf of Rosas. Only a few remnants of Mesozoic occur on its margin. The whole of the *mass*

[1] Maps of these 'Klippen' are given by L. Bertrand, Bull. Soc. géol. France, 1902, 4e sér., II, pl. i; and Douvillé, op. cit., 1905, 4e sér., V. The following occur in the 'Klippen': Trias and ophite, altered Jurassic limestone, Cenomanian, Senonian, Danian, and several divisions of the Eocene. All the dislocations are older than the Aquitanian.

of the Roc de France, inserted in the mountains like an obtuse wedge, pointing away from Spain, *has been moved towards the north.*

West of the Tech and the frontier from Camprodon to Amélie-les-Bains, which marks a pinched-in belt of Devonian and Carboniferous, lies the broad primary mass of the *Canigou; this has been driven towards the south, so that the line of the upper Tech may be regarded as the boundary between the two movements* [1].

From this point onwards the whole of the southern side of the Hautes Pyrénées shows a movement towards the south, and a considerable part of it has been resolved into flakes which face in the same direction. Thus, for example, the Spanish mountains situated to the south of the granite mass, which bears the Maladetta (3,404 meters), are formed of folds or flakes of Palaeozoic beds overturned towards the south. The Trias consists here, as in the north, of gypsum and ophite; it appears as a narrow belt surrounding the Mesozoic beds [2].

Thanks to the zeal of French investigators, foremost among whom stand Bresson and Carez, we are able to obtain a clear insight into the structure of the range both in the valley of the Gave de Pau, which leaves the mountains near Lourdes, and also in the valley of the Gave d'Ossau, which adjoins the former on the west [3]. South of Lourdes the Mesozoic belt strikes east and west; it consists of lower Cretaceous, with Jurassic and a little Trias; the folds are overturned towards the north. Below Argèles they terminate suddenly along a steep dislocation striking east and west. Aptian marls are steeply upturned, and south of the dislocation lower Devonian dips steeply to the south. The Palaeozoic formation which begins here is at first folded towards the north, but below Luz the beds are steeply upturned; dipping first in one direction and then another they yield finally to the southern movement which now dominates as far as the Spanish frontier. The strike is W. 30° N. in this region.

Let us follow this direction towards Laruns on the neighbouring Gave d'Ossau.

Here Turonian and Senonian crop out over a considerable area from beneath the Devonian; in the south-west, towards Eaux Chaudes they rest in autochthonous superposition upon hornblendic granite. Basement segments of ophite and Trias, as well as Flysch with Fucoids, rest upon the Cretaceous. The mighty sheet of Devonian and Carboniferous which was

[1] O. Mengel, Bull. serv. Carte géol. (1905), 1906, XVI, pp. 414–422, and op. cit. (1906), 1907, XVII, pp. 217–225, map.

[2] L. Bertrand, Bull. serv. Carte géol., XVI, p. 388.

[3] The chief sources of information are Bresson's above-mentioned work in Bull. serv. Carte géol., XIV; Carez, Géologie des Pyrénées françaises, and, in particular, Report on the meeting of the French Geological Society in the western Pyrenees, in the Bull. Soc. géol. France, 1907, 4e sér., VII, pp. 81–110.

thrust here from the west-south-west over the Cretaceous has left behind these relics.

The exposures on the Gave de Pau are no less instructive. Its highest affluents, the Gave de Gavarnie and the Gave d'Héas, are separated by a mass which projects to the north (Pic de Pimené, 2,803 meters; Mont Herran, 2,789 meters), and consists of sediments extending from the upper Silurian to the lower Carboniferous. The rivers unite near Gèdre. They have both eaten their way through the overthrust sheet (S + D + H, fig. 21) and the Cretaceous (C), and together form a crescent-shaped

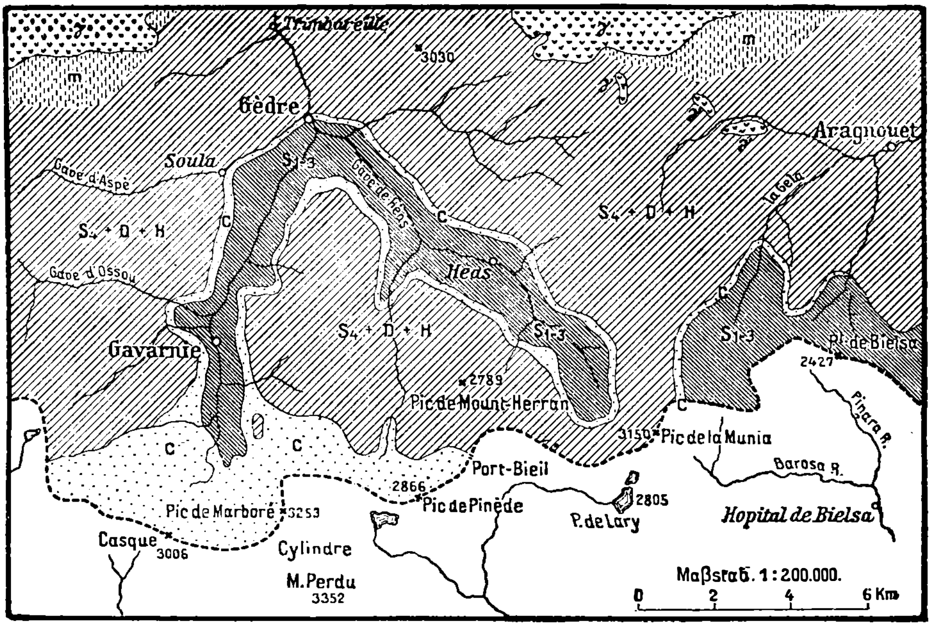


FIG. 21. *Gavarnie and the French frontier near Mont Perdu.*

S_{1-3}, Silurian, altered by granite; S_4 + D + H, upper Silurian, Devonian and Carboniferous; C, upper Cretaceous; γ, granite; m, contact zone of the granite.

window, which terminates on the west in the Cirque de Gavarnie, and on the east in the Cirque de Troumousse. At the bottom of the window, the basement, formed of lower Silurian altered by granite (S_{1-3}, fig. 21), is laid bare; overlying this, in autochthonous association with it, comes the Campanian with Rudistes, and above this, extending up to the lofty peaks of the Pimené, Mont Herran and the Pic de la Munia (3,150 meters), that part of the overthrust sheet which lies in the bend of the window. Bresson conjectures that the great movement towards the south took place along the thick graptolite slates. Hence it follows, since the substructure is lower Silurian, that an apparently normal succession might occur wherever the Cretaceous has completely disappeared in consequence of rolling out.

In any case the autochthonous superposition of the Cretaceous proves that S_{1-3} must have been exposed before the deposition of that formation.

The Cirque de Gavarnie ends in a mighty wall formed of steeply folded Campanian and Danian. The Palaeozoic sheet does not extend so far. On the ascent to the pass of Gavarnie the boundary between the sheet and the Cretaceous is quite steep [1].

Since the ascending Cretaceous is continuous with that exposed in the window, this boundary cannot be a fault. The piled-up folds of the Cretaceous limestones now form, on the Spanish frontier, a series of peaks over 3,000 meters in height (Marboré, 3,253 meters), and on the other side of the frontier they form Mont Perdu (3,352 meters). Nummulites have been found both on the Marboré and about the peaks of Mont Perdu.

Thus it appears that the substructure S_{1-3} was overlain by an autochthonous series extending from the Campanian to the Eocene, and that the whole of this overlying series was seized by the overthrust sheet, down to its lowest member, in which Hippurites are transformed into plate-shaped discs, and was carried along with the sheet and rolled out. Its sudden ascent and swelling out in the Cirque de Gavarnie and on the Spanish frontier indicate perhaps nothing more than a great bulging up at the margin, where it was relieved from the load of the overlying sheet. This accords with the occurrence of piled-up Cretaceous synclines, open towards the south, which de Margerie described so far back as 1886 as occurring in the Cylindre (3,327 meters), between Marboré and Mont Perdu [2].

Basses Pyrénées. It has been mentioned above that fragments of Flysch with Fucoids rest upon the Cretaceous of Eaux Chaudes. According to Bresson's observations, this Flysch is continued a good 30 kilometers further towards the west, enclosed between the substructure and the Palaeozoic sheet which has been thrust from the north [3]. Then, north of the Pic d'Anie (2,504 meters), this caught-in strip grows continually broader, till finally, where the Hautes Pyrénées have terminated on the Pic d'Anie, it forms in their place the imposing Flysch range which runs out from Sainte Engrâce north of Pampelona.

This Flysch is upper Senonian; towards the summit fossils of the Danian are found, and it thus corresponds in age with the Bavarian Flysch.

[1] L. Carez, Géologie des Pyrénées françaises, II, pl. IX, fig. 2. In Port Bieil on the south-east side of the Pimené we see still more clearly the superposition of Campanian and Danian, op. cit., pl. VIII, fig. 2; Barrois, Mission d'Andalousie, pp. 292 and 298 et passim for the relation of the Cretaceous to the superposition. Pimené is not included in fig. 21; it lies near the north end of $S_4 + D + H_1$, to the south of Gèdre.

[2] E. de Margerie, Notes géologiques sur la région du Mont Perdu, Ann. Club alp. franç., 1886, XIII, pp. 609–625; Douvillé and Bertrand also ascribe these folds merely to a 'refoulement', Bull. Soc. géol. France, 1907, 4e sér., IV, Meeting in the west Pyrenees, pp. 98, 99.

[3] A. Bresson, Feuille d'Urdos, Bull. serv. Carte géol., 1906, XVI, pp. 385–392, map.

It is distinguished as Spanish Flysch, in opposition to that on the north side, which is regarded as Cenomanian.

The following transverse section across the Basses Pyrénées is derived from the works of E. Fournier[1]:—

On the north lies the Cretaceous plain of Mauléon. Then follows a long anticline. Its north side consists of a normal series ranging down into the Trias, dipping towards the north or slightly bent over in that direction. In the axis lower Carboniferous occurs, or a thick Rothliegend-conglomerate (Poudingue de Mendibelza). The south side is always strongly overfolded towards the south, but the southern limb is but slightly represented, and generally only by Trias. This is separated from the Flysch by a thrust-plane which runs through the whole area, and dips towards the north. Then follows the Flysch and Cretaceous limestone range, which is much higher than the preceding, and here forms the orographic axis of the Pyrenees (Pic d'Orhy, 2,017 meters).

On the boundary plain between the Trias and the north border of the Flysch some lower Silurian crops out near Sainte Engrâce in a cleft; and in accordance with the movement directed towards the south, a recumbent sheet of Permian, Cenomanian, and Silurian lies upon the Flysch[2].

The West and South. A general map of the neighbourhood of Labourd, followed by a more detailed map of the northern district, has been published by Stuart-Menteath. A map of the south-west region has been furnished by de Yarza, of the south-east by Mallada. Termier has described the granite of Aja[3].

In the extreme north-east of the mass, near Hasparren, lies granitic gneiss forming Mont d'Ursouia (678 meters) and scarcely rising above the plain in front of it. It is adjoined by an area of Palaeozoic rocks forming an irregular ellipse, about 60 kilometers long towards the south-west; close to the border of this the granite of the Peña de Aja (816 meters) makes its appearance. In isolated localities upper Cretaceous occurs in transgression.

The map by Stuart-Menteath leaves no room to doubt that the anticline of Trias and Jurassic which approaches from Sainte Engrâce and forms the

[1] E. Fournier, Étude géologique sur la partie occidentale de la Chaîne des Pyrénées entre la Vallée d'Aspe et celle de la Nive, Bull. Soc. géol. France, 1906, 4e sér., V, pp. 699–723.

[2] Map and section are given by Bresson, Bull. serv. Carte géol., XVI, pp. 390-391.

[3] P.W. Stuart-Menteath, Sur la géologie des Pyrénées de la Navarre, du Guipúzcoa et du Labourd, Bull. Soc. géol. France, 1881, 3e sér., IX, pp. 304–333, map; Note sur une carte géologique de la haute et de la basse Navarre, op. cit., 1891, 3e sér., XIX, pp. 917–921, map; R. Adan de Yarza, Descripción física y geológica de la Provincia de Guipúzcoa, Mem. Com. Mapa geol. España, 1884, 175 pp., map, and Provincia Guipúzcoa, Geol. agric., Bosquejo petrogr., 4to, S. Sebastian, 1900, 26 pp., map; Mallada, Reconocimiento geológico de la Provincia de Navarra, Bol. Com. Mapa geol. España, 1882, IX, pp. 1–64, map; Termier, Le Granite de la Haja ou des Trois Couronnes, Bull. Soc. géol. France, 1907, 4e sér., VII, pp. 9–17.

north side of the Basses Pyrénées rests against the east side of the mass of Labourd and strikes to the north-west towards Hasparren. From there on, the same zone makes a bend towards the west, and the observations of de Yarza and Mallada show that almost all the rest of the mass as far as Roncevalle is girdled round by similar deposits. Upon these rests a broad mantle of Cretaceous limestone and Flysch which extends along the coast through Fuenterrabía, is continued through Guipúzcoa and unites north of Pampelona with the Flysch of the principal chain of the Pyrenees.

From this it appears that the Pyrenees are separated from the sea, along the Bidassoa and near San Sebastian, by a continuous zone of Flysch. In this region, according to de Yarza, they are folded towards the north, and in places even overfolded. The Flysch of Guipúzcoa is also folded towards the north. Rising out of it is a mass of ophite, 16 kilometers in length, 6–8 kilometers in breadth.

The 'Klippen' of Biarritz run parallel to the strike of the Flysch, along the lower course of the Bidassoa, but in Biscaya where the land is equally covered with Flysch a strike to the north-west is evident. It finds expression in a long ridge of ophite, possibly the continuation of similar masses previously mentioned; then in a long anticline of lower Cretaceous, striking through Bilbao; and finally in the long syncline of Eocene, which for a part of its course follows the upper Ebro and runs from Alava to Burgos. The folding in Biscaya is intense and directed towards the sea; i. e. towards the north-east[1].

Near Entrambasaguas, close to Santander, not far west of the region where the anticline of Bilbao approaches the sea, and thence onwards to beyond the Picos d'Europa (Peña de Cerredo, 2,642 meters), Termier followed a range consisting of overthrust sheets (Trias to Eocene) and further south of Palaeozoic beds; from its general attitude we must assume that this complex emerges south of the Flysch range[2]. Its termination, with folding towards the north, lies at Oviedo (II, p. 126).

Hence we may conclude that this range cannot be assigned to the Pyrenees[3].—

Only a few words are necessary with regard to the southern flanks.

[1] A. de Yarza, Descripción física y geológica de la Provincia de Alava, Mem. Com. Mapa geol. España, 1885, 175 pp., map; and Provincia de Vizcaya, op. cit., 1892, 192 pp., map.

[2] P. Termier, Sur la structure géologique de la Cordillère cantabrique dans la province de Santander, C. R. Acad. Sci. Paris, 27 nov. 1905.

[3] This view has also been expressed by Penck (Die Picos d'Europa und das Kantabrische Gebirge, Hettner, Geogr. Zeitschr., 1897, III, pp. 278–281); he believes that the tectonic continuation lies in the Sierras de la Demanda, de Urbion, and de Moncaya. In the first of these the strike is east and west (Larrazet, Recherches géologiques sur la région orientale de la province de Burgos, &c., Paris, 1895, transl. in Bol. Com. Mapa España, 1895, XXII, pp. 121–143), while to the south towards Soria and Moncaya the south-easterly direction of the Ebro makes its appearance (R. Chudeau, Contribution à l'étude géologique de la Vieille-Castille: Thesis, 8vo. Paris, 1896, 92 pp., map).

Scarcely anything need be added to the earlier descriptions by de Margerie and Schrader, and of Mallada [1].

The south foot of the high mountains is bordered by a Mesozoic zone, chiefly Cretaceous and of no great breadth, which comes from the north-west; to this the Cretaceous Flysch of Sainte Engrâce belongs. It is followed by a broad zone of moderately folded Eocene, striking from Pampelona through Jaca and onwards (Zone de l'Aragon). This again is bounded on the south by a fresh outcrop of Trias with ophite, and Cretaceous, which begins as a long and narrow strip between R. Aragon and R. Gallego, then proceeding north-east of Huesca it recedes irregularly towards the north, and next increasing in breadth and extent, once more reaches the Pyrenees on the upper Segra (Zone des Sierras). In this last part of its course it is formed of repeated arc-like fragments (Sierra del Monsech, 1,693 meters). In this way the 'Zone de l'Aragon' is closed in towards the south-east. This outcrop occurs in the north-west in the form of an anticline or a fracture, and some movement towards the south is still perceptible.

The valley of the Ebro is occupied by Miocene deposits.

Summary. In front of the Pyrenees lie two alien masses, that of Mouthoumet, which is evidently a part of the Montagne Noire, and that of Labourd. It is surrounded by folds which are connected with those of the Pyrenees. Were it not for this fact we might easily assert that the Pyrenees terminate east of the Labourd and that this mass lies outside the Pyrenees.

In contrast to the other younger European chains the Pyrenees clearly exhibit one movement directed towards the north and another towards the south. Where these movements meet, a steep or more or less fan-shaped arrangement arises, and probably sharp dislocation also, which, as we saw in the Gave de Pau, brings lower Devonian against Albian.

The effects of the movement towards the north may be traced from the Var through the whole of Provence; they are seen around the Mouthoumet and within its west border exhibiting flatfolding with Mesozoic sediments. They are manifest in the mass of the Roc de France through its course from the south-east of the Tech to the south foot of the Pyrenees. The great overthrusts of the north side of the Pyrenees (Trois Seigneurs, S. Barthélemy, &c.), the Petites Pyrénées, all the folds striking towards the north-west as far as Dax, and still further out beneath the plain the outer border of the Basses Pyrénées, which also surrounds the gneiss of Labourd, the Flysch zone of the Bidassoa, the mountains of Biscaya and the north of Spain as far as the Picos d'Europa—all these also belong to the movement

[1] E. de Margerie et Schrader, Aperçu de la structure géologique des Pyrénées, Ann. Club alp. franç. (1891), 1892, XVIII, 65 pp., map, pp. 605 et seq. One of the principal sources of information is still L. Mallada, Descripción física y geológica de la Provincia de Huesca, Mem. Com. Mapa geol. España, 1878, 439 pp., map.

towards the north. It was felt from Cannes to Oviedo. It was a general movement, perhaps associated with a syntaxis in west Guipúzcoa. Not only Mouthoumet but Labourd also was set floating towards the north, and along with them, apparently, the whole of that part at present overthrust towards the south.

The movement towards the south is very powerful but limited in extent. According to existing observations it begins on the Tech, at the south-east side of the Canigou; soon penetrates deeply into the Pyrenees, then includes the whole breadth of the Hautes Pyrénées, flattens out on the other side of Urdos, opens up the pinched-in syncline of Flysch in the direction of the Basses Pyrénées, and dominates it up to its termination, with the exception of the northern border. Towards the south, in the forelying Cretaceous and Tertiary sierras, folding towards the south is also present; it flattens out, however, before reaching the Ebro.

This local limitation points to subsidence. This is also suggested by the fact that, at the bottom of the window near Gavarnie, Cretaceous lies in autochthonous superposition on the lower Silurian, and thus afforded a denuded surface upon which a series ranging from the Campanian to the Eocene was deposited.

It is easy to imagine that a mass undergoing movement towards the north and consequently at the same time in a state of stress would, if interrupted by a subsidence, resolve this stress in the opposite direction, that is towards the south. This supposition would be in accord with the steep, fan-like disposition of the beds, otherwise hard to reconcile with the adjacent overthrusts towards the north.

At the same time a truly puzzling fact must be taken into account.

The Pyrenees lie more deeply within the pre-Permian structure of the Altaides than any other of the younger chains of Europe. Their so-called primary series consists simply of fragments of the Altaides. The strike (W. 30° N.) of the part moved towards the south coincides with the strike of Karpinsky's lines (W.N.W. to N.W.). As in the case of these lines the intensity decreases towards the west-north-west, the south limb is let down, and the movement, in contrast to the general northerly movement, is directed towards the south. These characters we term Asiatic, whether their occurrence in the Pyrenees is accidental or has a deeper significance can only be determined when the nature of these lines is known in greater detail. The fact that the movement towards the south terminates in front of the mass of the Roc de France does not support the theory of relations with Asia.—

The younger basic intrusions of the Pyrenees are instructive with regard to other mountains. That they have altered the adjacent rocks in the zone of contact has been demonstrated beyond doubt by Lacroix [1].

[1] A. Lacroix, Les Phénomènes de contact de la Lherzolite et de quelques Ophites des

They occur here sometimes as rounded masses, at others as parts of dykes, and again as intercalations which may reach a length of from one to four kilometers. According to the detailed accounts of Carez, two groups of intrusions may be distinguished. One belongs to the lower Lias and contains ophites only. The second ranges into the Gault and presents, in addition to ophite, lherzolite, serpentine, diorite, peridotite, and anorthosite (the latter as a dyke in peridotite [1]).

Here then we find repeated the series of green-rocks which at various horizons occurs at Ivrea and in the Piedmontese Alps, in the salt-bearing Trias of the East Limestone Alps, in the Lepontine sheets, in the Apennines, and in north-east Corsica, and in Elba, as well as throughout the whole course of the Mediterranean Atlas and the Betic Cordillera, from Tunis to Gibraltar, and thence to the Balearic isles. Lacroix has shown that in the Pyrenees biotite-granite by absorption of limestone passes into peridotite with hornblende. In this work we start from the theory that by far the greater part of these green-rocks, along with the peridotites, were originally deep-seated rocks. This view is supported by the presence of nickel ores.

Steinmann has drawn attention to the frequent association of these intrusions with the Radiolarian shales of the deep sea, and has sought to discover some causal connexion between the green-rocks and the deep sea [2]. The association is no doubt not uncommon, and may be observed at localities remote from one another; and we shall have occasion later to mention also the frequent occurrence of highly basic rocks in the middle of the Oceans. In the Pyrenees, the south of Spain, and the north-west of Africa, however, they occur in sediments of a kind which is not known in the deep sea, and in these cases the facts are not favourable to such a generalization.

In Europe these green intrusions, or fragmentary traces of them, are to be seen at hundreds of localities within the regions of great dislocation which extend from the Wolfgang-See to the margin of the Sahara. We do not find them in the foreland either in the north or the south, and in Europe we regard them therefore as accompaniments of the tectonic movements.

Pyrénées, Bull. Soc. géol. France, 1895, 3e sér., VI, pp. 307–446; Étude minérale de la Lherzolite des Pyrénées et de ses phénomènes de contact, Nouv. Arch. Mus. hist. nat. Paris, 1894, 3e sér., VI, pp. 209–308, and Livret Guide, Congrès internat. Paris, 1900, no. III, 34 pp., in particular p. 16. In a particular case, Lacroix shows that ejections of labradorite and andesite lavas made their appearance within the Rhaetic period: Les Tufs volcaniques de Segalas (Ariège), C. R. Acad. Sci. Paris, 20 janv. 1896.

[1] Carez, Géologie des Pyrénées françaises, III, pp. 1694 et seq., in particular p. 1702.

[2] G. Steinmann, Die geologische Bedeutung der Tiefseebildungen und der ophiolitischen Eruptiva, Ber. naturf. Ges. Freiburg i. B., 1905, XVI, pp. 44–46.

CHAPTER VII

LAURENTIA AND THE NORTHERN ISLANDS

1. The United States chain. 2. Laurentia. Greenland. 3. Islands of the north Atlantic. Iceland.

1. The United States Chain.

Far to the north, in Kennedy channel and Grant Land, Feilden and de Rance encountered a folded mountain range (II, p. 42). Much new light has been thrown upon it by the discoveries of Sverdrup and Schei in Eureka sound and Ellesmere Land [1]. Low has combined these observations with older ones, and has attempted a fresh sketch of the geological map of Arctic North America [2]. The range has been named the United States chain. We will now describe its principal characters, proceeding from the extreme north southwards.

Aldrich advanced as far as the north coast of Grant Land; mica-schists and metamorphic rocks are marked there on the map; the Challenger range borders this coast.

The north-east of Grant Land is a rias coast. Between Markham fjord and Feilden peninsula (cape Joseph Henry, lat. 82° 42′ N.) mountains of considerable size strike out to sea in an east-north-east direction. They consist of upper Carboniferous (and Devonian ?). Fairly high mountains, such as mount Grant (4,900 feet = 1,500 meters), mount Cheops and others, join them towards the interior, and it is doubtless here that the greatest heights of this northern chain occur. It is not impossible that the rocks of the north and of Heiberg island (long. 93° W., lat. 81° 22′ N.), which are probably Carboniferous and are traversed by intrusive rocks, correspond to the south-westerly continuation of this chain [3].

In the north-east of Grant Land, Feilden's Rawson beds make their appearance, a thick series of sediments which in all likelihood must be

[1] A. G. Nathorst, Sverdrup's Polar Expedition, 1898-1902; Ymer, 1902, pp. 529-534, map; O. Sverdrup, The second Norwegian Polar Expedition of the *Fram*, and P. Schei, Summary of Geological Results, Geogr. Journ., 1903, pp. 38-69, and map; further, P. Schei, Preliminary Report of the Geological Observations made during the second Norwegian Polar Expedition of the *Fram*, op. cit. tom. cit.

[2] A. P. Low, Report on the Dominion's Government Expedition to Hudson Bay and the Arctic Islands on board the D. G. S. *Neptune*, 1903-1904, 8vo, Ottawa, 1906, 355 pp., map. Here we may also refer to the beautiful map by Peary in Bull. Am. Geogr. Soc., 1903, XXXV (to p. 496).

[3] E. Etheridge, Quart. Journ. Geol. Soc., 1878, XXIV, pp. 612-635. Also the observations by Tschernyschew in Mém. Com. géol. Russie, 1902, XVI, p. 690 et seq.

correlated with the Trias of the south-west, as Schei also conjectures. They strike across from cape Bryant in north Greenland, and extend along the east side of Robeson channel to Polaris bay. West of the channel they crop out again in steeply upturned folds, and form cape Rawson, Black cape, &c., as well as the whole of the west coast as far as Scoresby bay, where they meet the foreland, that is, the Palaeozoic belt of the Canadian shield. The boundary evidently runs obliquely through the channel from Polaris bay to Scoresby bay.

Lady Franklin sound with Archer fjord, and next Hazen lake and Greeley fjord, which opens towards the west, probably lie in the strike of the mountains.

Schei describes folded formations from the north side of Greeley fjord, where species of Daonella and Halobia have been met with. The Trias extends on both sides of Eureka sound; Kittl describes Trachyceras from Schei's collections made in Bay fjord, and Protrachyceras and Halobia from Bear peninsula [1]. On the south side of this peninsula upper Carboniferous crops out. As we proceed further towards the west the accounts become less definite. Little is known of Sverdrup archipelago. The country lies lower, and Schei believes that the folding is not continued into Heiberg island. We know nothing of the interior, however.

The Trias of Eureka sound is an alternation of limestone and shales, with numerous sills, as is so commonly the case in regions towards the north, as for instance in Verkhoiansk.

As affording some support to the notion that Sverdrup archipelago belongs for the greater part to the Trias, we may adduce the fact that McClintock observed isolated patches of Jurassic deposits on the opposite coast of Parry archipelago (as shown for example by Harpoceras found at Wilkie point, Prince Patrick Land, lat. 76° 20′ N.). Trias, however, has never been observed there, and the substructure appears to be the flatly bedded Carboniferous of the Shield (II, 40, figs. 4 and 42) [2].

While all these questions remain open, there is at the same time no doubt that here in the north the Shield encounters a Mesozoic series otherwise foreign to it, and beneath this it plunges out of sight. In like manner the existence has been established of a fragment of folded mountains which extends with a south-west to west-south-west strike at least as far as Greeley fjord, and over Kennedy channel down to Scoresby bay, and this, judging from the arrangement of its rocks (mica-schist in the Challenger mountains) is folded towards the south, so that the Shield plays the part of foreland.

[1] E. Kittl, Die Triasfossilien von Heureka Sund, Report of the second Norwegian Expedition of the *Fram*, 1898-1902, no. 7, 8vo, Kristiania, 1907, 48 pp.

[2] Salter, in Belcher's travels. Tschernyschew conjectures upper Carboniferous. According to the lists upper and lower Carboniferous may well be present.

This folded range presents the characters of the Asiatic arcs, and may be regarded as a terminal part of the Asiatic structure extending across the North Pole.

Miocene beds containing leaves are met with here and there; they lie horizontal.

2. LAURENTIA.

That vast region of North America which is formed of ancient rocks overlain by horizontal Cambrian sediments has received the name of Laurentia. It comprises the whole of the Canadian shield; but if we are to regard it as a tectonic unit, we must include the whole of the flat-bedded superstructure up to some natural boundary[1]. Such a boundary is presented by the Rocky mountains, the United States chain, and, for nearly their whole length, the Appalachians also. The Colorado plateau, a fragment of table land, bounded on the east by the southern branches of the Rocky mountains, ought also, perhaps, to be regarded as a part of Laurentia.

In the south, Laurentian rocks crop out in the Ozark mountains. Then they reappear outside the Appalachians in Burnet county (Texas), and in these, as in the north, the gneiss is overlain by horizontal Potsdam sandstone. Still further towards the south-west, borings have revealed granite beneath the Cretaceous of the Plateau (IV, p. 79). Thus Laurentia, growing gradually narrower as it proceeds southwards, extends as far as lat. 30° N. and even still further south.

In the north, the lower Silurian Trenton limestone extends in isolated patches across the broadest part of the Shield in a flat transgression.

In *Minnesota* the lower horizons of the Silurian are seen to disappear. In *Manitoba*, according to Dowling's observations made on the south border of lake Winnipeg, the abraded pre-Cambrian folds are directly overlain by a light-coloured sandstone, with obvious false bedding, and upon this rests the thick Trenton limestone, followed by the Utica beds. Only these two members of the lower Silurian are represented here[2]. Much further north, on the *river Talzoa*, south of lake Doobaunt (lat. 62–63° N.), about 500 kilometers west of the north-west shore of Hudson bay, Burr Tyrrell found an isolated patch of Trenton limestone in the midst of the ancient rocks of the Shield[3]. Another great patch of the same kind is mentioned by Bell on

[1] Lawson, Note on the Pre-Palaeozoic Surface of the Archaean Terrane of Canada, Bull. Geol. Soc. Am., 1890, I, pp. 163–173; A. G. Wilson (The Laurentian Peneplain, Journ. Geol. Chicago, 1903, XI, pp. 615–669) gives a list of the works dealing with this subject. For details concerning the dipping beneath the Potsdam Sandstone: S. Weidman, The Pre-Potsdam Peneplain of the Pre-Cambrian of North Central Wisconsin, op. cit. tom. cit., pp. 289–313.

[2] D. B. Dowling, Report on the Geology of the West Shore and Islands of Lake Winnipeg, Ann. Rep. Geol. Surv. Canada, new ser., XI (1898), 1901, F, pp. 34, 62 et seq., map.

[3] Burr Tyrrell, Expedition through the Barren Lands of North Canada, Geogr. Journ., 1894, IV, p. 443, map.

the lower course of the *Nelson river* as it approaches the south-west side of Hudson bay [1]. In this southern region of the Shield, where the Potsdam sandstone marks the beginning of deposition, the Trenton limestone starting from the north of the St. Lawrence above *Quebec*, encroaches upon all the older horizons for a long distance towards the north, till it rests directly upon the pre-Cambrian rocks [2]. These sediments lie horizontal, in so far as they are not disturbed by faults.

In the east the case is similar.

The island of *Akpatok*, situated in the bay of Ungawa, which is surrounded by Archaean rocks, consists of Trenton limestone; Whiteaves has investigated the fossils and pointed out their resemblance to those of Manitoba [3]. An important contribution to our knowledge of the Silurian has been furnished by Schuchert's studies [4]. At the head of Frobisher bay (in lat. 63° 44′ N., long. 68° 56′ W.) lies 'Silliman's fossil mount' distinguished by the abundant presence of Trenton fossils. It is an insignificant horizontal patch resting on dark mica-schist. Then these same beds broaden out over the vast lake-basins of south Baffin Land, where Boas collected fossils from them, and they surround a large part of Fox channel. Now we approach the border of the Shield. In north Somerset finely stratified sandstone is seen beneath the Trenton limestone; in other parts of this region the Trenton stage rests directly on the Archaean rocks.

In the north the border is more complex than was once supposed. It attains a considerable breadth on the west in its course from Prince Albert Land through Melville island. The Parry islands, as is well known, consist chiefly of sandstone with Coal measures (II, p. 41), and this is followed towards the north by Carboniferous limestone containing abundant fossils. On the north the Carboniferous limestone is overlain by patches of Jurassic. Towards the east, in north Devon, the belt becomes narrower. The pre-Cambrian substructure advances towards the north across Jones sound, and also forms the whole of the south-east part of Ellesmere Land as far as lat. 79° N. The southern part to about long. 84° W. also belongs to it. As the belt becomes narrower, the formations which occur on its outer or northern side disappear. On Jones sound Schei distinguishes lower Silurian, upper Silurian, marine Devonian, and finally Devonian sandstone, from which Nathorst described magnificent fronds of Archaeopteris [5]. The Erian armoured fish (Ostracoderms) are also present. The Carboniferous of the

[1] R. Bell, Rep. Geol. Surv. Canada, new ser., XI, 1901 (1898), M, p. 16.

[2] Explanation of the sheet Three Rivers (Eastern Townships Map) by R. W. Ells, Supplement to Ann. Rep. Geol. Surv. Canada, new ser., XI (1898), 1901.

[3] R. Bell, Summ. Rep. Geol. Surv. Canada, 1897–1898, p. 82.

[4] C. Schuchert, On the lower Silurian (Trenton) Fauna of Baffin Land, Proc. Nat. Mus. U.S.A., 1900, XXII, pp. 143–177.

[5] A. G. Nathorst, Die oberdevonische Flora des Ellesmere-Landes, Report of the second Norwegian Arctic Expedition, no. 1, 22 pp., map.

Parry islands has disappeared, unless we may regard the upper Carboniferous limestone on Bear island as its last representative. Further north the pre-Cambrian of the Shield advances so far that at the bottom of Bay fjord (lat. 79° N.) it actually reaches the waters of Eureka sound on the west side of Ellesmere Land.

On the east side, in the Kane basin, Schei came upon Cambrian beds with Anomocare and several subdivisions of the lower Silurian; they occur in Bache peninsula, Norman Lockyer island, and as far as cape Prescott (lat. 79° 10′ to 79° 30′ N.). Further north, collections were made by Feilden; they have been described by Etheridge. We will only mention that abundant upper Silurian fossils were collected as far north as Offley island (lat. 81° 16′ N). In lat. 81° 6′ N., Bessels bay, *Bronteus flabellifer* was found; in lat. 81° 40′ N. a graptolite was obtained from the Drift, and in lat. 82° 30′ N. a Pentamerus was found.

These latter finds were all made in Greenland. The broad Palaeozoic belt which completely surrounds the Shield in the south and west, and with the same flat bedding borders it on the north from Banks Land onwards, passing in Ellesmere Land into the north-east direction, advances across Kennedy channel and Hall Land without any doubt further and further into Greenland (II, pp. 44, 72). Thence onwards it is accompanied for some distance in the north by marginal fragments of the United States chain; on the other side of cape Bryant such fragments are not known, and the coasts of Nares Land and Hazen Land, with their numerous fjords, up to the extreme north of the adjacent islands, that is as far as Peary's cape Morris Jesup (lat. 83° 50′ N.), probably belong to the border or to the pre-Cambrian rocks of the Shield itself.

The east side of Kennedy channel is alone sufficient to show *that Greenland is a part of Laurentia.*—

We must not fail to observe the extraordinary breadth maintained by the pre-Cambrian range within this common boundary as it makes its advance to the sea.

On the north side of the Belle-Isle strait a strip of Cambrian, crossing over from Newfoundland, rests horizontally upon the gneiss. It belongs to an older stage than the Potsdam sandstone, with which the border of the Shield begins elsewhere in the south [1]. It extends into the neighbourhood of cape Charles, in about lat. 52° N.; cape Camperdown, part of Bache peninsula, where Schei found beds containing Cambrian Tribolites above the granite, marks the inner margin of the northern belt, and lies in lat. 79° 6′ N. *The distance between cape Charles and cape Camperdown thus amounts to more than 27 degrees of latitude.*

The sixtieth parallel runs nearly through cape Chudley in north

[1] Walcott, Bull. U.S. Geol. Surv., 1891, no. 81, pp. 50 and 253.

Labrador and cape Farewell in south Greenland. In Labrador the ancient formations face the Atlantic Ocean for eight degrees of latitude. Thence onwards the coasts of Greenland lie opposite to them; but although Hudson bay is scarcely more than 200 meters deep, no bottom was reached in the middle of Baffin bay at a depth of 5,250 meters. For this reason Boas explains Baffin bay as a true inbreak. Daly has published an excellent summary on the coast of Labrador [1], and from this we may extract the following observations to complete the account we have already given of Hudson bay (II, pp. 30, 31).

On the south gneiss makes its appearance. In lat. 55° N., on the promontory of *Pomiadluk*, the gneiss is covered by an extremely thick mass of pre-Cambrian conglomerate, with a quartzose cement; this is involved in the pre-Cambrian folding of the gneiss, and somewhat further north, in *Aillik* bay, we meet with quartzites showing similar relations. Still further north we reach the great mass of gabbro which surrounds the bay of *Nain* and furnishes the iridescent crystals of labradorite to our collections. From this point the *Kiglapait* range advances towards the sea; its direction is east and west—that is, opposed to the general strike; it probably consists of basic eruptive rock, possibly corresponding, along with the mass of Nain, to the great masses of gabbro, situated much further to the west on the upper branches of the *Koksoak river*, which have been made familiar to us by the descriptions of Low. Then we reach the mountain group of *Kaumajet* (1,200 meters) with precipitous cliffs descending to Mugford harbour (about lat. 59° N.); only the lowest part of these, however, consists of gneiss. Above this follows a flat intrusive dyke of diabase, and then, alternating with basic rocks, come schist, quartzite, and limestone. The upper part of the cliff is formed of basalt, and bombs lie on the slopes; here we are already in the region of the Greenland basalts. We now reach the highest range of the east coast of North America, Torngat, the range of evil spirits (2,200–2,300 meters—according to other estimates as much as 3,000 meters). It is extremely wild, broken up into jagged peaks; on the coast only biotite gneiss and crystalline schists have been observed; towards the interior Adams has also found table mountains formed of ancient sediments like those of Mugford harbour. Cape Chudley is an outlier of this ancient range. These heights, as already pointed out, are of particular interest, since they are the remains of a relief which is older than the Cambrian period. It is possible that the sediments of Mugford harbour will some day be correlated with

[1] Boas, Peterm. Mitth., Ergänzungsheft no. 30, 1885, p. 39; R. A. Daly, The Geology of the north-east coast of Labrador, Bull. Mus. Comp. Zool., 1902, XXXVIII (Geological Series, V, no. 5), pp. 205–270, maps; also A. S. Packard, The Labrador Coast, 8vo, New York, 1891, 514 pp., maps. On p. 504 this author puts forward the theory that the fjords are troughs.

the Torridon sandstone of the western Hebrides, which lies almost in the same latitude.

Both coasts of *Hudson strait* are described in the works of Low and Bell[1]. There are no hills of any considerable height, and in general the dominant characters are those of the Shield. The flat Silurian island of Akpatok has already been mentioned. The north coast of the strait is distinguished by thick beds of crystalline limestone, in which dark graphitic gneiss is intercalated. In the region between lats. 62° 45′ and 64° N. Bell counted twelve of these beds with an average thickness of 660 meters; the limestone contains garnet, pyrites and white felspar[2].

Greenland. Archaean rocks and basalts with intercalated plant-bearing beds, which range from the lower Cretaceous into the Tertiary, make their appearance on the west coast. Between lats. 70° 15′ and 70° 45′ N. a marine intercalation of Senonian also occurs (II, 73)[3].

On the east coast, between lats. 72° and 74° N. (II, 72), Nathorst has succeeded in showing the presence of a superposed Palaeozoic series, which, although cut through by faults, resembles a fragment of the border of Laurentia[4].

Cape Dalton (lat. 69° 24′ N.) has afforded a surprising discovery. O. Nordenskjöld found there marine fossils, in which Rawn recognized Tertiary species of West European type. They probably correspond with those of Hochstetter foreland and Spitzbergen[5].

[1] A. F. Low, Report on an Exploration of part of the South Shore of Hudson Strait and of Ungawa Bay, and R. Bell, Report of an Exploration on the North side of Hudson Strait, Ann. Rep. Geol. Surv. Canada, new ser., XI, 1898, L and M, 47 and 38 pp.; further, Low, op. cit., 1900, XIII, D, 84 pp., and DD 31 pp., maps; also Steinmann and Bücking, Zur Geologie des Cumberlandgolfes, in Ergebniss der deutschen Polar-Expedition, Allgemeiner Theil, II, no. 6, 11 pp. (according to collections by Dr. Boas).

[2] For the west coast of Baffin Bay also, Steinmann and Bücking, Zur Geologie des Cumberlandgolfes, Ergebniss der deutschen Polar-Expedition, II, no. 6, 11 pp. The data referring to the east coast between latitudes 69° and 73° were collected by M. Belowsky, Beiträge zur Petrographie des westlichen Nord-Grönland, Zeitschr. deutsch. geol. Ges., 1905, LVIII, pp. 15–92.

[3] Stanton, in David White and C. Schuchert, Cretaceous series of the west coast of Greenland, Bull. Geol. Soc. Am., 1898, IX, pp. 356 and 360, confirms the Senonian age and sees a resemblance to certain species of the Fort Pierre stage of the United States.

[4] A. G. Nathorst, Bidrag till nordöstragrönlands Geologi, Geol. Fören. Stockh. Förh., 1901, XXIII, pp. 275–306, map; also Två Somrar i Norra Ishafvet, 2 vols., 8vo, Stockholm, 1900; and A. Smith-Woodward, Notes on some upper Devonian Fish-remains discovered by Professor Nathorst in East Greenland, Bihang k. Vet. Akad. Handl. Stockholm, 1900, XXVI, iv, no. 10; for the Jurassic, also B. Lundgren, Meddel. Grönland, 1895, XIX, pp. 191–214; further, Madsen, op. cit., 1904, XXIX, pp. 157–210, map, and Frech, op. cit., tom. cit., pp. 279–285. According to Frech, *Caryocistis granatum*, a fossil of the lower Silurian of Russia, was found on drift-ice in East Greenland, Lethaea Geognostica, 1897, II, p. 89, note 2.

[5] J. P. J. Ravn, The Tertiary Fauna at Kap Dalton in East Greenland, Meddel. Grönland, 1904, XXIX, pp. 93–104.

The south side of Scoresby sound (lat. 70° 20′ N.) consists of gneiss, covered by basalt, and in the inner ramifications of this sound Ryder encountered only Archaean rocks, with here and there sandstone of undetermined age [1]. The same ancient rocks, chiefly gneiss, also form the shores of the inner arms of all the fjords far up to the north, and probably the greater part of the substructure of the whole of Greenland. On the north shore of Scoresby sound, however, between long. 22° and 23° W., lies *Hurry inlet*, a long narrow bay running to the north; cape Stewart marks the west side of the entrance. From this locality E. Bay describes sandstone with Rhaetic plant-remains, Jurassic with marine shells, shales, basalt, and sandstone. The same series forms the whole of the west side; the east side consists of gneiss (lat. 70° 30′ to 71° 30′ N.), which appears to be separated from the gneiss masses of the interior. Nathorst regards Hurry inlet as a meridional fault with a downthrow to the west; on one of the *Fame islands* (lat. 70° 50′ N., at the head of Hurry inlet) he met with an eruptive rock, which, according to Bäckström's determination, is Monchiquite. The Jurassic of Hurry inlet seems to make its appearance again much further to the north, at the entrance to Oscar's fjord (lat. 72° N.).

We now reach the Palaeozoic rocks which strike across most of the fjords as far as lat. 74° N. The west, i. e. all the inner arms of Oscar's fjord and Franz-Josef fjord, is formed of pre-Cambrian rock striking north and south. The Silurian, which follows it towards the east, shows some folding, though it is not certain that this may not have been produced by dragging [2].

To the north, a fault running north and south separates the Silurian from a zone of Devonian which follows it on the east. To the east of this again, in the narrow belt which separates it from the open sea, a long zone of basalt sets in. On *cape Parry* (lat. 72° 30′ N.) Dusén observed rocks in which Bäckström recognized Aegyrine-syenite and a rock (Sölvsbergite) resembling Tinguaite; he assigns these to the same petrographical province as the Fame islands. On *cape Franklin* (lat. 73° 15′ N., at the entrance to Franz-Josef fjord) and at the head of Musk Oxen fjord (lat. 73° 42′ N.) granite was met with. Since the thick Silurian does not reappear to the east of the Devonian at these two localities, we must suppose that the Devonian is cut off on the east by a meridional fault. All the points mentioned above, however, the eruptive rocks of the Fame islands and cape Parry, and the ancient granites of cape Franklin and the Musk Oxen fjord, although distributed over no less than three degrees of latitude, lie on the same meridional line between long. 22° and 22° 30′ W. Nathorst

[1] C. Ryder, Den östgrönlandske Expedition udf. 1891–1892, 3 del, Meddel. Grönland, 1896, XIX, E. Bay, Geologi, pp. 145–187, map.

[2] 'Probably folding in a trough.' The Devonian, however, exhibits no folding, and that of the Silurian may be pre-Devonian.

conjectures that the Jurassic outcrops of *Kuhn* island (lat. 74° 45′ N.) are also let down in the gneiss. The same observer draws attention to the distribution of the basalts over a long zone following the coast, and from this fact we may conclude that the structure of this coast also must have been affected by meridional subsidences. Cape *Broer Ruys* (lat. 73° 30′ N.) is regarded as an ancient centre of eruption.

Here for the first time, on the east coast of Greenland, the characters which may be regarded as distinctive of Laurentia vanish beneath the Ocean. Laurentia extends from south Texas to the Arctic Ocean through 53 or 54 degrees of latitude, and from the mouth of the Mackenzie to the east coast of Greenland through more than 110 degrees of longitude. It is not known, however, whether the Palaeozoic sediments of eastern Greenland are really part of the marginal belt, or a downthrown fragment of the 'roof', or a Caledonian fragment. Nor do we know how far the ancient rocks of south Greenland and Labrador extend beneath the Atlantic Ocean.

Laurentia is a very ancient unit. *It behaves towards all the younger folds as a foreland.*

Nevertheless, the structure of Laurentia is by no means uniform. In those places where the pre-Cambrian basement has been studied in detail, as, thanks to the abundant presence of metalliferous ores, is the case, for example, in the regions around lake Superior, a diversified series of sedimentary rocks with various foldings, unconformities, and transgressions has been revealed lying above the oldest gneiss and granite and beneath the Cambrian beds. The work already accomplished in this region, as well as the magnitude of the problems which still remain unsolved, may be seen from the writings of Van Hise, Shirley Bailey, and Lloyd Smith on the mineral region of Marquette in Michigan [1].

Amidst so much that is unknown, it remains in any case certain that the folds of Laurentia were for the greater part already worn down before the Cambrian period, or at least before the Potsdam sandstone, and that their strike is as completely independent of the strike of the Appalachians as it is of the western Cordilleras.

In the Marquette region, mentioned above, an east-and-west strike prevails; and the question arises as to whether irregularities in the surface of the oldest gneisses may not be the cause of broad transverse folds. The peninsula of Keweenaw advances towards the middle of lake Superior in the direction of Michipicoten island in the form of an arc. It is probably part of a trend line, for the whole region surrounding the lake on the west is characterized by a south-west strike corresponding to the course of the

[1] C. R. van Hise and W. Shirley Bailey, The Marquette Iron-bearing District of Michigan, including a chapter on the Republic Trough by H. Lloyd Smith, Monogr. U.S. Geol. Surv., 1897, XXVIII, 608 pp., Atlas.

arc, and it seems as though the same arc might dominate all the land between lake Winnipeg and Hudson bay.

In Labrador the prevalent pre-Cambrian strike is north-west or north-north-west, it is the same in Hudson strait; in western Greenland, on the other hand, the strike is said to be north-east, and about the great fjords of eastern Greenland it is north and south. But much work remains to be done before a correlation of the data can be attempted.

Greenland is a horst standing between subsidences of different age. The Mesozoic seas are represented in the east by Trias and Jurassic sediments of Arctic character, in the west by the upper Senonian transgression (II, p. 294). At the same time the horst is a fragment of Laurentia. How far its Laurentian rocks are continued beneath the Ocean is, as we have seen, not known, but it is not impossible that they may reach the western Hebrides which lie in the latitude of Labrador.

3. Islands of the North Atlantic.

Having obtained some knowledge of Laurentia, let us now consider Nansen's beautiful bathymetrical chart of the north Polar sea, or Hudleston's description of the coasts of western Europe[1]. Towards the north, near lat. 80°, the sea is narrowed by a plateau advancing from the east. Except in a few localities this maintains a height of 200 meters. It includes Spitzbergen along with King Charles Land, Franz-Josef Land, Hope island and Bear island (II, p. 66). All the islands have a tabular structure, except where they are formed of pre-Devonian rocks; they lie between the branches of the Uralides, and we may justly regard the plateau as a continuation of the plain of the Petchora[2]. From the base of

[1] F. Nansen, The Norwegian North Polar Expedition, Scientific Results, 1904, vol. IV, pl. I; W. H. Hudleston, On the East Margin of the North Atlantic Basin, Geol. Mag., 1899, dec. IV, vol. VI, pp. 97–105 and 145–157, maps.

[2] For the stratigraphy, E. T. Newton and J. J. H. Teall, Rocks and Fossils from Franz-Josef Land, collected by the Jackson-Harmsworth Expedition, Quart. Journ. Geol. Soc., 1897, LIII, pp. 477–519 and 646–661; R. Koettlitz, Geology of Franz-Josef Land, op. cit., 1898, LIV, pp. 620–645; F. Nansen, The Norwegian North-Polar Expedition, 1893–1896, Scientific Results, II; J. F. Pompecki, Jurassic Fauna of Cape Flora, Franz-Jozef Land, with a geological sketch by F. Nansen, and op. cit., III, A. G. Nathorst, Fossil Plants from Franz-Josef Land; further, Bidrag till Kung Karls Lands Geologi, Geol. Fören. Stock. Förh., 1901, pp. 341–378; Pompecki, Marine Mesozoic of King Charles Land, K. Svenska Vet. Ak. Förh., 1899, pp. 449–464; G. de Geer, Rapp. om d. Svenska Geologiske Expedition till Isfjorden, Ymer, 1896, pp. 259–266; A. Smith-Woodward, Fish-remains collected in Spitzbergen, Bihang Svensk. Vet. Ak. Handl., 1900, XXV, afd. IV. no. 5, pp. 1–5; J. G. Andersson, Stratigraphie und Tektonik der Bären-Insel, Bull. Geol. Inst. Univ. Upsala, 1899, IV, pp. 243–280, map; Nathorst, Några Upplysningar till den nya Karten öfver Beeren Eiland, Ymer, 1899, pp. 171–185. maps; Nathorst, Zur fossilen Flora der Polarländer, 4to, 1894–1902. De Geer thought he observed folding on the Eisfjord in Spitzbergen (op. cit., p. 263). Nathorst ascribes these movements to dragging

the Mesozoic onwards the stratified succession resembles not that of the north Atlantic, but of the polar regions and the north Pacific Ocean [1]. The most surprising fact, however, is the occurrence of marine shells of Miocene type both in Spitzbergen and east Greenland (I, p. 288; II, p. 73).

This plateau is a fractured area; the islands which are known in greatest detail are cut through by faults with a prevalent north-and-south direction. The dislocation of Wijde Bai in Spitzbergen (II, p. 68, fig. 8) is older than the upper Devonian. Traces of the Caledonian system possibly exist. Two faults, one with a strike to north-north-west on Swedish promontory, and another with a strike to north-north-east in King Charles Land, are, according to Nathorst, younger than the Neocomian and older than the flora with *Ginlco digitata*. Other faults are later than the Tertiary flora. The subsidences have thus occurred at different periods. The entire plateau, however, seems to break off along an almost straight line which runs from about lat. 80° N. towards the south-south-east. This fracture lies not far west of Spitzbergen, and only terminates a little south of lat. 70° N., in the immediate neighbourhood of the Norwegian coast, i. e. north of the Lofoden islands, where the last remains of the polar sediments are let down along a fault, with a throw, as estimated by Vogt, of 400 meters at least. This fault strikes north-north-east in accordance with the direction of a considerable submarine cliff which has been traced between lats. 64° and 68° N. [2]. Similar facts are afforded by the coast of Greenland. In that region we have become familiar with meridional fractures which cut through the crust from lat. 70° 30′ to 73 or 74° N.; there also a steep submarine cliff occurs, which strikes to the south-south-west, nearly parallel to the coast. Off Franz-Josef fjord and cape Broer Ruys in particular, the sea bottom sinks rapidly from an edge at 400 meters down to 2,400 meters. Between the east-and-west slope there are long intervals, situated in the meridian of Greenwich and west of it, which lie below 3,000 meters.

To the south-west and south-south-west of these abysses lie the *volcanic islands*, first Jan Mayen, next Iceland and the Faröes, then further away

along faults, Fossile Flora, I, pp. 9, 10. The lowest stage on Bear island is upper lower Silurian (Lindström, Öfvers. K. Vet. Akad. F. Handl., 1899, pp. 41–47); this is covered unconformably by upper Devonian with Holoptychius and *Archaeopteris hibernica*. The lower Carboniferous is absent. A stage with *Athyris ambigua* is assigned to the middle Carboniferous; this is followed by several stages of the upper Carboniferous, which also contain indications of intervening transgressions (Tschernyschew, Mém. Com. géol. Russie, XVI, 2, p. 687), and above this marine Trias (J. Böhm, Zeitschr. deutsch. geol. Ges., 1899, p. 325).

[1] J. F. Pompecki has attempted to determine tbe outlines of this sea, Aucellen und Aucellen ähnliche Formen, N. J. f. Min., Beil.-Band XIV, 1901, pp. 319–368, map; also Aucellen im fränkischen Jura, op. cit., 1901, I, pp. 18–36.

[2] J. H. L. Vogt, Söndre Helgeland, Norges Geol. Undersög., no. 29, 1900, 178 pp., and maps, in particular pp. 4–8.

St. Kilda and Rockall [1], and finally, in a peculiar trough, the islands of the inner Hebrides. Towards the east and south lies the mainland with its islands, the Lofoden, Shetlands, Orkneys, and others.

The steep descents to great depths which occur in the north have been regarded by Hudleston and Vogt as due to tectonic causes. Although an exaggerated impression of this steepness is given by the usual methods of representation, yet in places it is really considerable. The generally flat bedding and the concordant character of the sediments in east Greenland and Spitzbergen, as well as the frequent occurrence of more or less meridional faults, and the corresponding direction of the great abyssal depths, lend probability to this view.

The extreme north is characterized far and wide by tabular flows of basic lavas. In Siberia they make their appearance far to the south of the amphitheatre. They approach from Mongolia, rest on the summits of the Tunkin Alps, in the depressions of Nishni Udinsk and Kansk, and at numerous localities in the tableland, from the Yenisei in the west to the meridian of 110° in the east. Sometimes they form the summits of the Goltzi, and are older than the valleys; at others they have flowed down into the valleys. On the Angara they probably date back to the age of the Tungusian flora (lower Gondwána).

From the lowermost part of the Yenisei, and from Dickson's harbour, these flows are continued to Franz-Josef Land, where at least a part of them is of Jurassic or lower Cretaceous age. The lavas and dykes in Swedish promontory are to be referred to the same period, and probably also the closely related diabases of Stans promontory, Hinlopen strait, and other parts of the archipelago of Spitzbergen [2]. It would seem that in these tabular islands no flows of Tertiary or later date have as yet been certainly recognized. The case is different in the west; basalts associated with Tertiary plants are mentioned as occurring at several localities along the coast of east Greenland. The Tertiary beds of cape Dalton contain basaltic detritus. In the extreme north-east, at the entrance to Peary channel, there stands, like a mighty corner stone, the basalt rock of Navy

[1] St. Kilda is formed of gabbro with dykes of granophyre, outcrops resembling others in Ireland; W. J. Sollas, Volcanic district of Carlingford and Slieve Gallion, I, Relation of the Granite to the Gabbro of Barnave, Trans. Roy. Irish Acad., 1894, XXX, pp. 477–511; A. J. Cole, Geology of Slieve Gallion, Sci. Trans. R. Dublin Soc., 1897, VI, pp. 213–248. The island of Rockall, along with Helen's Reef (lat. 57° 36′ N., long. 13° 42′ W.), consists, according to the few fragments obtained from this almost inaccessible reef, of an Aegirine-quartz-albite rock (Rockallite); the sea bottom is strewn with basalt: W. Spottswood Green, Brown, and Barrington, Rockall Island and Bank, Trans. Roy. Irish Acad., 1897, XXXI, pp. 39–48, maps.

[2] A. Hamberg, Ueber die Basalte des Kung Karl-Landes, Geol. Fören. Stockh. Förh., 1899, XXI, pp. 509–532; H. Backlund, Diabases du Spitzberg oriental, Mission scientifique pour la mesure d'un arc de méridien, Mission Russe, 1907, II, 29 pp., map; in this work these diabases are regarded as more recent than the upper Jurassic (p. 10).

cliff, with a precipitous fall of 1,100 to 1,200 meters[1]. At the entrance to Robeson channel, and extending up to lat. 81° 45′ N., leaf-bearing beds and basalts are again associated (I, p. 287); in Disko island, on the west coast, Cretaceous basalts lie beneath them. In west Ellesmere Land the Tertiary beds occur without basalts; thence, in association with basalts, they are found at several points nearly as far as the mouth of the Mackenzie; the leaf-bearing beds are steeply upturned in New Siberia, and basaltic lavas occur in the northernmost part of the neighbouring continent. Then follow the isolated outliers of the basic lavas of Siberia, until finally those of Dickson's harbour are once more reached.

At a distance of 129 kilometers west-south-west of Suderöe, the most southerly of the Faeröes, lies the middle of the Faeröe bank, which extends from north-north-east to south-south-west for a distance of 90 kilometers. Post thinks that it marks the site of a volcano[2]. From this point onwards the basaltic flows may once have extended in an unbroken course over the inner Hebrides and considerable parts of Scotland and Ireland. Their remains must be assigned to the Tertiary aera (I, pp. 156, 288)[3]. The existing state of the Faeröes leaves no room for doubt that they are the remains of a once much larger area.

The investigations of Archibald Geikie in this region have furnished results of great value for the study of volcanic activity.

The whole of that part of the sea to the north of the basaltic plateau of Antrim presents the characters of an irregular fault-trough. These are produced by the inclination of the intercalated plant-bearing beds, which even on the Faröe islands is considerable. Fig. 22 shows a small reef of basalt rising from the sea, on which the bed of a stream has been preserved with pebbles from the mainland.

Nothing, however, is more significant than the vast extent of the injections. The Whin sill (I, p. 154), 120–130 kilometers in length, may serve as an example. Steeply ascending dykes run in large numbers from

[1] Peary, Geogr. Journ., 1893, II, p. 310.

[2] H. v. Post, Om Färöarnes uppkommst, Geol. Fören. Stockh. Förh., 1902, XXIV, pp. 274 to 282; in particular p. 280.

[3] Geikie's description differs from that given in this work (I, p. 155) which follows Judd; according to Geikie's results the gabbros are masses which have penetrated into the basalts, while the granophyres and granites are still later intrusions. The History of Volcanic Action during the Tertiary Period in the British Isles, Trans. Roy. Soc., Edinburgh, 1888, XXXV, pp. 21–184, maps; Relation of the Basic and Acid Rocks of the Tertiary Series of the Inner Hebrides, Quart. Journ. Geol. Soc., 1894, L, pp. 212–229; The Tertiary Basalt-Plateaux of north-west Europe, op. cit., 1896, LIII, pp. 331–405; and, in particular, The Ancient Volcanos of Great Britain, 8vo, 1897, II, pp. 107–478; on the other hand, Judd, The Tertiary Volcanos of the Western Isles of Scotland, Quart. Journ. Geol. Soc., 1889, XLV, pp. 187–218; The Propylites of the Western Isles of Scotland, &c., 1890, XLVI, pp. 341–384, and On Intrusions of Tertiary Granite, &c., op. cit., 1893, XLIX, pp. 175–195 et passim.

the east coast of Yorkshire to Donegal bay on the Irish coast, and to the island of Lewes in the western Hebrides. Their course is almost always rectilinear, and is completely independent of the structure of the land. They cut through the great fault which bounds the Scottish fault-trough on the south (II, p. 78, fig. 10). Their prevalent direction is north-west to west-north-west, whence some approach is made on the north to a radiate arrangement. At many localities these dykes occur so closely crowded together that we must assume extensive fissuring of the sub-structure. The longest of them is Cleveland Dyke, which has been traced from the east coast of Yorkshire across the whole kingdom towards the west-north-west as far as Solway firth, a distance of 177 kilometers; and if some considerable outcrops in Ayrshire may be regarded as its continuation, it reaches a length of 300 kilometers[1].

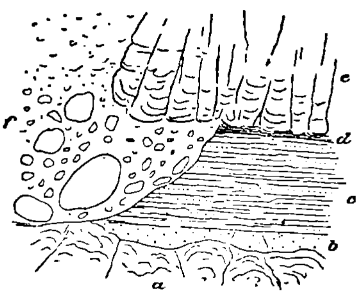


FIG. 22. Pebbles from the mainland on the basalt cliff of Dun Beag (Sandry island, between Runn and Canna) (after A. Geikie). *a*, amygdaloid basalt; *b*, tuff; *c*, shaley ash; *d*, carbonaceous shale; *e*, amygdaloid basalt; *f*, pebbles.

Geikie concludes that during the Tertiary aera *a vast reservoir of lava* or a series of such reservoirs must have existed beneath the whole of this region[2]. The thickness of the sediments cut through by the dykes, from the base of the Silurian upwards, is estimated at 5,300 meters, but the magma basin must have lain much deeper.

The Eriboll zone of Caledonian disturbance, which includes some of the most remarkable dislocations known anywhere in the earth's crust, affords no boundary to the reservoir, and we are led to the conception of *lava basins, the outlines of which are independent of the structure of previously existing mountain ranges.*

Iceland. These observations also lead us to a different interpretation of the significance of the active volcanos of *Iceland and Jan Mayen.*

A large number of the middle Tertiary species of Europe, such as *Sequoia Sternbergi*, *Fagus Deucalionis*, and *Liriodendron Procaccinii* occur in the Surturbrand, i. e. the plant-bearing beds intercalated with the basalts of Iceland. This flora is the same as that which is found, for example, at cape Lyell in Spitzbergen, where it is not associated with basalts, and in the island of Mull, where it is interbedded with basaltic flows. For this reason Nathorst has long been of opinion that the

[1] For the petrology, J. H. Teall, Petrological Notes on some North of England Dykes, Quart. Journ. Geol. Soc., 1884, XL, pp. 209-246.

[2] A. Geikie, Ancient Volcanos, II, p. 178 et passim.

American species in the European floras must have migrated across a continuous tract of land, which led from Greenland to Iceland and onwards [1]. Judd maintains that Antrim, the Hebrides, the Faröes, and Iceland form one and the same petrographical province [2]. *Possibly*, says Geikie, *the present active vents of Iceland and Jan Mayen are the descendants in uninterrupted succession of those that supplied the materials of the Tertiary basaltic plateaux, the volcanic fires slowly dying out from south to north* [3]. As regards the nature of the igneous rocks, Bäckström has shown that there is complete correspondence between those of Scotland and Iceland, extending down even to their respective batholites, with the single exception that in Iceland granophyres form the terminal member of the series, while in Scotland granites also occur [4].

When we first referred to the island of Iceland (II, p. 131), Theodor Thoroddsen had just entered on those important investigations which have since afforded us a clearer insight into the connexion existing between fractures of the crust, volcanic eruptions, and hot springs, than is to be obtained, perhaps, from any other locality in the world [5]. But even previously to Thoroddsen's work it was evident that the outline of the island had been partly determined by subsidences, and it is these alone which we propose to consider now.

It is well known that the island consists of a thick tabular mass of successive basaltic sheets which is traversed by a number of recent volcanic products.

Let us begin our study in the north-west peninsula. Here the lie of the Surturbrand has revealed the unexpected fact that *the basaltic basement is traversed by concentric arcuate caldron fractures,* and large fragments having the form of circular strips or segments have been let down along these fractures [6].

[1] A. G. Nathorst, Polarforskningar, Bidrag till Forntidens Växtgeografi, in Nordenskjöld, Studier och Forskningar foranl. af min Resor i höga Norden, 8vo, Stockholm, 1883, p. 258 et passim. A remarkable fact is the occurrence of marine deposits which are not more recent than the English Red Crag (II, p. 132); Jeffries and S. Wood, Quart. Journ. Geol. Soc., 1885, XLI, p. 96, and Pjetrusson, op. cit., 1906, LXII, pp. 712–715. According to Pjetrusson the so-called Palagonite formation was produced by ice; Moræner in den Islandske Palagonitformation, Overs. K. danske Vid. Selsk. Forh. Kopenhagen, 1901, pp. 147–170; also Geogr. Mag. Edinb., 1900, pp. 265–293; on a shelly Boulder-Clay in the so-called Palagonite Formation of Iceland, Quart. Journ. Geol. Soc., 1903, LIX, pp. 356–361.

[2] J. W. Judd, Quart. Journ. Geol. Soc., 1886, XLII, p. 54.

[3] A. Geikie, Trans. Roy. Soc. Edinb., 1888, XXXV, p. 75.

[4] H. Bäckström, Beitrag zur Kenntniss der isländischen Liparite, Geol. Fören. Stockh. Förh., 1891, XIII, pp. 637-682, in particular p. 671 et seq. For the union of Norway with Spitzbergen, and Pettersen's Arktis (II, p. 67).

[5] In particular, T. Thoroddsen, Island, Peterm. Mitth., 1906, Ergänzungshefte nos. 152 and 153, 358 pp., maps.

[6] T. Thoroddsen, Nogle Iagttagelser over Surtarbrandens geologiske Forhold i det

Breidi fjord on the west coast and Húna Flói on the north coast are subsidences cutting into the basalt, and almost separating the laciniated peninsula from the rest of Iceland, to which it is joined by an isthmus not more than 7 or 8 kilometers broad. Several (apparently four) concentric caldron fractures cut through the peninsula, they are accompanied in places by hot springs. The first of these is the most important; it runs from the Isar fjord to the Talkna fjord, each of the segments formed by the fractures present a steep fall *towards the interior*, and a gentle slope towards the exterior (fig. 23).

In the state of Kansas, U.S.A., caldron fractures were produced in 1879 as a result of the extraction of salt, and gave rise to a salt pool near Pearlette but in this case the steep faces of the circular strips were turned *towards the exterior* [1]. In 1895 a bed of quicksand beneath a part of the town of Brüx discharged itself laterally into some lignite mines; in this case it was observed that the sinking of the ground began along the periphery, and advanced gradually towards the spot at which the subterranean discharge occurred. When at a later time the phenomenon was repeated, fissures originated at some distance outside the periphery formed during the first catastrophe, and the subsidence passed on as before towards the centre of discharge [2].

As an illustration, the discharge below Brüx affords a better example than the pumping out of the salt near Pearlette. When the consolidation of a great casting proceeds unequally, some of the metal remaining molten at one spot may find its way out at the side, leaving a hollow cavity, which the foundry master calls a 'Lunker'. So with regard to the north-west of Iceland, we might say that a 'Lunker' had broken in.

Faxa fjord is a regular caldron fracture on the western coast, accompanied by volcanos and hot springs. The long basaltic horst, which separates it from Breidi fjord, bears at its extremity the volcano Sneffels-Jökel. On the south the boundary of the fjord is formed by the volcanic peninsula of Reykjanes [3].

On the northern fjords arcuate inbreaks do not occur till we reach long. 17° 30′ W. Then we find a broad trough-like inbreak, which runs

nordvestlige Island, Geol. Fören. Stockh. Förh., 1896, XVIII, pp. 114–154, in particular p. 147; Islandske Fjorde og Bugter, Geogr. Tidsskr., 1902, XVI, pp. 58–82; for the isthmus, Höjlandet ved Langjökull, op. cit., 1900, XV, pp. 3–14, map.

[1] W. Johnson, Ann. Rep. U.S. Geol. Surv., 1901, XXI, 4, p. 708 et seq., in particular pl. CXXXVIII.

[2] F. E. Suess, Jahrb. k. k. geol. Reichsanst., 1898, XLVIII, p. 491 et seq.

[3] T. Thoroddsen, Snæfellsnes i Island, Ymer, 1890, pp. 144–188, map; Geologiske Iagttagelser paa Snæfellsnes og i Omegn af Faxebugten, Bihang Vet. Ak. Handl. Stockholm, 1891, XVII, afd. II, p. 95; also Verh. Ges. Erdkunde, Berlin, 1893, Geografiske og geologiske Undersögelser ved den sydlige Del af Faxa flói, Geogr. Tidsskr., 1903, XVII, 56 pp., map et passim.

through the whole of Iceland, first towards the south and then in an arc towards the south-west, so that the peninsula of Reykjanes, to the south, becomes its northern boundary. This fault-trough, which is sharply defined in the north, includes the largest and most remarkable of the recent volcanos of Iceland. It also includes within its arc all the caldron fractures mentioned above.

Its western edge is continued from the north along the western border of the Skálfandi fjord, and thence for a distance of 150 kilometers towards the south as a steep basaltic cliff rising 500–600 meters above the bottom of the trough. The eastern edge runs along the base of the peninsula of Langenes. Skálfandi fjord, Husavik, Tjörnes, Axar fjord, and Thistil fjord

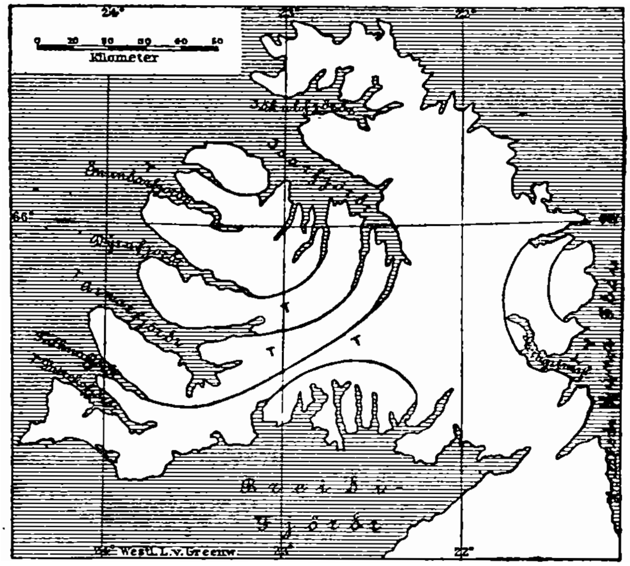


FIG. 23. *The north-west peninsula of Iceland.* (After Thoroddsen.)

lie within the subsidence. In this region earthquakes are of frequent occurrence. The downthrown band is traversed as far as Myvatn and beyond by numerous fissures, which strike north and south, parallel to the margins of the fault-trough. They separate lofty horsts from deep fault-troughs; hot springs and volcanos accompany their course like beads on a thread; great lava floods have proceeded from them[1].

From about lat. 65° 15′ N. onwards the fissures turn towards the south-

[1] T. Thoroddsen, Vulkaner i det N. O. Island, Bihang k. Handl. K. Svensk. Vet. Ak., 1888, XIV, Afd. II, no. 5, 71 pp., map; also Mitth. Geogr. Ges. Wien, 1891, XXXIV, pp. 117 and 245; Fra det N. O. Island, Geogr. Tidsskr., 1896, XIII, 24 pp., map, and 1898, xiv, pp. 7–28, map, and in particular Die Bruchlinien Islands und ihre Beziehungen zu den Vulkanen, Peterm. Mitth., 1905, pp. 49–53, map.

south-west, and afterwards more towards the south-west; maintaining this direction they reach the north side of the Vatna Jökull with its ice mass, which, entering from the east, overflows a large part of the downthrown region. On its south-west side the long fissures striking to the south-west set in, among them the Eld-gjá cleft, 30 kilometers in length, the equally long Laki cleft, on which about a hundred eruptive centres occur[1]. In this way the principal zone with its numerous volcanos, while still of considerable breadth, reaches the south coast in numerous south-westerly lines, and is still further prolonged in the chain of the Vestmanna islands and the Fuglasker beyond Reykjanes into the sea. On the peninsula of

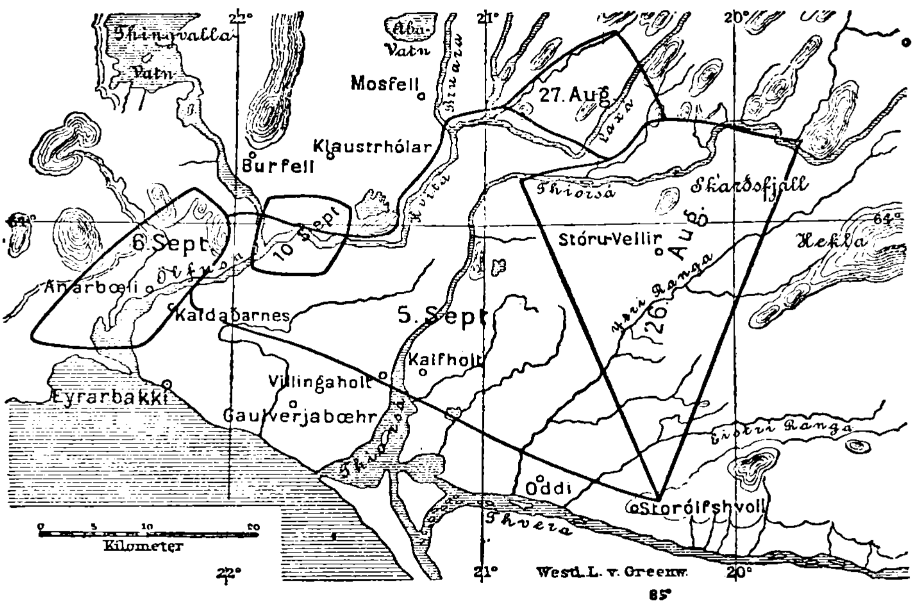


FIG. 24. *Earthquakes in Iceland.* (After Thoroddsen.)

Reykjanes, Thoroddsen counted at least 30 volcanos and over 700 craters. The soundings made by the Ingolf expedition show that a submarine ridge is continued beyond the Fuglasker very far out in the same direction to the south-west[2].

[1] A. Helland, Lakis kratere og lavaströmme, Universitätsprogramm for 2 Sem., 1885, Kristiania, 1886; Thoroddsen, Fra Island indre Höjland, Geogr. Tidsskr., 1889, 24 pp., map; and Rejse i Vester-Skaptafells Syssel, op. cit., 1894, XII, pp. 167–234, map et passim.

[2] T. Thoroddsen, Geografiske og geologiske Undersögelser ved den sydlige Del af Faxa flói, Geogr. Tidsskr., III, pp. 11 and 21; Islandske Fjorde og Bugter, op. cit., 1902, XI, p. 7. The submarine ridge, as it is represented on the map of the Ingolf expedition, is so extremely long and narrow that it suggests a dragging of the ashes through the sea, such as occurred in the Kuriles, Geogr. Tidsskr., 1898, XIV.

In the region south-west and west of Hecla is a low-lying strip of land bordering on the sea and separated rather sharply from the higher land in the north. Here violent earthquakes occur; in the case of one which was felt in 1896, it seemed as though more or less polygonal areas or fragments of the Crust could be distinguished which were disturbed on different days. This also is a downthrown area; in 1896 the shocks always proceeded from the boundary towards the higher land. In spite of their violence the adjacent volcano of Hecla showed no signs of activity[1].

These events mark the continuation of that great process by which the great basaltic plateau of the north has been broken up and let down into the deep Atlantic. Notwithstanding the enormous thickness of the basalt substructure, which is estimated at 3,000 meters, we can hardly regard these movements as deep-seated tectonic dislocations; *they all move in a 'panzer'; Iceland is a 'panzer' horst*[2].

[1] T. Thoroddsen, Jordskjælv i Islandske sydlige Lavland, Geogr. Tidsskr., 1898, XIV, pp. 93-113, XV, pp. 1-29; Peterm. Mitth., 1901, pp. 53-56, map.

[2] [*Panzer*, literally a coat of mail; an armadillo is a Panzerthier, an ostracoderm a Panzerfisch. We might translate 'carapace', but it seems better, for several reasons, to retain the German word in connexion with the equally German 'horst'.—Note by Ed.]

CHAPTER VIII

AFRICAN FRACTURES. CAPE MOUNTAINS

1. African fractures. East Africa to lake Rudolf. Lake Rudolf to Syria. Summary. Cameroons. Plan of the African fractures. 2. Cape mountains.

1. African Fractures.

East Africa to lake Rudolf. In 1881 Joseph Thompson wrote: 'There seems to be sufficient evidence to show that in some earlier period a great line of volcanic activity extended from the Cape through lake Nyassa, Ugogo, and Mount Kilima Njaro to Abyssinia, running parallel to the Ocean and at no great distance from it[1].' Douvillé in 1886 expressed a similar view and even suggested that the Abyssinian escarpment and the Dead Sea as far as Lebanon might be the further continuation of this line[2]. It was not until 1887–88, when Count Teleki and von Höhnel, travelling from the south, had succeeded in reaching lat. 5° N. that light was thrown on the real state of affairs[3].

A great fracture of the earth's crust proceeding from the far south extends through East Africa. It does not terminate until after traversing Syria it has splintered up within the outer arcs of the folded ranges of the Taurus. For long distances it runs with the meridian, then suddenly diverges every now and again in an oblique direction to the north-west or north-east, but always returns to the north-and-south line; it generally adheres to the neighbourhood of long. 36° E. The geological map of Cape Colony marks a meridional fault between lat. 29° 49′ and 28° 13′ S. in long. 23° E., which cuts through very ancient sediments[4].

The Karoo ends on the east in a subsidence (I, p. 393). At its foot, towards the sea, lie the remains of the Pondo range, which will be discussed below. At about lat. 27° 30′ S. a considerable meridional fault sets in, which runs through almost 4 degrees of latitude near to the meridian of 27° E.; this is Molengraaff's 'grande faille de l'Est'. It cuts off the ancient granites of Swaziland on the east, and brings next to them a long

[1] J. Thomson, Notes on the Geology of East Africa, in To the Central African Lakes and back, 8vo, London, 1881, II, p. 304.

[2] H. Douvillé, Bull. Soc. géol. France, 1885-1886, 3e sér., XIV, p. 240.

[3] L. R. v. Höhnel, A. Rosiwal, F. Toula, and E. Suess, Beitrag zur Kenntniss des östlichen Africa, Denkschr. k. Akad. Wiss. Wien, 1891, LVIII, pp. 447-584, maps.

[4] A. Rogers, Geological map of the Colony of the Cape of Good Hope, sheet XLV, 1907.

downthrown strip of Karoo sandstone, which is followed towards the east by an equally long strip of diabase and amygdaloidal melaphyre. The latter is marked on the maps as the *Lebombo mountains*. In Zululand and Mozambique it forms the boundary between the Mesozoic sediments and the plain of the east coast [1].

Molengraaff regards the Lebombo fault as forming part of the East African system of fractures.

Trough faults first make their appearance in their typical form a little south of lat. 15° S. The east border of lake Shirwa appears to be a fracture; the surface of the lake is said to lie at a level of 500 meters; soundings have revealed depths of 785 meters [2]. The lower part of the Shiré river lies between two parallel marginal faults, which further to the

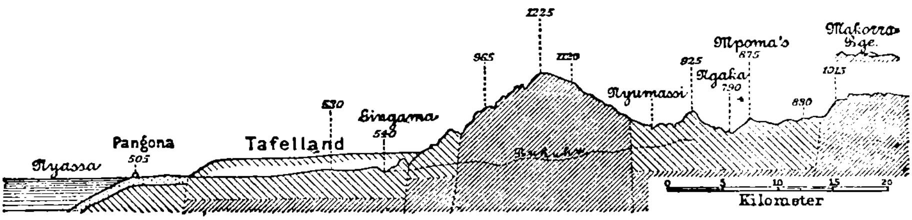


Fig. 25. *Faults on lake Nyassa* (after Bornhardt); the vertical scale is ten times the horizontal. Archaean rocks and sandstone.

north bound *lake Nyassa* (504 meters). East of this lake, on the high-level gneiss, Bornhardt observed repeated meridional faults and also Karoo beds with remains of the Gondwána flora let down in fault-troughs. The fault-trough of lake Nyassa, the axis of which in its southern part lies in long. 34° 30′ E., runs from about lat. 10° 15′ S. onwards towards the north-west. Its breadth, at first from 40–50 kilometers, has here diminished to 30 kilometers [3].

We will now supplement the accounts of Bornhardt by those of Dantz [4].

Beyond the north end of lake Nyassa, in Awa-Nkond Land, we first enter on a strip of alluvium. Then follows a conspicuous group

[1] G. A. F. Molengraaff, Géologie de la République Sud-Africaine du Transvaal, Bull. Soc. géol. France, 1901, 4e sér., I, pp. 13–92, maps, in particular p. 86.

[2] Geogr. Journ. London, 1899, XIV, p. 319.

[3] W. Bornhardt, Zur Oberflächengestaltung und Geologie Deutsch-Ost-Africa's (in Deutsch-Ost-Africa, Wissenschaftliche Forschungsresultate, veröffentlicht im Auftrage der Colonial-Abtheilung des auswärtigen Amtes), 8vo, Berlin, 595 pp., maps; in particular pp. 161, 193, 197, 434; also Potonié, op. cit., p. 495 et seq. For a general survey, E. Freiherr Stromer von Reichenbach, Die Geologie der deutschen Schutzgebiete in Ost-Africa, 1896, 8vo, München, pp. 1–110, maps.

[4] Dantz, Reisen in Deutsch-Ost-Africa in den Jahren 1898, 1899, 1900, Mitth. deutsch. Schutzgebiete, 1902, XV, p. 34 and continuation, maps; in particular 1903. XVI, pp. 127, 136, 188; also op. cit., 1900, XIII, p. 41.

of volcanos with several craters (Rungwe, 3,170 meters); these lie in the fault-trough itself. The trough then divides. One branch, the *Rua trough*, runs towards the north-east; the eastern border is not so well marked as the western. The latter unites further on with the eastern border of the great East African fault-trough. The other branch of the Nyassa trough runs far to the north-west, nearly following the strike of the gneiss; it includes lake *Rukwa*, which has no outflow.

The Rukwa trough disappears in lat. 7° S., but to the west of it, from lat. 8° 45′ S. onwards, the long trough of *Tanganyika* sets in, running to north-north-west. Sprigade has shown that the river M'Kamba turns in the north round the end of the western border of the Rukwa trough and enters lake Tanganyika north of Karema [1]. This is one of those remarkable signs of irresolution in the behaviour of the watersheds of the oldest districts, which have been pointed out by Livingstone, Cameron, and in particular Cornet [2]. The fractures and subsidences pass over towards the west into the region of the Congo. Lakes Bangweolo and Moero are certainly described as shallow lake-swamps, but Cameron and Stanley mention a hot spring on the way to the Lualaba. L. A. Wallace observed hot springs between lakes Tanganyika and Moero, on the east border of the restricted and fairly independent marshy depression of Wantipa, which lies at the foot of a cliff over 240 meters in height [3].

P. Reichard mentions the small volcanic cone of Sambululu, and at no great distance from it hot springs, situated east of lake Upemba, one of the lagoons which accompany the course of the Lualaba [4]. Finally, Cornet has shown that the Lualaba, from lat. 9° 15′ S. to lat. 7° 45′ S., lies, with its lagoons, in a fault-trough. This is Cornet's *trough of Upemba*; it runs south-west and north-east, with a length of 200 kilometers and a breadth of 30–45 kilometers. On the north-west it is bounded by the Hakansson mountains, in the south-east by the Manika range. Hot springs accompany its eastern margin, but they also occur on the Lufila, on the other side of the Manika range [5].

The fact that lake Tanganyika lies in an inbreak of the earth's crust

[1] P. Sprigade, Begleitworte zu der Karte der Gebiete am S. Tanganjika und Rukwa-See, Mitth. deutsch. Schutzgebiete, 1904, XVII, pp. 97, 98, map.

[2] J. Cornet, Observations sur les terrains anciens du Katanga, Ann. Soc. géol. Belge, 1897, XXIV, mém., pp. 25-190, maps, in particular p. 108.

[3] L. A. Wallace, Geogr. Journ., 1899, XIII, p. 614 et seq., map; Buttgenbach's geological surveys refer to a line somewhat further to the north: Ann. Soc. géol. Belge, 1906, XXXII, mém., pp. 315-327, map.

[4] P. Reichard, Mittheilungen der Africanischen Gesellschaft, 1883–1885, IV, p. 304. It was here that Dr. Reichard's companion, Dr. Böhm, succumbed to fever on March 27, 1884.

[5] J. Cornet, Les Dislocations du bassin du Congo, I, Le Graben de l'Upemba, Ann. Soc. géol. Belge, 1905, XXXII, mém., pp. 205-234, map; Sur la distribution des sources thermales au Katanga, op. cit., 1906, XXXIII, mém., pp. 41-48.

was already recognized by Stanley. Sprigade's map shows that it maintains a very uniform breadth of about 35 kilometers in its course from south to north, until in lat. 7° 30′ S. the east coast recedes a little; then between lats. 7° 20′ and 7° S. it recedes still further, so that from this point onwards the breadth is somewhat over 50 kilometers. It is possible that parallel fractures advance towards the lake. At the same time the sides of the trough rise high above the lake, which lies at a level of 899 meters, while at its north end the east side rises to a height of over 2,500 meters, and the west side to 3,290 metres. The highlands on both sides consist of steeply folded mica-schists, talc-schists, and quartzite. East of lake Tanganyika these are covered by sandstone, which probably belongs to the Karoo.

North of the lake the fault-trough maintains the same breadth; its direction turns gradually out of the north into the north-north-east, and within it, between lats. 2° 30′ and 1° 40′ S., lies lake *Kivu*, discovered by Van Götzen in 1894.

Herrmann gives the following account of it:—About 70 kilometers from the north end of lake Tanganyika, which is marked by a hot sulphur spring, the trough is crossed obliquely by a ridge formed by a broad block of mica-schist, only partially faulted down; on the south side it is traversed by basalts, and accompanied by hot springs. The south foot of the ridge lies at a height of 980 meters; on its north side is lake Kivu, with its surface at 1,455 meters, the Rusizi cuts through the ridge with a fall of 475 meters, thus affording a passage from lake Kivu into lake Tanganyika. On the west side of lake Kivu the edge of the highland lies at a height of 3,500 meters, on the east at a height of 2,800 meters. At the north-east of the lake the eastern side forms a recess like a caldron. Close by rises the great volcanic group of the *Kirunga* (*Mfumbiro*). Herrmann counted eight lofty mountains bearing craters (Kari-simbi, 4,475 meters). Their united lava-flows, chiefly leucitic, are dammed up by the west side of the trough; on the south-east they lie up against the border of the caldron like extensions, but with interruptions, so that a chain of small lakes is formed. Smaller craters occur down to lake Kivu [1].

North of the Kirunga volcanos, the trough returns to its usual form. As we pass beyond lat. 1° S. a broad lake bottom shows that we are approaching *lake Albert Edward*; we are now in the fluvial region of the Nile; the Kirunga volcanos form the watershed in the trough between the Nile and the Congo.

[1] Herrmann, Das Vulkangebiet des centralafrikanischen Grabens, Mitth. deutsch. Schutzgebiete, 1904, XVII, pp. 42–64, map; v. Beringe, Reisen im Gebiete der Kirunga-Vulkane, op. cit., 1901, XIV, pp. 20–39, map. The active volcano of Namilagira is described by G. A. Graf v. Götzen, Durch Africa von Ost nach West, 8vo, Berlin, 1895, et passim; in particular Kersting, op. cit., p. 233 et seq.

Lake Albert Edward (915 meters) is overshadowed towards the north-east by the highest non-volcanic mountain of Africa, mount *Ruwenzori.* Stanley first saw it from a distance in 1888; Stairs reached it in 1889, and regarded it as a volcano; Stuhlmann showed in 1891 that it was a fragment of the ancient crust standing between two dislocations; Scott Elliot has crossed the mountain several times. Grauer climbed one of its outlying peaks, and the Duke of the Abruzzi, the highest peak of all (Monte Margherita, 5,064 meters) [1]. Ruwenzori is a horst, about 80 kilometers in length, which stands within the trough next its eastern side. Its steeper slope is towards the west, and its highest parts are probably formed of granitic gneiss. Small crater-bearing mountains occur at its eastern and southern foot [2].

It is a remarkable fact in connexion with this horst that it rises about 2,000 meters higher than the neighbouring highland, of which, nevertheless, it forms a part.

The trough, still maintaining the parallelism of its walls, and with scarcely diminished breadth, extends beyond lake Albert Edward and includes *lake Albert* (590 meters), then the waters of this lake plunge over the Murchison falls, and there the trough comes to an end [3].

Lake *Victoria Nyanza*, owing to its very different and more circular outline, the character of its shores, which are for the most part flat, and its independent central position, was originally regarded as a shallow basin lying between the inbreaks, though Stuhlmann held from the first that its western shore is a fracture [4]. In Ankole, that is towards lake Albert Edward, numerous small craters are said to occur [5]. Herrmann recognized a number of fractures between the Victoria Nyanza and lake Tanganyika. Dantz, after an investigation of the southern districts, came to the conclusion that the lake had been produced by a shallow caldron subsidence, and he marked a fracture on the north side of Speke gulf [6]. Thus it seems possible that all

[1] Duke of the Abruzzi, The Snows of the Nile, Geogr. Journ., 1907, XXIX, pp. 121–147, map.

[2] G. F. Scott Elliot, The Geology of Mt. Ruwenzori and some adjoining regions of Equatorial Africa, Quart. Journ. Geol. Soc., 1895, LI, pp. 669–680, map.

[3] In travelling to the north of the Ruwenzori from the south-east, we must follow a steep descent of 500 feet to a plain; this is obviously alluvial, and to reach the Semliki we descend another 400 feet over terraces; A. B. Fisher, Geogr. Journ., 1904, XXIV, p. 256, map.

[4] F. Stuhlmann, Mit Emin Pascha ins Herz von Africa, 8vo, Berlin, 1894, p. 728; on p. 834 we read that the whole of the intermediate lake region is traversed by meridional fissures.

[5] Geogr. Journ., 1902, XIX, p. 24.

[6] Herrmann, Der geologische Aufbau des deutschen West-Ufers der Victoria Niansa, Mitth. deutsch. Schutzgebiete, 1899, XII, pp. 168–173, map; Dantz, op. cit., 1902, XV, pp. 63, 164, 198; also Gedge, Proc. Geogr. Soc., 1892, p. 322, and Capt. H. G. Lyons, On the Variation of Level of Lake Victoria (W. Garstin, Report upon the Basin of the Upper Nile), 4to, Cairo, 1904, App. III, p. 1.

the vast region lying between the troughs may one day prove to be a fractured area.

It is not until we reach the south-east of the Unyamwesi tableland that the arrangement of the several fractures again becomes clear. They have been determined chiefly by O. Baumann, H. Meyer, and C. Uhlig. Dantz has indicated them on a sketch-map [1]. On the whole a tendency towards a radiate arrangement seems to exist in the neighbourhood of Kilima Njaro and the commencement of the East African trough. The trough of the Wembere steppe strikes to the north-east; the outrunners of the western side of the Rua depression, which proceed from the north of lake Nyassa, strike to the north-north-east. In front of the main fault, in lat. 4° 28′ S., rises the volcano of Gurué (3,100 meters). The main fault (Uhlig's zone of fracture) unites on the Natron lake with the western fracture of the East African trough. A broad horst probably extends from the south up to the north border of the Lettima mountains, south of Kilima Njaro. The trough of the Pangani strikes to the north-north-west; its east side is formed by the Paré mountains and the western slopes of Usambara [2].

The down-thrown *steppe of Wembere* deserves some attention. At a distance of 70 kilometers from its commencement, the bottom of this trough, according to Baumann, lies at 1,120 meters. Its sides, though not high, are clearly marked. Towards the north-east the tableland rises gradually to a height of 2,020 meters, while at the same time the bottom of the trough sinks lower. The trough terminates in the salt lake of Eyassi (1,050 meters) which, according to Jaeger's accounts, is shut off on the north-east by two volcanos. Beyond these, towards the north-east, is the great Ngorongoro crater, situated close to the west edge of the East African trough. East of lake Eyassi lies another trough, with lake Hohenlohe, discovered by Werther. Wembere lies chiefly in granite and gneiss; its north-eastern part, along with lake Eyassi, in lavas [3].

The East African trough, i.e. the stretch of land which extends through eight degrees of latitude, from Kilima Njaro (lat. 3° S.) to the north end of lake Rudolf (lat. 5° N.) has been investigated of late years by numerous observers; the whole of its southern part in particular, as far as lat. 1° 30′ S.

[1] O. Baumann, Durch Massailand zur Nilquelle, 8vo, Berlin, 1894, maps, in particular p. 133 et seq.; H. Meyer, Kilimandjaro, 8vo, Berlin, 1900, maps, in particular pp. 288–342; Dantz, Mitth. d. deutschen Schutzgebiete, 1903, XVI, pl. II.

[2] I have not sufficient data to form an opinion as to the significance of the occurrence of eruptive rock on the mountain of Jombo (lat. 4° 26′ S., long. 39° 3′ E., nepheline syenite with dykes of camptonite) and on the adjacent island of Wasin. J. W. Gregory, Quart. Journ. Geol. Soc., 1900, LVI, pp. 223–229; both localities lie near the German-English frontier.

[3] O. Baumann, Durch Massailand zur Nilquelle, p. 139; Stromer v. Reichenbach, Die Geologie der deutschen Schutzgebiete in Ost-Afrika, p. 66 et passim; F. Jaeger (Zeitschr. f. Erdk., 1908, p. 264) describes Ngorongoro as formed not by explosion but 'probably by the after-sinking of the imperfectly solidified magma into the funnel'.

has been studied by Uhlig and Jaeger, Kilima Njaro by H. Meyer, and mount Kenya by Gregory; but the main features of the structure as they were determined by L. v. Höhnel and mapped out by Toula have not been seriously altered [1]. Of chief importance is the fact that the existence of long trough-like subsidences has been confirmed. The lines of fracture sometimes cut through the ancient crust, sometimes the superposed lavas, so that within the subsidence horsts formed of the ancient crust stand beside those formed of lava. Even recent volcanos have been cut through. C. Uhlig found that the side of the trough south-west of the Natron lake is formed by successive cliffs; the western side belongs to the ancient crust. The middle part of the border cuts through three great volcanos, so that their lava streams end on its slope, which is about 1,000 meters in height [2].

The western side is more nearly continuous than the eastern. It begins as far south as lat. 6° S., with a north-north-easterly direction. The scarp of Mau begins in lat. 3° 15′ S. and runs without interruption at least as far as lat. 1° N. It consists chiefly, though not exclusively, of lavas. In the north the narrow horst of Kamassia, formed of Archaean rock, lies in front of it. The scarp of Suk, a continuation of Mau, runs off to the north-north-west, and does not turn back to the west side till it has reached the middle of *lake Rudolf*. Thus an independent fractured area arises to the south-west of the lake between the rivers Trrguel and Kerio.

The eastern side only becomes continuous on reaching lat. 2° 30′ S. It is affected by the interlocking of extensive sheets of lava in which step subsidences occur, as, for instance, in Kikuyu, to the south-west of mount Kenya, and in Leikipia to the north-west of that mountain. Then come the great volcanos themselves: Kilima Njaro with Kimawensi (5,148 meters), Kibo (5,888 meters), and Mweru (4,558 meters), which appear to stand over a transverse fissure; it is more probable, however, that they surmount the radial troughs which converge from south to north; then follow Doenyo Ngai (active), Gelei, and many others, such as mounts Suswa, Longonot, and Chibcharanjani. Further towards the west is mount Elgon (4,558 meters); to the east, mounts Kenya (5,138 meters), Andrews (active, on the

1 C. Uhlig, Der sogenannte Grosse ostafricanische Graben zwischen Magad und Laua ya Mueri, Hettner, Geogr. Zeitschr., 1907, XIII, pp. 478–505, map; H. Meyer, Kilimandjaro; J. W. Gregory, The great Rift Valley, 8vo, London, 1896, 413 pp., maps; The Geology of Mount Kenya, Quart. Journ. Geol. Soc., 1900, LVI, pp. 205–222, map et passim; F. Toula, Geologische Uebersichtskarte, op. cit., Tektonische Skizze, op. cit., p. 576.

2 C. Uhlig, Zeitschr. Ges. Erdk., 1905, p. 121. This distinguished explorer mentions (Geogr. Zeitschr., 1907, pp. 489, 501) that he has observed lavas overlain by quartzite mica-schist north-west of lake Natron (Magab), and conjectures, but with considerable reserve, that the trough may have arisen by overthrusting. It would be interesting to know whether intercalation in sills occurs. I know of no case of overthrusting in any other part of the African fractures.

border of the steppe Sukuta), Teleki (active), and the volcanos of Höhnel island, Kulall, and Lubur on the north-west shore of lake Rudolf [1]. Finally, we may mention the crater of Ngorongoro (between lats. 3° and 3° 30′ S.), which is 20 kilometers in diameter. Between these marginal fractures, horsts, and volcanic mountains the waters collect in a long chain of lakes without outflow. The water level stands at 1,010 meters in lake Manyara, at 608 meters in the Natron lake; then it rises in the several lakes until it reaches 1,869 meters in lake Naivasha, and falls again in lake Rudolf to 400 meters.

Numerous hot springs are associated with the trough; in the middle of it, on an island in the Baringo, intermittent hot springs occur. There are many other features also connected with the East African trough which seem likely to afford fresh information as to the nature of volcanic phenomena. Mount Kenya, for instance, is regarded by Gregory as a volcano so completely dismantled that a core of coarsely crystalline rock (kenyte) is now exposed, and Mackinder, who succeeded in ascending its highest peak, obtained from it a specimen which, as Sollas confirms, actually resembles this rock [2].

In any case, a fairly large mass of ancient rock occurs to the north-west of lake Rudolf (Lamarr, near Höhnel); but it is possible that a subsidence may extend directly up to lake Stefanie. Max Weber has given a sketch-map showing the course of the trough from lake Rudolf to Danakil; it is based chiefly on the results obtained by Neumann and by Italian investigators. In accordance with the observations of K. Schmidt, the trough of lake Rudolf is represented as flattening out towards the north, and from the northern third of the lake a branch is sent off in a north-easterly direction to *lake Stefanie.* This agrees fairly well with earlier observations [3].

The trough now turns towards the north-east and runs between the Abyssinian highland in the north and the Somali segment (Diddi, highland of the Arussi) in the south, as far as Adis-Abeba and Ankober.

[1] As late as July, 1895, the volcano of Teleki was observed by Donaldson Smith (from some distance, it is true) to be smoking violently, and glowing at night (Geogr. Journ., 1896, VIII, p. 230). In May, 1897, it was visited by Cavendish; he states that according to the accounts of the inhabitants the lake had risen six months previously, until it reached the volcano, and a violent explosion had occurred. At the time of his visit a sheet of lava only was to be seen. On the other hand, 4–5 kilometers further south a new volcano, that of Luttur, had arisen, 130 feet in height. About 80 kilometers south of the lake, Cavendish discovered the active volcano of Sugobo (or Andrews, op. cit., 1898, XI, p. 390 et seq.), 300 feet in height. Welby's account of 1899 leaves it doubtful whether he had not mistaken Luttur for Teleki (op. cit., 1899, XIV, p. 318, and 1900, XVI, p. 298). The whole matter needs explanation.

[2] H. J. Mackinder, Geogr. Journ., 1900, XV, p. 481. Here the mountain was assigned a somewhat less height.

[3] Max Weber, Petrographische Ausbeute der Expedition Neumann-Erlanger nach Ost-Afrika und Abessynien, 1900–1901, Zeitschr. Geogr. Ges. München, 1906, I, pp. 637–660, map.

The region which succeeds lake Stefanie has been made known by the travels of Bottego and the collections made by the greatly lamented Sacchi, which have been worked out by A. d'Ossat and Millosevich [1]. Volcanic rock forms not only the east side and the north of lake Stefanie but also all the mountains from the lower Omo in lat. 5° 30′ N. to *Queen Margherita lake* (Abbaya or Pagadé); the east side of this lake consists of basalt, the west of rhyolitic rocks. In fact, we conclude from the accounts of Erlanger and Neumann that the long chain of lakes which marks the trough from lake Stefanie through Ciamò (Gandjule), Queen Margherita lake, and others up to lat. 8° N. lies wholly, or almost wholly, in recent volcanic rock. At the same time there are separations and connexions of the most various kinds.

Neumann found that lakes Ciamò and Queen Margherita are without outflow during low water, but at high water are connected with lake Stefanie by the river Sagan. The group of lakes situated north of lat. 7° N. (Schale, Lamina, Korre) is separated from the preceding by the volcano of Fike, and from lake Zuaj by the volcano of Alutu [2].

Between lake Zuaj and Adis-Abeba rises the mountain of *Zukuala*, which bears a sacred crater lake. Here the Abyssinian trough terminates, and we now enter the vast volcanic region of Afar (Danakil). It is bounded on the west by the meridional scarp of the Abyssinian highland, which consists of gneiss and a Mesozoic series, and on the south of the northern border (running east and west) of the Somali segment, which is formed of flatly-bedded Mesozoic sediments. Further on, this same northern border forms the south coast of the Arabian gulf. Towards the north-east Afar extends to the Red Sea [3]. It is an inhospitable land, strewn over with volcanos, lava fields, and hot springs. It contains several tracts within it which lie below the level of the sea. The surface of lake Assal, near Tajura lies at —170 meters. Volcanic eruptions are not infrequent; in June, 1907, the volcano Afdera (near the coast, north of lat. 13° N.)

[1] G. de Angelis d'Ossat e F. Millosevich, Seconda spedizione Bottega, Studio geologico sul materiale raccolto da M. Sacchi (publ. by the Soc. Geogr. Ital.), 8vo, Rome, 1900, 212 pp., map.

[2] In particular C. Freiherr von Erlanger, Verh. Ges. Erdk. Berlin, 1901, p. 240, map, pl. VIII; and O. Neumann, Von der Somali-Küste durch Süd-Ethiopien zum Sudan, Zeitschr. Ges. Erdk. Berlin, 1902, I, pp. 1–32, map; in particular Neumann, pp. 17, 30; Graf E. Wickenburg, Von Dschibuti bis Lamu, Peterm. Mitth., 1903, pp. 193–198, maps; also P. Maud, Explorations in the South Borderland of Abyssinia, Geogr. Journ., 1904, XXIII, pp. 522–579, map.

[3] Denkschr. k. Akad. Wiss. Wien, 1891, LVIII, p. 567 et seq.; Vicomte E. de Poncins, Bull. Soc. géogr. Paris, 1898, XIX, p. 454 et seq.; Fritsche, Peterm. Mitth., 1890, p. 113, pl. 9; U. Grubenmann, Beiträge zur Geologie von Abessynien, Mitth. Thurgau. Natf. Ges. Frauenfeld, 1896, XII, 20 pp.; and many other works, enumerated in Dainelli, Marinelli e Mori, Bibliografia Geografica d. Col. Erythr., Riv. geogr. ital., 1907, XIV, pp. 1–72.

formed a new crater, and poured forth a great stream of lava. Detailed information on special areas has been furnished by Dainelli and Marinelli. According to these investigators, lake Alel Bad in North Afar, lies in a region stretching north-west and south-east, of which about 5,000 square kilometers lie below the sea-level, and of this area a half lies below −100 meters. The deepest place lies at −120 meters. It is a salt plain; at its north-west end rises the extinct volcano of Marahé, and at its south-east end the volcano of Erto-Alé, an eruption of which is recorded in older accounts. Further to the north-west a similar region borders the east foot of the Abyssinian tableland up to the spot where it reaches the west side of the gulf of Zula (Massaua); within this region rises the volcano of Alid and a great number of small eruptive centres extend as far as the remains of the volcano of Jalua, which lies near the gulf [1].

The precipitous boundaries of the Abyssinian and Somali highlands meet near Ankober almost at a right angle. If we imagine the low-lying country of Afar to be submerged beneath the sea, these boundaries become coasts, and the new outline corresponds in a truly striking manner with that of the Arabian coast, which lies opposite. That the Red Sea is itself a fault-trough has been mentioned previously (I, p. 374). Soundings made by the 'Pola' have shown that the greatest depth, 2,190 meters, occurs in lat. 22° 7′ N.[2]. A number of volcanic islands rise from the sea. At Mount Sinai the trough divides in a fork; or, more correctly, its western part is continued as the *Gulf of Suez*, while the *Gulf of Akabah* represents a new trough which arises with a divergent direction close to the meridian of 35° E., and running to the north-north-east approaches the meridian of 36° E. In Jubal strait, near the entrance to the gulf of Suez, the bottom ascends almost immediately from −1,000 meters to −80 meters, and does not sink again below −82 meters throughout the rest of its course to Suez. The gulf of Akabah is separated from the sea by a block which lies at a level of −141 meters west of the island of Tiran, and east of this island rises to −16 meters, but beyond this block considerable areas lie below −1,000 meters; the greatest depth is 1,287 meters, and the coasts are very steep [3].

The Cretaceous and Eocene beds which overlie the Archaean formations,

[1] G. Dainelli e O. Marinelli, Della condizione altimetrica e dei limiti della grande depressione Dancala, Riv. geogr. Ital., 1896, XIII, fasc. 7, 19 pp., map, op. cit., 1906 and 1907, several passages on the volcanos of Danakil, in particular Erto-Alé and Marahó; also Escursione al Vulcano Alid, op. cit., 1907, XIV, 20 pp., map. Maps of Afar, e. g. Fritsche (Zeila to Ankober), Peterm. Mitth., 1890, pl. 9, and K. Schmidt (Galla lands), op. cit., 1905, pl. XVII.

[2] J. Luksch, Expedition auf S.M. Schiff 'Pola' in das Rothe Meer, VI, Physikalische Untersuchungen, Denschr. k. Akad. Wiss. Wien, 1898, LXV, pp. 351–422, maps, in particular p. 354.

[3] J. Luksch, ibid., p. 358.

once extended without interruption across the whole breadth of the Red Sea to Arabia; this is shown by the long step-faults, running parallel to the shore of the Red Sea, which were observed by E. Fraas near Kosseir, and by Barron and Hume in the same locality, and also two degrees further north on the Gebel Zeit, actually in the region of the gulf of Suez[1]. Jebel Atáka, near Suez, is cut through by a fault, with a downthrow towards the sea (I, p. 371); Beyrich believed that the Miocene of Suez is also occasionally faulted down into troughs (I, p. 379).

Isolated fractures and the occurrence of basalt show that inbreak and subsidence have left their traces as far west as the Nile and even beyond. It seems to be generally admitted that a long trough, like an inbreak, or a series of fractures, borders the Nile from Cairo to Keneh, i.e. for a distance of 4 degrees of latitude[2]. The true state of affairs is not yet fully understood. The whole of the Syrian coast is likewise a comparatively recent dislocation (I, p. 373).

On an earlier page (I, p. 380) we have mentioned the occasional incursion of Mediterranean waters into the Erythraean region, and of Erythraean waters into the existing region of the Nile; this subject has been treated in detail by Blanckenhorn. Hume has since shown that Mediterranean deposits, easily recognized by the presence of the great *Ostrea giengensis*, reach the east side of southern Sinai, where they are steeply upturned along faults. Mount Sinai is cut through in places by a number of submeridional faults. It is evident that some of the fractures at least are more recent than *Ostrea giengensis*[3].

The gulf of Akabah is continued as a trough into the Wady Arabah, at the bottom of which P. Musil, as he kindly informs me, observed an isolated occurrence of dark lava. On the other side of a Cretaceous threshold, + 230 to 240 meters in height, we reach the deep asymmetrical trough of the *Dead Sea* which is continued in the valley of the Jordan (I, p. 373)[4].

[1] E. Fraas, Geognostisches Profil vom Nil zum Rothen Meer, Zeitschr. deutsch. geol. Ges., 1900, LII, pp. 1-50, map; T. Barron and W. F. Hume, La Géologie du Désert oriental de l'Égypte, C. R. VIII[e] Congrès géol. Paris, 1900, 33 pp., map.

[2] e.g. T. Barron and W. F. Hume, op. cit.; also H. J. L. Beadnell, op. cit., and Geol. Mag., 1901, new ser., Dec. IV, vol. VIII, p. 28; and, in particular, M. Blanckenhorn, Die Geschichte des Nilstroms in der Tertiär- und Quartärperiode, sowie des paläolithischen Menschen in Aegypten, Zeitschr. Ges. Erdk. Berlin, 1902, pp. 694–762, maps. Depéret and Fourtau have shown (C. R. Acad. Sci. Paris, 13 août 1900) that near Suez, the first Mediterranean stage, a representative of the Schlier and the second Mediterranean stage may be recognized; also Blanckenhorn, Centralbl. f. Min., 1900, pp. 209-216.

[3] W. F. Hume, The Topography and Geology of the Peninsula of Sinai (South-east portion), Survey Department, Egypt, 8vo, Cairo, 1906, 280 pp., maps, in particular p. 145.

[4] These more northerly stretches were described in greater detail in Denkschr. k. Akad. Wiss. Wien, 1891, LVIII, p. 572 et seq.

It extends to lake Huleh; then a change occurs, of which Diener has given the first detailed description [1].

The trough turns off to the north-north-east and forms, between Lebanon and Anti-Lebanon, the long valley of the *Bekâa*, which contains the ruins of Baalbek. At the same time a divergent branching or virgation of fissures occurs, extending obliquely across Anti-Lebanon and far to the north-east beyond Palmyra. Here, in the desert of Palmyra, Diener has discovered marine Pliocene beds at a level of +650 meters. This bulging up of the ground and splitting up of the fractures has been caused either by a deformation of the earth in the neighbourhood of the folded arc of the Taurus, or, as Blanckenhorn believes, by the lava-covered subsidence of the Damascene which lies towards the south and south-east.

On the other side of the Bekâa, that is beyond lat. 34° 30′ N., Blanckenhorn has studied the country as far as the Amanus, that is, into the region of the Tauric folds; he has also given an admirable survey of the structural lines of the whole of Syria [2]. The trough returns again to the meridional direction, cuts through the basalt of Homs, thereby forming the little Bekâa, and extends through the plain of el-Ghâb along the east side of the Ansarieh-range, which is faulted down in steps, as far north as lat. 35° 50′ N., where the range sinks beneath the sediments of the second Mediterranean stage. In this northern tract traces also exist of a virgation directed to the north-north-east or north-east.

We have now reached the depression of el-Amk (lake el-Bahra, 140 meters), north-east of Antioch. Blanckenhorn conjectures that the fractures do not end here, and that their continuation is directed towards the north-east, that is, it lies in the strike of the Tauric folds between the Drusen range and the Amanus. In fact F. Schaffer has since traced a trough for a distance of 150 kilometers in the valley of the Kara-Su, and into the neighbourhood of Marash; it is accompanied by flows of basaltic and doleritic lava (III, p. 319) [3].

Survey of the East African troughs. The area traversed by the fractures (disregarding that of the Lebombo mountains) extends from lat. 15° S. to lat. 37° 30′ N.; *its length amounts to* $52\frac{1}{2}$ *degrees of latitude.* At the same time the frequent divergence from a definite meridional zone, and

[1] C. Diener, Libanonische Grundlinien der physischen Geographie und Geologie von Mittel-Syrien, 8vo, Wien, 1886, 412 pp., maps. Here a doubtful dome of basalt, Tell-el-Rurâb, is marked south of Palmyra within the virgation. Further west (in about long. 37° 40′ E.) von Oppenheim mentions the twin volcanos of Abd and Abde (slave and slave-girl), Verh. Ges. Erdk., 1894, XXI, p. 209.

[2] M. Blanckenhorn, Die Strukturlinien Syriens und des Rothen Meeres, in Festschrift für Freiherr von Richthofen zum 60. Geburtstag, 8vo, Berlin, 1893, pp. 113–180, maps.

[3] F. Schaffer, Geologische Studien im südöstlichen Kleinasien, Sitzb. k. Akad. Wiss. Wien, 1900, CIX, pp. 498–525, in particular p. 524; and op. cit., 1901, CX, pp. 5–18, in particular p. 16; also Peterm. Mitth., 1901, p. 133.

the equally frequent return to it, deserves attention. The axis of lake Nyassa lies in long. 34° 30′ E., the more northerly axis of lake Rudolf in long. 36° E., and far to the north the axis of the Dead Sea and the valley of the Jordan lies in long. 35° 30′ E.

It cannot be shown that all parts of this great system of fractures and inbreaks are of the same age. Kohlschütter, in particular, believed that older troughs have been cut through by more recent, thus he supposed that the Rukwa trough is continued across lake Tanganyika to the Lukuga, thus cutting through Tanganyika, and similarly that a trough which follows the Wembere is cut off near the crater of Ngorongoro, north of lake Manjara, by the meridional trough of East Africa [1]. On these points we must await more detailed information. Lake Tanganyika is frequently spoken of as one of the older members of the system. Its strange fauna is regarded as a marine relic; yet a medusa, which is one of its most characteristic forms, has also been discovered in lake Victoria.

Issel justly lays stress on the fact that the sea did not enter the Erythraean trough until a late period [2]. The series of middle and upper Tertiary sediments, as it is presented by the greater part of the Mediterranean coasts, as it is still to be seen in Suez, and in part even near Scherm on the south of Mount Sinai, is here absent, with the exception of some recent deposits, possibly corresponding to those Erythraean beds which extend at a level of +67 meters as far as the pyramids of Ghizeh into the lower valley of the Nile (I, p. 379). These beds possibly indicate the first filling of the Red Sea. All the other downthrown areas, with the exception of the Syrian coast line, present no trace whatever of an ingress of the sea. The terraces of lake Rudolf, the lower Omo, lake Stefanie, and Afar contain shells of the existing Nilotic fauna. The terraces of the Dead Sea and the Jordan contain existing freshwater shells; in the lake of Tiberias fishes of the Nile live even at the present day (I, p. 385). The recent Melanopsides beds were followed by lava-flows [3], and in the north the movements appear to have been so recent that similar sediments are found faulted down in troughs of still more recent date.

It is not until we reach the north that we find the deposits of the

[1] E. Kohlschütter, Die kartographischen und geophysischen Arbeiten der Pendel-Expedition der Königlichen Gesellschaft der Wissenschaften zu Göttingen in Ost-Afrika, Verh. XIII. deutsch. Geographen-Tags zu Breslau, 1901, pp. 133–153, map. For the latter place, C. Uhlig's map, Hettner, Geogr. Zeitschr., 1907, XIII, and F. Jaeger's map, Zeitschr. f. Erdk., 1908.

[2] A. Issel, Morfologia e genesi del Mar Rosso, III° Congr. geograf. ital., Firenze, 1899, 17 pp., map; also Bull. Soc. géol. Belge, 1899, XIII, Mém., pp. 65–84.

[3] F. Noetling, Die Lagerungsverhältnisse einer quartären Fauna im Gebiete des Jordanthales, Zeitschr. deutsch. geol. Ges., 1886, XXXVIII, pp. 807–823, map; and Geologische Beschreibung der Umgebung von el-Hammi, Zeitschr. deutsch. Palästina-Ver., 1886, X, pp. 59–88, map.

third and fourth Mediterranean stage making their appearance on the coast; as already mentioned, marine sediments reach the desert of Palmyra.—

Three independent processes may be distinguished here: first, the rending open of the ground; second, the subsidence of the walls of the fissure; third, the welling up of lava. Not that these processes are strictly separated in point of time; the trough-faults in lavas, like that of Mau, show that, in some districts, great flows have been followed by great inbreaks. But the rending open is evidently the primary, and the appearance of lavas the secondary or accompanying phenomenon.

We must not form too rigid a conception of such troughs, as though they were strips of land let down between two parallel faults. Step faults are to be seen on lake Tanganyika and in the lava fields which lie before mount Kenya, on the west coast of the Red Sea also, and more to the north on mount Lebanon and the slopes of the Jebel Ansarieh. We shall form a more correct picture if we think of these step faults as repeated on both sides, down to the middle of the valley bottom—many long strips, which become wedge-shaped below, being let down along them to unequal depths. In this way horsts have been left standing within the field of subsidence, for example, Kamassia, west of lake Baringo, and the threshold to the south of lake Albert Edward. The decrease in the formation of fissures is clearly seen in North Syria, where the virgation and many other circumstances point to the advance of the process from the south towards the north.

Any attempt to explain the situation from local causes, such as a particular position of the fault-planes, which have been supposed to diverge downwards, is seen to be impossible in view of the vast extent of the area involved. A process which finds expression over more than 52 degrees of latitude, must have its origin in the structure of the planet itself. For this great region we are led to assume the existence of *tensions in the outer crust of the earth which have acted in a direction perpendicular to that of the fissures*, and, in this case, as it happens, perpendicular to the meridian.

The phenomenon is a *rending asunder caused by contraction*; the fissures have opened *from above downwards*.

This fact has an important bearing on the origin of volcanos.

There are some great segments of troughs, e.g. lake Tanganyika, 700 kilometers in length, in which hot springs occur, but no volcanos. On the other hand, there are some very insignificant fissures in Syria which are bordered by chains of small volcanic outbursts. If we restrict our attention to mount Kenya or the group of the Kirunga volcanos on lake Kiwu, we shall seek in vain for dykes or chains of volcanos which might indicate a connexion with other volcanos. Yet a survey of the whole shows us that they form part of a common scheme in dependence on the great system of fissures.

The clefts rent open from above downwards, and the clefts between subsided blocks, have in some places rendered volcanic outbreaks possible, in others not; in many places the eruptions still continue at the present day. Whether large or small crater mountains should arise has probably been determined by quite secondary movements. Along the axis of the East African trough there is evidently great volcanic activity. In the trough itself there are only a very few great volcanic cones; this is probably owing to the fact that it is within this trough that the greater part of the tectonic changes is effected, so that no funnel has time to grow old, and new ones are continually arising.

Kamerun. Anno Bom, St. Thomas, Princes Island, and Fernando Po form a series of volcanos running in a straight line between north-north-east and north-east. St. Helena is also frequently included in this series. On the mainland this corresponds first with the great volcanic Kamerun range. According to the description of the south-west Kamerun given by Esch, all the rest of the land to a little beyond lat. 5° N. consists, with the exception of a less-elevated belt of Tertiary and Cretaceous sediments near the sea, of ancient crystalline rocks with superposed recent volcanos[1].

Esch terms it a fractured region; this description is supported by the above-mentioned Kamerun range with its numerous craters (3,665 meters), by the ancient crystalline horst of Rumpi in the north-west (rising to 2,000 meters, 40 kilometers long), the Bakundu subsidence, the fractured district of Nkosi, with its numerous small eruptive centres[2], the trough of Kidde, the horst Kopé, with the volcanos crowning it (2,050 meters), and finally, the transverse range of Manenjuba, with the great crater of Ebogga (2,110 meters).

South-west Kamerun thus presents a structure which resembles that of the south-west half of the East African trough, with the following points of difference: in Kamerun the fractures do not bound a continuous trough, the general strike of its fractures is not north and south but north-north-east, corresponding to the line running from Anno Bom to Fernando Po, and finally, that its waters flow freely to the sea.

From the valuable investigations of Passarge in Adamaua, we know that precisely similar relations prevail fromlat. 7° 30′ N. to lat. 10°30′N. where we

[1] E. Esch, in Esch, Solger, Oppenheim and Jaekel, Beitrag zur Geologie von Kamerun, 8vo, Stuttgart, 1904, 298 pp., map, in particular pp. 1–43; Der Vulcan Etinde in Kamerun und seine Gesteine, Sitz. k. preuss. Akad. Wiss. Berlin, 1901, pp. 277–299 and 400–417.

[2] 'Their activity seems to have been continued for a short period only, and with a few exceptions they seem to have served as funnels for the common centre of eruption, by which it was able to relieve itself of excessive gas pressure,' Esch, op. cit., p. 35. Other volcanos are described by P. Rohrbach, Zeitschr. Ges. Erdk., 1907, pp. 254–256.

approach the region of lake Chad, which is without outflow. The resemblance in structure is so great that the designation 'Kamerun line' arose, not in the south, but here in the north, and was indeed given by Passarge[1].

Here, too, the land consists of ancient crystalline and recent volcanic rocks. Here, too, the prevalent direction is N. 30°–35° E.; the east-and-west direction seldom occurs. The Tschebtsche range, a ridge of granite and gneiss, 1,400–2,000 meters in height, extending to the north-north-east, is probably a horst, according to Passarge; it lies in the continuation of the horsts of south-west Kamerun. It bears a sheet of basalt, upon which stand isolated rocky cones; on both sides of the Walles augite-andesite makes its appearance. In the north, where the outrunners of the Tschebtsche mountains meet the Benue, and slightly east thereof (between long. 12° and 13° E.), small volcanic hills (Gabriel, Elizabeth, Maduju) border this river. The rectilinear east border of the Atlantíca range, and that of the Mandara range, which lies in its continuation, follow the direction to N. 35° E., as likewise does the valley of the Faro[2].

The lines of fracture which characterize the structure of Kamerun from the very margin of the ocean, extend to lat. 10° 30′ N. and beyond. Then commence the vast alluvial plains of lake Chad and lake Schari, and in addition to the problem of the continuation of the Kamerun line, we meet with a hydrographic phenomenon of a peculiar kind. Barth was already aware that a connexion exists between lake Chad and the Niger. Lenfant has thrown light upon the situation[3].

The river Kabi discharges itself above Garoua into the Benue. About 120 kilometers above this confluence it forms a cataract 50 meters high, then follow other rapids, and finally, the very long and narrow lake of Tuburi, which is connected by a small watercourse, only filled at high water, with the Logone, and consequently through lake Schari with lake Chad. In other words, during high water in the Logone its overflow passes over the rapids of the Kabi to the Niger and the Ocean.

A vast alluvial tract, perfectly horizontal to the eye, borders the Logone and is continued to lake Chad. The rocky rapids of the Kabi reveal the basement of this alluvial land. At a distance of 360 kilometers from the rapids, on the south-east border of lake Chad, a little group of rocks again emerges from the plain; it is called Hadjer-el-Hamis (the five stones) and is only 100 meters high. It has been described by Lacoin[4]. According to Gentil it is formed of a rhyolite with aegyrine and riebeckite,

[1] S. Passarge, Adamaua, 8vo, Berlin, 1895, 573 pp., maps, in particular p. 387.

[2] Further west, in about lat. 9° N., long. 10° E., Boyd Alexander mentions Mount Wase as probably a volcanic neck, Geogr. Journ., 1907, XXX, p. 121.

[3] Lenfant, De l'Atlantique au Tchad par le Niger et le Benouë, La Géographie, 1904, IX, pp. 321-342, map.

[4] L. Lacoin, Sur la géologie du pays de l'Oubangui au Tchad, Bull. Soc. géol. France, 1903, 4e sér., III, pp. 484–496.

which was exposed as it cooled to the direct influence of water vapour and acid fumaroles, such as Lacroix assumes in the case of rhyolites of Somaliland[1]. The same rock was observed by Foureau in the bed of the Logone, near Kusser (a little above Fort Lamy), and there possibly disturbed by slipping. Lenfant obtained precisely the same rock from near the cataracts of the Kafi.

Further study will show whether or not these outcrops belong to the volcanic zone of fracture of the Kamerun, and whether this zone reaches lake Chad in the rhyolites of the Kabi, the Logone and the Hadjer-el-Hamis. At present it is known to extend as far as lat. 10° 30′ N., *that is, through twelve degrees of latitude starting from Anno Bom.*

Plan of the African fractures. Proceeding from west to east the map shows us first the Kamerun line as a zone of fracture and inbreak extending into the mainland at least as far as lat. 10° 30′ N. Its continuation to lake Chad is uncertain. It is also difficult to perceive, from existing observations, whether any relations exist with the volcanic occurrences which run north and south through Aïr and far to the north through Ahaggar.

The short trough of Upemba is the most westerly member known of the long East African troughs. Towards the north these fractures extend through the Red Sea and Syria to the Taurus; towards the west lie the fractures on the Nile and the but little known fractures of the east Sahara. In the midst of Europe lies the Rhine trough.

It is an undeniable fact that lines make their appearance on the borders of the Indian ocean which indicate a relationship with the African fractures. The scarp of the Quathlamba in South Africa and that of the Sahyádri in East India have already been brought into comparison (I, p. 418). We must now add the Lebombo fracture, which runs in South Africa from lat. 27° 30′ S. through four degrees of latitude towards the north. While Madagascar has hitherto only been recognized as a horst in a general way (I, p. 414), Lemoine's investigations now show that a long and rectilinear fracture, in addition to others of less importance, extends along the whole of the east side, and has been the determining factor in the outline. It extends from Fort Dauphin to the north-north-east across the island of Ste Marie to Cape Maroala, a distance of ten degrees of latitude, and is possibly continued in the islands which follow on the north[2]. As regards

[1] L. Gentil in Foureau, Documents, II, p. 728 et seq. Similar rocks are met with at great distances from one another, for example, on the Mouny between lake Chad and Zinder, near Zinder itself and in Aïr; Chudeau, Bull. Soc. géol. France, 1907, 4e sér., VII, p. 341; Lacroix, C. R. Acad. Sci. Paris, 2 janv. 1905 (for Zinder) et passim.

[2] P. Lemoine, Études géologiques dans le Nord de Madagascar, Contribution à l'histoire géologique de l'Océan Indien, 8vo, Paris, 1906, 520 pp., map, in particular pp. 235, 457 et seq. From earlier surveys we might conjecture that lake Alaotra in Madagascar, situated between Antananarivo and the east coast, belonged to a trough parallel to the fracture of

the Sahyádri fracture we know that it cuts through the gneiss from lat. 8° N. to 16° N., and thence to lat. 20° N., through the lavas of the Deccan. In front of it lies, still unexplained, and with a divergent, more north-and-south direction, the line of the Laccadive, Maldive, and Chagos islands [1].

The position of these lines has helped to determine the contours of the Ocean. Not that they can be held responsible for the subsidence of its bottom; it would be more correct to suppose, as in the case of the Variscan fractures, that they have been produced by other causes, but have been made use of by the subsidence and have formed its boundary.

All the fractures and troughs mentioned above, with the exception of the Rhine trough, lie in a tableland, which was denuded, perhaps over its whole extent, certainly over India and Africa, before the deposition of the lower Gondwána, and since then it has not been subjected to folding.

Many of these fractures are distinguished by their great length, and, with the exception of the slightly bent Tanganyika trough, by their rectilinear course. Many of them show a striking preference for a course approaching the meridional. They are nearly always accompanied by volcanos. But the most remarkable fact is that they are confined to a restricted part of the earth's surface. Nothing similar is to be observed in Asia (with the exception of Syria and the Indian peninsula) or in America. It is true that fissures produced by tension (disjunctive lines) and bordered by volcanos are known in folded regions of these continents, but their course is always arcuate in accordance with the strike of the folds. The Rhine trough is the only one of these fractures which enters the region of the Altaides [2].

The repetition of meridional fractures in the most northerly part of the Atlantic region (Greenland to the Lofoden islands) is the only feature which affords some ground for comparison between this region and the Indian Ocean. We hesitate for the present to class the volcanic line of the inner Hebrides and the ancient trough of Christiania with these fractures.

Where these lines correspond to a sea-coast, as in Syria, Madagascar, and other localities, no trough, and, as a rule, no volcanos are to be seen. When the troughs possess clearly defined boundaries, and are fairly broad for long distances we observe a striking uniformity of breadth. In the Upemba trough the breadth has been estimated at 30–45 kilometers, in the Tanganyika trough at 35 or 40—and in the broadest parts at 50 kilo-

the coast; later observations throw some doubt on this; Baron, Geology of Madagascar, Quart. Journ. Geol. Soc., 1889, XLIV, p. 306, pl. XIII, and 1895, LI, p. 58.

[1] A very good description of it is given by A. Agassiz, Coral Reefs of the Maldives, Mus. Comp. Zool. Harvard Coll., 1903, XXIX, pl. 7.

[2] It must be remembered that in contrast to this the ancient troughs of India, formed before the deposition of the upper Gondwána, approach more closely to the east-and-west direction.

meters, in the Nyassa trough at 30–50, in the south part of the Rhine trough at 32–34 kilometers. The great East African trough is very irregular, terraces occur, then follow secondary troughs and horsts, so that it is difficult to arrive at a definite estimate. At a very narrow part in lat. 2° S. it is possibly only 20 kilometers broad. The Red Sea is much broader than all these troughs, but its breadth is very equable. Luksch gives the maximum for the northern half as 334 kilometers. The southern and very deep part of the gulf of Akabah possesses a breadth of water amounting to 27·8 kilometers, so that the distance between its shores must be very nearly 30 kilometers, or perhaps more. A trustworthy determination of further figures is to be desired.

In the foregoing description no mention has been made of a common feature of the volcanic rocks which have made their appearance along the African fractures, namely, the large amount of alkalies they contain and the comparatively small amount of magnesia and lime. The fact only attains its full significance when we make a comparison with other regions.

2. The Cape Mountains.

As opposed to Laurentia and Northern Asia we are accustomed to describe Brasil, Africa, and the Indian peninsula as southern masses. As a matter of comparison we do so with justice. But Brasil and Africa are crossed by the Equator, the Indian peninsula lies to the north of it, and we see from the map that as soon as we consider the earth as a whole they form a central rather than a southern girdle. This mode of expression has given rise to a certain preconceived opinion with regard to the connexion between these masses of land and the true south, or Antarctic.

In South Africa, however, unquestionable traces of independent folding occur south of the equator, and scarcely more remote from it than is the Great Atlas on the north. The ancient mass of Africa does not reach the Cape of Good Hope, and has no continuous connexion with any ancient masses of land in the Antarctic region.

South Africa has been described as a tableland of Karoo beds framed in by folded ranges on the west and south. Towards the south-east this frame is interrupted and the tableland lies open towards the sea; on the east and north-east, traces of the frame again appear (I, p. 387). At the time when the description given in the first volume of this work was written it was not possible to determine the relations existing between the tableland and the ranges bordering it. Subsequent observations have shown that the folding of the bordering ranges of the west and south extended into the time of the Variscan and Armorican foldings of Europe, and perhaps even persisted beyond the close of the Permian period; it is also clear *that the Karoo is a true foreland.* This fact becomes particularly striking when we compare this region with India. There the marginal arcs advance towards the foreland of the peninsula from north, west, and east; here they advance towards the Karoo from south, west, and apparently from the east also.

I take this opportunity of gratefully acknowledging the detailed information which I received many years ago from the late Herr Schenck, directing my attention to this result; the facts asserted by him have since been confirmed by the work of the geological survey of Cape Colony.

Rogers has shown that the folded range of the west meets that of the south in true syntaxis [1]. He suggests in a letter that the whole of the western folds shall be called the *Cedar mountains*, and the southern folds the *Zwarte mountains*. The angle of syntaxis lies near Karoo Poort, and the bend of the folds is continued inland across Worcester towards the south-west corner of the coast.

The stratified succession is the same in both chains, and supplemented by what has already been said, is as follows: 1, ancient phyllites (Malmesbury beds), penetrated by granite, which is often altered into gneiss; 2, purple-coloured slates and sandstones with worm tracks (Ibiqua beds; incidentally the doubtful Cango beds may also be referred here); 3, unconformity; Table-mountain sandstone; 4, sandstone and shales with Homalonotus, Leptocardia, and other species (Bokkeveld beds). This is the Devonian of the Falkland islands and of Matto grosso, the Icla shales of the Bolivian Andes, and the upper Helderberg of the United States [2]; 5, shales with Spirophyton, and Cyclostigma (Witteberg beds); 6, unconformity; then the series of the Karoo from the Dwyka conglomerate, which has been shown to be of glacial origin, up to the Stormberg beds of the Trias; 7, unconformity and summit of the high-lying, plant-bearing beds. At a lower level there follow, in the south and east only, fluviatile gravels, towards the upper part sands and shales, with Palaeozamia and other plants; also beds with Psammobia and Ostrea (Enon conglomerates and Wood bed) [3]; then marine sediments, namely, 8, Neocomian (Uitenhage beds); 9, the Aptian stage, according to Kilian, found further north, in Algoa bay [4]; finally, 10, the Cretaceous beds of Natal, which, according to Kossmat, are not older than the lower Senonian [5].

The *Cedar mountains* run to the north-north-west, and the folding

[1] A. Rogers, Ann. Rep. Geol. Comm. Cape of Good Hope (1903), 1904, p. 13; the violent movements which occur in the direction of Worcester in the syntactic chains are described by E. Schwarz, op. cit. (1905), 1906, p. 261 et seq.

[2] E. Schwarz, Detailed Description of the Bokkeveld Beds at the Gamka Poort, Prince Albert, Ann. Rep. Geol. Comm. Cape of Good Hope (1899), 1900, pp. 33–49.

[3] A. Rogers and E. Schwarz, Report on the Survey of Parts of the Uitenhage and Port Elizabeth Divisions, Ann. Rep. Geol. Comm. Cape of Good Hope (1900), 1901, pp. 3–18.

[4] W. Kilian, Ueber Aptien in Süd-Africa, Centralbl. f. Min., 1902, pp. 465–468.

[5] F. Kossmat, Die Bedeutung der südindischen Kreideform, &c., Jahrb. k. k. geol. Reichsanst., 1894, XLIV, pp. 459–478, in particular p. 463.

is directed from west to east. The Oliphant river runs for the most part in a longitudinal valley. The older rocks, that is the Malmesbury beds, make their appearance in the west; granite occurs in them, as for example in Table mountain; they are sometimes covered by Table-mountain sandstone. Piquet Berg is a syncline of this sheet of transgressive Table-mountain sandstone. The Malmesbury beds are not so intensely folded as the Bokkeveld and Witteberg beds which succeed them on the east and attain a height of 1,932 meters; the height of the ancient rocks is much less. The south part of the range appears to be overlain conformably by the Dwyka conglomerate; and the folding is continued into the lower horizons of the Karoo series, in which overthrust flakes occur. Further north, however, the situation is different. The advance folds flatten out; first the Witteberg and then the Bokkeveld beds gradually disappear—owing to excessive denudation, which must have preceded the deposition of the Dwyka conglomerate—and the conglomerate then extends gradually not only over the remains of these beds, but also over the Malmesbury slates. In lat. 31° 30′ S. the range has wholly disappeared. Granite and gneiss now set in and extend beyond the Orange river. The Langeberg is a long strip of Dwyka conglomerate resting on gneiss. The strike to the north-north-west persists in the gneiss far to the north, but it is not certain that this gneiss is a continuation of the granite and gneiss of the Cedar mountains[1]. Thus the Cedar mountains must be older than the Dwyka conglomerate; they have been affected by posthumous movement in the neighbourhood of the syntaxis, and exposed to very great denudation before the beginning of the Dwyka.

The *Zwarte range* runs almost at right angles to the Cedar mountains as it joins them in syntaxis; it possesses a similar structure, but the folding is directed from south to north. The syntaxis presents a number of peculiarities which may possibly throw some light on the manner in which great folded ranges are stowed reciprocally one against the other; we shall return to this point later. Near Worcester, in the midst of the region of syntaxis, Schwarz observed a great fault; it strikes in a horse-shoe, corresponding with the bend of the syntactic folds. On the east it is continued, with a gradual decrease in throw, along the south side of the Langeberge for a distance of more than 140 kilometers. It brings a long strip of the lower subdivisions of the Karoo series alongside of the Malmesbury phyllites; this corresponds to a vertical throw of 12,000–15,000 feet.

[1] A. W. Rogers and A. L. Du Toit, Geological Survey of Parts of the Division of Ceres, Southerland, and Calvinia, Ann. Rep. Geol. Comm. Cape of Good Hope (1903), 1904, pp. 9–70 maps; A. Rogers, Geological Survey of Parts of the Division of Piquetberg, Clan William and Van Rhyn's Dorp, tom. cit., pp. 139–167; for the north, A. Rogers and E. Schwarz, Report on the Survey of Parts of the Clanwilliam, Van Rhyn's Dorp, and Calvinia Division, op. cit. (1900), 1901, pp. 19–54 et passim.

To the south of this fracture three or four bands of Table-mountain sandstone which form the summits of the folds and perhaps also the edges of flakes strike nearly east or east-south-east, and contribute the most conspicuous element to the mountain structure. In the direction of the syntaxis, i. e. towards the west, their strike bends back in an arc, and as they unite they form in this way, in the midst of the syntaxis itself, a zone of Table-mountain sandstone striking to the south-west, which proceeds from the neighbourhood of Worcester and reaches the sea in the peninsula east of False bay, that is in cape Hangklip [1].

On the outer border of the range the folding is continued as a number of long anticlines and flakes into the lower members of the Karoo series, which appear on the map as a sort of indentation thrust in between the Witteberg beds. Towards the north the folds gradually die away, but a few indications of the movement are still to be seen 20–30 kilometers further north, in the outrunners of Klein-Roggeveld. These folds of the outer border have one feature in common, they all dwindle away towards the east. In this way the fact that the more recent folding, which occurred after the deposition of the Dwyka, increases in the direction of the angle of syntaxis, is expressed here also.

Further east, on the other side of the river Gouritz and east of lake Prince Albert, the northern chain of the Zwarte range runs from west to east, and the parallel valley of the Zwart river separates it from the equally parallel chain of the Tyger mountains. North of these mountains lies the Karoo [2].

Still further east the strike turns more and more out of the east into the east-south-east. The range, as it sinks beneath the sea, forms an oblique rias coast in St. Francis bay, and Algoa bay, and on the Great Fish river.

Throughout the length of the Zwarte range from Worcester eastwards down to the sea we observe the now isolated traces of an ancient longitudinal valley, indicated by patches of the Enon conglomerate. The conglomerate presents a close resemblance to the existing alluvial deposits, but contains partings with Estheria. Near Swellendam a boring failed to reach the lower limit of one of these patches at a depth of 800 feet. This conglomerate, which is of very nearly the same age as the European Weald, has not been folded, but presents here and there steeply upturned beds.

[1] Corstorphine, Rogers, and Schwarz, in Ann. Rep. for 1897 and 1898; and, in particular, E. Schwarz, Geological Survey of the Divisions of Tulbagh, Ceres, and Worcester, op. cit., (1905) 1906, pp. 259–290.

[2] C. Sandberg (Tectonic Remarks on the probable Big Tygerberg inverted Fold, Trans. Geol. Soc. S. A., 1906, IX, pp. 82–89) regards the Tygerberge as the brow of a plunging sheet; this view is contested by Schwarz (The Tygerberg Anticline, Geol. Mag., 1907, no. 5, IV, pp. 487–490).

Rogers observes that the existing rivers of the Zwarte range flow from the north hither as though they would enter the mountains, cross the ancient longitudinal valley, and then reach the sea across the older rocks of the inner zones [1]. The situation is the same as in Chili, where the transverse valleys coming from the Andes cut through first the longitudinal valley and then the coastal ranges.

In the south-east the tableland of the Karoo meets the sea; a fragment of the African structure is missing (fig. 44; I, p. 388). From the St. John's river onwards, however, the rocks of the Zwarte range crop out again, now more gently folded and with a north-north-east strike. The same structure seems to be continued into Natal, but there is a lack of recent observations (I, p. 393). These are the remains, as yet but little known, of a third range, the *Pondo mountains*. Dr. Rogers has kindly communicated to me by letter his conjecture that in the south-east a second syntaxis, similar to that of Worcester, exists beneath the sea [2].

Thus this region seems to present the advance of three great folded ranges, such as we have seen in the Indian peninsula and towards the north of the Pacific Ocean. In this way Africa is shown to possess, even more clearly than before, the characters *not of a southern but an equatorial foreland*, and the southern hemisphere here presents unmistakable traces of a repetition of the Asiatic structure, but with a movement towards the north.

At the same time, however, we perceive the remarkable fact that the Indian chains with which we have instituted a comparison were still in course of formation even after the Miocene period, while in Africa the mountain formation ceases in the Permian, at latest in the lower Trias. In this respect South Africa presents a much stronger resemblance to the pre-Permian part of the western Altaides, which lies in the corresponding meridians, than to any other part of the periphery of Asia. At the same time the Cape mountains are not formed by back-folding, and the Zwarte range, at least, is not a free branch.

[1] A. Rogers, The geological history of the Gouritz River System, Trans. S. A. Phil. Soc., 1903, XIV, pp. 375–384, map.

[2] This theory is also indicated in Rogers's Introduction to the Geology of Cape Colony, 8vo, 1905, 463 pp., map, in particular p. 27, fig. 3, and p. 96; also D. Draper, Marble Beds of Natal, Quart. Journ. Geol. Soc., 1895, LI, pp. 51–56.

CHAPTER IX

THE OCEANIDES

Relations of the Oceanides to the south. Fore-deeps forming the boundaries of Asia. The line of Ruahine, Kermadec, and Tonga. The first Australian arc. New Guinea to New Caledonia. Second Australian arc. The Carolines, Fiji. Third Australian arc. Virgation coming from New Zealand. Polynesia. Paumotu, Raroia, Samoa. Summary. Atolls.

Relations of the Oceanides to the south (II, p. 149). Van Diemen's Land is a fragment of Australia. The east coast, common to both, extends through more than 34 degrees of latitude up to the south of New Guinea. Tertiary sediments, which elsewhere in Australia extend into the interior, especially from the south coast, are absent on the east coast. It is therefore regarded as a recent fracture. On the west coast of York peninsula, in the gulf of Carpentaria, apposed limestones are described as occurring in terraces. These are absent from the whole of the east coast, and, extended along its northern half, lies the great Barrier Reef. Agassiz has pointed out how the mountains which accompany this coast again and again project towards the north in high and narrow rocky promontories, and in islands, scarcely separated from the mainland, such for example as Hinchinbrook island, which rises to over 900 meters. In front of this rocky coast lies a broad submarine plain descending gently as it passes out to sea, and rising into smaller islands which sometimes attain a height of over 300 meters. Here lie the lifeless remains of an ancient reef, and the living reef follows next its margin. Between lats. 18° 30′ and 15° 30′ S. a broad plain, to all appearance but slightly submerged, extends in front of the reef, and is separated from it by depths of 1,100 to 2,300 meters [1].

The outlines of the coast might lead us to suppose that the seaward face of Australia is formed by a series of more or less parallel fractures.

The whole of the east coast is accompanied by the alternating ranges of the Australian Cordillera, in which the folding is at least older than a part of the Carboniferous. The seaward face, or zone of fracture, may therefore be regarded as a longitudinal fault, and for this reason J. W. Gregory describes the east coast as belonging to the Pacific type, the south coast to the Atlantic type [2].

[1] A. Agassiz, Visit to the Great Barrier Reef of Australia, Bull. Mus. Comp. Zool., 1898, XXVIII, pp. 95–148, maps.

[2] J. W. Gregory, Geography of Victoria, 8vo, Melbourne, 1903, p. 32 et seq.

The Cordillera is continued, according to Haddon, Sollas, and Cole, in islands, formed chiefly of granite, from York Peninsula across Torres Strait, and it terminates on the margin of the great southern plain of New Guinea in the granite hill of Mabudauan [1].

The succession of marine strata in Australia presents many more gaps in the Mesozoic series than that of Timor, New Caledonia, or New Zealand. The Cretaceous system, which often begins with the Aptian stage, extends over broad Archaean regions; according to recent observations the desert sandstone is assigned to it. In the west a transgression of the Jurassic zone of *Stephanoceras Humphresianum* is known (II, p. 160). This transgression has an important bearing on comparisons to be drawn later.

We have already seen that *Auckland* consists of granite, Tertiary sandstone, and volcanic rocks. *Macquarie* is formed, according to Ferrar and Prior, of a dolerite, which shows signs of dynamic action (slickensides, &c.); from *Campbell island* doubtful Mesozoic, Cretaceous and volcanic rocks are known; from the *Antipodes* dolerite and phonolite; from *Bounty island*, granite; and from *Chatham island*, mica-schist, Miocene limestone, and volcanic rock are mentioned (II, p. 149). These islands are not arranged on perceptible lines, and their characters afford no definite answer to the question whether the Australian mass is continued towards the south. It is only beyond lat. 66° S., and particularly lat. 70° S., that observations begin to present continuity.

The *Balleny islands* extend towards the south-east; they are volcanic; in 1839 Captain Balleny discovered an active volcano among them.

Scott island (long. 179° 55′ W., lat. 67° 24′ S.) is formed, according to Prior, of phonolitic trachyte.

In the neighbourhood of the Antarctic circle there are indications of a great continent. These begin west of the Gauss mountain (lat. 66° 48′ S., long. 89° 30′ E.) which consists of leucite basalt [2]. Wilkes Land belongs to this continent, and probably the whole of South Victoria Land up to long. 180° or even further. Dumont d'Urville, judging from ice-borne boulders, had already conjectured that it was formed largely of granite and gneiss. Philippi mentions red quartzite obtained from the crops of penguins. Borchgrevinck obtained garnet-bearing aplite and mica-schist from cape Adare, where widely distributed lavas also occur [3].

[1] A. C. Haddon, W. J. Sollas, and G. A. J. Cole, Geology of Torres Straits, Trans. Roy. Dub. Soc., 1894, XXX, pp. 419–476, map. The Murray Islands, Uga, and Erub, consist of recent lavas.

[2] E. Philippi, Geologische Beschreibung des Gaussberges, in Deutsche Südpolar-Expedition, 1901–1903, edited by E. von Drygalski, II, pp. 49–71.

[3] David, Smith, and Schofield, Notes on Antarctic Rocks, collected by Mr. C. E. Borchgrevink, Journ. Proc. Roy. Soc. N.S.W., 1895, XXIX, pp. 461–492; G. T. Prior, Petrographical Notes on the Rock specimens collected in Antarctic Regions during the voyage of H.M.S. *Erebus* and *Terror* under Sir J. C. Ross, Min. Mag., 1900, XII, pp. 69–91.

We now follow the accounts furnished by the *Discovery* under Captain R. Scott, and in particular the geological observations of his companion Ferrar[1]. Indications of the presence of land extend in an almost easterly direction as far as the meridian of the Balleny islands, and south of these islands, a coast which is known in greater detail begins near cape North, in lat. 70° 30′ S., long. 166° E. It runs along South Victoria Land almost to long. 171° E. and then turns nearly due south. Ross travelled along this coast as far as the volcanos of Erebus and Terror, which lie off it between lats. 77° and 78° S. Scott, in a journey which tried his powers of endurance to the utmost, explored it as far as lat. 83° S. From lat. 79° or 80° S. onwards it trends more to the south-south-east. It corresponds to the lofty east border of a great elevated plateau of dolerite and sandstone, which extends through 13 degrees of latitude. On its ice-covered surface, between lats. 77° and 78° S., Scott travelled westward into the interior for a distance of more than 300 kilometers and at a uniform height of 9,000 feet.

At the east foot of this plateau four or five volcanic cones rise along the coast. The little off-lying islands have only furnished volcanic rock as far as Ross island, which bears the four great volcanos, Erebus (3,998 meters, active), Bird, Terra Nova, and Terror. Crater mountains, both large and small, occur between Ross island and the border of the plateau, particularly towards the south-west. At the base gneiss occurs, and with it steeply upturned beds of white granular limestone. These are followed by granite at greater heights.

The edge of the plateau is visible near long. 161° E., lat. 77° 45′ S., beneath the inland ice. Here Ferrar observed a sheet of dolerite as much as 700 feet in thickness extending from a height of 8,000 feet downwards, beneath this came horizontally stratified sandstone (Beacon sandstone) with Carbonaceous matter, traversed by sills and some pipes of dolerite. It is visible for a thickness of 2,000 feet. The whole series rests on granite and gneiss. The regions which lie further south are unknown except as to their contours. In lat. 80° S. Barne obtained a fragment of schist, and horizontal bedding is mentioned, but this may only indicate flows of basalt. In lat. 83° S. mount Markham rises to a height of 15,100 feet (4,612 meters) as estimated by Scott.—

These characters, notwithstanding the number of recent volcanos, do not indicate a Pacific structure. The horizontal position of the sandstones, the wide distribution of gneiss and granite, and all the contours show that this plateau belongs to the Atlantic type. As regards South Victoria, we must agree with Ferrar that the coast is broken off. It recalls the fractures

[1] Captain R. F. Scott, Voyage of the *Discovery*, 2 vols., 8vo, maps, London, 1905, in particular H. T. Ferrar, Summary of Geological Observations, II, pp. 437–468, and Nat. Antarctic Expedition, 1901-1904, Natural History, I, Geology, 4to, 1907, 160 pp., maps (published by the British Museum).

of East Africa rather than a Pacific arc, and this comparison is in complete accordance with the conclusions of Prior based on the nature of the rocks. Whether or not King Edward VII Land, which is situated further east (lat. 76°–78° S., long. 100°–150° W.), and has furnished loose fragments of ancient rocks, must be referred to the same type, can hardly be determined at present. It is certain that the regions lying still further east, such as Graham's Land, possess a different structure.

Philippi believes that the Gaussberg also exhibits the Atlantic type, since the nature of the eruptive rock in South Victoria Land is the same as that which characterizes the Atlantic regions. The significance of this character will be discussed later. Professor Gregory, who is well acquainted with Australia, also assigns South Victoria Land to the Atlantic type.

This view is well founded. The Gaussberg, Wilkes Land, and South Victoria are to be regarded as a continent of Atlantic structure; we may name it *Antarctis.*

In connexion with this discussion, it must not be overlooked that the structure of the Cape mountains suggests the existence of a wide extension of folded mountains both to the east and the west. But of this there are no visible indications. It must also be borne in mind that the south of New Zealand presents a range of divergent structure which strikes out to sea through Stewart island, and the continuation of this is also quite unknown (II, p. 147).

Fore-deeps forming the boundaries of Asia. The island world of the Pacific, although it only appears as isolated peaks and fragments rising out of the vast expanse of Ocean, yet claims on account of its wide distribution a prominent place in the plan of the earth's surface. The parts exposed to view are arranged in long and often arcuate lines; and it is becoming increasingly clear that most of these are the trendlines of recent mountain chains. We have already seen that in Java the beds with Lepidocyclina are folded, and Verbeek's description of Leitimor shows that in this island also very recent coral beds are carried up to a considerable height, inclined, and occasionally folded [1].

Recent folds of similar character are met with at several localities in Oceania, in a striking form, for instance, in the New Hebrides.

The grouping and classification of the whole swarm of islands would, however, hardly be possible if the investigations of recent years had not revealed the instructive fact *that the greatest abyssal depths, having the form of elongated furrows, lie in front of the outer border of the arcs of Pacific type.*

These deeps were first described as 'channels'. Supan suggested in 1899 that they should be called 'troughs', but with the express reservation

[1] R. D. M. Verbeek, Description géologique de l'île d'Ambon, Jaarb. Mijnw. Ned. O.-Ind., 1905, XXXIV, 323 pp., atlas.

that the term should be taken to apply only to their form and not to their mode of origin. As fresh facts were brought to light Supan conjectured that the troughs were connected with foldings [1]. It is indeed obvious that this is the case.

We have frequently pointed out that elongated deeps or depressions lie in front of the more recent folded ranges. Examples are afforded by the valley of the Guadalquivir, the Persian Gulf, and the thick alluvial deposits of the Ganges. These depressions are frequently masked by sediments which fill them up, as, for instance, the delta of the Tigris and Euphrates, and that of the Ganges and Brahmaputra. The obliteration is even more complete when brought about by marine Tertiary deposits. In Central Europe the special question of frame-folding has to be taken into account, yet it must not be forgotten that the Tertiary marls fill great depressions in front of the brow of the Carpathians as well as of the Alps.

These depressions mark the subsidence of the foreland beneath the recent folds. They have received the name of 'fore-troughs'. But they are not troughs in the usual sense of the term; their two sides are of different structure, and it therefore seems advisable to call them '*fore-deeps*'. With one or two exceptions, *all marine abysses which sink below a depth of 7,000 meters are fore-deeps in a tectonic sense and indicate the subsidence of the foreland beneath the folded mountains.* Thus we are brought back to the question, whether the greatest deeps, like the highest mountains, are not the most recent [2]. For the present, however, we will consider only the distribution of these deeps in the south-western or western part of the Pacific Ocean, and not their connexion with the structure of the mountains.

With this object we must first examine the map of the Oceanic depths between the Marianne islands and Celebes, which has been published by Schott and Perlewitz [3]. In addition to the more remote fore-deep of the Liu-Kiu islands, which sinks over an elongated tract below a depth of 7,000 meters, this map marks an abyss, which runs from the east side of the Marianne islands around Guam, and then to the south-west; a second shorter depression, east of Yap, with a south-south-westerly direction; a third east of the Pelew islands, running at first almost north and south, and then further south towards the south-west; and a fourth, lying east of the Talur islands, which starts a long way off from the east side of the Philippines.

These several fore-deeps are thus arranged in a series of oblique

[1] A. Supan, Die Bodenformen des Weltmeeres, Peterm. Mitth., 1899, pp. 177–196, map, in particular p. 180; Die Sundagräben des Malaischen Archipels, op. cit., 1907, pp. 70–71, map.

[2] Are Ocean Depths Permanent? Nat. Science, March, 1893, pp. 180–187, in particular p. 181.

[3] G. Schott and P. Perlewitz, Lotungen J. N. M. S. 'Edi' und des Kabeldampfers 'Stephan', Arch. deutsch. Seewarte, 1906, XXIX, no. 2, 38 pp., maps.

coulisses which all strike, at least in their southern half, towards the south-west or south-south-west. *They mark the eastern boundary of the Asiatic system.*

The Marianne islands, Yap, the Pelew, Philippine, and Talur islands are to be included, therefore, in Asia. To the east of them lie the Oceanides.

We will now consider certain details.

In the *Bonin* islands Nummulitic limestone is said to occur (III, p. 146). According to later investigations by Yoshiwara the islands are arranged in two series. One of them, the *Ogasawara* chain, lies in the east between lat. 27° 40′ and 26° 38′ N. (Plymouth island or Muko-shima, the Parry group or Chichi-shima, Barley islands or Haha-shima, and many smaller islands). This series is formed of Eocene limestone with Nummulites, alternating with older eruptive rocks and rising to a height of over 600 feet; horizontal Lepidocyclina limestone rests against it unconformably. In the northernmost island, Stapleton or Ototo-shima, serpentine is said to occur [1]. The second series of the group runs west of the first from Lott's Wife to the Sulphur islands; this is marked by active volcanos, and it forms the continuation of the line of the Fuji volcanos which cuts through Honshiu. Near Sulphur island or Iwō-shima a new island, Neo-shima, arose in the winter of 1904–5 [2].

The Ogasawara chain must thus be regarded as the remains of one of the younger Cordilleras.

The *Marianne* islands form an arc slightly convex to the east; no cordillera is visible. Fritz states that all the islands of this arc lying north of lat. 16° N. are young volcanos of regular form; at their foot is coral limestone which scarcely rises above the sea level, while the six islands situated south of lat. 16° N. are covered with limestone up to their very summits and are clearly broken up into terraces [3].

Alexander Agassiz enumerates twelve active volcanos as occurring in the northern Marianne islands which extend up to the Farallon de Pajaros; he recognized a connexion extending through 20 degrees of latitude from Guam to Japan. *Rota* is about 800 feet (243 meters) in height and is a typical limestone plateau. Mau presents five terraces in the north and seven in the south, and traces of two recent negative movements of not more than 3 to 4 feet each. *Guam* likewise shows limestone terraces; the lower sometimes deeply incised; in places the limestone rises in vertical cliffs as much as 150 meters in height, and rows of caves are to be seen in

[1] S. Yoshiwara, Geological Age of the Bonin Islands, Geol. Mag., 1902, Dec., IV, vol. IX, pp. 296-303, map.

[2] Zeitschr. Ges. Erdk., 1905, p. 382; on the 2nd January, 1905, it was about 150 meters high.

[3] Fritz, Bericht über die Insel Rota (Mariannen) 14° 7′ 30″ N., Mitth. deutsch. Schutzgeb., 1901, XIV, pp. 194–204; and Reise nach den nördlichen Mariannen, op. cit., 1902, XV, pp. 96–118.

their face, corresponding to the heights of former terraces which have been destroyed by land slips. This is no doubt a consequence of interruptions in the negative movement, for the action of rain would have been to produce, not a line of caves, but vertical funnels. On the east side the coral limestones are stratified and dip towards the sea. Considerable disturbances have been observed in the limestone; Agassiz regards them as connected with the eruption of volcanic rock, which has altered the limestone in contact; we should be inclined rather to regard them as produced by tectonic folding. The west coast of Guam, like the island of Rota is marked by a very recent negative movement of 3½ to 4 feet[1].

The fore-deep of Guam is one of the most remarkable existing. It bends in an arc around the south side of the island. Flint has collected the most important numerical data concerning it[2]. South-east of Guam, about 40 kilometers from the shore, −2,079 meters was sounded, at about 80 kilometers from the shore, of −4,090 meters. At a distance of about 130 kilometers (lat. 12° 51′ N., long. 145° 46′ E.) the *Albatross* found −8,802 meters, and not far from this spot the *Nero* sounded −9,636 meters, the greatest depth which has as yet been discovered. Then the sea bottom rises in the direction of the Ocean. From −8,985 meters we soon pass to an isolated summit lying at only −4,592 meters; Schott and Perlewitz describe it as a horst; then the Ocean extends far and wide with a depth of about 5,700 meters.—

Volckens and E. Kaiser state that the island of *Yap* together with Rümong and Map consist of amphibolite and actinolite schist. In Map a breccia is said to occur which contains boulders up to a meter in diameter formed of fresh gabbro and pyroxenite, as well as amphibolite and hornblende ,syenite[3]. This recalls the association of gabbro and amphibolite in Mentawei and Java (III, p. 236), where these rocks are not older than the middle Cretaceous.

According to Schott and Perlewitz an almost level sea bottom extends west of Yap at −3,000 to −4,000 meters; then it rises very rapidly up to the island. To the east the submarine slope to about the same depth is gentler, and then the bottom suddenly sinks to −7,538 meters.

[1] A. Agassiz, Coral Reefs of the tropical Pacific (Reports on the Scientific Results of the Expedition by the steamer *Albatross*, IV), Mem. Mus. Comp. Zool., 1903, XXVIII, 410 pp., maps, in particular p. 365 et seq. From the Farallon de Pajaros, E. Kaiser mentions augite-andesite, and from Saipan andesite-obsidian, Jahrb. k.-preuss. geol. Landesanst., 1903, XXIV, p. 114 et seq.

[2] G. Volkens, Ueber die Karolinen-Insel Yap, Verh. Ges. Erdk., 1901, XXVIII, pp. 62–76, map; E. Kaiser, Beitrag zur Petrographie und Geologie der deutschen Südsee-Inseln, Jahrb. k. preuss. geol. Landesanst., 1903, XXIV, pp. 91–121, map, in particular p. 114 et seq.

[3] J. M. Flint. Contributions to the Oceanography of the Pacific, Bull. U.S. Nat. Mus. Washington, 1905, no. 55, 62 pp., maps.

On the other side of the fore-deep, towards the east, there is a broad ascent to −4,000 meters. The fore-deep itself mounts rapidly along its longitudinal axis, that is towards the north-east and south-west, to −6,000 meters.

The *Pelew* islands consist, according to Kubary and Wichmann, of augite-andesite and tuff, which form the great island of Babelthuap, and a group adjoining it on the south; superposed on this is limestone. Semper mentions domes of limestone reaching a height of 200 feet; according to Kubary it forms on the southern island of Angaur a steep rock, 500 feet in height. It is described as coarse grained, compact, crystalline, well-stratified and fossiliferous.

Rolled pebbles of syenitic granite occur on the coast; but on the island of Malakal they also occur up to a height of 500 meters [1].

Some shallows on the north give to this chain of islands the form of an arc convex towards the south-east. On the west the sea bottom does not sink much below −4,000 meters; on the east the fore-deep consists of a northern half lying at −8,138 meters and a southern half below −7,000 meters. The boundary between the two halves rises up to −6,254 meters.

The *Tulur* islands are almost entirely sedimentary (III, p. 262).

The soundings of the 'Planet' show, according to Brennecke's account, an elongated fore-deep lying off the Philippines at a distance of about 25 or 45 knots east of the coast. In lat. 12° 23′ N., only 25 knots from Samar, the bottom was not reached at −8,900 meters; east of Mindanao −8,500 was sounded in lat. 8° 35′ N., and in lat. 7° 5′ N. the bottom was not reached at −8,554 meters. From this point the fore-deep turns towards the south-south-east, arrives east of the Tulur islands with soundings of −7,243 meters, and is continued as a furrow of −5,100 meters along the east side of Morotai [2]. Thus confirmation is given to the conjecture *that Almahera belongs to the Philippines*, and at the same time the eastern boundary is determined by the great virgation of which Borneo forms part (III, pp. 261, 265).

The Carolines and New Guinea belong to quite another system.

We have already seen that no limit is known to the arc-producing force of Asia in the direction of the Ocean (III, p. 146). Towards the south-east this boundary extends along the east side of the Marianne islands, from Yap, through Pelew, to Almahera.

The line of Ruahine, Kermadec, and Tonga. Many years ago Dana attempted to determine the trend-lines of Oceania. He was able to dis-

[1] J. Kubary, Die Palau-Inseln in der Südsee, Journ. Mus. Godeffroy, 1873, IV, pp. 177–238; A. Wichmann, Zur geologischen Kenntniss der Palau-Inseln, op. cit., 1875, VIII, 255–259; map of these islands by L. Friederichsen, op. cit., IV, pl. 1; K. Oebbeke, N. J. f. Min., 1881; E. Kaiser, Jahrb. k.-preuss. geol. Landesanst., 1903, XXIV, p. 113.

[2] W. Brennecke, Forschungsreise S.M.S. 'Planet', Ann. d. Hydrogr., 1907, pp. 193–198.

tinguish: (1) *Hawaii* (with Fanning and Marquesas); (2) the *Polynesian chain* (Ralik and Radak, Gilbert, Ellice, Samoa as far as Tubnai and Paumotu). He found that Samoa lay in an embayment caused by a bending of the strike out of the south-east into the east-south-east direction; (3) the *Australian chain* (on the other side of the Caroline islands, which may be regarded as a connecting link, all the islands from the zone of the Admiralty islands to the New Hebrides, as far as Australia); this group is arranged more nearly in the form of an arc; (4) the *New Zealand chain* (Macquarie, New Zealand, as far as the north end of the Tonga islands). This chain strikes to the north-north-east almost perpendicular to the generally prevalent north-west direction [1].

This conception of the facts reveals much insight; Dana's transverse line of New Zealand is in fact a main boundary. Following Dana as to the essential points we shall here name the western region the Australian; the eastern region, however, we shall speak of, in correspondence with general usage, as the Polynesian. Hawaii will be considered later.

In the south island of *New Zealand* (II, p. 143) two ranges, now visible only in fragments, encounter one another. One of these, but little known, strikes to the south-east across Stewart island. The other, folded towards the east-south-east, strikes to the north-north-east. Its western and older zones disappear on Tasman bay; the eastern zones, which are Palaeozoic and Mesozoic, form the Ruahine range on the east side of North island. Where the older western zone of the south, consisting chiefly of gneiss and ancient schist should make its appearance in North island, we encounter instead a zone of subsidence, Hochstetter's Taupo zone, situated to the west of the Ruahine zone. This zone, beset with numerous smaller eruptive centres, includes the great volcanos Ruapehu and Tongariro, and the fissure of the volcano Tarawera, which, previously regarded as extinct, opened up on June 10, 1886, with disastrous consequences.

In the bay of Plenty, situated on the continuation of the Taupo zone, lies the volcano of White island, and P. Smith has shown that the same volcanic line is continued to the very active volcanic islands of the *Kermadec* group which also run towards the north-north-east [2]. In Raoul (Sunday island) boulders of hornblende granite are met with [3].

[1] J. D. Dana, Manual of Geology, 2nd ed., 1875, p. 29 et seq., et passim. Among later attempts we may mention T. Arldt, Parallelismus der Inselketten Oceaniens, Zeitschr. Ges. Erdk., 1906, pp. 323–346, and 385–404, map.

[2] Percy Smith, Geological Notes on the Kermadec Group, Trans. N.Z. Inst., 1887, XX, pp. 333–344.

[3] A. P. W. Thomas, Notes on the Rocks of the Kermadec Islands, Trans. N.Z. Inst., 1887, XX, pp. 311–315. The boulders appear to have been cast up by eruption; it is doubtful whether they are of great age, or have been produced from the base of the funnel. Speight mentions tachylite from Macaulay island; elsewhere andesites prevail, op. cit., 1895, XXVIII, pp. 625–627.

Both Smith and Lister regard the *Tonga* islands as a still further continuation of the same line, as indicated by the Minerva bank and a submarine ridge. These islands also run towards the north-north-east. They consist of an eastern and a western zone; the western is formed by a series of volcanos. Falcon volcano was a slightly submerged reef in 1867, emitted smoke in 1877, once broke into eruption in 1885, stood at a height of slightly over 60 meters in 1887, and in 1889 was again almost entirely washed away. Metis likewise arose in quite recent times. Several others of these volcanos have been seen sending forth steam.

The eastern zone consists of terraced limestone. On *Eua*, the most southerly island, a block of uralitised gabbro has been found, either in place, or brought up by volcanic agency; loose crystals of garnet and tourmaline also occur. The core of the island was formed by an ancient eruption, which carried up torn-off limestone fragments to a great height. This core is mantled by limestone which is divided into terraces, and these are higher on the outer, and lower on the inner side, as though there had been a sufficient interval between the negative movements for the growth of an atoll. The highest step in the limestone occurs at a level of 500 feet (152 meters). The limestone is invaded by volcanic dykes.

The other islands of the eastern zone, *Tonga Tabu*, the *Hapai* and the *Vavau* group show no volcanic basement; the terracing is particularly well marked in the Vavau islands; Lister distinguishes among them, some with one terrace, some with two terraces, and some with three. In this respect they resemble the Loyalty islands (II, p. 315). The highest platform reaches a level of 520 feet (158 meters).

Lister believes that these islands have formed on volcanic banks, perhaps like that of the Falcon[1].

We might hesitate to suppose that a connexion, passing through the Kermadec group, should exist between New Zealand and the Tonga islands, which are 16–17 degrees of latitude distant from it, but the Tonga islands themselves follow the same strike through $3\frac{1}{2}$ degrees of latitude as far as Amargura, and a very considerable fore-deep lying on the east side confirms the supposition.

Even in lat. 35° S. (east of the northern extremity of New Zealand) the sea bottom lies at −8,000 meters; in lat. 30° 27′ S. (east of Kermadec)

[1] J. J. Lister, Notes on the Geology of the Tonga Islands, Quart. Journ. Geol. Soc., 1891, XLIV, pp. 590–617, map; Geogr. Journ., 1890, XII, p. 157; numerous details are given by C. Phillips, The Volcanos of the Pacific, Trans. and Proc. N.Z. Inst., 1898, XXXI, pp. 510–551, 1899, XXXII, pp. 188–212; according to a note in this work communicated by Hector (XXXI, p. 514) Falcon was produced by an eruption of rhyolite, a rock rare in these regions and recalling New Zealand. A chart of the depths is given by O. Krümmel, Die tiefste Depression des Meeresbodens, Hettner's Geogr. Zeitschr., 1899, V, pp. 509–512, pl. 10; also A. Agassiz, Coral Reefs, pp. 175–203, pl. 213, 214. The last-named map shows the contrast between the two series of islands.

the *Penguin* sounded −9,428 meters, in lat. 28° 44′ S. (north-east of Raoul) −9,413 meters, in lat. 23° 29′ S. −9,193 meters; on the south-east of Eua (Tonga islands) −8,700 meters is still met with, and south-east of Keppel (North Tonga) −8,280 meters. The three points with a greater depth than 9,000 meters lie 600 kilometers distant from one another. They are separated by intervals of −7,000–8,000 meters.

These depths are the more remarkable since the whole of the sea situated towards the west seldom reaches −4,000 meters, and that on the east sinks at most to −5,000 meters. Towards Samoa the depths rapidly decrease, and the volcanic mountains of Samoa are evidently alined in another direction—east-south-east. The boundary must be drawn west of Samoa. In this way the archipelago is divided into the Australian portion and the Polynesian portion. That the depression is a true tectonic fore-deep is shown by its position in front of the mountains of northern New Zealand (Ruahine) which are folded towards the east.

Jensen, who described an eruption which occurred in 1906 in Tofua (Tonga group), would extend the line from New Zealand even as far as Samoa; he regards the depths as true fore-deeps, and the whole line as possibly produced by overfolding from the west-north-west [1].

First Australian arc. The Australian archipelago, bounded on the north-west and east by the greatest depths so far known, is divided into three arcs. The first and innermost runs from New Guinea into the north-north-west peninsula of New Zealand. It falls into two adjacent arcs; New Guinea, Louisiade, New Caledonia, New Zealand, form one, and North Mecklenburg, Solomon islands, New Hebrides, the other. In both ancient rocks are exposed. The second arc is formed by the Caroline, Radak, Gilbert, Ellice, and Fiji islands. The third arc, almost a straight line, includes Tonga, Kermadec, and north-east New Zealand.

New Guinea (II, p. 165; III, p. 243). Our previous descriptions of this great island were very bare, and even now we can scarcely offer more than isolated and disconnected data. Yet New Guinea measures thrice the length of the Alps between Lyons and Vienna, and it is traversed by a long and lofty mountain range.

The contrast between New Guinea and the ancient mass of Australia would be still sharper were it not for a vast stretch of hilly country and plain which adjoins the south side of the mountains, and probably occupies the whole of the southern part of New Guinea, from the gulf of Papua

[1] A submarine eruption situated outside the southern continuation (Taupo zone), yet within the conjectured continuation of the great depths, took place outside Open bay, New Zealand, on Dec. 18, 1877, Ann. Hydrogr., 1878, VI, p. 370; also Rudolph, Submarine Erdbeben und Eruptionen, Gerland, Beiträge zur Geophysik, 1887, I, p. 359; J. Jensen, Geology of Samoa and Eruptions in Savaii, Proc. Linn. Soc. N.S.W., 1906, XXXI, pp. 641-672, in particular p. 661 et seq.

nearly up to the western end of the Charles Louis range. On the south margin of this lower lying land rises the granite hill of Mabudauan, which belongs to Australia. A considerable area is drained by the Fly river. D'Albertis, M'Gregor, and others have explored this region; the data which are of most value to us were collected by the expedition of Edelfelt and Bevan, who explored the Strickland river (left tributary of the Fly) in 1855. In the first hill ranges on the upper Strickland marine Tertiary beds were observed, and further up the river in lat. 6° 35′ S. a fossil shell (Inoceramus or Aucella) was found; middle Jurassic Ammonites occur enclosed in nodules. They are compared with *Stephanoceras calloviense*, *S. Blagdeni*, and *S. coronatum*, and point to an horizon not far removed from the middle Jurassic transgression of western Australia [1].

Still further north, finally, in lat. 5° 30′ S., on the Palmerston river, 3¾ degrees of latitude from the hill of Mabudauan and the coast, we reach the foot of mount Blücher and mount Donaldson, which are foothills of the principal chain. Ten Brink recalls the fact that in the year 1623 Jan Carstens, sailing along the south-west coast in lat. 5° 14′ S., saw a snow-covered range in the interior of the island, and that these snowy peaks were not seen again until the year 1881. These highest summits, probably reaching as much as 5,000 meters, are shown on a sketch map by Ijzermann as the eastern continuation of the Charles Louis range, in long. 137° 11′ E., lat. 4° 14′ S.[2]

The presence of middle Jurassic beds leads us to suppose that the south of New Guinea must stand in some tectonic relation to Australia.

1. *British New Guinea.* For a study of the south slope of the eastern part of New Guinea, Maitland's account of 1891 is the most important source of information; it includes all the observations previously made, particularly those of M'Gregor [3].

Three elements contribute to the formation of the range, namely, a broad zone of ancient schist, which includes the uppermost parts in the interior, then a steeply upturned and folded zone of limestone extending along part of the south coast, and finally recent volcanos.

From long. 146° 15′ E. to about 148° 30′ E. the limestone zone (Maitland's Moresby beds) has been thoroughly investigated. It is formed of light-coloured limestones with bands of chert striking N. 30° W. In Hall

[1] R. Jack and R. Etheridge, jun., Geology and Palaeontology of Queensland and New Guinea, 8vo, Brisbane, 1892, with map and atlas, p. 696 et seq.

[2] A. J. Ten Brink, Het 'Sneeuwegebergte' op Nieuw Guinea, Natuurk. Tijdschr. v. Nederl. Indië, 1893, LII, pp. 41-75; J. W. Ijzerman, Report in Tijdschr. Nederl. Aardrijksk. Genootsch., 1904, XXI, pp. 339-354, map.

[3] A. Gibb Maitland, Geological Observations in British New Guinea in 1891, Blue Book, Queensland, 1892, 30 pp., maps; also Salient geological Features of British New Guinea, W. Austr. Nat. Hist. Soc., April 11, 1905, 26 pp. A copy of Maitland's geological map of this region is given by Haddon, Geogr. Journ., 1900, XVI, p. 268.

sound (long. 146° 35′ E.) they have afforded foraminifera and Tertiary shells, but the latter are different from those which occur in the Tertiary beds of Australia [1]. It is possible that the so-called Boioro limestone of the south coast (long. 149° 30′ E.) belongs to this limestone zone, which apparently includes sediments of various age. Perhaps the hard, shell-bearing limestone of Tumu (long. 144° 15′ E.), which occurs in the north-west near the head of the gulf of Papua, must also be referred here.

The folding of the limestone zone preceded the eruption of the lavas. A broad mass of lava advances in cape Suckling (long. 146° 45′ E.) towards the sea. It descends from mount Yule (Kovio), a fairly independent mass which rises in the south of the principal chain. Jullien and de Rycke estimate its height at 3,400 meters, and that of mount Marie, which belongs to the principal chain, at 4,500 meters [2].

M'Gregor crossed the principal chain or *Owen Stanley range*, through the valley of the Vanapa river, east of cape Suckling. It consists of steeply-folded schists; on mount Victoria (4,000 meters) the schist resembles gneiss; towards the north it is followed by clay slate. Mount Skertchley (3,733 meters) on the north side has frequently been visited by gold diggers [3]. The schists of the principal chain extend in long. 147° 15′ E. nearly down to the south coast; there they include a granitic mass, against which the limestone zone rests. Then a region of recent volcanic activity attaches itself to the south side of the principal chain, near the headwaters of the Laloki, and great platforms of volcanic breccia, such as the Astrolabe plateau, step unconformably over the upturned limestone. Mount Obree, in the principal chain (long. 148° 5′ E.) appears to be an outlier of this volcanic region. East of this the principal chain again rises and reaches a height of 3,422 meters in mount Suckling, situated on its north side and formed of greenish quartzite.

Mount Dayman (2,812 meters) rises like mount Obree within the principal chain, bears a crater, and sends off a lava stream towards the north-east. Then the range decreases in height. In long. 149° 30′ E. the above-mentioned limestone of Boioro, folded and traversed by diorite, makes its appearance on the south-coast. From long. 149° 45′ E. onwards a series of crater mountains begins with the island of Mugula (Dufaure) and joining New Guinea, forms the harbour of Pouro (Mullen's Harbour); volcanic rocks prevail from this point as far as Milne bay.—

Let us turn our attention to the north side.

With the exception of the promontory situated between Goodenough

[1] Tenison Woods, Proc. Linn. Soc. N.S.W., 1883, VII, p. 381.

[2] P. P. Jullien et de Rycke, Deux voyages d'exploration, C. R. Soc. Géogr. Paris, 1898, pp. 206-209, map.

[3] W. Macgregor, Journey to the Summit of the Owen Stanley Range, New Guinea, Proc. R. Geogr. Soc., 1890, new ser., XII, pp. 193-223, map.

and Collingwood bays, which is formed of coral limestone, nothing but volcanic rock is known on the north coast as far as long. 148° E., i.e. up to the German frontier. Part of the lava seems to have come down from the great mountains. Cape Trafalgar (long. 149° 15′ E.) proceeding in isolation into the sea, bears the smoking volcano of mount Victory.

Beneath the lavas lie the ancient schists of the principal chain; miners prospecting for gold have followed them from the Owen Stanley range up to the German frontier and towards the sources of the Hercules river.

As the recent volcanos of the south-east are continued into the sea, and at the same time the height of the range decreases, these gold-bearing schists reappear, according to Jack and Maitland, in all the larger islands of the *Entrecastreaux* group, where they are associated with granitic gneiss. Further to the north-east also, in Murua (Woodlark), Maguire mentions schists with gold-bearing quartz veins [1].

The *Louisade* islands were long ago recognized by McGillivray and Dana as parts of New Guinea. The gold-bearing quartz occurs, according to Maitland, in Tagula (Sudest), in vertical clay slates. This slate has been observed as far as Rossel island (long. 154° 15′ E.) [2].

2. *German New Guinea.* At the mouth of the Hercules river, near Adolfshafen, Rüdiger found a rocky prominence of schistose rock. Schleinitz noticed that ancient rocks advance nearly to the coast on the south side of Hüon gulf [3]. According to Rüdiger the Francisca river flows over fragments of quartz and granite and the Parsee peninsula consists of granite [4].

Coral limestone forms the neighbourhood of Finschhafen; limestone seems to occur all round about the Sattelberg, 970 meters in height, and also upon it [5].

A region which extends from the mouth of the Markham river towards the north-west, and then through the broad valley of the Ramu (Ottilien) river as far as lat. 4° S., seems to be separated from the main range as a fairly independent mass, or it may be that the range itself swerves in a gentle curve. This region is divided into two parts by Astrolabe bay;

[1] W. Macgregor, Proc. R. Geogr. Soc., 1892, p. 327; H. R. Maguire, Impressions of a Year's Sojourn in British New Guinea, Queensland Geogr. Journ., 1901–1902, new ser., XVII, pp. 117–143, in particular p. 135 et seq.

[2] A. G. Maitland, Salient Features of British New Guinea. W. Austr. Nat. Hist. Soc., April 11, 1905, p. 22 et seq.

[3] Freiherr von Schleinitz, Beschreibung der Nordküste von Kaiser Wilhelms-Land von Cap Cretin bis zu den Legoarant-Inseln, Nachrichten über Kaiser Wilhelms-Land und den Bismarck-Archipel, publ. by the New Guinea Company of Berlin, 1889, V, pp. 48–87, map, in particular p. 55.

[4] H. Rüdiger, Der Hüon-Golf im Südosten von Kaiser Wilhelms-Land, Verh. Ges. Erdk. Berlin, 1897, XXIV, pp. 280–295, map, in particular pp. 288 and 293.

[5] Schneider, Nachrichten von Kaiser Wilhelms-Land, 1886, II, p. 85 et seq.; Warburg, op. cit., 1890, VI, p. 20, map in 1889, V.

its southern part, or the Maklai coast, is dominated by the *Finisterre range.*

Winter and Hellwig, who accompanied the Zöller expedition, travelled up the river Kabenau, which flows into Astrolabe bay. On this journey they first crossed a chain formed of sedimentary rock; then conglomerates and tuffs with fossils, and finally came upon porphyry. At that point the river turns towards the east.

The Finisterre range consists for the greater part of recent volcanic rocks; its highest point, mount Gladstone (2,390 meters), appears to be formed of augite-andesite. It is bounded on the south by the Kabenau, and south of the river valley we meet with porphyry. From this point two great ranges may be seen, on the south, the *Kraetke range*, running to the east-south-east, and on the west the still loftier *Bismarck range*, running to the south-east. The latter forms part of the principal chain of New Guinea [1].

The *Oertzen range* (Tajomanna, about 1,100 meters) may be regarded as a north-westerly continuation of the foothills of Finisterre. Lauterbach observed on its crest steeply upturned conglomerates composed of gigantic boulders of diorite, gabbro, hornblende-andesite, altered clay slate, and limestone, embedded in a hard blackish-green matrix [2].

This conglomerate also occurs further north on the Nuru river. Travelling up stream Lauterbach reached the Ssigauu mountains, formed of dark clay slate, tuff, and sandstone, and then on the other side of the watershed, between the Nuru and Ramu, soft laminated clay, steeply upturned, with small seams of coal. The great longitudinal valley of the Ramu begins behind the Finisterre range and there reaches the average breadth of 30 kilometers. It follows the north-east foot of the Bismarck range, the summits of which are here 4,300 meters in height, and separates it from the mountain ranges situated near the coast. One of the foothills (990 meters) has been ascended; it consists of gabbro and peridotite; the streams carry diorite, gneiss, and quartz boulders [3].

Dutch New Guinea. Our knowledge of the north-western part of this country was considerably increased by Wichmann's journeys, made in 1903 [4]; and the studies of G. Boehm and Wanner enable us to again

[1] Winter und Hellwig, Finisterre-Gebirge, Nachrichten von Kaiser-Wilhelms-Land, 1889, V, pp. 3–15, map.

[2] K. Lauterbach, ibid., 1896, p. 39, and Bericht über die Kaiser-Wilhelms-Land-Expedition im Jahre 1896, Verh. Ges. Erdk. Berlin, 1897, XXIV, pp. 51–69, map, in particular p. 53, and Die geographischen Ergebnisse der Kaiser-Wilhelms-Land-Expedition, Zeitschr. Ges. Erdk., 1898, XXXIII, pp. 141–175, maps.

[3] The identity of the Ramu and Ottilia rivers was subsequently established by Tappenbeck, Nachr. v. K.-Wilh.-Land, 1898, pp. 51–59, map.

[4] A. Wichmann's reports in Bull. nos. 43, 44, and 46 of the Maatsch. van het Natuurkund. Onderzoek d. Nederland. Kolon. (Neu-Guinea-Expedition, 1903, Bull. nos. 3, 4, and 6), 8vo, Leiden.

approach the question as to whether New Guinea is continued towards the west into the region of the Sunda islands (III, p. 243). We will first follow the accounts of Wichmann.

Green eruptive rocks (gabbro, serpentine, and others), extend from the south-east of Halmahera to the islands which lie off the north-west end of New Guinea (III, p. 262). No continuation is known here, and not until we reach long. 140° 18′ E. is gabbro again mentioned; it occurs in an island in the gulf of Tanah Merah; the island of Misotti in Humboldt bay (long. 140° 43′ E.) consists of serpentine. I do not know whether the chloromelanite, which occurs between these two localities on the Tarare river and furnishes material for the well-known stone clubs of Humboldt bay should be referred here. According to Wichmann it forms beds in the clay slate. The gabbro pebbles of the Tami river (long. 140° 55′ E.) are possibly derived from the higher mountains of the range.

Ancient crystalline rocks and phyllites occur not only in the island chain of Peling-Misol, which strikes east and west, but also in the peninsula of Beru. In the south-east clay slate and a folded red conglomerate occur.

On the south-west shore of Geelvinck bay ancient rocks and folded quartzites occur in places; the island of Roon is formed of gneiss; in the northern islands of the bay ancient schists and diabase predominate. Further east pebbles of crystalline schist come from the Cyclops range, and in Tarare bay marble, gneiss, and schorlaceous quartz crop out (long. 140° 32′ E.). Mesozoic sediments, of which we shall speak later, are known at several localities, and extend indeed far towards the east. They occur on the river Paparó, not far from the isthmus which unites Beru with the mainland, then further towards the south-east, on lake Jamur, and again in long. 139° 50′ E. on the Tawarin river (Walckenaer bay).

The next series mentioned by Wichmann is formed of steeply upturned Miocene clays and sandstones; they are coal-bearing and contain Arca and Ostrea. On the eastern side of the area a bed containing Melania is included with them. They were met with from long. 139° 45° E. onwards along the sides of rivers flowing into Walckenaer bay, and also at several other localities as far as long. 140° 55′ E. So far as we can judge from the accounts they always lie towards the interior. Possibly they form the outer boundary of the folded chain which immediately succeeds them.—

The north coast of M'Cluer inlet is flat, while the south coast with its off-lying islands is a rias coast of steeply-folded Alveolina limestone, with a north-west strike [1]. It extends in the south to lat. 4° S. On the east

[1] C. Schlumberger has shown that a so-called Alveolina limestone from north-west New Guinea does not contain Alveolina, but a new species of the genus Lacazina (L. Wichmanni); and that the Eocene age must therefore be based on other contempo-

side pebbles of Alveolina limestone, granite, diabase, and other rocks are brought down from the higher mountains and carried northwards by the river Tawarin.

Dark Crinoidal limestone (Carboniferous or Permian) occurs at the mouth of the Belangkat river, south of the Alveolina limestone. The locality cannot lie very far from the western end of the Charles Louis range.—

Let us again turn our attention to the Mesozoic sediments.

In the Sunda islands—Taliabu, Mangoli, and Misol in the north, and Buru and Ceram in the south, G. Boehm has observed a series of fossiliferous beds ranging from the Trias up to the middle Cretaceous, and containing faunas which show a striking resemblance to those of Europe. To this series the Mesozoic patches met with by Wichmann in the north of New Guinea must be assigned. *Phylloceras strigile* of the Spiti fauna occurs in the island of Taliabu, and also at a distance from this island, but in similar nodules, on the above-mentioned river of Tawarin (long. 139° 45′ E.) [1].

At the same time, however, there is this important difference that in the northern series of islands the later deposits rest undisturbed on the ancient rocks, while in the southern they are folded. Wanner found that the folding in the west of Buru affects even the Cretaceous containing Tissotia, and it is particularly intense over the east of Ceram. Indeed, in the latter locality great boulders make their appearance, which seem to be basement fragments, and Radiolaria occur in association with a basic eruptive rock. From the south-east coast of eastern Ceram also the Bate range runs to the north-east, and north of this is a second range extending first east and west and then north-west and north till it reaches the north coast [2].

In Taliabu the Jurassic beds are horizontal or inclined, but never folded, and Misol is a field of fracture, while the southern line of islands resembles Timor, both as regards its structure and the succession of its strata.

It has been already suggested (III, p. 243) that Buru and Ceram might represent the continuation of the southern peninsula of New Guinea; a view that has been adopted by G. Boehm [3].

raneous fossils. Martin mentions as such Orbitoides and Cycloclypeus, Bull. Soc. géol. France, 1894, 3e sér., XXII, pp. 295–298.

[1] G. Boehm, Beitrag zur Geologie vom Niederländischen Indien, I. Div., South coast of the Sula islands Taliabu and Mangoli; I. section, Boundary beds between the Jurassic and Cretaceous; Palaeontographica, 1904, supplement IV, 46 pp.; Geologische Mittheilungen aus dem Indo-Australischen Archipel, I, N. J. f. Min., 1906, Beil. Bd. XXII, pp. 385-412, map, et passim.

[2] J. Wanner, Geologische Mittheilungen aus dem Indo-Australischen Archipel, III, Zur Geologie und Geographie von West-Buru, N. J. f. Min., 1907, Beil. Bd. XXIV, pp. 133–160, and IV, Triaspetrographie der Molukken und des Timorarchipels, tom. cit., pp. 161–175

[3] G. Boehm, Geologische Mittheilungen aus dem Indo-Australischen Archipel, I, p. 404.

We may assume, pending further information, that the principal cordillera of New Guinea extends to Buru. The northern islands from Taliabu to Misol, together with the peninsula of Beru and the north coast of New Guinea (inland from Walckenaer bay to the folded band of Miocene), will then represent the foreland.

Survey of New Guinea. When we consider how great is the distance which intervenes between the Celebes and Rossel island (Louisiade), and how deficient is our information we shall readily understand that definite conclusions as to the structure of this region are at present beyond our reach. M'Gregor has certainly crossed the south-eastern part of the great range, and a regular postal service has now been established which runs from Port Moresby over a pass 2,000 meters above the sea and puts the north into communication with the south[1]. But beyond this, towards the north-west, the great range of the interior (Bismarck, Victor Emmanuel, and Charles Louis range) has never yet been trodden by a white man's foot. Consequently, we can only offer the following views as conjectures which, subject to correction, may help us to comprehend the general plan of this important part of the globe.

1. Halmahera must be assigned to Asia.

2. Asiatic directions of strike, which are chiefly meridional, meet a series of islands (Taliabu to Misol) running east and west, and forthwith the active volcanos come to an end. Ancient formations occur in these islands, and superposed upon them are undisturbed Mesozoic beds. These stratigraphical relations are continued across the peninsula of Beru, the islands of Geelvinck bay, and at least as far as Walckenaer bay. Their evidence, more particularly in Beru (Arfak range), points to the presence, not of a recent cordillera, but of older mountains.

3. On the coast between long. 140° 18′ and 140° 43′ E., that is, north of the supposed continuation of the rocks of Beru, isolated exposures of gabbro and serpentine occur. They are followed on the east by a long interval not yet explored, and then great boulders of similar rocks are encountered in a steeply-folded conglomerate of the Oertzen range, which may possibly be connected with the sharply-folded beds of the Kabenau river. These features, which recall Halmahera and the Philippines, appear, along with the andesite range of Finisterre, to stand more or less in independence of the rest. The longitudinal valley of the upper Ramu marks their boundary.

4. In association with these rocks we find along the north coast from long. 140° 7′ to 140° 14′ E. (between Walckenaer and Humboldt bay) isolated outcrops of basalt and andesite, the beginning, probably, of a series of volcanic reefs, and further on of recent volcanos, which first follow the coast and then, as we shall see directly, depart from it and run towards

[1] R. Pöch, Zeitschr. Ges. Erdk., 1907, p. 163.

New Britain. The position of the limestone on the Sattelberg (Finschhafen, forming part of Finisterre) is quite uncertain.

5. South of the island of Ramu our knowledge is confined to the altitudes of the great range, and does not extend to its structure. In Hüon gulf, granite and ancient rocks reach the sea. In all probability they belong to the great range which extends from this point through the Owen Stanley chain to the extreme south-east. This range consists of schist with gold-bearing quartz, gneissose in places, penetrated by isolated granite masses. Here and there it bears a volcano. Towards the south-east recent volcanos become more frequent. The Entrecasteaux islands and the Louisiade archipelago are its continuations.

6. The islands of Buru and Ceram, in the northern part of this region, present the characters of a folded cordillera, and the rias coast which forms the beginning of the Charles Louis range, south of M'Clure inlet, represents their continuation. Its age is post-Miocene; its northern outer border extends through the region south of Walckenaer bay. How far it runs to the south-east, or whether the southern mountains, such as the Owen Stanley range, belong to it is quite uncertain.

7. The only indication of a recent cordillera in the south-east of the region makes its appearance on the south side of the great mountains as a range of folded limestone. It lies on the north-east side of the gulf of Papua, and borders the south coast with a strike of N. 30° W. A part of it (Moresby beds) is regarded as Tertiary.

8. The south of New Guinea is formed of low-lying and hilly land. The granite boss of Mabudauan belongs to Australia. The Tertiary and Jurassic beds—the Jurassic extending to lat. 6° 35′ S. on the upper course of the Strickland—have as yet thrown no light on the structure. Hence it appears that between the Philippines (Halmahera) and the supposed continuation of the cordillera of New Guinea (Ceram, Buru) another independent and older element makes its appearance, of which the most conspicuous part is the peninsula of Beru. It follows from this, however, that the cordillera of Timor and its possible relation to Australia call for renewed investigation (III, p. 241). Meanwhile, Hirschi has afforded us further information as to the variety of the folded Mesozoic deposits of that island [1].

The islands to the north-east of New Guinea. Just off the north coast of New Guinea begins a long series of volcanos, in great part active, and, after running for some distance parallel to the coast, turns off in an arc towards New Britain. There is no reason, as we have seen, why the isolated andesites and basalts which Wichmann met with between Walckenaer bay and Humboldt bay should not be referred to this series. To the east lie the reefs and islands of Bertrand, Guilbert, and d'Urville;

[1] H. Hirschi, Geologische Mittheilungen, etc., V, Zur Geologie und Geographie von Portugiesischem Timor, N. J. f. Min., 1907, Beil. Bd. XXIV, pp. 460–474, maps.

Roissy island (long. 144° E.) brings us already into the series of the *Le Maire* islands, the connexion of which with the arc running towards New Britain has already been described by W. Powell and Kärnbach.[1] After Roissy island comes Volcano island, then Dampier, Rich, Crown, Long, Lattin, Tupinier, and Ritter islands, all beset with volcanos; the curve they describe finally reaches *New Britain* in the volcanos of Below (2,100 meters) and Hunstein. The discoveries of Freiherr von Schleinitz show that the concave north coast of the elongated island of New Britain is formed by a series of volcanos and isolated mountains, which are also probably volcanic, connected by low-lying land. The line of Below and Hunstein and the crater mountain of cape Gloucester is continued through this series as far as mount Raoul (lat. 5° 11′ S.).

It is difficult to say whether this series leading to mount Raoul indicates an advance of the whole arc towards the north-east, that is, towards cape Hollmann, while a new series of volcanos advances behind it; or whether this new series itself is a continuation of the first. On the peninsula to which mount Raoul belongs other volcanos occur (Credner, Engler, and others, as far as Duportail and Nord-Sohn), and these extend towards the great group of active volcanos which rises along Blanche bay on the north border of Gazelle peninsula [2].

Running in an arc from Le Maire islands across Dampier strait and along the north coast of New Britain is a very active line of volcanos, the position of which in the general tectonic plan is still unsolved. The only indication we possess as to the inner structure of New Britain is the conjecture of Graf Pfeil that the mountain ranges of the interior run transverse to the course of the island and parallel to New Guinea [3].

This conjecture is supported by the structure of *New Ireland.* Here Liversidge mentions porphyry, diorite, and dark limestone, different from the coral limestone, and also some grey crystalline limestone at a height of 760 meters (II, p. 164) [4]. This agrees with the statement of Graf Pfeil

[1] W. Powell, Proc. R. Geogr. Soc., 1883, new ser., IV, p. 511; Kärnbach, Nachrichten von Kaiser-Wilhelms-Land, 1893, IX, p. 43.

[2] Freiherr von Schleinitz, Begleitworte zur Karte der Nordküste des westlichen Theiles der Insel Neu-Pommern, Zeitschr. Ges. Erdk., 1896, XXXI, pp. 137–154, map; Begleitworte zur Karte des östlichen Theiles, op. cit., 1897, XXXII, pp. 349–359, map; also Nachrichten von Kaiser-Wilhelms-Land, 1889, V, p. 81. It is possible, but not definitely established, that two cone-shaped peaks 2,000 meters high in the south-east of Rook island are volcanos. The catastrophe of the 13th Feb., 1888, is said to have originated in this island; it gave rise to a great sea wave which reached the coast of New Britain and swept away the travellers von Below and Hunstein and their whole expedition.

[3] J. Graf Pfeil, Studien und Beobachtungen aus der Südsee, 8vo, Braunschweig, 1899, p. 190.

[4] A. Liversidge, Rocks from New Britain and New Ireland, Journ. Proc. R. Soc. N.S.W., 1882, XVI, pp. 47–51.

that the southern part of the island is volcanic, while the elongated part extending to the north-west is a ridge formed of sedimentary rocks, possibly resting on an older substructure; the slope of this ridge is steep towards the south-west, and gentle towards the north-east; it represents the most easterly of the folds which run parallel to New Guinea. We shall regard New Ireland as the continuation of the Solomon islands, where a similar limestone, in all probability Mesozoic, is stated to occur.

The islands of the *Bismarck* archipelago as far as the Admiralty islands have as yet furnished only volcanic rocks and recent coral limestone [1].

New Ireland to Hunter island. This long chain of islands includes as its principal members, New Ireland, the Solomon and Santa Cruz islands, and the New Hebrides. It is characterized by one principal direction of strike, which forms, according to the form and position of the islands, an arc slightly convex to the north-east. The islands have also many other characters in common.

We may begin with *Guadalcanar*, one of Solomon islands. This great island was visited by Foullon, who was killed by the natives when attempting to penetrate into the interior; his name must be added to the long list of victims whose discoveries we cannot mention without a word of reverent gratitude. His observations on this island have not been published. The volcanic rocks alone have been described by Hansel.[2] Through the kindness of Professor Berwerth the whole of the collections have been placed at my disposal.

Andesite, dolerite, and porphyry have been met with in Guadalcanar, besides recent volcanic rocks. Peridotite, gabbro, and serpentine occur in numerous fragments, but a light grey limestone has also been observed, precisely resembling one of the Mesozoic limestones of the Apennines or the Alps. It is traversed by striated slickensides which indicate powerful dynamic action [3]. A rolled-out green rock with serpentine on the fibrous surfaces also occurs in the collection. Guadalcanar must thus be regarded as the fragment of a cordillera, in the structure of which green intrusive

[1] A. Hahl, Bismarck-Archipel und Salomons-Inseln, Mitth. deutsch. Schutzgebiete, 1899, XII, pp. 111, 112; G. Thilenius, Geologische Notiz aus dem Bismarck-Archipel, Globus, 1900, pp. 201–203; Pflüger, Geologische Bemerkungen über den Bismarck-Archipel, Mitth. deutsch. Schutzgebiete, 1901, XIV, pp. 131–138; in this work it is stated that augite granite and syenite are brought down from the Baining range (New Britain).

[2] H. Freiherr von Foullon, Reiseskizzen aus Australien, Verh. k. k. geol. Reichsanst., 1894, p. 164; Hansel, Ueber einige Eruptivgesteine von der Inselgruppe der Neu-Hebriden, in Jahresberichte Staats-Ober-Realschule XVIII, Bez. Wien, 1901, 56 pp.

[3] Foullon writes of this limestone, 'in place between two streams which flow into Wanderer's bay' (south-west coast).

rocks play a similar part as in the cordillera of New Caledonia, Cuba, or the Apennines.

Guppy, who has made valuable observations on the Solomon islands, has not visited Guadalcanar, but his results are in complete accord with the preceding. The Florida islands, a little north of Guadalcanar have afforded specimens among which Judd recognized a rock allied to granulite, another allied to so-called trap-granulite (hornblende, enstatite, and plagioclase), and diallage serpentine [1]. Guppy says of the latter that it is generally somewhat schistose, and at one locality inclined at an angle of from 60° to 70°. Serpentine is mentioned as occurring in San Cristoval and Ysabel; gabbro in Santa Anna, the most southerly island of the group; quartz porphyry and quartz diorite at several localities. One of the most remarkable finds, and worthy of closer investigation, is a hard grey limestone, containing numerous shells of a Rhynconella; it forms the island of Poperang in the Shortland group (south of Bougainville) [2].

The active volcanos of the Solomon islands are not arranged in an independent series, but stand, so far as can be seen, between the isolated remains of the cordillera. A lofty, smoking cone rises in Bougainville; Simbo (Eddystone, Narovo, west of New Georgia) and Saro (north of Guadalcanar) are active centres of eruption.

The Solomon islands are surrounded in many places by recent limestone in terraces, extending up to a height, according to Guppy, of about 500 feet; in addition, marine tuffs of fairly recent age occur. Guppy observed a uniformity in the displacements of the strand for a distance of more than 600 kilometers.

The islands to the north, Outong-Java, Simpson, and others, are low coral reefs [3].

Our knowledge of the structure of the *New Hebrides* has been greatly increased by Mawson's investigations [4]. The asserted presence of older rocks in the larger islands has not been confirmed, and the existence of

[1] H. B. Guppy, Solomon Islands, their Geology, &c., 8vo, London, 1887, maps; Observations on the Recent Calcareous Formations of the Solomon Group, Trans. R. Soc. Edinb., 1887, XXXII, pp. 545-581; W. W. Watts and E. T. Newton, Notes on the Rocks from the Solomon Islands, Geol. Mag., 1896, pp. 358-365 (relates to volcanic rocks from New Georgia); Judd in Guppy, p. 30. D'Urville brought back serpentine from Ysabel.

[2] Davidson regarded the species as identical with *Rhynconella Grayi* hitherto known only from a single example found living in Fiji; Guppy doubts this, Solomon Islands, pp. 82, 120. Recent Calcareous Formations of the Solomon Group, Trans. R. Soc. Edinb., 1887, XXXII, p. 565. It might well be a Mesozoic limestone.

[3] Hochstetter, Reise der Novara, II, p. 153.

[4] D. Mawson, Geology of the New Hebrides, Proc. Linn. Soc. N.S.W., 1905, pp. 400-485, maps. As early as the summer of 1901 a number of enterprising French colonists, coming from Vaté and other islands of the New Hebrides, crossed Espiritu Santo along two lines, Bol. Soc. Geogr. Lisboa, 1903, pp. 389-392, map.

serpentine in Aneityum remains doubtful, but it has been definitely ascertained that a steeply upturned and folded zone of Tertiary Lepidocyclina limestone strikes through these islands. Thus, in this case also, there is no doubt that parts of a more recent folded range rise from the Ocean. Mawson believes there is overfolding towards the west, but since this opinion is founded on a single section to the south-west of Espiritu Santo the question as to the direction of the movement must for the present remain open.

The whole arrangement resembles a virgation open towards the north-north-west. A long single series of islands, with only a few volcanic stacks lying off them to the east, extends from Hunter island in the south, through Mathew, Aneityum, Tanna, and Eromango, to Efate in the north. The trend of this series is to the north-north-west, and its principal continuation is to be found in the two great islands of Malekula and Espiritu Santo. This branch corresponds with the Tertiary folded range mentioned above. From Efate a second branch strikes almost due north through Epi, Ambrym, and the elongated islands of Aragh-Aragh (Pentecost) and Aurora. Between these two branches, or more exactly between the islands of Espiritu Santo and Aurora lies the island of Aoba, and further north the islands of the Torres group and the Banks group also lie between the directions (if produced) of the two islands just mentioned, and they strike between north-north-west and north. The maps of the British Admiralty show this arrangement very clearly.

According to Mawson the deposition of the Tertiary beds in Espiritu Santo was accompanied by intrusions of andesite; these were followed by an extensive subsidence along the whole eastern side, and on the subsided area volcanic eruptions then commenced, which however brought to the surface not andesitic but basaltic rocks, and these still continue to the present day. Upon the whole of this series rests a coating of recent coral limestone. The limestone is terraced, but in the west the terraces reach a height of 2,000 feet (609 meters), while towards the east their height is considerably less. Mawson concludes that the greater elevation in the west is connected with the persistence of mountain-building movements, and that the depression towards the east has been produced by subsidence in the direction of the more recent basaltic eruptions. At the same time smaller elevations may be among the immediate effects of volcanic action, as the result, for instance, of the intrusion of sills.

Purey-Cust has drawn attention to the significance and continuity of this volcanic zone. Apart from many ruins of volcanic cones we may enumerate the following, taken in order from north to south: Tinakula (active; north of Santa Cruz); Vanikoro (crater), Vanua lava (hot springs); Gaua (crater, south of Vanua lava); Merlay (crater, east of preceding island); Ambrym (great eruption, 1874); Lopevi (active, 1,449 meters, south of the preceding); Tongoa (hot springs, south of Api); Hinchinbrook (crater, north of Efate); Eromango (submarine eruption near the east coast); Tanna (active); Mathew (active); and Hunter island [1].

Outside this line, which runs through twelve degrees of latitude, no fore-deep is known. The line clearly separates the great western subdivision of the Australian arcs into an inner (Solomon islands to New Hebrides) and an outer arc (Caroline, Fiji islands), which converge in the direction of New Zealand.

New Caledonia (II, p. 162). This great island has already been represented as part of a mountain chain which strikes to the north-west. In the north-west and over a good part of its eastern side it consists of ancient crystalline rock, part of which presents a divergent strike. This is followed towards the west and south-west by a sedimentary series, which includes Trias and a coal-bearing series. A great band of serpentine also, of unknown age, occurs in the south-east, but isolated bosses of it are found throughout New Caledonia up to its north-west extremity, as well as in the outlying islands still further to the north-west. Since this description was written, investigation has made unexpected progress. The coal-bearing beds, previously referred to the Lias, belong to the Cretaceous. Pelatan has discovered that these Cretaceous beds are overlain by serpentine. Piroutet has observed a similar relation, and Glasser is of opinion that the whole sheet of serpentine and peridotite, about 1,000 meters in thickness and recognizable over an area of 520 kilometers in length and 50 kilometers in breadth, is thrust up over the Cretaceous along an almost even plane [2].

The facts, however, appear to go much further. Deprat and Piroutet have shown that a stratified series occurring along the south-west coast of Numea for a distance of 150 kilometers is of Eocene age, and lies below the Trias with Monotis. This latter fact caused it to be regarded as Carboniferous, and a nummulite (*Nummulites pristina*) which is found in it was explained as a Carboniferous precursor of the genus. We now know

[1] H. E. Purey-Cust, Eruption of Ambrym Island, 1894: Geogr. Journ., 1896, VIII, pp. 585-602. Some of these islands have been described by C. C. Frederick, Geological Notes on certain Islands in the New Hebrides, Quart. Journ. Geol. Soc., 1893, XLIV, pp. 227-232 (with appendices by Teall and Hinde). For further eruptions Ann. Hydrogr., 1878, VI, pp. 370–374.

[2] A. Bertrand, L'Archipel de la Nouvelle Calédonie, 8vo, Paris, 1895, 458 pp., maps. Here Pelatan's geological map is reproduced; on the geological structure, pp. 54–96, in particular pp. 73, 80. Pelatan regards the serpentine as a flow. Piroutet, Note préliminaire sur la géologie d'une partie de la Nouvelle Calédonie, Bull. Soc. géol. France, 4e sér., III, pp. 155–177, map, in particular p. 173 et seq.; E. Glasser, Richesses minérales de la Nouvelle Calédonie, Ann. Mines, Mém., 1903, 10e sér., IV, pp. 299-392, 397–536, and V, pp. 29-154, 503-701, maps, in particular IV, p. 352 et seq.; M. Lévy, C. R. Acad. Sci. Paris, Nov. 7, 1904, p. 716.

a number of species from this locality which closely resemble those found in the Eocene of the Sunda islands[1].

Towards the interior of the island, overlying the Eocene, come Trias, Lias, some additional Jurassic, Cretaceous, and then serpentine. These formations are regarded as overthrust, and it is supposed that the crystalline rocks of the east coast and of the north-west belong to a second flake. It is stated that the Mesozoic beds are upturned against these crystalline rocks and overthrown towards the south-west.

This latter point should be decisive in judging of the direction of the movement. If we accept the views of the distinguished observers we have cited, then it follows, as Glasser also supposed, that the movement was directed towards the south-west. The mighty layer of serpentine will then lie on the boundary between two overthrust sheets, and the movement, as we shall see later, will probably correspond to a backfolding on the inner side of the inner arc of a virgation. As opposed to these far-reaching conclusions, however, we must bear in mind that great patches of serpentine are also known to occur upon the ancient crystalline rocks, as for example, in mount Tchingou. Leaving details for further investigation, we will therefore confine ourselves for the present to the observation that in the midst of the Pacific Ocean tectonic movements may be recognized which do not yield in importance to those of the Alps.

It is a remarkable fact that Kilian and Piroutet mention Holcostephanus and Virgatites as occurring in New Caledonia, genera which are usually regarded as boreal[2]. Virgatites also occurs in the South American Andes; it thus appears as though the remarkable extension of Arctic forms to the south along the west coast of America were continued into the midst of the Ocean.

The Second Australian Arc. Nowhere over the whole of the long stretch from Yap towards the east, and south-east as far as Fiji, do we meet with ancient rocks or considerable heights. The further we advance out into the Ocean the more sockle and substructure disappear. The *Marshall* islands (Radak and Ralik), *Gilbert* and *Ellice* islands are simply atolls, and this is true of by far the greater part of the *Caroline* islands. The group of Truk, Ponape, and Kusaie is volcanic; Feys (Tromelin, West Carolines), a few islands in the group of Oroluk (32 meters, middle Carolines), the isolated island of Nauru (about 80 meters) lying west of the Gilbert islands and Paanopa (67 meters), are formed of terraced limestone, possibly of Tertiary age.

The divergent arrangement of *Radak*, *Ralik*, and the Carolines is clearly

[1] Deprat et Piroutet, Sur l'existence et la situation tectonique anormale de dépôts éocènes en Nouvelle Calédonie, C. R. Acad. Sci. Paris, 16 janv. 1905, pp. 158–160; J. Deprat, Les Dépôts éocènes Néo-Calédoniens, Bull. Soc. géol. France, 1905, 4e sér., V, pp. 485–516.

[2] Kilian et Piroutet, Bull. Soc. géol. France, 1905, 4e sér., V, p. 113.

seen on the map; the elongation of the larger atolls in the direction of the principal trend is well shown, and is particularly obvious in the Gilbert group.

The Caroline islands appear to consist of several parallel zones, separated by considerable depths. These facts suggest that in this case also the lower part of the sockle is formed of folded ranges [1].

None of these islands, however, afford much that bears directly on the problem before us, beyond their long drawn out curves.

The *Fiji* islands lie between the volcanic line of the New Hebrides and the volcanic line of Tonga. Their eastern part, the Lau islands, is a long zone of low coral islands running almost north and south. Towards the west volcanic rocks rise from isolated islands; a few craters (Thombia in the Ringgold islands, Totoya) also occur. Still further towards the west and north-west the rocks increase, and the islands become larger until we reach the two great islands of Viti Levu and Vanua Levu.

A large part of *Viti Levu* was investigated by Kleinschmidt, in 1876. His collections enabled A. Wichmann to establish the existence of ancient rocks in these islands [2]. About the same time the occurrence of Tertiary fossils was made known by Tenison Woods (II, p. 164). A second series of investigations begins with the visit of A. Agassiz to Fiji in the years 1897–8; to him we owe an admirable survey of the smaller islands and the recent reef formations, as well as the discovery of upturned older limestone in the south-west of Viti Levu. This limestone has been closely investigated by E. C. Andrews [3]. In 1903 Woolnough published the first attempt at a geological map of Vitu Levu; after a second visit to the island he supplemented the map by an exhaustive description, published in 1907 [4].

Viti Levu is a mountainous island of irregular elliptical form, 150 kilometers in length and 112 kilometers in breadth. Horizontal masses of tuff, talcose or soapy to the touch (soapstone), cover the greater part of the

[1] A. Kirchhoff, Umrisse zu einer Landeskunde der Carolinen, Hettner's Geogr. Zeitschr., 1899, V, pp. 545-562; A. Krämer, Nauru, Globus, 1898, LXXIV, pp. 153-158 et passim; F. W. Christian, Exploration of the Caroline islands, Geogr. Journ., 1899, XIII, pp. 105-136, and Scot. Geogr. Mag., 1899, XV, pp. 169-178; M. Friedrichsen, Carolinen, Mitth. geogr. Ges. Hamburg, 1901, XVII, pp. 1-27 et passim.

[2] T. Kleinschmidt's Reisen auf den Viti-Inseln, Journ. des Museums Godeffroy, XIV, 1879, pp. 249–283; A. Wichmann, Beitrag zur Petrographie des Viti-Archipels, Tschermak, Min. Mitth., 1883, V, pp. 2-60.

[3] A. Agassiz, Islands and Coral Reefs of Fiji, Bull. Mus. Comp. Zool., 1899, XXXIII, 167 pp., maps; E. C. Andrews, Notes on the Limestones and general Geology of the Fiji islands, with special Reference to the Lau Group, &c., op. cit., 1900, XXXVIII, Geol. Ser. V, no. 1, 50 pp., map.

[4] W. G. Woolnough, Continental Origin of Fiji, Proc. Linn. Soc. N.S.W., 1903, XXVIII, pp. 457–496 and 500–540, map; A Contribution to the Geology of Viti Levu, op. cit., 1907, XXXII, pp. 431–474, map.

island. The tuff is associated with limburgite lavas, and along with these forms the highest point of the island (Tama-na-ivi, 1,387 meters). It includes badly-preserved marine shells; beds of Tertiary limestone are intercalated with it.

The next older member is a rock previously regarded as ancient schist, but now recognized by Woolnough as a trachytic tuff rendered schistose by pressure. It strikes to the north-north-east, and is covered unconformably by lavas.

Somewhat to the south-east of the centre of the island rises the considerable ridge of Medrausucu, and west of this lies a granitic plateau, probably a horst, bounded by two faults running west-north-west. The granite is also visible in many places in the river courses, and is said to extend, along with other ancient rocks, over a distance of from 32 to 64 kilometers.

In the south-west of the island we come upon older limestone (according to Andrews, dolomite also); it is hard, bluish-yellow in colour, and dips at an angle of 50°. Woolnough compares it with pebbles obtained from Guadalcanar and Ysabel. It is overlain by a thick regularly stratified limestone containing shells, which dips at an angle of 15°. This limestone reappears as the substructure of the great atoll of Vanua Mbalavu in the Lau islands. It is, no doubt, the same as that which Dall regarded as middle or upper Tertiary [1].

Still more recent is the limestone of the south-east coast containing great teeth of Carcharodon; it occurs alternately with the beds of tuff.

On the whole, the characters of a folded range do not seem to me to be completely established here. The central granitic part of Viti Levu might belong to an ancient mass rising between folded ranges, as happens in South Borneo.

A monograph on *Vanua Levu* has been published by Guppy [2]. The island is 150 kilometers in length, on an average only 30 kilometers in breadth, and elongated towards the east-north-east. It stands on a submarine sheet of basalt, which also occurs outside Viti Levu, and is formed entirely by the coalescence of a considerable number of volcanic mountains, some of them attaining a height of 1,000 meters. In the south rises the wide-spreading mountain of Seatura (798 meters); it is built up in the same fashion as Mauna Loa. The south and centre of the island consist of basic rocks; only occasional bosses of acid rocks rise out of them here and there. Acid rocks, however, form the north of the island; this gives off the peninsula of Undu, which is directed towards the north-east and

[1] A. Agassiz, Tertiary elevated Limestone Reefs of Fiji, Am. Journ. Sci., 1898, 4th ser., V, pp. 165–167.

[2] H. B. Guppy, Observations of a naturalist in the Pacific: I. Vanua Levu, A Description of its leading Physical and Geological characters, 8vo, London, 1903, 392 pp., map.

presents a series of heights, 22 kilometers in length, formed of ash and pumice; dykes of quartz porphyry and oligoclase-trachyte, and volcanic necks are visible, but no craters.

Numerous hot springs occur.

Third Australian Arc, and Summary. The principal members of this arc, Tonga, Kermadec, and the Ruahine range of New Zealand, as well as its volcanic line and the foredeep situated on the east, have already been discussed. The account of *New Zealand* previously given (II, p. 146) may now be supplemented by some remarks on the structure of the north-west peninsula.

The curvilinear course of the west coast of New Zealand was ascribed to the presence of recent littoral bars. The peninsula itself consists of isolated outcrops of Palaeozoic rocks, united by recent lavas and sediments; thus, its direction does not represent the direction of the strike, and the Ruahine, running towards the north-east, is the only continuous folded range.

These isolated Palaeozoic outcrops, but little marked in the relief, contain gold-bearing quartz veins, and consequently have been closely investigated. The accounts we have of them, and particularly those given by Cox, show that the beds, both on the east and west of Hauraki bay, strike towards the north, with deviations towards the north-west, and much more rarely towards the north-east. This has also been observed by C. Fraser, and on the east in Coromandel by J. H. Adams [1]. The northerly direction corresponds neither to that of Ruahine range nor to that of the north-west peninsula, but it seems to show that a ramification is in preparation. In the west, indeed, on the south side of Kawhia harbour (south of lat. 38° S.), an anticline of Mesozoic beds rises from the sea and strikes towards the north-north-west [2].—

In order to obtain a general idea of the whole we must first consider those features which are most pronounced, and then proceed from these to those which are not so obvious.

The western limit is given by the great foredeeps, which extend from Guam to the termination of the Philippine deeps near the Tulur islands. Similarly the eastern limit is marked by volcanos and the foredeep east of the Tonga—Kermadec—New Zealand line. Thus Samoa is excluded.

[1] S. H. Cox, Geology of the Rodney and Marsden Counties, Rep. Geol. Explor., 1879–1880, pp. 13–38, map, in particular 23; Gold Fields of the Cape Coleville Peninsula, op. cit., 1882, pp. 4–51, map, in particular pp. 6, 11, 13 et passim; C. Fraser and J. H. Adams, The Geology of the Coromandel Subdivisions: Bull. Geol. Surv. New Zealand, no. 4, 1907, 154 pp., maps, in particular p. 26.

[2] A. M'Kay, Geology of the Kawhia District, Bull. Geol. Surv. New Zealand, 1883–1884, pp. 140–148, map. In the Cretaceous of the upper Waipa (east of Kawhia) boulders of granite and gneiss occur, although these rocks are not known in place in the whole of the north island; J. Park, Trans. and Proc. New Zeal. Inst., 1892, XXV, pp. 353–362.

Another line of volcanos, and an extremely long one, strikes east of the New Hebrides. New Guinea with Entrecasteaux and the Louisiades form a unit. New Ireland, the Solomon group, and the New Hebrides form another unit, and describe an arc convex towards the north-east.

All the arcs and fragments of arcs are so arranged within the Kermadec line that they seem to whirl towards the bifurcation of northern New Zealand.

Thus the plan assumes the form of a virgation proceeding from New Zealand and opening out towards the north-west and west. Secondary virgations open out in the New Hebrides from Efate towards Espiritu Santo on the one hand, and on the other towards Aurora; and there is also the far more considerable radiation which starts from the Ellice and Gilbert islands and is directed towards Rodak, Ralik, and the Carolines.

It is possible that recurvature sets in towards the Asiatic boundary.

At the same time there are many doubtful points. First among these is the question whether the Australian cordillera along with the recent down-break on the east coast may be regarded as an inner arc. If so, the whole structure would be concentric about an ancient vertex. But the manner in which the cordillera is continued across Torres strait scarcely favours this view. We may entertain the theory that compensation by an oblique strike occurs in the principal chain of New Guinea, or that another coulisse exists, extending, for instance, through Chesterfield, Kelso, and Lord Howe islands, and we might find support for such views by an appeal to zoological distribution, but it is better for the present to avoid such conjectures.

A second doubtful point is raised by the direction of the volcanic range of New Britain; a third by the lie of the beds in New Caledonia; yet another by our ignorance of the relations between the Charles Louis chain in New Guinea and the band of Moresby beds in the south, and so on. In the hope of solving old problems, we create new ones.

The repeated occurrence of the group of green rocks in so many of these islands need not at present be discussed.

Polynesia. A complete contrast to the adjacent group of the Marquesas is presented by the chain of the *Paumotu* or *Low islands*, which is more than 1,500 kilometers in length, strikes to the north-west and consists of atolls. In this group Agassiz has sought to obtain special confirmation of the view that the atolls are simply built up on peaks and ridges, in this case consisting of Tertiary limestone, denuded down to the sea level; that is, that they rest without a substructure on an abraded sockle. The following account is derived from his description [1].

The western part of this extensive archipelago rests on a common ridge at −14 to −1,500 meters. Towards the south-west, especially from long. 140° 30′ W. onwards the depths increase; they soon exceed 4,000 meters;

[1] A. Agassiz, Coral Reefs of Tropical Pacific, 7-134, maps, 201-207.

at the same time the islands become smaller and fewer in number and finally cease. Not a few of the atolls are as much as 70 kilometers in length, and they are very much elongated towards the north-west; the whole archipelago presents, in consequence, a clearly-marked strike in the same direction. But the north side of this north-westerly trending main range meets time after time with rows of atolls having a divergent strike to the north-east. These divergent rows appear indeed to be given off like spurs from the main range. As examples we may cite Ahé and Manihi (long. 146° W.), Takapolo and Takaroa (long. 145° W.), further Raroia (Barclay de Tolly) and Takume (Wolchonsky), the two together over 60 kilometers in length (long. 142° 15′ W.), Amanu (long. 140° 45′ W.), and other smaller atolls.

This singular fact, pointed out by Agassiz and clearly seen on any large map, leads us to suppose that the gently-curved main range of the Paumotu islands is in fact the *eastern outer border* of another system of east Polynesian arcs now visible in these few fragments only, and *that the atolls striking to the north-east mark the beginning of a third arcuate system.*

This third arcuate system, which we may call after its largest atoll *Raroia*, can only be traced by a series of coral islands, and its further continuation, if it has any, is purely hypothetical. Its existence is founded on the presumption that in this case also the arcs cut into one another, in other words that this part of Polynesia is built up on the same plan as the island festoons of East Asia. The boundary should run through lat. 14° 45′ S. and long. 146° 30′ W., lat. 16° 25′ S. and long. 142° 30′ W., lat. 18° S. and long. 140° 55′ W.

Beneath the great atoll of Rangiroa, in the north-west of the Paumotu group, lies, according to Agassiz, a belt of Tertiary limestone, 4 or 4½ meters in height; this seems to be part of the sockle, still exposed to view, it is exposed up to a slightly greater height in Niau, and may be recognized in yet other atolls by rolled fragments in the reef. But towards the south-west margin of the Paumotu group a few terraced limestone islands occur which are of greater height, such as Makatea (Metia, of Dana; II, p. 317) 70 meters high and affording Tertiary fossils, like those of Viti Levu; and further to the south-east, Henderson island, with limestone which is possibly Mesozoic (II, p. 315).

These higher limestone islands, Makatea, Niau, and Henderson, lie on the south-west (inner) border of the main range of Paumotu.

The lofty *Tahiti* or *Society* islands are separated from the Paumotu group by an ocean tract more than 200 kilometers broad and more than 4,300 meters deep. While the Paumotu islands scarcely rise above the surface of the sea, the principal island of Tahiti reaches a height of 2,231 meters, and there are several others of these islands which exceed

1,000 meters. They are of purely volcanic origin. In spite of these contrasted characters they run so strikingly parallel to the Paumotu islands that the existence of some connexion between these otherwise dissimilar island-chains has frequently been conjectured. The Society islands lie on the inner side of the limestone islands of Paumotu, just as in Tonga where the volcanic series lies on the inner side of the limestone plateaux situated more to the east. They terminate near long. 152° 30′ W.; Mehetia, close to long. 149° W., is also a crater; in the same direction, towards the south-west, follows a long interval with depths of over 4,400 meters, and then, where we might expect to find the line from Mehetia continued, we come to Hereheretue (St. Paul, long. 145° W.). This, though separated from them by another abyss no less deep than the preceding, forms the first of a chain of atolls—the *Gloucester group*—which continue in the same direction. This group possesses a calcareous substructure; it occupies, however, the same position with regard to the Paumotu as Tahiti. It lies on a narrow ridge surrounded by depths of over 4,000 meters.

A further enumeration of the islands to the south-west, such as Gambier island, the isolated volcanos of the Cook group, and numerous atolls would be scarcely profitable, since no connexion can be made out among them.

The *Samoa* or Navigator islands strike to the west-north-west, in correspondence with the curvature of the arc trending hither from the Paumotu and Tahiti islands. Dana perceived that the volcanic activity has shifted along the line of the Samoa islands from east to west [1]; all later observers are in accord on this point. On the east all traces of craters have been obliterated; in Upolu, lying in the middle of the series, they may be recognized as a long train corresponding with the general strike. Sawaii, the great island in the north-west, bears quite recent eruptive cones.

On October 29, 1902, an eruption of long duration began in Sawaii; the locality, however, does not lie at the extreme north-western end of the series, and the eruption has therefore been regarded as indicating a backward movement to the east [2]. There are also data referring to a submarine eruption which is said to have taken place in 1866 in the extreme south-east within the island group of Manua.

If our view of the relation of the Paumotu group to the Kermadec line is correct then the Polynesian arc is cut through at this point by the Australian arc.

[1] J. D. Dana, A dissected volcanic mountain—some of its revelations, Am. Journ. Sci., 1886, 3rd ser., XXXII, pp. 247–255.

[2] G. Wegener, Die vulcanischen Ausbrüche auf Sawaii, Zeitschr. Ges. Erdk., 1903, pp. 208–219; Reinecke, Peterm. Mitth., 1906, pp. 86–88; Manavanu-Ausbruch, Zeitschr. Ges. Erdk., 1906, pp. 686–709, map. Jensen conjectures that the volcanic lines of Tonga and Samoa intersect each other (cf. note 1, p. 301).

Hawaii. In the midst of the Pacific Ocean, rising from depths of 4,300 to over 5,000 meters, lies an extremely long series of islands extending in a west-north-west to east-south-east direction, from long 180° to 155° W. In the west-north-west these islands are small and low, some of them presenting extremely steep submarine declivities [1]. Towards the east-south-east the volcanic substructure beneath the limestone covering becomes more and more exposed to view, and the islands increase in height and extent, until Hawaii, the largest of all, concludes the series. On Hawaii stand the mighty volcanos of Mauna Kea and Mauna Loa, which mount from their broad base to a height of more than 4,000 meters above the surface of the Ocean.

The glowing lava lake which lies in Kilauea, as well as the similar lake on the summit of Mauna Loa, have attracted so much attention that the peculiar arrangement of the volcanos in plan has been comparatively neglected.

The clear insight of J. D. Dana enabled him to recognize this arrangement at his first visit [2]. He pointed out that a volcanic zone proceeding from Kauai (lat. 22° N.) separates into two divergent lines in Oahu, one of which runs through the east of Molokai and Maui to the volcanos of Kohala and Mauna Kea in Hawaii, while the other and more southerly extends from the west of Molokai through Lanai and Kahoolawe to Hawaii, where it includes the volcanos of Hualalai and Mauna Loa. The position of Kilauea in this system was doubtful, but Dana finally assigned it to the northern line. At the same time he pointed out that the volcanos situated to the west-north-west are the older and more profoundly denuded, those in the middle, as in Maui, better preserved, but only those situated at the end of the series are still active. These all lie in Hawaii, and include Hualalai, which as late as 1805 and 1811 discharged lava from openings on its flanks, but has since been dormant, and Mauna Loa and Kilauea, which are still in full activity.

These facts indicate a general displacement of the volcanic activity towards the east-south-east. It is not confined to a single arc as in the Aleutian islands, nor does it wander along transverse lines, as in Central America, but it extends along a definite line, or stagnates for a considerable period at one end of this line or this pair of lines.

As early as 1888, when the volcano in Sawaii (Samoa) was already regarded as extinct, Dana called my attention, in a long letter, to the fact that in this island also the largest volcano stands at the end of the island-chain.

[1] A submarine reef south-west of Midway island descends at a distance of about 2,880 meters to the extent of 2,320 meters (from −249 meters to −2,469 meters); Flint (note 3, p. 297), p. 5.

[2] J. D. Dana, History of the Changes in the Mauna Loa Craters, Am. Journ. Sci., 1888, XXXVI, pp. 167–172.

We have already pointed out that an account referring to a submarine eruption off the south-east of Samoa, in 1866, is opposed to the view that a migration of activity takes place in a constant direction. In the islands of Hawaii also there are not a few of the smaller and secondary craters in the central islands which do not accord with Dana's generalization. Hitchcock has described secondary craters well preserved and evidently recent along the south coast of Oahu [1]. Of these the best known is Diamond Head (Leahi), near Honolulu. There, as in several other similar eruptive centres, numerous corals and fragments of shells were ejected with the ashes; thus, the temperature cannot have been very high. A comparatively small extraneous basaltic flow which approaches Diamond Head is even more recent than this crater. The corals and shell-bearing beds which alternate on Diamond Head with beds of land shells, were regarded by Dall as of Tertiary age, and as indicating a subsidence followed by elevation. The beds dip toward the sea; Bishop and Branner regard the whole deposit as of aeolian origin; it is a dune formation of coral sand [2].

Molokai, like Maui, consists of two large and ancient volcanos. In Molokai the western volcano is profoundly denuded, and the eastern is for the greater part sunk beneath the sea along a mighty fault. Dana had already recognized the presence of the fault; it has been described by Lindgren. It strikes east and west, and forms a great cliff 1,000 meters in height along almost the whole north coast of the island. Beneath the cliff, towards the north, lies Kalaupapa, the peninsula of the lepers. On this downthrown part there is a smaller secondary crater [3].

We may fairly conclude that Dana's view is correct as regards the great volcanos, but that when the principal craters became extinct sporadic smaller eruptions occurred on the flanks and at the foot of the ancient giants. This is in harmony with Dutton's views on the subject [4].

The lavas of the Hawaii islands have been described as mainly felspar-basalts, or as olivine-basalts, according to the locality where they were found. Dalton points out the entire absence of acid rocks and the 'phenomenal' quantity of olivine and augite, especially the former, in most of the more recent flows from Mauna Loa. From one point in the great

[1] C. H. Hitchcock, Geology of Oahu, Bull. Geol. Soc. Am., 1900, XI, pp. 15–57; and W. H. Dall, Notes on the Tertiary Geology of Oahu, tom. cit., pp. 57–60, maps.

[2] S. E. Bishop, Brevity of Tuff-Cone Eruptions, Am. Geol., 1901, XXVII, pp. 1–5; J. C. Branner, Notes on the Geology of the Hawaiian islands, Am. Journ. Sci., 1903, 4th ser., XVI, pp. 301–316. On the other hand, Hitchcock, Bull. Geol. Soc. Am., 1906, XVII, pp. 469–484, map.

[3] W. Lindgren, Water Resources of Molokai, U.S. Geol. Surv. Water Supply and Irrigation Papers, 1903, no. 77, 62 pp., map, in particular pp. 12–15; also H. Schauinsland, Ein Besuch auf Molokai, der Insel der Aussätzigen, Abh. Naturw. Ver. Bremen, 1900, XVI, pp. 513–543.

[4] C. E. Dutton, Hawaiian Volcanos, U.S. Geol. Surv., IV, Ann. Rep., 1884, pp. 81–219, maps, in particular p. 217.

cliff of Molokai Lindgren mentions very coarse-grained olivine-diabase as an uncommon variety: it is also said to occur in Kauai. Möhle describes olivine gabbro from Molokai, and olivine bombs from the more recent secondary centres of eruption in Oahu [1].

Summary. With the Paumotu arc and the indications given by the Raroia group in the south, and the Hawaiian zone in the north, the trend-lines of Oceania—so far as we can discern them at all—come to an end. Beyond their limits lie isolated islands or groups which do not follow a linear arrangement.

As regards the *Marquesas* this distinction is doubtful. They form a series of islands 350 kilometers in length, arranged in four groups from north-west to south-east. With the exception of a small island in the extreme north-west and some smaller and isolated occurrences, no coral beds are known in the Marquesas, scarcely even a coastal belt. The islands are high and rocky and descend in steep cliffs to the sea. They are regarded as basaltic, but an early account by Jardin records the existence of a great variety of other rocks. In particular peridotite is mentioned from Nuka-hiva, and a rock probably resembling gabbro, and along with these a fine-grained leptynite with microscopic garnets [2].

Neither in the Marquesas nor in any other of the more remote and scattered islands as far as the immediate neighbourhood of the American coast is any trace known of rocks other than volcanic, and these are only rarely accompanied by recent coral or Lithothamnium limestone.

Easter island, though it possesses a uniform outline, except for two little reefs in the south-west, actually consists of a group of crater mountains [3]. The *Galapagos* islands are an archipelago of crater mountains and present no signs of a linear arrangement [4].

[1] F. Möhle, Beiträge zur Petrographie der Sandwich- und Samoa-Inseln, N. J. f. Min., 1902, Beilage-Bd. XV, pp. 66–104, in particular pp. 80 and 84.

[2] E. Jardin, Essai sur l'histoire naturelle de l'Archipel de Mendana ou des Marquises, Mém. Soc. Sci. Nat. de Cherbourg, 1856, IV, pp. 49–64, in particular p. 58. The determination of the rocks was made by C. d'Orbigny; here, too, a conglomerate is mentioned 'of fragments of scoria, and micaceous trachytic fragments with a matrix of cinerite, and piled up around them blocks of porphyroid peridotite, with crystals of pyroxene and peridote'. Similar rocks are mentioned by Grange (Dumont d'Urville), Voyage au Pôle Sud, Géologie, 1854, II, p. 210.

[3] C. Vélain, Roches volcaniques de l'île de Pâques, Bull. Soc. géol. France, 1889, 3e sér., VII, pp. 415–429, small map; Vere Barclay, Mission à l'île de Pâques, C. R. Soc. Géogr. Paris, 1899 (1900), pp. 169–176, map. A series of other works by Geissel, Cooke, Agassiz, and others is concerned with the gigantic statues on this island. That these are all overturned in rows in the same direction seems to confirm the general assumption that the island was visited by a catastrophe; cf. Agassiz, General Report of *Albatross* Expedition, Mem. Mus. Comp. Zool., 1906, XXXIII, pl. 29. I once thought I observed in the cave at Adelsberg that a number of old stalactites were overturned in the same direction.

[4] T. Wolf, Besuch der Galapagos-Inseln, Sammlung von Vorträgen herausgegeben von

These islands recall the group-like arrangement of the Atlantic islands, and the serial arrangement which prevails in Polynesia does not extend so far as the neighbourhood of the western coast of America.

The arc of the Aleutian islands is convex towards the south, the arc of the Kuriles and the succeeding Asiatic arcs towards the east, and the Oceanic arcs as far as Hawaii towards the north-east. All the arcs seem to strive towards that part of the Ocean in which the linear arrangement is absent, and where islands either do not occur or are arranged in groups as in the Atlantic.

The greater the distance from Australia the rarer are the traces of ancient continental land; till at last only volcanos and atolls are left, which scarcely rise above the ocean level. Yet these, in so far as they present themselves in series, are the projections of submarine trendlines on the surface of the sea (II, p. 320).

The investigations of the last twenty years enable us to distinguish two parts in an atoll; the sockle and the crown. Sometimes we can also see a foundation to the sockle, formed by a fragment of ancient crust, as in Entrecasteaux; or this ancient foundation may be covered with sediments of various age, ranging up into the Tertiary aera, and forming the sockle, as in Viti Levu; or there may be only a Tertiary plateau, such as in Makatea (West Paumotu), or finally, only volcanic rock or an active volcano remains visible.

New Guinea and Espiritu Santo show that post-Miocene folding is by no means excluded. A chain which has been folded up in the quiet abysses of the ocean is protected from the destructive action of the atmosphere. But when it reaches the region where the waves can act upon it the case is altered. Whatever rises above the sea-level is exposed to the eroding breakers, to rain and storms; deep channels are excavated in it; dolinas and karst features are produced in the limestone. Frequently the limestone succumbs altogether and is denuded away, until it forms a plateau only just awash.

The volcano, also, may pile up its cone in the abysses undisturbed; if the eruptive activity is sufficient it will rise above the line of the waves, but the ashes, less resistant than other formations, will be more rapidly swept away. This was the case with Graham island (Julia) (II, p. 319), and Lister has described the same process in Falcon island (Tonga).

Surfaces of this kind, produced by denudation of the sockle, whether they consist of limestone or volcanic rock, often bear the crown seated directly upon them. This fact has been established by Agassiz in many

Frommel und Pfaff, 8vo, Heidelberg, 1879, pp. 259–300, map; G. Baur, New Observations on the Origin of the Galapagos Islands with remarks on the Geological Age of the Pacific Ocean, Am. Nat., 1897, XXXI, pp. 661–680 and 864–896.

cases, and Voeltzkow has observed similar relations in the coral islands of the Indian Ocean.

The steepness of the outer slopes of such islands is to some extent comprehensible when we are dealing with a denuded volcano, but it is scarcely likely that all these islands rest on volcanos, and the depths surrounding them are very great. Agassiz states that the western islands of the Paumotu group are probably surrounded by the isobath of 800 fathoms (1,403 meters); towards the south-west, however, about midway towards Tahiti, depths of over 5,000 meters have been sounded, and about the same distance towards the north-east a depth of 5,751 meters [1].

We will now give a little more attention than has hitherto been possible (II, p. 318) to the valuable observations of the *Challenger* and the descriptions of Murray. We may conceive that little calcareous shells sink to the bottom in great quantity. They are dissolved at great depths, but accumulate in moderate or lesser depths. In the abysses red clay is deposited only in trifling quantity, but on those submarine elevations which rise above the level at which carbonates are dissolved, accumulation occurs. The result is *an exaggeration of the relief*. Thus, the depths persist, while the ridges increase in height and may even grow into peaks.

Thus, during a long period of rest not only may a great sockle of limestone arise, but at some remote period, when the level of the ocean was higher, the deposit of limestone may even have grown up to a height above the sea-level as it now exists. It has then been denuded in terraces, owing to intermittent negative movement, and successive stages, three, two, or one in number, have been left behind, or perhaps, only the platform to which the crown adheres. In most cases even this is invisible.

It is easy to understand how at first sight of an atoll the comprehensive mind of Charles Darwin should have received the impression of general subsidence. On the other hand, it is equally easy to understand that the terraced islands, such as Lifu (Loyalty islands, II, p. 316, fig. 31) should have been regarded as proofs of elevation, and that maps should have been produced which represent the Ocean as a region of irregularly alternating elevation and subsidence.

The regular terraces must, before all, be distinguished from the recent folds: folding is certainly able to transform terraces already present, as in Espiritu Santo, but could never give rise to terraces which run horizontal through several degrees of latitudes. In cases where determinable fossils occur, as in the terraced limestone of Christmas island, south of Java, or in the remains of the Vicksburg stage, frequently mentioned by Agassiz and of about the same age, all uncertainty vanishes, and we see that the build-

[1] A. Agassiz, Coral Reefs of the Tropical Pacific, p. 25 et seq.

ing up of the sockle must have begun since the Aquitanian period at least. In those places where the Tertiary limestones have reached their existing height as a consequence of tectonic folding, the atolls also exhibit a definite strike, as in the Paumotu islands.

The highest level at which a clearly marked terrace occurs was formerly believed to be 100 meters. Recent observations place it at about 500 feet (152·4 meters).

The case is similar for the volcanic sockle. When Graham island (Julia, Ferdinandea), made its appearance, in the summer of 1831, it was believed that a new mountain range was about to unite Sicily and Tunis, that Malta would lose its military importance, and the strait of Messina acquire the significance of the strait of Gibraltar; the political movement of those days is even expressed in the struggle over the name of the new island[1]. There are distinguished investigators, even at the present day, who overrate the elevating activity of volcanos. This is certainly able to raise isolated loose blocks or fragments to a considerable height, as is shown by a great mass of Goniastraea, which has been found in volcanic tuff in Viti Levu at a height of 393 meters. They are also able by the lateral intrusion of sills, or in some other way, to cause smaller local elevations, as in the case of the temple of Serapis. They do not, however, produce such extensive and uniform movements as occur in terraced islands, and similar terraces are seen on islands and coasts which are quite remote from volcanos. Yet, notwithstanding the valuable investigations quite recently made, and notwithstanding the objections which such distinguished investigators as Semper, Murray, Agassiz, and so many others have raised to the views of Darwin and Dana, it must still be admitted that the depth of the enclosed lagoon has not yet been completely explained. Thus, the view that the crown has been built up by corals during positive movement has still some foundation (II, p. 321). The existing state of observations seems to afford most support to the view that the strand is affected by two kinds of movement, a slight positive movement of considerable duration, interrupted from time to time by a transitory negative episode which produces a new terrace. The presence of terraced islands shows that in Oceania the total negative movement is greater than the positive.

[1] J. Gosselet, Constant Prévost, Coup d'œil rétrospectif, Ann. Soc. géol. du Nord, 1896, XXV, pp. 211, 229.

Addendum. Mr. Speight, of Canterbury College, New Zealand, has kindly sent me a paper announcing the successful return of a scientific expedition which had been sent to the southern islands; it also states that the Snares, Campbell, and Auckland islands contain ancient rocks, and must certainly be regarded as parts of an ancient continent.

CHAPTER X

ENTRY OF THE ASIATIC ISLAND FESTOONS INTO AMERICA

Introduction. Taimyr. 1. *Anadyrides.* Arc of Verkhoiansk. Delta of the Lena. Yana, Indigirka, Kolyma. Penshina and Anadyr. 2. *Alaskides.* Romanzof range. Seward and Chuchken peninsulas. Alaska range. Peninsula of Alaska. Aleutian islands. Kenai range. Summary.

In the following pages we will first consider in greater detail the north-east of Asia, in conjunction with what has already been said concerning island festoons, and we will then trace its relations with America.

Long and narrow foredeeps sunk much below the general level of the sea-floor, which lies at −4,000 to −5,000 meters, surround the Asiatic system both on the north and south of the Pacific Ocean. The depth outside the Liu-Kiu islands sinks below −7,500 meters, outside the Kuriles −8,513 meters was sounded, and south of the Aleutian islands more than −7,000 meters. The island festoons are marked by long rows of volcanos; *notwithstanding their parallel course these are independent of the foredeeps.* Not infrequently they are separated from the foredeep by a cordillera or by fragments of a cordillera.

A series of long chains converges from the south towards the middle of the sea of Okhotsk (III, p. 122). The most important of these are: the Aldan range along the west coast (Djugdjur, Nemerikan, Primorskii-Khrebet), the Bureya range (Little Khingan) which, attended by many secondary chains, reaches the south-coast, then the Sikhota Alin, and finally, Saghalien, with a great part of Hokkaido. It was observed by Bogdanowitsch that the granite and porphyry of the Djugdjur are younger than the Jurassic coal beds, while the rocks composing the chains between the Djugdjur and the sea are of much greater age. Towards the north, i.e., towards the town of Okhotsk and for a short distance beyond it, the folding of these mountains becomes less intense. Its place is taken by longitudinal fractures. On the Marekanka, where marekanite occurs (III, p. 124) rhyolites also are now known; andesite is more widely distributed than was previously supposed [1].

The whole of the wedge-shaped fascicle of chains, from the Djugdjur to Saghalien, may be termed the *Ochotides.* On the south its lines proceed

[1] K. J. Bogdanowitsch, Beschreibung der Lagerung des Marekanites in der Nähe der Stadt Ochotsk, und Geologische Skizze der West-Küste des Ochot'schen Meeres, 64 pp., maps.

far into Manchuria, thus showing its close connexion with the eastern Altaides of inner Asia. North of Okhotsk it meets a second fascicle, which extends from the arc of Kamchatka and the Kuriles into the delta of the Lena. This comprises, in addition to the Kamchatka and the Kuriles, the chains of Yishiga to the north of the sea of Okhotsk and the short chains on its north-west side, as well as the great arc of Verkhoiansk. They converge, as far as can be seen from existing accounts, towards the region of the Anadyr; we shall term them the *Anadyrides.*

Another group is formed by the *Alaskides.* These include all the mountain ranges situated between the Aleutian islands and the Arctic chains of Alaska. They converge towards the east, and in the meridian of the gulf of Chugatsk (Prince William, long. 146°–148° E.), their several arcs enter into syntaxis with the American chains (II, p. 196). Towards the west the line of the Aleutian islands meets that of Kamchatka in a manner which shows an independence just as great as that of the Kuriles with regard to the line of Saghalien-Hokkaido (III, p. 141).

We may, therefore, describe these three fascicles as so many virgations, which are all open towards the south or west, converge towards the north or east, and are convex towards the east or south; their volcanos and foredeeps lie to the east or south, i.e., on the Pacific side.

A few words concerning an isolated and little-known fragment of a folded range, which is visible near cape Tsheljuskin, may precede our description of these groups.

Tolmatschew and Backlund have shown that the east Siberian tableland, consisting of a sheet of diabase resting on horizontal Palaeozoic beds (III, p. 29) reaches lat. 68° N. between the affluents of the Chatanga and the Yenisei, and then breaks up towards the east into separate tabular fragments. Flat-lying Cambrian beds surround lake Eche (Esse, also Jessei), the lower Monero, and a considerable part of the Chatanga: they contain Anomocare and Archaeocyathus. At one locality upper Silurian corals were met with.

Beneath this disintegrating platform gneiss is visible. Tolmatschew states that the Cambrian rocks on the upper Anabar resemble gneiss, and recalls the fact that Tschekanowski found pebbles of granite on the Olenek and Argasala. Tolmatschew has also observed gneiss on the upper Chatanga. According to Backlund's description this structure extends between the Chatanga and Anabar to about lat. 72° N. and then terminates in step-faults. Along one of these faults the Mesozoic transgression with Aucella and Belemnites must also come to an end [1]. Nordenskjöld has also observed

[1] J. P. Tolmatschew, Sixth Report of the Chatanga Expedition, Izvestija Imp. ross. Geogr. Obsch., 1906, XLII, p. 792 et seq. (in Russian); general map, op. cit., 1905, XLI, p. 620; H. Backlund, On a Gneiss mass in the north of Siberia, Bull. Acad. Imp. Sci. Saint-Pétersb., 1907, pp. 797, 798 (in Russian), and Trudi geol. Mus. Peter der Grosse, 1907,

gneiss and mica-schist in the west of the island of Taimyr (Actinia harbour, to the west, outside Taimyr bay)[1].

This extensive outcrop of gneiss from beneath horizontal Cambrian beds forcibly recalls the Canadian and Baltic shields. A fact worthy of attention but difficult to explain is the wide distribution of salt. Palaeozoic salt has been mentioned as occurring up to lake Ubsa-Nor, in the valley of the lakes (III, p. 86), and as far as Minusinsk (III, p. 78), where it lies between marine Devonian and beds containing the Culm flora. Here in the north we have probably before us the continuation of the gypsum and salt deposits of the Vilyui, which are there regarded as part of the red lower Silurian (III, p. 33). Backlund mentions gypsum and salt of Palaeozoic age on the middle course of the Monero, and again, but far to the north, between the mouths of the Anabar and Chatanga, the salt mountain of Uerüntumus, which is supposed to be Mesozoic. Belemnites have been obtained from the island of Preobrashenskij, which lies off the coast[2].

This is the structure of the land through which Middendorff, starting from Turuchansk, travelled towards the north under the greatest difficulties. In lat. 69° 30′ N. he reached the lakes of the uppermost part of the Paisina and the Sywerma range. There he was still in the region of the basic eruptive rocks of the lower Yenisei. He travelled up the Dudypta towards the north-east and then reached the upper Taimyr through the tundra. This river flows for some distance along the south foot of the low range of *Byrranga*, and expands in lat. 74° N. to form a lake. Before this occurs it carries with it pebbles containing *Belemnites Panderi*, Aucella and other fossils[3].

The lake now gives off a broad process elongated towards the north, which crosses the Byrranga range. On the sides of this passage amygdaloid lava is to be seen; the range itself consists of folded clay slate and greywacke. The steeply inclined beds are exposed at several places on the lower Taimyr. The island of *Baer* (lat. 75° 30′ N.) consists of diorite and diorite schist.

From the hills near the mouth of the Taimyr Middendorff saw the Byrranga range extending towards the north-east as far as the eye could reach. The coasts in this direction were rocky, as at the mouth of the

I, pp. 91–170; Travaux et résultats de l'Expédition de la Khatanga, La Géographie, 1908, XVII, pp. 117–124, map.

[1] A. E. Freiherr von Nordenskjöld, Die Umseglung Asiens und Europas, Ger. ed., I, Leipzig, 1882, p. 289; Vega-Expedition, vet. jakt., 1882, I, p. 14. As regards Lonely island situated far to the north, I only know that it is high and rocky, Mohn, Peterm. Mitth., 1879, p. 57. Toll has made important alterations in the map of the east coast of Taimyr Bay, Bull. Acad. Imp. Sci. Saint-Pétersb., 1902, V sér. XVI, p. 195 et seq., maps.

[2] B. Lundgren, Ofv. k. Vet.-Akad. Förh. Stockholm, 1881, no. 7, pp. 3–7.

[3] A. T. von Middendorff's Reise in den äussersten Norden und Osten Sibiriens, 1848; I, 1, pp. 195–215 (Geognostische Betrachtungen bearbeitet von G. v. Helmersen); also 1867, vol. IV, passim; Keyserling, Jura-Versteinerungen vom Taimyr, op. cit., I, p. 253.

river itself. From the accounts published by Pronschischtschew and Laptew in the eighteenth century, Middendorff obtained the information that the east coasts of Taimyr peninsula towards Saint Thaddeus bay are precipitous, and that snow-covered mountains lie north of this bay and surround it with their steep declivities. Middendorff concluded that the Byrranga range sends off a branch into the point of Taimyr peninsula, and Helmersen also was of opinion that cape Tsheljuskin belongs to it [1]. Indeed Nordenskjöld has actually seen mountain chains on this peninsula, and on cape Tsheljuskin he came upon vertically upturned phyllites and clay slates, but with a strike from west-north-west to east-south-east [2].

This is the only existing observation on the true strike. It is possible that the diabase of the Yenisei forms a large part of the Byrranga range and its continuation towards Taimyr.—

Arc of Verkhoiansk. An arcuate range, forming a watershed, runs towards the south-west between the Anadyr and Omolon. Its eastern slopes approach the sea of Okhotsk, but it is separated from this sea by a long strip of land on which a narrow ridge, the Kava range, inserts itself. Towards the sources of the Okhota it recedes from the sea; includes, besides the sources of the Kolyma, those of the Indigirka and Yana; is accompanied along its south foot first by the river Aldan, and then for a long way on the west side by the Lena; finally it accomplishes a slight bend at its north-western extremity by which its outermost offshoots, striking to the west-north-west, reach the delta of the Lena and even the mouth of the Olenek. The manner in which the hydrographic system is shut out is remarkable.

Maydell has clearly shown that two different ranges meet together near the Okhota. The northern range, which we assign to the arc of Verkhoiansk, he terms the *Kolyma range.* Its direction and structure are different from those of the Aldan range (Djugdjur) [3].

The region of encounter lies above the Okhota and above its great tributary the Arka. A large part of the arc of Verkhoiansk is here known by the inhabitants as the *Oimekon plateau.* The Kolyma and Indigirka flow from this point towards the north. On the east, the ridge which

[1] A. T. v. Middendorff, op. cit. I, p. 215, and IV, p. 205, note. Two of the specimens obtained by Middendorff have been examined by Chrustschow; one is of trachytic type (Taimyrite), the other is a granitic rock, Bull. Acad. Imp. Sci., Saint-Pétersb., 1893, III, pp. 421–431.

[2] A. E. Törnebohm, Under Vega-Expeditionen insamlade bergarter in Nordenskjöld Vega-Expedition vet. jakt., 8vo, Stockholm, 1887, IV, p. 119.

[3] Baron G. Maydell, Reisen und Forschungen im Jakutskischen Gebiete Ost-Sibiriens, II, in Schrenk und Schmidt, Beiträge zur Kenntniss des russischen Reiches, 1896, 4. Ser., vol. II, pp. 219, 223 et seq., map. The ethnographer Jochelson arrived very near to the almost unknown western side of the Kolyma range: Jochelson, An den Flüssen Jassatschna und Korkodon, Izvestija Imp. ross. Geogr. Obsch., 1898, XXXIV, pp. 255–290, map, in particular p. 278.

forms a watershed is termed, as already mentioned, the Kolyma range. Towards the west it bears the name of *Sordoginskij-Khrebet*, then for a long distance onwards it is known as the *ridge of Verkhoiansk*, a little later it becomes the *Orulgan*, and finally, as it extends towards the Arctic Ocean, the *Khara Ulach*.

This great arc consists of folded strata. Nowhere throughout its whole extent, from the watershed of the Anadyr to the mouth of the Lena, have gneisses or pre-Palaeozoic rocks as yet been discovered. The Aldan and the Lena separate it sharply from the east Siberian tableland, the Cambrian sediments of which are to be seen within a short distance lying undisturbed.

For the extreme north-west and the west of this region we have the accounts of two admirable observers. The first is Tschekanowski, who has described the structure at the confluences of the rivers and in parts of the western arc [1]. The journeys of Baron von Toll have given us detailed information of the same regions, and especially of the structure of the valley of the Yana and the New Siberian islands, which lie off the north coast [2].

In 1850 Meglitzky described a transverse section of the region, starting from the mouth of the Aldan [3]. In 1891 Tscherski investigated the regions further to the east; he also started from the Aldan, crossed the Verkhoiansk range in lat. 62° 40′ N., traversed the upper basin of the Indigirka and reached Verkhne Kolymsk. Shortly afterwards he fell a victim in the deserts of the Kolyma to the hardships imposed upon him by his enthusiasm for our science [4].

As regards the regions which follow to the east, and particularly for the fragment of arc to the east of the Omolon there is a dearth of exact information. We are thus forced to rely almost wholly on the configuration of the surface, until we again reach the far north where the travels of Ferdinand v. Wrangell and his companion Matjuschkin, performed under

[1] Diaries of the Expedition of A. L. Tschekanowski to the rivers Lower Tunguska, Olenek, and Lena, publ. by the Imp. Russian Geographical Society, 8vo, St. Petersb., 1896, maps, pp. 195–275 r.

[2] Schrenk, Bunge, and Toll, Expedition nach den Neu-Sibirischen Inseln und dem Jana-Lande, Beiträge zur Kenntniss des russischen Reiches, 3. ser., vol. III, maps; Baron E. von Toll, Wissenschaftliche Resultate der von der kaiserlichen Akademie zur Erforschung des Jana-Landes und der Neu-Sibirischen Inseln in den Jahren 1885–1886 ausgesandten Expedition, I, The Palaeozoic Fossils of the island of Kotelny, Mém. Acad. Imp. Sci. Saint-Pétersb., 1889, XXXVIII, no. 2, and II, Tertiary Plants of the Islands of New Siberia, by J. Schmalhausen, with an introduction by Baron von Toll, op. cit. XXVII, no. 5; Baron E. von Toll, Geological Sketch of the New Siberian islands, op. cit., 1899, VIII, ser. IX, no. 1, maps, r.

[3] N. Meglitzky, Geognostische Beobachtungen auf einer Reise in Ost-Sibirien im Jahr 1850, Verh. russ. k. min. Ges., 1850–1851, pp. 118–162, map.

[4] J. D. Tscherski, Report on the exploration of the region of the rivers Kolyma, Indigirka, and Jana, Mém. Acad. Imp. Sci. Saint-Pétersb., 1893, vol. LXXIII, no. 5, 35 pp., maps (in Russian).

great difficulties in the years 1820 to 1840, make it possible to establish some connexion with the east and north-east, described in more recent works [1].

The delta of the Lena. Let us follow Tschekanowski down this river. The western border of the neighbouring range of Verkhoiansk shows plant-bearing sandstone, often white and containing geodes; north of lat. 69° N. the course of the river approaches closer and closer to the mountains. The folds become more distinct, the banks rocky and steeper. Near Ajakit (*a*, Fig. 26) the Khara Ulach advances close to the river as a range of snow mountains; the left bank also has now become higher. It consists of the same plant-bearing sandstone, and we can already make out that the beds of the mountains on the right are inclined, not only more steeply, but in an opposite direction to those of the sandstone on the left. The banks become steadily higher and the strata in place of undulating curves present violent dislocations. The Lena now flows within a folded range [2].

Tschekanowski left the Lena near Ajakit, and turned north-west to the Olenek. There also the plant-bearing sandstone forms the foundation; it is accompanied by the Inoceramus beds of the Volga stage and both are thrown into broad folds [3].

The lower course of the Olenek, running north-west, is accompanied on its right side by a short ridge of Trias limestone; this begins at the rock of Mengiläch (*b*, Fig. 26), famous as a rich locality for lower Trias fossils (zone of *Ceratites subrobustus*), and extends like a spur right down to the mouth of the river [4].

Toll's description of the rocks of the delta of the Lena provides us with the following: Below Ajakit and north of lat. 71° N., before we reach the head of the delta, precipitous limestone cliffs rise on the right shore to a height of 760 meters. At the extreme point of the right shore, which advances into the alluvial land, upper Carboniferous fossils occur, among them *Spirifer Mosquensis.* Immediately to the west of this range Trias crops out. It forms a small part of the right shore and several of the adjacent islands, from the island of Tass-Ari (*c*, Fig. 26) down to the head of the delta [5].

To the east of this range of hills lies the Borchaya bay in the Arctic

[1] F. von Wrangell, Reise längs der Nord-Küste von Sibirien und auf dem Eismeere in den Jahren 1820 bis 1824, ed. by Engelhardt, 8vo, Berlin, 1839.

[2] A. L. Tschekanowski, Diaries of the Expedition to the rivers Lower Tunguska, Olenek, and Lena, publ. by the Imp. Russian Geographical Society, 8vo, St. Petersburg, 1896, maps, p. 229.

[3] J. Lahusen, Inoceramen-Schichten an der Olenek und der Lena, Mém. Acad. Imp. Sci. Saint-Pétersb., 1886, 7e sér., XXXIII, no. 7.

[4] Tschekanowski's description of the rock of Mengiläch, published as a translation by F. Schmidt in E. von Mojsisovics, Arktische Trias-Faunen, Mém. Acad. Imp. Sci. Saint-Pétersb., 1886, 7e sér., XXXIII, no. 6, p. 4.

[5] Toll in Mojsisovics, Ueber einige arktische Trias-Ammoniten, Mém. Acad. Imp. Sci.

Ocean; on the peninsula which projects from the range where it forms the east coast, south of lat. 72° N., a mammoth was found in 1799.

The extreme end of the folded range, however, is not reached on the Olenek. The spur which separates the Lena and Olenek has been named the *Tshekanovski-Khrebet* by von Toll, and on the other side of it he has observed another range of hills accompanying the sea coast as far as the

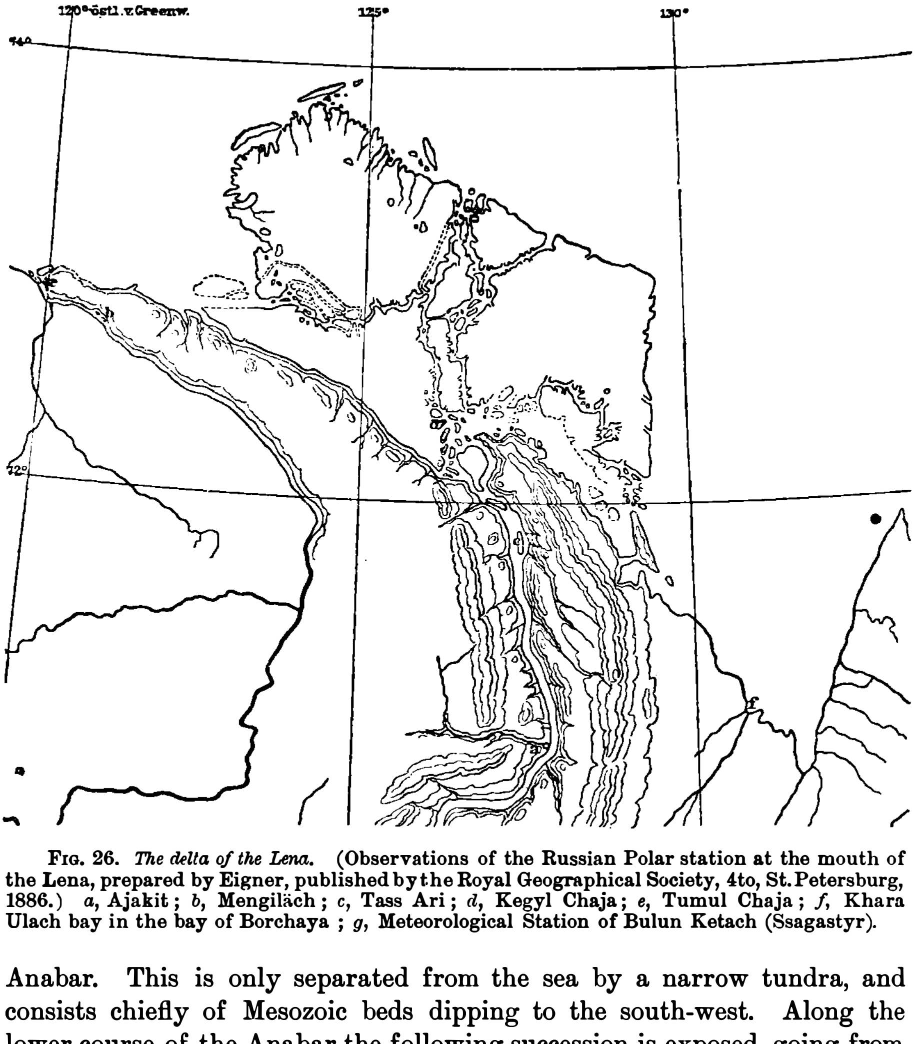


FIG. 26. *The delta of the Lena.* (Observations of the Russian Polar station at the mouth of the Lena, prepared by Eigner, published by the Royal Geographical Society, 4to, St. Petersburg, 1886.) *a*, Ajakit; *b*, Mengiläch; *c*, Tass Ari; *d*, Kegyl Chaja; *e*, Tumul Chaja; *f*, Khara Ulach bay in the bay of Borchaya; *g*, Meteorological Station of Bulun Ketach (Ssagastyr).

Anabar. This is only separated from the sea by a narrow tundra, and consists chiefly of Mesozoic beds dipping to the south-west. Along the lower course of the Anabar the following succession is exposed, going from

Saint-Pétersb., 1888, 7e sér., XXXVI, no. 5, p. 13 et seq.; Mojsisovics, Waagen, und Diener, Entwurf einer Gliederung der pelagischen Sedimente des Trias-Systems, Sitzb. k. Akad. Wiss. Wien, 1895, CIV, pp. 1288 and 1295, note 9; Noetling, Lethaea mesozoica, I, p. 200, Diener, Alter der Olenek-Schichten, N. J. f. Min., 1908, pp. 233-237.

north to south: Lias (with *Amaltheus margaritatus*), Volga stage, Neocomian, Oxfordian Lias. Von Toll calls this range *Prontshishtshev-Khrebet*. Here the foreland begins, namely, the region of the basic eruptive rocks and the Palaeozoic platform (III, p 31).

These are the free ends, divided into coulisses, of the arc of Verkhoiansk.

Sad memories attach to these localities. In 1735, Lieutenant Lasinius with thirty-five companions succumbed, in the Khara Ulach inlet of Borchaya bay (*f*), to scurvy and the hardships they had undergone. At the extreme point of the Trias spur (*e*) on the Olenek the daring explorer Prontschischtschew and his wife lost their lives in 1736. On the island of Kegyl Khaja (*d*, at the end of the Trias islands of the Lena) Lieutenant De Long and almost the whole crew of the *Jeannette* died of starvation while endeavouring to make their way back from the discovery of Bennett Land, where the admirable investigator Baron von Toll passed away in 1902. Even amidst the ice the laurel flourishes.

The Yana. Plant-bearing beds and the Volga stage border the left bank of the Lena from the north to Yakutsk. On the right bank Bunge observed upper Devonian shales and sandstone in lat. 67° N.; the same rocks were encountered by von Toll on the summit of the watershed which runs north and south of lat. 65° N., near the sources of the Dulgalach, and were there covered by glauconitic sandstone of the Volga stage with Inoceramus[1]. Meglitzky, travelling across the range from the mouth of the Aldan towards the north-east, observed undulating plant- and coal-bearing beds which extend up to a considerable height, and then as far as the summit of the pass steeply upturned beds of Carboniferous with *Productus mesolobus* and other fossils[2].

Within this arc three rivers flow fairly parallel to the north-north-east, first the great Omoloi, which reaches Borchaya bay by a bend to the north-north-west, then Butantai and Dulgalach, which are the left tributaries of the Yana. The Omoloi and Butantai are separated by the range of *Kular*; it extends towards the north-east and its last spur reaches the left bank of the Yana in lat. 70° 23′ N. Here rises the rock of Magyl[3], noted for its lower Trias fossils. While, as we have already seen, Devonian, Carboniferous, and the Volga stage surround the watershed in the south; in the north, on the other hand, Toll and Bunge have observed Trias with *Pseudomonotis Ochotica* distributed over a remarkably wide area, as at many

[1] E. von Toll, Geological Sketch of the New Siberian islands, Beiträge zur Kenntniss des russischen Reiches, 1899, VIII, ser. IX, no. 1, maps, p. 9 (in Russian).

[2] N. Meglitzky, Geognostische Beobachtungen auf einer Reise in Ost-Sibirien im Jahre 1850, Verh. Russ. k. min. Ges., 1850–1851, p. 140.

[3] Mojsisovics, Arktische Trias-Ammoniten, Mém. Acad. Imp. Sci. Saint-Pétersb., 1888, 7e sér., XXXVI, no. 5, p. 13 et seq. Bunge found a fossil resembling *Gryphaea dilatata* in lat. 67° 30′ N., so that doubtless recent deposits are also present: Toll, Geological Sketch, &c., p. 8.

points on the Butantai, the Dulgalach, and the Yana. It is thrown into folds and extends through six degrees of latitude[1]. In this vast region of shales and sandstone rise isolated mountains of eruptive rock. Quartz porphyry occurs above the town of Verkhoiansk. On the Adytsha (right tributary of the Yana) granite crops out (Yninach-chaja, 1,625 meters).

The watershed between the Yana and the Indigirka is formed by the imposing range of *Köch Tass*, the northern part of which directed towards the north-north-west bears the name of *Tass Hajachtach*. Wrangell has crossed this part between lat. 67° and 68° N. Both on the summit of the watershed and on the banks of the Indigirka black schists are encountered striking from west to north, that is, at right angles to the mountains, and in accordance with the general structure of the arc of Verkhoiansk[2]. Near lat. 70° N. the Tass Hajachtach reaches the Yana. On its extreme northern border, already beyond lat. 70° N. von Toll's map marks the Trias. Then follows on the north a broad tundra from which rises a series of four domes of basic eruptive rock. The fourth dome is somewhat broader than the others; it includes the promontory of *Swjatoi Noss*; here von Toll mentions olivine basalt. Surak-tass near the promontory has the form of a volcano with a crater.

The Indigirka. The watershed between the Ochota and Indigirka is of primary importance in a study of north-eastern Asia. Fortunately we have a valuable description of this region by Tscherski[3].

In long. 136° E. Tscherski left the Aldan; he travelled obliquely across the mountains to Oimekon on the upper Indigirka and thence to the Kolyma (Pl. II). The scenery is alpine, with steep descents and sharp peaks. A considerable mountain mass, the *Suantar-Chayata*, rises on the threefold watershed between the Allach-yuna (Aldan-Lena), Okhota, and Suantar flowing to the Indigirka. Its highest part, situated between the uppermost branches of the Suantar, is always, according to the natives, covered with snow, but in the whole of the remaining region as far as the Kolyma none of the peaks reach the snow-line, although some attain a height of 2,300 meters above the sea. We only meet with 'Aufeis' (naledei, or in Yakut, taryn), namely, strips of ice in the valley bottom, only a few meters in thickness, but sometimes reaching a length of 12 kilo-

[1] E. von Toll, Beiträge zur Kenntniss des russischen Reiches, 3. ser., III, pp. 317–319; Schmalhausen, op. cit., II, p. 3 et seq.; Toll, Geological Sketch, p. 11 et seq.

[2] F. von Wrangell, Reise längs der Nord-Küste von Sibirien und auf dem Eismeere in den Jahren 1820 bis 1824, 8vo, Berlin, 1839, I, pp. 170, 173.

[3] Tscherski's account was written in Verkhne-Kolymsk not long before his death; the heights given are not relative to the sea-level, but to the Lena near Yakutsk (65 meters, the town 90 meters); they have been given unaltered in fig. 27. The figures in the text have been converted into heights above sea-level. The statement that Yakutsk lies at a level of 500 feet is due to some error; cf. Maydell, Reisen und Forschungen, &c., I, Beiträge zur Kenntniss des russischen Reiches, II, p. 423.

meters. In the south, near the Aldan, they occur at a height of 900 meters above the sea, but in the north, on the Kolyma, they are not found below 1,480–1,490 meters. This is the form taken by the glaciation of the coldest part of Asia [1].

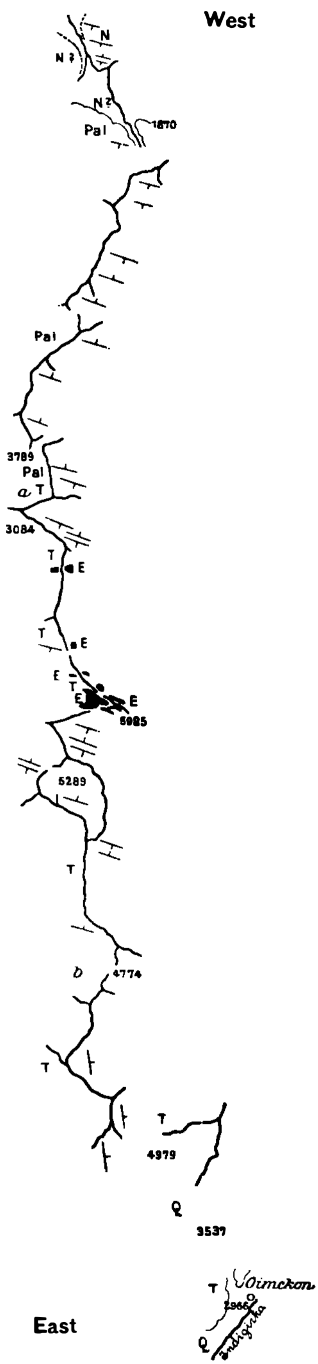
The mountainous region falls into four great ranges which may be seen on plate II. The first of these is the great range of the watershed, which Tscherski terms the ridge of *Verkhoiansk* (7,700 feet, about 2,340 meters); it extends to that uppermost branch of the Indigirka, flowing from the east-south-east, to which the maps have often erroneously assigned the name of Oimekon. On the other side of the Indigirka follows the range of *Tass Kystabyt* (6,800 feet, 2,075 meters); it is continued towards the north-west in a flat ridge about 1,580–1,600 meters in height; the north slope is almost rectilinear and descends steeply to the Nera. The third range is the *Ulachan Tshistai* (over 7,200 feet, 2,200 meters); it is about 100 versts broad, and at a height of as much as 6,200 feet (1,828 meters) presents a valley 7 kilometers in breadth surrounded by lofty summits. From this valley the upper course of the Nera flows towards the south-south-west until it meets the Kven Ulach coming in the same direction from the Tass-Kystabyt, and, uniting with this stream it turns towards the north-west. The range reaches its greatest height in its north-eastern part; it terminates on the Moma, the Boroll Ulach, a tributary of the Moma, and the rocky valley of the Kygyl-Balyktach. On the other side of these rivers follows the *Tomus-Chaya* (7,900 feet, 2,411 meters, 90 kilometers in breadth); its northern end turns round to the north-east; in lat. 65° 50′ N. its height suddenly decreases. On the other side of the Tomus-Chaya the valley of the Kolyma broadens out; and where it does so lies Verkhne-Kolymsk.

The form of these ranges does not accord with the strike of the rocks. The rocks fall into two principal series; the first includes Palaeozoic limestone, slate, and greywacke; the next, sandstone and shales containing *Pseudomonotis ochotica*, often plant-remains as well; it is accompanied and invaded by great bands of eruptive rock.

From the Aldan onwards the outer border of the mountains presents plant-bearing beds (*N?* fig. 27), either Neogene or belonging to the Volga stage, folded with a strike to the north-north-east, that is, at right angles to the watershed. Then follows a great oblique syncline striking N. 10°–15° E., and composed of limestone with Favosites and Halysites; it is steeply upturned towards the east, and there reveals a lower-lying Palaeozoic slate. Upon this rests in discordance a great thickness of Trias (*a*, fig. 27) striking N. 10°–20° E. The watershed between the Dyby and Kerachtach, that is between the Lena and Indigirka, is formed by a range of eruptive rock (1,878 meters) rising from the Trias shales. The strike of the Trias to

[1] Cf. Maydell, Ueber die Taryne, Reisen und Forschungen, II, pp. 1–33.

the north-north-east is maintained throughout the course of the upper Suantar as far as the little river of Oemi, which flows into the Tomskaia, another branch of the Suantar. Here (*b*, fig. 27) an opposite inclination of the beds sets in; *the strike becomes east-north-east*, and this direction is maintained as far as the Indigirka.



The strike of the folds from the Aldan to the Suantar is thus north-north-east, and thence onwards east-north-east, or in other words: *the strike of the Aldan range is continued up to the Suantar, where it encounters the strike of the arc of Verkhoiansk.*

Tass-Kystabyt lies wholly within the Trias, and in its neighbourhood the greatest intrusions of eruptive rock occur. One of these was followed by the travellers along the upper tributaries of the Indigirka for a distance of 42 kilometers, and an equally important ridge occurs on the slope turned towards the Nera. Parallel folds of Trias shales form the next succeeding slope of the Ulachan Tshistai; the strike is still east-north-east; after a short diversion to the north it becomes east and west on the upper Artyk, and then regularly west-north-west in the Boroll Ulach; the dip is generally towards the north. Intrusions of granite occur. A second Palaeozoic band of greater thickness now makes its appearance, forming the high peaks of the Boroll Ulach, and of the Kygyl-Balyktach; it strikes, like the Trias, to the west-north-west, and occupies the whole of the south-west half of the Tomus Chaya. In general, the structure is that of a saddle, about 90 kilometers broad, but here. too, an intercalation of eruptive rock, 24 kilometers

FIG. 27. *The mountains of Verkhoiansk* between the Aldan and Indigirka (section from west to east). (After Tscherski.) Pal = Silurian; T = Trias; E = eruptive rock; N = leaf-bearing Neogene ? or Volga stage; Q = recent alluvial land. *a*, unconformable bedding of T on Pal; *b*, change of strike in T. The heights (English feet) refer to the Lena above Yakutsk (= 214 feet above sea level).

in breadth, sets in on the north-east side. Further away, but always with the same strike to the west-north-west, Palaeozoic folds rise out of the Trias. Trias also forms the mountains at a still greater distance, until finally, as we approach Verkhne-Kolymsk, more recent sediments appear with leaves of dicotyledonous plants and beds of lignite.

Tscherski started with the older view that the Aldan range and the Kolyma range were continuations of the Stanovoi, bent in an elbow near the sources of the Okhota. He perceived, however, that the two Palaeozoic zones striking in opposite directions, north-north-east on the Chandyga and west-north-west on the Kygyl-Balyktach, follow the same directions as the two limbs of the elbow on the upper Okhota, and he regarded them

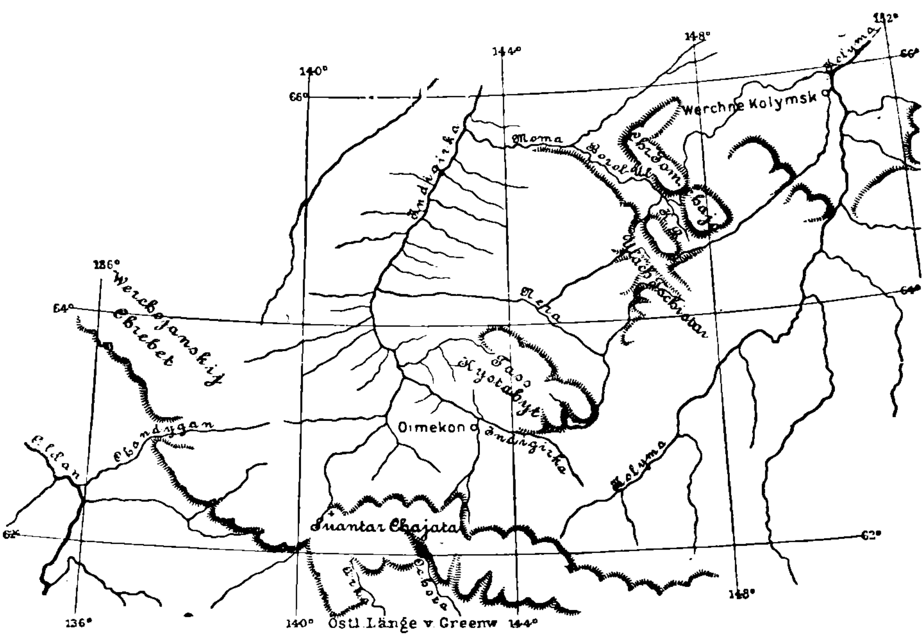


Fig. 28. Sketch of the upper course of the *Indigirka* and *Kolyma*. (After Tscherski.) (*K.B.* = Kygyl-Balyktach.)

as horsts of an older mountain system. The situation is more simply explained by supposing, as suggested above, *that those parts of the mountains which strike to the north-north-east still belong to the Aldan range.* This range would then also include the Suantar Chayata. In any case, the region from Suantar to Verkhne-Kolymsk follows the normal strike of the arc of Verkhoiansk. The unconformity at the base of the Trias which occurs both in the north and south reveals a similar, older plan; the younger folding is continued, as on the lower Lena, at least into the Volga stage; in this region also no gneiss nor pre-Palaeozoic schists have been met with.

We have already pointed out (III, p. 125) that a bend made by the mountains near Okhotsk from a north-north-east into a north direction, such as is shown on the maps, cannot be inferred from the strike of the rocks. Erman crossed the mountains, travelling from the Furth along the Aldan (Aldanskij Perewoss) to Okhotsk, and in this region and as far as the Marekanka (east of Okhotsk) encountered rocks striking constantly to the north-north-east. In order to compare his observations (III, p. 124) with those of Tscherski, the data given in Maydell's map have been transferred to Tscherski's map (pl. II), on which Erman's route has also been marked [1].

On the Aldan Erman saw sandstone and clay, the same, he supposed, as that in which Sauer, Billing's companion, observed fossil tree-trunks; it is probably the continuation of the beds marked *N?* on fig. 27. Up the Bielaya through Gastarnach to the Sem Khrebti the range is formed of limestone; its north-north-easterly strike shows its correspondence with Tscherski's Palaeozoic limestone on the Chandyga and the upper Dyby. The Sem Khrebti consist, as far as Allach-junsk, of light grey clay slates with a talcose lustre, dipping steeply to the south-west; the lie would correspond with that of the lower Palaeozoic slates west of *a*. Some dark clay slates on the east side of the Allach-juna, pthanites with traces of Equisetum above Antsha, and a craggy eruptive rock, believed to be phonolite, may then represent the Trias zone with its plant-remains and eruptive rock up to the change in strike between the rivers Suantar and Oemi; here the north-north-easterly strike of the Aldan mountains terminates on the line followed by Tscherski (*b*, fig. 27). On Erman's route, however, other zones succeed, striking to the north-north-east: the first of these is composed of sandstone, conglomerate, and greywacke. This zone includes the Kapitansberg, and extends across the sources of the Judoma to the upper Ketanda, where Erman reached a broad zone of porphyry, which comprises the greater part of the Ketanda, and also a large part of the Arka, Okhota, and Kuchtui. We have already seen that Bogdanowitsch came upon more recent rocks and also andesitic rocks in these regions.

Since the strike to the north-north-east prevails in all the mountains to the south and west of the watershed between the Suantar and the Oemi, and also as far as the great Marekanka, this region must be assigned, in a tectonic sense, to the Aldan range.

Kolyma. From the mouth of the Indigirka to that of the Kolyma no hard rocks are known on the coast of the Arctic Ocean; a few promontories reach a height of over 20 meters; according to Kosmin they consist only of grey loam. It is not until we reach the Bear islands, outside the Kolyma, that the conditions change [2].

[1] Erman, Reise um die Erde, III, p. 89.

[2] Kosmin in Wrangell, Reise längs der Nordküste, &c., II, p. 32 et seq.

The west bank of this river is formed by a broad plain as far as Sredne-Kolymsk and beyond; the right bank is rocky. On this side the Kolyma receives, between lats. 68° and 69° N., first the Omolon, and then, after a great bend, the Great and Little Anuj. Between the latter and the Arctic Ocean lies a considerable group of mountains. Its south-west part is the most important; in the *White mountains* it reaches, according to Wrangell, a height of 764 meters. The river Poginden, flowing from the north into the Little Anuj, bounds the White mountains on the east. Its spurs extend across the great Baranycha as far as Chaun bay.

As early as 1797 Billings observed heights formed of schist and quartz north of Nishne-Kolymsk on the margin of the Arctic Ocean, and Wrangell mentions similar outcrops along the lower Kolyma. On the Little Anuj and lower Poginden, between about lats. 68° and 68° 36′ N., and long. 165°–166° E., these rocks strike between N.E. and N. 80° E.; they are here accompanied by conglomerate, as is the case with the Trias shales near the sources of the Kolyma. On the lower Baranycha, on the other hand, between about lat. 68° 34′ and 69° 9′ N., similar shales with beds of conglomerate strike N. 30° W. According to these ancient observations *the normal strike of Verkhoiansk appears to terminate at the sources of the Poginden.* The watershed is formed of conglomerate. These two regions furnish an identical 'transition greenstone'. The promontory of the Great Baranow, corresponding to the prolongation of the outcrops on the lower Baranycha, is formed by two rocky ridges of schist and light-coloured granite striking to the west-north-west; the Little Baranow and the Bear islands consist of similar rock [1].

We receive the impression *that the advance of the rocky bank on the east side of the lower Kolyma,* that is of the two promontories of Baranow along with the Bear islands, *really corresponds to the rias coast of a mountain range striking to the north-west or west-north-west, and cut off obliquely by the arc of Verkhoiansk.* We shall see directly that Bogdanowitsch arrived at a similar result.

On the Beresovka, which flows into the Kolyma below Sredne-Kolymsk, porphyry and diabase are recorded by Tolmatschew [2].

This is all the information we possess concerning the structure of the arc of Verkhoiansk. It confirms the statement that no pre-Palaeozoic rock has hitherto been met with, and that the heights between the mouths of the Lena and Olenek are the free ends of the arc. On the other hand, an important point is left undecided. In 1898 I assumed, on the analogy of

[1] M. Sauer, Billing's Reise nach Sibirien, &c., 8vo, Berlin and Hamburg, 1803, p. 79; Wrangell's Reise, II, pp. 122–124, Poginden, II, pp. 118–119; Baranicha, II, pp. 102–107, Baranow Mountains, I, p. 302; Bear islands, II, p. 143; Transition greenstone.

[2] J. P. Tolmatschew, Bodeneis am Flusse Beresowka, Berichte der kaiserlich-russischen Akademie der Wissenschaften zur Ausgrabung eines am Flusse Beresowka gefundenen Mammuths, 4to, St. Petersburg, 1903.

the structure of many Asiatic arcs, that the folding of this arc is directed towards the exterior, that is towards the convex side; shortly afterwards Baron von Toll expressed the opinion that the lie of the folds suggests a movement towards the interior, that is towards the concave side. Although Emerson and Bogdanowitsch regard my first opinion as correct, I now adopt the conclusion of this experienced investigator who has crossed the range by several different routes [1].

Penshina. Of the little-known ranges which border the sea of Okhotsk on the north some account is furnished by Sljunin. It appears, in the first place, that in front of the Kolyma range, that is, the watershed of the Kolyma, an independent range extends towards the sea, which Sljunin describes as the Morskij Khrebet (the Lake mountains); it will be termed here, in order to avoid confusion, the *Kava range* [2].

The Kolyma range is, as we have seen, distinct from the Aldan range, which is divided into long rocky ridges, and it is more like the border of an extensive plateau. The rivers, which flow towards the south and south-east, have excavated deep and narrow valleys; but if we ascend one of these valleys to the summit, we find ourselves on a high-lying tundra-like region, and observe that many of these rivers arise in lakes or marshes.

Some of the marshes drain on one side to the sea of Okhotsk, and on the other to the Kolyma [3]. Sljunin describes the heights as a continuation of the plateau of Oimekon; to the east, towards Ghishiga, he came upon diorite and diabase in its spurs. So far as it is permissible to draw conclusions from such observations, we may conjecture that the Trias clay-slates with diabase, which occupy the space, 400 kilometers in breadth, between the Suantar and Boroll Ulach, and are so widely distributed along the Kolyma, also play the most important part in the formation of the Kolyma range.

To the east of Okhotsk and the river Inja the little cape of Shilkan makes its approach near long. 145° 30′ E.; it marks the beginning of the Kava range (pl. II). To the east of this point the river Kava flows down from the Kolyma range in a north-and-south direction; bends, at a right angle, to the east, and separates the Kolyma from the forelying Kava range by a considerable longitudinal valley which extends as far as the point where the river enters the bay of Taun. The Kava range is continued with

[1] Asymmetrie der nördlichen Halbkugel, Sitzb. k. Akad. Wiss. Wien, 1898, VII, p. 90; E. von Toll, Geological Sketch, p. 16; Suess in B. C. Emerson, The tetrahedral Earth, Bull. Am. Geol. Soc., 1900, XI, note to p. 97; Bogdanowitsch, Skizze der Tschutschken-Halbinsel, 1901, p. 142, note.

[2] H. W. Sljunin, The Land of Okhotsk and Kamchatka, 2 vols., 8vo, St. Petersb., 1900, map, in particular I, p. 169 et seq. (in Russian).

[3] Maydell, Reisen und Forschungen, II, p. 368 et seq.; also K. Hikisch, Orographische Skizze von Neu-Sibirien, Sapiski Imp. ross. Geogr. Obsch., 1897, XXXI, p. 38 et seq.

an easterly direction in several islands through the bay of Taun, and it forms the promontory which plunges beneath the sea towards the east, in the Jam islands. On the south side of this peninsula Sljunin met with petroleum [1], elsewhere he came across a hot spring, some beds with lignite, and others with impressions of fish and shells; on cape Iret (about long. 155° 30′ E.) he found graphite, and on the east end of the peninsula loose nodules of chalcedony, such as are scattered on the opposite coast of Kamchatka, indicating far and wide the presence of disintegrated amygdaloid basalt.

Finally, further to the north-east outside the Kava range, where the Kolyma range recedes further from the sea than is shown on the maps, Sljunin describes a group of recent volcanic centres near the sources of the stream of Kalalagi (long. 157° 30′ E.). Pumice and sulphur are mentioned as occurring in the neighbouring valleys [2].

None of these occurrences are known in the Oimekon plateau or the Kolyma range; they indicate a correspondence with the coast of Kamchatka and parts of the peninsula of Taigonoss to be mentioned directly, and in a less degree also with the andesitic features which Bogdanowitsch mentions on the Marekanka near Okhotsk. On the promontory of Warchalam (lat. 61° 36′ N.) in the interior of Ghishiga bay we reach rocks of another kind. Here, in the north-eastern arm of the sea of Okhotsk, a number of hilly ranges occur of no considerable height or length, and all directed to the north-north-east, in which granite, syenite, gneiss, mica—schist, and clay slates are said to occur [3]. The *Russian range* situated west of Penshina bay is the first of these; it consists of low hills and terminates at cape Barchalam. The second is the *Taigonoss range*, which runs down the peninsula on its eastern side. The next is the *Innaichat range*, it strikes for some distance towards the interior, west of the lower course of the Penshina. Finally, there is the *Mametshi range*, which borders the east side of Penshina bay, and thus separates the tributaries of the Great lake (Bolshoe Osero) from the sea. The lake discharges to the north of this range through the Talofka. The interval between these ranges and the sea is occupied by the tundra, and wherever the foundation of the peat moss is exposed, either on the sea coast or along the rivers, Tertiary beds are revealed, characterized sometimes by sea-shells and sometimes by brown coal. In most places they are accompanied by basaltic tuff, and by inter-

[1] This is the only way in which I can explain a passage in I, p. 120.

[2] H. W. Sljunin, The Land of Okhotsk and Kamchatka, I, p. 114.

[3] C. von Ditmar, Ein paar erläuternde Worte zur geognostischen Karte Kamtschatka's, Bull. phys. math. Acad. Imp. Sci. Saint-Pétersb., 1856, XIV, pp. 241–250, map; Reisen und Aufenthalt in Kamtschatka, Beiträge zur Kenntniss des russischen Reiches, 1890, 3. ser., VII, pp. 466–676, in particular p. 515; Sljunin, I, p. 121 et seq.; Bogdanowitsch, Geologische Skizze von Kamtschatka, Peterm. Mitth., 1904, p. 59 et seq., maps.

calations of basalt and trachyte. This is the case at Mametsha, along the Talofka on the east side of Penshina bay, and on both sides of Ghishiga bay. Dall has referred the shells of Coal bay (lat. 60° 17′ N., long. 161° 55′ E.) to the Miocene; they present sub-tropical characters [1].

Kamchatka and the Kuriles. We now return to our previous account of this region (II, p. 170) with the object of tracing out such indications as exist of a continuation towards the Anadyr, and also in order to insert a general observation arising out of a new and important description of Kamchatka by Bogdanowitsch [2].

On the coasts of the island of *Karaga* (lat. 58° 30′ to 59° 12′ N.) inclined Tertiary beds occur which strike to the north-east. The interior of the island, over 600 meters in height, is unknown [3].

Although mount Shevelutsh (lat. 56° 40′ N.) is the most northerly peak of the principal zone of volcanos, yet traces of volcanic activity are to be seen much further north, and hot springs reveal their presence amidst the snow even in those places where the marshes render travelling impracticable in summer, and a covering of snow conceals the land in winter. Sljunin gives a list of these springs which carries them as far north as lat. 59° N.; they are also known on the Tamlat (lat. 59° 25′ N.). The same observer mentions sulphur as occurring in beds in Jaigwyn bay (west of Korff bay, lat. 60° N.), and Ditmar obtained accounts of hot springs in the peninsula of Olutor (lat. 60° to 60° 30′ N.) [4].

Beyond lat. 60° N. Kamchatka loses its mountains and a broad tundra forms the land. The inhabitants of Olutor state that it extends from Kultushnoje (at the head of Korff bay) across level country up to the Talofka and the sea of Okhotsk [5].

[1] W. H. Dall, Subtropical Miocene Fauna in Arctic Siberia, Proc. U.S. Nat. Mus., 1893, XVI, pp. 471–478; also Krahmer, Russland in Asien, 8vo, Berlin, 1902, V, p. 73, map.

[2] K. Bogdanowitsch, Peterm. Mitth., 1904, p. 59 et seq.; for the volcanos of the west, W. N. Tjuschow, The West Coast of Kamchatka, Izvestija Imp. ross. Geogr. Obsch., 1906, XXXVII, 520 pp., map (in Russian), and Bogdanowitsch, ibid., Preface, p. ix.

[3] Postels in Lütke, III, pp. 91–94; a map of the island is given by Barrett-Hamilton and Jones, A Visit to Karaginski Island, Geogr. Journ., 1898, XII, p. 281.

[4] H. W. Sljunin, The Land of Okhotsk and Kamchatka (in Russian), I, pp. 184, 209; C. v. Ditmar, Reisen und Aufenthalt in Kamtschatka, Beiträge zur Kenntniss des russischen Reiches, 1890, 3. Ser., VII, pp. 670, 795; Erman, Reise um die Erde, I, 3, p. 376. The latter mentions sulphur, as a sublimation, on the river Tamlat, and to the north of it on the mountain of Olotur. An illustration of the outcrops on Korff bay, or rather of the snow covering upon them, is given in Vanderlipp-Hulbert, In Search of a Siberian Klondyke, 8vo, New York, 1903, p. 244. From the description we should suppose that the crater of a flat volcanic cone occurs here.

[5] Ditmar, Reisen und Aufenthalt in Kamtschatka, Beiträge zur Kenntniss des russischen Reiches, 1890, 3. Ser., VII, p. 670. Sljunin certainly marks several mountain ranges north of lat. 60° N., but since he has carefully marked the routes followed by himself, we see that it can only be a question of watersheds, which were entered on the old maps in the usual diagrammatic fashion.

This brings us to the plain of the *Parapolski Dol.* It begins in about lat. 60° N., close to the west coast of Kamchatka, is bounded there on the east by the most northerly part of the mountains, includes the Great lake, is separated on the west by the ridge of Mametshi from Penshina bay, and then broadens out and reaches as far as Bering sea. This is the '*Peat-sea*'. Maydell, travelling from Markovo (Anadyrsk) towards Ghishiga, crossed only low spurs of the Kolyma range; Kennan found nothing but a low watershed between the Penshina and the Main, the great tributary of the right side of the Anadyr [1]. From this line eastwards as far as the sea no continuous mountain range is known to exist—at least there are no trustworthy accounts of any such range known to me. It is true that the promontories of Navarin and St. Thaddeus are rocky and of considerable height, but it is possible that they are of the same nature as those isolated volcanic hills of the Tertiary land, which are of frequent occurrence in these northern regions.

A single exception is presented by the hilly range of *Palpal,* which has scarcely been visited as yet by any investigator. It is surrounded by a broad bend of the river Main. The glaciated boulders, which come down from its northern slope into the plain of the Anadyr, consist, according to Bogdanowitsch, of microcline granite, quartz porphyry, syenite, augite porphyry, and other rocks. The plain, in this case also, is formed of Tertiary beds with brown coal. On both sides of the liman [2] of the Anadyr rise hills of basalt and andesite. Similar rocks form the island of Aljumka (sarcophagus). On the south of the liman clay-slates are visible [3].

Whether or not the mountains on Holy Cross bay must also be assigned to this zone will be discussed later.

The Tertiary deposits, interspersed in many places with volcanic products, extend, probably without interruption, from the sea of Okhotsk to the Palpal hills and the Anadyr. A broad connecting region extends between the sea of Okhotsk and Bering sea. These Tertiary deposits, where they occur in Coal bay, are, as already mentioned, regarded by Dall as Miocene; a later date is assigned by Schmidt and Bogdanowitsch to similar sediments on the west coast of Kamchatka. In many localities the occurrence of folding is recorded.

Let us now return to Kamchatka.

The important additions made by Bogdanowitsch to our knowledge of this peninsula indicate in general the same main features as those described

[1] Baron G. Maydell, Reisen und Forschungen im Jakutskischen Gebiete Ost-Sibirien's, II, in Beiträge zur Kenntniss des russischen Reiches, 1896, 4. Ser., vol. II, p. 374; G. Kennan, Zeltleben in Sibirien, Ger. ed., p. 258. According to this work it should be possible to obtain a waterway for almost the whole distance between Bering sea and the sea of Okhotsk.

[2] [A 'liman' is the lagoon or bay behind a coastal bar.]

[3] Bogdanowitsch, Skizze der Tschutschken-Halbinsel, pp. 139, 140, note.

previously on the basis of Erman and Ditmar's observations, but a much greater importance is assigned to the volcanos in the interior, so that the short volcanic line on the west coast (II, p. 184) becomes relatively insignificant, as indeed was shown by Tjuschow's account. Looked at broadly, Kamchatka presents us first with an ancient cordillera, traversed by granite and porphyry and crowned by numerous volcanos; the cordillera and the volcanos alike adapt themselves to the north-east or north-north-east strike, wherever any definite direction is to be discovered; then, along the east coast, comes a main line of volcanos, in front of which lie some fragments of the cordillera next the sea. The volcanos in the interior are frequently characterized by crater lakes, but *at the present day all volcanic activity,* apart from the hot springs of the interior, *is confined exclusively to the principal line of the east.* It is this line alone which is continued into the Kuriles. From mount Shevelutsh (lat. 56° 40′ N.) to Hokkaido, that is over a distance of more than 13 degrees of latitude, there are 28 smoking cones as counted by the older observers. This list is incomplete, especially as regards the Kuriles. Bogdanowitsch regards the volcanos of this principal line in Kamchatka as more recent on the whole than those of the interior, and points to the lower hypsometric position of their eruptive centres. Be this as it may, there is an unmistakable *shifting of the volcanic activity outwards towards this arcuate principal line.*

We shall see that a similar displacement is in progress in the Alaskides. But at the same time we may observe that the arc of Verkhoiansk possesses no volcanic mountains with the exception of some basalt bosses on the Arctic Ocean, and that this great volcanic line includes all the volcanos situated near the outer border of the great virgation of the Anadyrides, and at the same time all the active volcanos of the entire region.

A long foredeep bounds the arc. Outside the Kuriles it sinks, as already mentioned, to −8,513 meters.

2. *Alaskides.*

The long folded ranges, which border the Pacific coast of America, are joined on the north-west by the group of the Alaskides in a sharply-marked syntaxis (II, p. 196)[1].

[1] Grewingk, in the first connected description of this region (II, p. 196, note 1), termed the peninsula *Alaeska*; later Russian investigators wrote *Aljáska*; under American influence the form Alaska has been exclusively adopted. Such alterations do not give rise to any difficulty; on the other hand, the name of Chugatsk bay, i. e. bay of Chug, has been retained in this work, although English and American maps use the name Prince William Sound and only use that of Chugatch for the lofty mountains to the north of the sound and an island at the south-west end of Kenai. The name has been transferred by mistake to the bay of Katshemak on the south-west coast of Kenai; cf. Dall. U.S. Geol. Surv. Ann. Rep., XVII, I, p. 789. *Kakat* means river, thus we do not write the river Melozikakat, but river Melozi; M. Baker, Alaskan Geographical Names, Ann. Rep., XXI, 2, p. 497.

The syntaxis is completed within a zone which extends between the meridians of 146° and 147° W., from the region of Chugatsk bay and the adjacent Copper river as far as the Arctic Ocean. The folded ranges of the Alaskides on the west of this zone strike towards the north-east, and those of northern Canada, situated on the east, strike towards the north-west. This contrast in direction was already observed by Grewingk. The tectonic homology between the Indian tableland and the northern part of the Pacific Ocean, which both play the part of forelands, has already been mentioned (I, p. 462). A similar homology is presented by the Karoo (IV, p. 286). Thanks to the arduous labours of American geologists we are now in possession of much more precise information as regards the syntaxis. Brooks at once perceived that all the more important chains of the interior undergo the same change of direction as is seen on the south coast, where it amounts to nearly a right angle. Four degrees of latitude north of this point Peters and Brooks observed the encounter, on the Chena, of the great Alaska range, striking north-east, with the Canadian gneiss ranges striking north-west[1].

When the syntaxis on the Jhelam was first described, distinguished Indian geologists admitted the correctness of the facts, for the most part determined by themselves, but they refused to regard the bend in the strike as a principal boundary, in this case the boundary between the Himálaya and the Iranian arc. They pointed to the complete correspondence of the outer, Tertiary chains (I, pl. IV), and the resemblance between the structure of the chains of Hazára and Kabul and that of the chains situated to the east of the Jhelam. This difference of opinion is fundamental. If we regard the stratified succession and nature of the rocks as determining the co-ordination of mountain chains, then the second interpretation may frequently be maintained. But when it is a question of determining the forces which have built up the mountains, then these characters take the second place, and the direction in which the tectonic forces have found expression will be decisive. Every syntaxis reveals a local opposition between two dynamic influences. It is for that reason that it forms a boundary. For that reason also no name given to a mountain chain should be carried on beyond a syntaxis.

In the syntaxis of Chugatsk, on its southern side, the mutual correspondence in the structure of the syntactic chains is just as great as on the Jhelam. Many a zone may be clearly traced from one side of the re-entrant angle to the other, and a train of recent volcanos follows the bend, a unique phenomenon, not to be found anywhere else on the face of the globe. Under these circumstances it is easy to see why the classification afforded by

[1] A. H. Brooks, Maps and Descriptions of Routes of Exploration in Alaska in 1898, U.S. Geol. Surv., 1899, 8vo, maps, p. 85; J. Peter and A. H. Brooks, Report on the White River-Tanana Expedition, tom. cit., p. 69.

a study of the United States and west Canada, and with it the names of the orographic subdivisions, should have been transferred to the Alaskides.

In the masterly account of the physical features of Alaska with which Brooks has enriched our science, the term '*Rocky-mountain system*' is applied, not only to the Rocky mountains of Canada and the Mackenzie, but to the whole of the Arctic branch of the Alaskides which possess a different direction and reach the Arctic Ocean north of Bering strait. In the same way the '*Central Plateau region*' is made to include the whole basin of the Yukon and the Kuskokvim as far as Bristol bay, and the '*Pacific mountain-system*' embraces not only the west coast of Canada and Chugatsk bay, but also the great Alaska range and the Aleutian islands [1].

For us the Alaskides form a tectonic unit, which is continued from the syntaxis across the Bering sea to Asia. Amatignak, the most southerly island of the Aleutian group, lies in lat. 51° 25′ N., and cape Barrow in lat. 71° 18′ N. For the whole of this distance, or at least as far as cape Lisburne and beyond lat. 69° N., the coast of Bering sea presents the appearance of a submerged virgation. Shelikof strait, with Cook inlet, Bristol bay, Norton sound, and Kotzebue sound are the characteristic embayments of this coast, and their divergent directions reveal some of the trend-lines of the virgation. Cook inlet opens towards the south-west, and Kotzebue sound, although not in accordance with the structure of those parts, towards the north-west. The first mountain arc extends from Chugatsk bay through eastern Kenai, Kadiak, and some islands off the coast. The Alaska range, bearing the highest summits of North America, begins on the Tanana, and finds its tectonic continuation in the peninsula of Alaska. North of Bristol bay the end of the Kuskokvim range advances in cape Newenham. Between lat. 61° 30′ and 62° N. older rocks reach the sea. This is also the case north of lat. 63°, where they probably represent the end of the Kaiyub mountains. Then the broad Seward peninsula advances, recalling by its form the Chukcham peninsula, which is also of great breadth, but distinguished by many characters from the long branches of the virgation, and rather resembling a foreign body inserted between them. North of Kotzebue sound the outrunners of the Arctic branch of the Alaskides reach the coast; they also form cape Lisburne.

All these arcs have a similar orientation, which is most sharply marked in the volcanic line of the Aleutian islands. All begin in the east and decrease in height towards the west. As in the Anadyrides the active volcanos are confined to a single line.

[1] A. H. Brooks, The Geography and Geology of Alaska, with a Section on Climate by C. Abbe, jr., and a topographical Map and Description thereof by R. U. Goode, U.S. Geol. Surv. Professional Papers, no. 45, 1906, 327 pp., maps. For certain trend-lines, compare also A. Spencer, Mountain System of British Columbia and Alaska, Bull. Am. Geol. Soc., 1904, XV, pp. 117–132, map.

In front of the Aleutian islands and the arc of Kenai there lies a fore-deep in which −7,319 meters, and in the extreme west −7,383 meters have been sounded. Towards the north, however, from Bristol bay to about long. 165° W. the sea is quite shallow. At the pass of Unimak or the island of Akutan a declivity begins which runs obliquely across Bering sea towards the north-west; gentle at first, it becomes steep as it passes south of the Pribilof islands. South-west of this group of islands, in long. 172° W., and scarcely 20 kilometers distant from them, the depth increases from −128 meters to −2,972 meters. This declivity runs in the direction of cape Navarin, but does not reach it; it appears to flatten out on the Asiatic coast, which it accompanies for some distance. The deepest place in the communication of Bering sea with the Pacific Ocean lies east of the Commander islands.

Bering sea is in fact divided into two sharply-separated parts, one lying to the south-west, in which depths of 3,900 meters occur, the other to the north-east in which depths of 130 to 140 meters are only reached near the margin, but elsewhere depths of less than 70 meters, or even less than 30 meters, prevail. A great plateau, covered by these comparatively shallow waters, extends from the boundary mentioned above, that is, the pass of Unimak, south of the Pribilof islands, and off cape Navarin, far northwards into the Arctic Ocean. Even in the latitude between cape Barrow and Wrangell Land (lat. 71° 30′ N.) the deepest of the numerous soundings gives only −58·4 meters.

The Aleutian islands to the west of the pass of Unimak must thus be regarded as the summits of a long, fairly narrow, and extremely steep ridge, but those to the east of Unimak as the elevated border of a plateau which descends on the south to great depths. This plateau is the continuation of the substructure of the adjacent Arctic Ocean.

A considerable part of the west coast of Alaska, particularly between lats. 64° 30′ and 59° 30′ N., is formed either by Tertiary beds, often accompanied by basalt, or by the vast alluvial land of the Yukon, which extends down to the sea. The great island of *Nunivak* (lat. 60° N.) consists, according to Dall, of almost horizontal Tertiary sandstone, covered by basaltic lavas [1]. The neighbouring coast presents the same structure and composition, according to Dawson, although cape Vancouver probably reaches a height of 300 to 450 meters [2]. The *Pribilof* group also, according to Stanley-Brown, is basaltic, with traces of marine Tertiary beds [3].

[1] W. H. Dall and G. D. Harris, Correlation Papers, Neocene, Bull. U.S. Geol. Surv., no. 84, 1892, p. 245.

[2] J. M. Dawson, Geological Notes on some of the Coasts and Islands of Bering Sea and Vicinity, Bull. Am. Geol. Soc., 1894, V, p. 134; ibid. Nunivak, p. 133.

[3] J. M. Dawson, Geological Notes, pp. 135–138; Emerson in Harriman, Alaska Expedition, IV, 1904, pp. 32–38.

Hall and *St. Matthew* islands, consist of lavas of different age; in St. Matthew porphyrites, tonalite, and aplite are said to occur, and porphyritic rocks form *Pinnacle* island, which rises close by to a great height and has been erroneously regarded as a volcano [1].

In the south-east part of Bering sea no submarine continuation is known, such as might be formed by the Kuskokvim chain for example; beyond cape Newenham everything is buried beneath the sediments of the plateau, and in the Pribilof islands the Tertiary beds with their basalts extend nearly to the edge of the declivity.

The range presents two striking interruptions. One of these is the *plateau of the Copper river*, situated on the zone of syntaxis between lats. 62° and 63° N.; it is a low-lying, more or less circular fragment of land, which is surmounted on the east by the great recent volcanos of the Wrangell group. The western border of this group is bounded in a regular arc by the Copper river, and on the other side of the river the plateau is covered up to the foot of the surrounding mountain range by the ashes and scoria of the Wrangell volcanos (fig. 33). The second break in the range is of another kind; it is caused by the *Yukon Flats*, a vast and ancient lake bottom, which includes the lower Porcupine river and the bend of the Yukon; near Circle City (not far from lat. 65° 30′ N.), the Yukon, and in about lat. 67° N., the Porcupine river, enter this plain; near Fort Hamlin (long. 149° W.) the Yukon emerges from it. Its form is that of an irregular triangle with an enlargement towards the south-east. On its southern borders lie rich gold-placers. Spurr has given a faithful description of it [2].

All accounts agree in affirming that the land about the Yukon has not been subjected to a general glaciation. The northern limit of the continuous ice sheet may perhaps be taken as about lat. 61° 50′ N. on the Lewes river, just above the mouth of the Big Salmon river, and lat. 62° 30′ N., to the north of the Alaska range (long. 150° W.). From this point onwards the valleys are narrower and terraced, until further north an independent region of local glaciation surrounds the Arctic branch of the virgation.

The Romanzov range. In 1826 Franklin observed between long. 140° and 146° W. several mountains near the Arctic coast, to which the names Buckland, Richardson, Romanzov, and Franklin mountains have been given. At that time it was supposed that these mountains, striking to the north-west, rose in coulisses one behind the other, so that the Franklin mountains

[1] Stanley-Brown, Note on Pribiloff-Islands, Bull. Am. Geol. Soc., 1892, III, pp. 496–500; B. K. Emerson, Alaska Expedition, IV, 1904, p. 31.

[2] J. E. Spurr, Geology of the Yukon Gold District, Ann. Rep. U.S. Geol. Surv., 1898, XVIII, 3, pp. 83–392, maps, in particular p. 200 et seq.

were the most westerly and, at the same, the most northerly. In more recent times Turner crossed a range in long. 141° W. and between lats. 68° and 69° N., which, according to his estimate, reaches a height of 6,000–8,000 feet (1,800–2,400 meters) [1]. The most detailed accounts are those of S. J. Marsh, who spent almost two years (1901–3) in these inhospitable regions, where he endured great hardships [2]. He is our authority for the following observations:—

A continuous mountain-chain directed east and a little north forms the watershed and runs towards the Mackenzie. A chain in front of it, marked on the maps as the *Franklin mountains*, rises in about lat. 69° N. On the Carter pass it is 4,000 feet high; some peaks may even reach a height of 5,000–8,000 feet. Its foot lies 20–54 kilometers distant from the sea. Sandstone, conglomerate, and crinoidal limestone were met with in the range, and on the coast boulders of granite and diorite.

The region extending south of the Franklin mountains to the principal chain is occupied by dark folded schists, which strike nearly east and west. Higher mountains as far as lat. 68° 10′ N. are crowned by limestone, with Crinoids and other fossils.

Near long. 146° W. the Kooguru river (Canning) marks the western end of the Franklin mountains; here the plain which extends in front of the principal chain to the sea attains a breadth of from 66 to 220 kilometers. The southern and eastern branches of the Kooguru are derived from glaciers of the principal chain. The most obvious feature in this chain is a great anticline of schist and sandstone, and to the south of this chloritic schist. West of the Kooguru the widely distributed limestone rests also upon the hills. Further towards the south-west, the prevailing rock, west of the Chandlar river and between lats. 68° and 67° N. is mica-schist with some crystalline limestone.

So far S. J. Marsh. According to common usage, this principal chain, situated south of the Franklin mountains, has hitherto been termed the *Romanzov chain*.

Two journeys, to which we are greatly indebted for knowledge of this region, have been made by Schrader, who started from the Yukon Flats, in the south. Where the Yukon makes its bend the Chandlar flows into it from the north; Schrader followed this river on his first journey. Beyond lat. 67° N. and between longs. 147° and 148° W. he reached the margin of the Flats, which is covered by basalt, and at the same time Archaean mountains, striking to the north-east, which he at once named the Romanzov mountains, and regarded as the continuation of the Arctic ranges. From this point he advanced as far as lat. 68° N. and then as he

[1] J. H. Turner, The Boundary North of Fort Yukon, Nat. Geogr. Mag. Washington, 1892, IV, pp. 196, 197.

[2] A communication in Brooks, Geography and Geology of Alaska, pp. 260–262.

returned explored the upper course of the Koyukuk. On his second journey Schrader started from lat. 66° N. on the Koyukuk, and following approximately the 152nd meridian reached the Arctic Ocean on the other side of lat. 70° 20′ N. in the basin of the Colville river [1].

An arcuate folded range, slightly concave towards the north, at least 125–130 kilometers broad, and on an average 1,800 meters in height, extends past the Yukon Flats on their north side; this has received the name of *Endicott range.* One part of it probably lies beneath the Flats; it seems to be marked by the Archaean rocks on the northern border of the Flats. It crosses the meridian of 152° between lats. 67° 10′ and 68° 25′ N. Beyond the northern border, that is beyond lat. 68° 25′ N. in the Endicott range, Schrader came upon a platform, the Anaktuvuk plateau, which extends to lat. 69° 25′ N.; beginning with a height of 760 meters it slopes downwards on the north to 240 meters, and is then followed by almost level country, which continues as far as the Arctic Ocean.

The most ancient rocks in this range, situated on the margin of the Flats, in long. 147° to 148° W. strike to the south-west. They are followed on the north by a gold-bearing zone of highly-altered rocks. In long. 152° W. the strike runs east and west. Here Schrader observed a zone of biotite and amphibolite schist, 10 kilometers broad, dipping to the south (Totsen series) and a second zone 24–32 kilometers broad, including highly-altered limestone with doubtful traces of upper Silurian fossils and mica-schist. Then follows an unconformable series of alternating sandstone, conglomerate, slate, and limestone, extending over a breadth of 80 kilometers and dipping to the south-east or south-west; in this zone lower Carboniferous fossils only have been found. A disturbance, not known in detail, exposes middle Devonian limestone on the east; the fauna recalls the Devonian of the Mackenzie. The presence of *Spirifer disjunctus* points to upper Devonian. A hard quartz conglomerate crops out from beneath the Devonian and divides it into a northern and a southern zone.

Thus we reach the northern border of the Endicott range; towards the west this border is probably formed by the Devonian, towards the east by the lower Carboniferous or some later stage. In front of the border lies a belt of talus. The southern and larger part of the Anaktuvuk plateau consists of slightly folded limestone with *Aucella crassicollis.* It is covered towards the north (perhaps unconformably) by upper Cretaceous with Scaphites and large Inoceramus shells.

The plain is formed of two Tertiary stages, one of which is described as

[1] F. C. Schrader, Preliminary Report on a Reconnaissance along the Chandlar and Koyukuk Rivers in 1899, Ann. Rep. U.S. Geol. Surv., 1901, XXI, 2, pp. 441–486, maps; Geological Section of the Rocky Mountains in North Alaska, Bull. Am. Geol. Soc., 1902, XIII, pp. 233–252; A Reconnaissance in North Alaska, U.S. Geol. Surv. Professional Papers, no. 20, 1904, 139 pp., maps.

Oligocene, the other as Pliocene. A remarkable sheet of unstratified sand (Goobie sands) extends over the Tertiary beds.

Finally, we reach the tundra. Schrader justly observes that the name Alaska range, if it had not been conferred elsewhere, should be assigned to this great watershed lying next the Arctic Ocean. When the first indications of the watershed were observed by Schrader on the border of the Flats he described them, as we have seen, as parts of the Romanzov range. After he had crossed from side to side he chose for them the name of *Endicott* mountains, by which this part of the range had been already indicated on Allen's map since the year 1885. The entire range as far as the west coast was regarded as belonging to the Rocky mountains, and consequently the Cretaceous plateau of Anaktuvuk and the tundra were compared to the prairie-land of the United States.

It would seem most satisfactory to retain for the whole chain, from its syntaxis in the east up to its western end, the name of the Russian statesman Romanzov, who almost a century ago equipped Kotzebue's expedition from his own private means, and to reserve the name Endicott for that middle region which cuts through the meridian of 152°, on the same principle as further west other parts of the Romanzov range bear the names of De Long, Schwatka, and Baird mountains.

Thus, by Schrader's journeys we are furnished, for the first time, with exact information on an important mountain range.

The north border of this range reaches the coast at *cape Lisburne*; here a broad, rich, coal-bearing region lies in front of it, which is not yet known in front of the Endicott range. The most detailed account has been furnished by Collier[1].

The northernmost point at which coal-beds occur is *Wainwright inlet* (lat. 70° 37′ N., long. 159° 45′ W.); where *Nageiopsis longifolia* and *Podozamites distantinervis* of the older Potomac of Virginia (Wealden) and *Baiera gracilis* of the Yorkshire Oolites have been obtained. Knowlton calls attention to the great resemblance between floras of these beds and the Jurassic floras of Siberia[2].

[1] A. J. Collier, Geology and Coal Resources of the Cape Lisburne Region, Al., Bull. U.S. Geol. Surv., no. 278, 1906, 54 pp., map.

[2] Grewingk (II, p. 196, note 1), p. 90; Captain Hooker's Report of the Cruise of the U.S. Revenue-Steamer *Corwin* in the Arctic Ocean, 8vo, Washington, 1881, pp. 29 and 48; Lesquereux, Proc. U.S. Nat. Mus., 1887, X, pp. 35–38, and 1888, XI, pp. 31–33; Lester Ward, Geographical Distribution of Fossil Plants, U.S. Geol. Surv. Ann. Rep., 1889, VIII, 2, p. 926; Knowlton, op. cit., 1896, XVII, 1, p. 827 et seq.; W. H. Dall, Report on Coal and Lignite of Alaska, tom. cit., in particular p. 820. Woolfe in Schrader, Preliminary Report on a Reconnaissance along the Chandlar and Koyukuk Rivers in 1899, U.S. Geol. Surv. Ann. Rep., 1901, XXI, 2, p. 111. Possibly the Mesozoic coal-field is not quite continuous; this is suggested by the presence of gold at Icy cape, north of lat. 70°, Rep. Min. Prod. for 1903, p. 49. Knowlton, in Bull. U.S. Geol. Surv., 1906, no. 278, p. 29.

From Wainwright inlet onwards the ice at many points thrusts fragments of coal up against the coast, until near cape Beaufort (lat. 69° 10′ N.) better exposures are reached showing a strike N. 25° W., and from this point onwards coal-beds are known as far as the Corwin mines (strike N. 75° W.) and the adjacent rivulet Thetis, east of cape Lisburne. Here, too, Mesozoic plants have been found. All these coal-beds strike to the north-west; they are folded and traversed by thrust-planes.

Near cape Lisburne (lat. 68° 50′ N., see II, p. 196) the Palaeozoic rocks crop out and form the end of the northern part of the Romanzov range, which extends through *cape Thompson* (lat. 68° 6′ N.). They are thrust towards the north over the Mesozoic coal-beds. The stratified succession from above downwards is as follows: thick white limestone with corals and Polyzoa, thinly stratified shales and limestone with brachiopods, trilobites, and other fossils, amongst these beds black shales and limestone with brachiopods, also Coal-measures with a lower Carboniferous flora (Lepidodendron, Stigmaria, and others), and finally, calcareous sandstone and shales, perhaps of Devonian age. Productus is known even at cape Thompson; Schuchert also mentions the upper Carboniferous *Spirifer condor* [1].

The Palaeozoic range, like its northern border, is overthrust in flakes towards the north; the lower Carboniferous coal-measures are repeated on the coast.

In the interior of the country, probably more than 300 kilometers east of cape Lisburne, fragments of coal have been obtained on the Chipp river (Ikpikpuk, long. 155° W.), and on the Colville river. Thus, although the coal series to the north of the Endicott range is no longer visible, it is possible that coals, the Mesozoic coals in particular, lie beneath the Cretaceous plateau of Anaktuvuk.

Grewingk states, on the faith of Fischer's observations, that lavas and hardened clay occur along the coast between mount Mulgrave (lat. 67° 40′ N.) and cape Krusenstern (lat. 67° 5′ N.).

Mendenhall furnishes information on the regions lying further south [2]. He travelled westwards from the Flats to the sea and observed highly altered rocks with a westerly strike in the southern part of the Endicott range. Near Dall City (lat. 66° 15′ to 66° 30′ N., about long. 150° W.) they are traversed by many granitic intrusions; near long. 151° W. in the

[1] C. Schuchert, Report on Palaeozoic Fossils from Alaska, U.S. Geol. Surv. Ann. Rep., 1896, XVII, 1, p. 899, and in Schrader (see previous note), p. 66; A. Hyatt, Report on the Mesozoic Fossils, &c., tom. cit., p. 907; Brooks, Geology and Geography of Alaska, U.S. Geol. Surv. Professional Papers, no. 45, 1906, p. 242; A. J. Collier, Coal Fields of the Cape Lisburne Region, in Brooks, and Other Mineral Resources of Alaska, U.S. Geol. Surv. Bull., no. 259, pp. 172–185. The presence of Trias has not been confirmed, Stanton, Bull. Am. Geol. Soc., 1905, XVI, p. 396.

[2] W. C. Mendenhall, Reconnaissance from Fort Hamlin to Kotzebue Sound, Al., U.S. Geol. Surv. Professional Papers, no. 10, 1902, 68 pp., maps.

same latitude, a mass of gabbro and serpentine succeeds, then to beyond long. 152° W. more recent andesitic rock is met with. A patch of Mesozoic (? Aucella) beds extends past Bergmann on the upper Kowak (Kobuk) and then this river, apparently flowing in a longitudinal valley, is bordered down to the sea by the so-called metamorphic series (mica schist, quartzite, and some limestone).

The peninsula of Choris at the entrance to *Eschscholtz bay* consists of similar schists; Chamisso and Puffin island, in its vicinity, are formed of gneiss-like granite. The resemblance of the rocks to those of St. Lawrence bay on the other side of Bering strait led Engelhardt so early as 1821 to conclude that Asia and America were once united [1].

To the south of Kotzebue sound graphitic schist and mica-schist again crop out, and also serpentine and hornblende schists. Then they disappear; the shore is strewn with boulders of olivine-bearing lava; near cape Espenberg is volcanic sand containing marine Tertiary shells. The Teufelsberg, situated to the south-west further inland, is of volcanic origin, according to Beechey; a lava stream proceeds from this point to the sea. Towards the gulf of Shishmaref the shores are flat.

The west thus presents itself to us as follows. The Romanzov range is continued to the coast. A northern branch, overthrust towards the north and containing lower Carboniferous coal-measures, disappears between cape Lisburne and cape Thompson. I presume that the name *De Long range* properly belongs to this branch. A second branch, consisting of older rocks and situated further towards the interior, comes from the Endicott range and separates the rivers Noatak and Kowak; this is the *Baird range.* Still further south, at several points in Eschscholtz bay, the deepest-lying, gneissose rocks make their appearance, and may perhaps be compared with the rocks observed by Schrader on the north border of the Flats. But from the Mulgrave mountains onwards and round about a large part of Kotzebue sound, lying transversely across the ends of the ranges, is a girdle of recent sediments, together with recent volcanic formations, and to this girdle belongs the whole northern part of Seward peninsula as far as Shishmaref bay and some distance beyond.

Seward peninsula. The ends of the mountain ranges cut off across their strike, and the volcanic formations near the border give to Kotzebue sound, along with the plain of cape Espenberg, the characters of a subsidence. Into the inner part of the sound, formed by Eschscholtz and Spafarief bay, two rivers are discharged, the Kiwalik and the Buckland, which come from the south and flow parallel to one another. They are separated by a long meridional ridge rising high above the country on

[1] M. v. Engelhardt (and Weiss) in O. von Kotzebue's Entdeckungsreise in die Südsee und nach der Bering-Strasse, 4to, Weimar, 1821, III (by A. von Chamisso), p. 191; a summary of all accounts in Grewingk, p. 70 et seq.

the east and west, and reaching in the south the valley of the Koyuk river which flows into Norton bay. This dividing ridge consists, according to Moffit, of isolated hills of granite, monzonite and quartz-diorite, in the south possibly of malignite also, surrounded by a great deal of andesite and here and there accompanied by more recent basalts [1].

An extensive region of very recent lavas surrounds lake Imuruk (lat. 65° 40′ N., long. 163° 10′ W.), and from this locality the basaltic lavas observed by Mendenhall in the valley of the Koyuk are possibly derived. Many of these lavas have flowed through the existing valleys.

Norton bay is surrounded by low-lying land formed of coal-bearing beds, marine upper Cretaceous and coal-bearing Oligocene or Kenai beds [2]. Tertiary, or even more recent, volcanic ejectamenta are met with, up to the shores of Bering sea, first near St. Michael, and then on as far as the Koyukuk. The region between Kotzebue sound and Norton bay is indeed a continuation of the country on the lower Yukon, and separates Seward peninsula from the interior of Alaska.

The peninsula itself presents none of the elongated chains which distinguish other parts of Alaska.

The abundance of gold in *Nome* led to a preliminary report on this locality by Schrader. Bogdanowitsch visited Nome before setting out on his journey into Chuchki land. Subsequently Brooks and his colleagues described the southern part of the district, and Collier thenorth- western part [3].

The broad depression which runs from Port Clarence to Golofnin bay is not determined by the structure of the country. The most important ranges follow a direction transverse to it; these are the *Kigluaik mountains* to the south of this valley (Mount Osborne 4,700 feet, 1,432 meters), and the *Bendeleben mountains* to the north of it. Both run to the west-south-west, but the Bendeleben mountains do not lie exactly in the continuation of the Kigluaik mountains, although their structure is similar. Towards Bering strait a considerable area is occupied by the *York mountains*.

Near *cape Nome*, in the most southerly part of the peninsula,

[1] F. H. Moffit, The Fairhaven Gold-Placers, Seward Peninsula, U.S. Geol. Surv. Bull., no. 247, 1905, 85 pp., maps.

[2] At several places, especially in the Aleutian islands, marine beds rest upon the Kenai deposits, but the name *Nulato* stage, hitherto employed for them, cannot be retained since it has been discovered that the typical locality, Nulato on the Yukon, is of upper Cretaceous age. Brooks, Geography and Geology, U.S. Geol. Surv. Prof. Papers, no. 45, 1906, p. 236.

[3] F. A. Schrader, Preliminary Report on the Cape Nome Gold Region, U.S. Geol. Surv., 8vo, 1900, 56 pp., map; K. J. Bogdanowitsch, Sketch of Nome, 8vo, 1901, St. Petersb., 116 pp., map (in Russian); A. H. Brooks, J. B. Richardson, A. J. Collier, and W. C. Mendenhall, Reconnaissance in the Cape Nome and Norton Bay Regions, Al., in 1900, U.S. Geol. Surv., 8vo, 1901, 222 pp., maps; Collier, A Reconnaissance of the north-western portion of Seward Peninsula, Al., U.S. Geol. Surv. Profess. Papers, no. 2, 1902, 70 pp., maps.

Bogdanowitsch observed ancient augen-gneiss, which occurs as boulders in Anvil creek, and he points out its resemblance with the gneiss of cape Novosiltzev (Kreulgun) on the coast of Asia. The American investigators make no mention of this occurrence, owing, perhaps, to the wider or narrower sense in which they use the term gneiss. Brooks mentions, first, white crystalline limestone with mica schist (Kigluaik series); this forms the greater part of the Kigluaik range, and, in association with granite intrusions, of the Bendeleben mountains also. Then follows graphite-bearing quartzite schist (Kuzitrin series), and, finally, a thick mass of the Port-Clarence limestone, in which Collier found Silurian fossils.

Greenstone and green schists, produced from gabbro or diabase, appear as sills in both the oldest stages. Granite, more recent than the greenstones, occurs at not a few places, either in bosses or dykes, and generally within the crystalline limestone of the Kigluaik stage. In lat. 65° 50′ N., long. 164° 10′ W., hot springs occur within one of these granite bosses; to the west of this locality another boss forms the conspicuous mass of the Ear mountains, and yet another forms *Cape mountain* (792 meters) which projects into Bering strait. The presence of tin has directed attention to these granite bosses. On Cape mountain, and the neighbouring part of York mountains, the tin ores occur close to the contact between granite and limestone, and in veins which proceed from the granite. On the east side of Cape mountain Collier discovered Devonian or Carboniferous fossils in the limestone [1].

Speaking generally, we may say that a considerable range of these granite mountains extends from Cape mountain towards the east-north-east, into the region south of Eschscholtz bay; some of them have furnished traces of tin, others of fluor spar, but others again, although included with the rest, are probably of much greater age. This is true in particular of the Kiwalik mountain (lat. 65° 30′N., long. 162° 10′ W.), which, according to Moffit's description, must doubtless be regarded as true gneiss.

Seward peninsula is a land bearing some fairly high mountains, formed of Palaeozoic and older systems, penetrated here and there by eruptive rocks of very various age. Data as to the strike are not concordant: in the north-western portion it is mainly east-and-west, in the southern more generally west-south-west. On the Kugruk (lat. 65° 55′ N., long. 162° 25′ W.) a bed of coal, probably upper Cretaceous, is mentioned; it is folded and strikes north and south.

The peninsula of the Chuchki. To the north of the plain of the Anadyr, *Holy Cross bay* cuts deep into the mainland. It is prolonged towards the

[1] Collier, Tin Deposits of the York Region, Al., Bull. U.S. Geol. Surv., no. 229, 1904, 57 pp., map, and no. 259, 1905, pp. 120–127.

north, that is into the interior, in two arms, Engaugyn bay and Etelkujum bay, and above these rises the mountain of *Matatshingai* (2,797 meters) which is, far and wide, the highest mountain in the land. Postels, the companion of Lütke, succeeded in reaching as far as Etelkujum bay; the rocks he obtained include, according to Jankowsky, trachytic taxite, augite andesite, and liparite. It may well be that the eruptive rocks at the mouth of the Amadyr are continued up to this point [1].

The south-east coast of Chuchki peninsula, which forms the Asiatic coast of Bering strait, is for the most part rocky. Metshigma bay and, north of this, St. Lawrence bay break up the hills. St. Lawrence bay appears to be separated only by a low watershed from the great Koljutshin bay, which opens into the Arctic Ocean, and perhaps this is also true of Metshigma bay, so that the hills in the interior are broken up into irregular groups, as frequently happens in high latitudes [2].

The isolated observations of Dawson, Nordenskjöld, and the older investigators have been brought into connexion by the detailed studies of Bogdanowitsch. His descriptions furnish us with the following facts [3].

The south-east part of the peninsula is rocky, high (up to 884 meters), and deeply divided by fjords. One of these fjords extends from the south-south-west into the mountainous land (Providence or Plover bay), a second comes from the south (Iskagan), and on the east side is a group of three fjords (the most northerly is the gulf of Konjam) separated from the open sea by two high rocky islands. These islands are called Ittygran (or Schirluk, 561 meters) and Arakam (or Kaine, 554 meters). The strait of Senjavin extends between the north coast of the island of Arakam and the mainland.

The bluff mountains and islands, between Providence and Senjavin bays, are formed (apart from their summits, which are possibly andesite) of a very varied series of rocks. From the débris on the slopes of the rocky shores of Iskagan bay Washington mentions comendite, quartz-porphyry, rhyolite, obsidian, and monzonite [4].

From cape Mertens onwards, which lies south of Ittygran and marks the entrance to the inner fjords, clay slates and white schistose limestone are continued onwards, according to Bogdanowitsch, beneath this mass of

[1] F. Lütke, Voyage autour du monde, 8vo, Paris, 1836, III, p. 48. Postels thought he observed porphyry with glassy feldspar, &c.; W. Jankowsky, Material zur Petrographie von Kamtschatka und der Heiligen Kreuz-Bucht, Trudi Naturf. Ges. St. Petersb., XXIII, pp. 61–70. Professor Löwinson-Lessing is kind enough to inform me that Jankowsky's specimens were collected by Postels.

[2] On this point see Bove in Nordenskjöld, Die Umseglung Asiens, II, pp. 32.

[3] K. Bogdanowitsch, Sketch of the Chuchki Peninsula, 8vo, St. Petersburg, 1901, 238 pp., maps (in Russian).

[4] H. S. Washington, Igneous Rocks from East Siberia, Am. Journ. Sci., 1902, 4th ser., XIII, pp. 175–184.

eruptive rocks. The same sedimentary rocks also occur at the base of the two islands Ittygran and Arakam, and in the inner fjords as far as Konjam and Senjavin. The clay slates soon pass into biotite schists; then the whole series is seen only at sea level; in some places it is traversed by granite dykes, but everywhere it is covered by the recent eruptive rocks and steeply folded, with a north-westerly strike, varying between N. 30° W. and N. 65° W.[1]

This strike to the north-west indicates the presence of an arc coming from Alaska, and Dawson's statement, that the grey granite which forms the adjacent part of the elongated St. Lawrence island coincides with that of the Asiatic peninsula, confirms this view [2].

To the north of the strait of Senjavin the situation alters. On the north coast the Maritsh rivulet enters the strait; towards its mouth the strike of the limestone and schist becomes north-and-south, and only 4 versts up the stream it is N. 40° E.; maintaining this direction it probably reaches the inner parts of Konjam. It seems as though an American and an Asiatic (Anadyr) direction were about to encounter each other. Cape Nigitshan is formed of porphyries, and still further north the tundra extends to Metshigma bay. Near this bay we meet with low hills of folded limestone striking N. 40° W.; brown coal is present. On both sides of the bay rise bosses of andesite and dacite; in some of these the original form of the crater has been preserved, as, for instance, in the conical mountain of *Nelpynja* on the north side of the bay, from which a flow of dacite has poured forth.

North of this point a higher range occurs (741 meters), which reaches the sea in cape *Novosiltzev* (Krleugun). From this range gneiss comes down in boulders towards the south to Metshigma bay; granite, often assuming the structure of gneiss, forms the promontory. A boss-like mass of olivine diabase appears on its summit. Gneiss-like granite also forms part of the south shore of St. Lawrence bay; in the interior of this bay, however, on its north side, and also near cape Nunjam and as far as cape Lütke, we again perceive the more recent eruptive granites of Senjavin and the sediments of these more southerly mountains, altered by contact [3]. On the other side of cape Lütke eruptive rocks of this kind have not yet been

[1] Bogdanowitsch, Sketch of the Chuchki Peninsula, pp. 112–124. Postels has already described the rocks of Arakam and recognized the prevailing north-west strike; see Postels in Lütke, Voyage III, pp. 32 and 44; a description of Konjam and its rocks is given by Nordenskjöld, Umseglung Asiens, II, p. 240.

[2] G. M. Dawson, Geological Notes on some of the Coasts and Islands of Bering Sea and Vicinity, Bull. Am. Geol. Soc., 1894, V, pp. 117–146, in particular p. 138 et seq.

[3] Specimens of white granular limestone with white mica and foliated graphite were collected by Eschscholtz on the gulf of St. Lawrence, Kotzebue, Entdeckungsreise in die Südsee und nach der Bering-Strasse, 4to, Weimar, 1821; Chamisso, op. cit., III, p. 169; Engelhardt (und Weiss), op. cit., III, p. 191.

observed. The gneisses can be traced as loose boulders from the mountains lying further towards the interior, but with the exception of some loose boulders of granite on cape Deshnev, the only rocks seen by Bogdanowitsch near cape Kuntugelen, and as far as cape Deshnev were schists, dark siliceous limestone and limestone breccia, that is, a normal sedimentary series, striking apparently east and west[1].

Disregarding the strike, we may therefore distinguish the following parts in the west coast of Bering strait: (1) a tract extending from Providence to Senjavin and beyond, formed of altered and folded sediments, penetrated and overlain by granite, syenite, and the like, and also by andesitic rocks; (2) a flat land of Tertiary sediments and recent eruptive rocks extending to Metshigma bay and beyond; (3) a doubtful range of gneiss and granite, which reaches the sea in cape Novosiltzev and is there penetrated by olivine-diabase; (4) the series of rocks on the south (Providence to Senjavin) which are repeated as far as cape Lütke; (5) normal sediments (slate and limestone) up to the Arctic Ocean.

We will now follow the range which includes cape Novosiltzev. It forms the watershed. Bogdanowitsch observes that he was struck by the resemblance in detail between the rocks of this range and the boulders he had seen in America, on the shore of Anvil creek, not far from Nome. So far as can be made out from the indications furnished by this indefatigable observer in respect to the north coast, the series of unaltered sediments continues from cape Deshnev for some distance towards the west; then follows a vast tundra, interrupted by isolated eruptive hills of recent date. Sheets of trachyte and melaphyre enter into the vicinity of the Serdze Kamen promontory, which is itself formed of granite. Bogdanowitsch, however, observes that this granite of the Arctic coast is different, both in its nature and its general mode of occurrence from the recent granite of cape Lütke and the strait of Senjavin, and it extends in bosses to the coast of Koljutshin bay. Here we reach the neighbourhood of Pitlekaj, the place at which Nordenskjöld's ship, the *Vega,* passed the winter, so that the accounts at our disposal are fortunately continuous. Törnebohm's description shows that in the tract extending from Idlidlja (west of the Serdze Kamen) through Pitlekaj to the island of Koljutshin, exposures of gneiss are met with, also a granulitic rock, and on the east side of Koljutshin bay granular limestone occurs in association with these rocks[2].

[1] H. S. Washington mentions Foyait with the description: south of *Whalen* or *Itshan,* East cape; surely this can only refer to the settlement Уэленъ on the north side of Deshnev?

[2] Törnebohm, Vega-Expedition, in Nordenskiöld Vega-Expedition Vetensk. jaktag., 1887, IV, p. 122. A loose boulder of granite from the lagoon of Pitlekaj was recognized as distinct from these rocks and identical with that of cape Nunjam (a little south of cape Lütke); so clear is the distinction between the recent granites.

It is, therefore, not improbable that a range of ancient granite and gneiss extends from Novosiltzev and the great mountains between Metshigma bay and St. Lawrence bay to the Arctic Ocean, east of Koljutshin bay, and to the island of Koljutshin. Bogdanowitsch states that south of this bay great mountains are to be seen running first to the west-north-west, then north-north-west, and finally north-north-east to the west of the bay, and probably as far as cape Onman (about long. 175° W.)[1].

On *cape Irkaipi* (long. 180°) and the neighbouring mountain of *Hammong Omang,* Nordenskjöld observed olivine-diabase resting on black shales with plant-remains, and perhaps belonging to the Permo-Carboniferous[2]. *Cape Jakan* (about long. 176° E.) presented breccia, sandstone, and porphyry tuff (strike north-and-south in a small exposure). In this neighbourhood the series of rocks begins which extends to cape Shelagskoi (Erri) on Chaun bay.

Bogdanowitsch points out that all the mountain ridges of this region are directed to the west-north-west, and conjectures the existence of a connexion between the rocks of Chuchki land, and those of Chaun bay. Here we must recall the fact that on the Poginden (right tributary of the little Anuj) the strike is still north-east to east-north-east, while on the lower Baranycha (long. 165° E.) it is N. 30° W. This is a similar contrast to that which occurs at the entrance to the strait of Senjavin, and these facts support Bogdanowitsch in supposing that two arcs are present; that which we call the American arc would thus extend to the Baranycha.

The promontory of Baranov also shows the elongation to the west-north-west, and consists, like the islands off its coasts, of schist and granite.

This west-north-west strike, oblique to the shore line, gives the character of a rias coast to the region of Pitlekaj and Koljutshin island, cape Shelagskoj and the rocky island of Rantan at the entrance to Chaun bay, and the promontories of Great and Little Baranov together with the Baranov islands[3].

[1] Bogdanowitsch, Sketch of the Chuchki Peninsula, p. 104; Cape Onman is described by Wrangell, Reise längs der Nord-Küste von Sibirien, etc., II, p. 214. To the west of this locality, in the direction of cape Wankarem, Wrangell observed lofty cliffs of granite porphyry. Wankarem is said to consist, like Irkaipi and cape Schelagskoi, of very fine-grained syenite with dark green hornblende.

[2] Törnebohm, Vega-Expedition, Vet. Arb., IV, p. 121.

[3] Bogdanowitsch saw reason to doubt the assumption that so large a part of the land should possess a structure striking to the west-north-west, owing to the repeated occurrence of beds striking to the north-east. On the whole, however, we see that the north-easterly strike prevails in the regions situated more to the south and west, the west-north-westerly strike in those more to the north. This is the case not only on the Anuj (Poginden), but also in the southern part of the Chuchki Peninsula. It is only at the head of the gulf of Konjam and on the Maritsh river that a north-easterly strike again occurs in places, but passing through a north-and-south direction. The north-easterly direction reappears in St. Lawrence Bay.

The relation of Asia to America. An attempt to determine the relation of Asia to America was made by Bogdanowitsch[1]. The subsequent works of American investigators have cleared up many doubtful points, but they also enable us to recognize the special difficulty of the problem. It lies in the fact that Seward peninsula is not so much a region of clearly-marked trend-lines as of locally limited intrusions of different ages. It is true that these intrusions are repeated on the Asiatic side. The Romanzov range strikes in full breadth out to sea. Kotzebue sound, with the low-lying land extending to Shishmaref, looks like a subsidence of the Romanzov range. The small fragment of sediments, near cape Deshnev, striking in the normal west direction, may possibly correspond with the Silurian, also striking to the west, in the northern hill-ranges of Seward peninsula.

The York mountains, about 600 meters high, are surrounded at a height of 600 feet (183 meters) by a sharply-defined terrace. On the other side of the tin-bearing granite of Cape mountain, the steep *Fairway Rock* rises from Bering strait; according to Lopp this also consists of granite. At a height of 600 feet it presents a flat summit, as though the terrace surrounding the York mountains were about to be continued across the sea[2]. The great *Diomedes island* consists, according to Dall, of syenite[3]. Tin has been obtained from it. Thus we may conclude that Cape mountain, with its crystalline limestone, altered by contact with the granite, along with Fairbank and Diomedes is the continuation of the intrusive rocks and the altered sediments which Bogdanowitsch encountered, extending from cape Lütke and Nunjam to St. Lawrence bay.

It is much more difficult to form an opinion as regards the region which follows to the south. Several circumstances tend to show that the range of granite and gneiss, which has been followed from Novosiltzev towards Pitlekaj and Kolyutshin and then to Chaun bay is really of considerable age. If so, it must be regarded as the most important line of the Chukchi country. Its direction to the north-west or west-north-west would correspond with the strike to N. 40° W. in the folds of the Tertiary land to the south of the neighbouring Metshigma bay, and would accord with the view that it forms a part of an arc of the Alaskides. But in Alaska itself the only indications of a continuation are afforded by Chamisso and Puffin islands in Eschscholtz bay and the Kiwalik mountain.

It might certainly be supposed that these latter localities, continuing the north border of the Flats, correspond to the innermost and southern-

[1] Bogdanowitsch, Sketch of the Chuchki Peninsula, p. 142 et seq.

[2] Brooks and others, Reconnaissance in the Cape Nome and Norton Bay Regions, Al., in 1900, U.S. Geol. Surv., 1901, pp. 34, 52, 59, 132, pl. XIII, map of York Region by Brooks.

[3] W. H. Dall, Ann. Rep. U.S. Geol. Surv., XVII, 1, p. 835.

most part of the Romanzov range; yet this view is without adequate confirmation [1].

In the substructure of Ittygran and Arakam, and as far as Senjavin, the direction to north-west or west-north-west is repeated. The grey granite of Providence and Senjavin corresponds, according to Dawson, with the granite on the west side of *St. Lawrence* island, which extends for a distance of 130 kilometers towards the west-north-west. On the summit of the island lie volcanic tuffs; cones of no great size are also said to be present. In the south of the island, Chamisso mentions granite in addition. Collin obtained a Carboniferous fossil from St. Lawrence [2]. These facts, however, lead us no further than the conjecture that, buried beneath the flat land of the lower Yukon there lies a region which is traversed in the same way as Seward peninsula by granitic intrusions.

King's island, which is small but lofty, is formed, according to Hooker, of basalt [3].

As the sea becomes broader towards the south, the difficulty in linking the facts together becomes greater. Towards the west, from Holy Cross bay onwards, the character of the coast seems to alter. The height of Matatshingai (2,797 meters), which is extremely great for these regions, with the andesite and liparite rocks known near its foot, even suggests the question whether, in spite of the great interval, a trace of the volcanic arc of Kamchatka may not be visible here. But the intervening area is, as we have seen, almost entirely unknown.

Let us return to the doubtful range of granite and gneiss extending from Novosiltzev to Kolyutshin.

We have seen that even on the Baranycha, west of Chaun bay (long. 167° E., lat. 68° 34′ to 69° 9′ N.), a strike to N. 30° W. occurs, and cuts off the north-easterly strike of the Kolyma, and with it the Anadyrides (IV, p. 341). We should suppose that if any connexion existed between this range and the Alaskides, north-westerly and north-north-westerly directions would gradually make their appearance in the west. According to Toll's investigations in the *New Siberian islands* this is in fact the case [4].

North of lat. 70° N., and east of the lower Jana, at the extreme end of the Tass Hajachtach, Trias crops out (IV, p. 336). Then follows a broad

[1] A. J. Collier, U.S. Geol. Surv. Bull., no. 229, p. 28, seems to suggest that the more recent tin-bearing granites follow the strike like those of Cornwall.

[2] J. M. Dawson, Geological Notes on some of the Coasts and Islands of Bering Sea and Vicinity, Bull. Am. Geol. Soc., 1894, V, pp. 138–148; Chamisso, in Kotzebue, Entdeckungsreise in die Südsee und nach der Bering-Strasse, 4to, Weimar, 1821, III, p. 170.

[3] Captain Hooker, Report of the Cruise of the U.S. Revenue Steamer *Corvin* in the Arctic Ocean, 8vo, Washington, 1881, p. 15.

[4] Baron E. von Toll, Geological Sketch of the New Siberian islands, Mém. Acad. Imp. Sci. Saint-Pétersb., 1899, 8e sér., IX, no. 1, 20 pp., map, in particular p. 16 (in Russian).

tundra, out of which, as we proceed towards Swiatoj Noss, basic eruptive rocks protrude; on the south side of this Noss we reach the Laptew strait. On the south side of *Ljächow island*, three degrees of latitude north of the Trias of the Tass Hajachtach, a formation is visible which is alien to the arc of Verkhoiansk. In this island four isolated granite bosses rise out of the flat frozen ground, which contains numerous remains of elephants. 'One cannot help thinking,' says Bunge, 'that if the temperature of the ground were to rise above zero even for a short period, that island would be converted into liquid mud and flow away [1]. Then only the granite bosses would remain, and possibly a continuous granite zone. It would be at least 70 kilometers broad.

Kotelny, the largest island of this archipelago, extends, in the vicinity of meridian 140°, for a distance of about 170 kilometers. In the south, Toll found Trias with *Pseudomonotis ochotica*; for the rest the island consists, apart from some basic eruptive rocks, of a hilly range formed of upper Devonian, with a strike to the north-north-west, on its west side, and another range formed of upper Silurian, the *Schmidt mountains* of Toll, with the same strike, on its east side.

The flat tract known as *Bunge Land*, which adjoins it on the east, and the extensive island of Fadejeff are only patches of frozen soil.

In the western part of *New Siberia*, which is the most easterly island, lie the much-discussed 'wood mountains' (II, p. 487). They present trunks of trees embedded in a Tertiary lignitiferous deposit, with leaves of *Sequoia Langsdorfi*, *Populus arctica*, and other species. The deposit is thrown into steep folds with a strike to north-north-west, and terminates in steeply upturned beds at cape Wyssoki, the extreme point of the island [2].

Thus we have evidence of the existence of Miocene or post-Miocene folding between lats. 75° and 75° 30′ N. It is impossible to resist the conjecture that the New Siberian islands also form part of the system of the Alaskides. The most recent folds occur in the east; that is, on the inner side, as in the Romanzov range.

In *Bennett Land* De Long met with eruptive rocks. Baron von Toll arrived off the island in August of 1901. The ice pack prevented his approach, but for a brief period the mist opened up and revealed the promontory of Emma, 2,000–3,000 feet high, and completely covered with snow. Fragments of volcanic rock, brought down by glaciers, were picked

[1] Bunge, Expedition nach den Neu-Sibirischen Inseln und dem Jana-Land, Beiträge zur Kenntniss des russischen Reiches, 3. Ser., vol. III, maps, p. 256.

[2] E. von Toll in J. Schmalhausen, Tertiäre Pflanzen der Insel Neu-Sibirien (Wissenschaftliche Resultate der von der kaiserlichen Akademie zur Erforschung des Jana-Landes u.s.w. ausgesandten Expedition, II), Mém. Acad. Imp. Sci. Saint-Pétersb., 1890, 7e sér., XXXVII, no. 5, p. 1 et seq.

up on the ice [1]. But this did not satisfy the intrepid explorer. He continued the exploration and paid for it with his life. The last record he made informs us that Bennett island repeats the structure of the ancient tableland of East Siberia; from the collections he made, Schmidt has described *Anomocare excavata* and graptolite slates, and Nathorst, plants belonging to the Trias and Jurassic [2].

Mountains on the lower Yukon. All the mountains which rise from the broad plain of the lower Yukon strike to the south-west.

The Koyukuk emerges from the older rocks south of lat. 67° N., but the long and not very high range of the *Yukon mountains*, directed to the south-west, which separates the Koyukuk from the Melozi, is either a continuation of the southern rocks of the Romanzov range, or a new divergent branch of the virgation. Its south-western end has not been explored.

The cañon, probably about 150 kilometers in length, by which the the Yukon leaves the Flats at their south-western end, near Fort Hamlin, is cut for the greater part in Devonian diabases and green schists; here lie the Ramparts of the Yukon [3]. Similar rocks and older schists form the long ridge of the *Gold mountains* between the Yukon and Melozi, and still further to the south-west, south of the Yukon, the *Kaiyuh mountains*, also directed to the south-west, which extend through the plain of the lower Yukon nearly to lat. 63° N. There they appear to bend in an arc toward the west, and it is probable that their continuation forms the promontories to the south of lat. 62° N. But with regard to the latter we have only short accounts by Dall.

The *Kuskokvim mountains*, lying still further towards the south, have been made known to us by Spurr [4]. Presenting a trifling elevation in the north, they continually increase in height towards the south-south-west. In about long. 154° 20′ W., north of lat. 63° N., the Kuskokvim river, coming from the Alaska range, enters these heights. It cuts through them in a long cañon, then turns towards the west, leaves the mountains, and flows towards the sea to the north of their continuations. The mountains are continued in the south-south-westerly direction, first as

[1] E. von Toll, Vorläufiger Bericht, Bull. Acad. Imp. Sci. Saint-Pétersb., 1902, 5e sér., XVI, p. 203.

[2] Peterm. Mitth., 1904, p. 105 (from the Petersburger Zeitung), and p. 273; A. Koltschak, The last expedition to Bennett island, &c., Izviestija Imp. ross. Geogr. Obsch., 1906, XLII, pp. 487–519 (in Russian); Schmidt, Protok. Petersb. Naturf. Ges., Nov. 1904, p. 434; Nathorst, Ueber Trias- und Jurapflanzen der Insel Kotelny, Mém. Acad. Imp. Sci. Saint-Pétersbourg., 1907, XXI, no. 2, 13 pp.

[3] L. M. Prindle and F. L. Hess, The Rampart Gold Placer Region, U.S. Geol. Surv. Bull., no. 280, 1906, 54 pp., map.

[4] J. E. Spurr, A Reconnaissance in South-West Alaska, U.S. Geol. Surv. Ann. Rep., 1900, XX, 7, pp. 43–264, maps.

isolated masses, and then as the *Oklune range* (Ahklun), on the north border of which (lat. 60° N., long. 160° W.) mount Oratia is believed to rise to a height of 7,300 feet (2,225 meters); this range projects into Bering sea, and forms cape Newenham.

In its northernmost part, the cañon of the Kuskokvim is cut through limestone containing middle Devonian corals; then follows, for a long distance down stream, a granite arkose, with plant-remains and Inoceramus, cut through by long and steeply-protruding porphyry dykes of a deep yellow hue. This is followed from about Kolmakof onwards (west of long. 159° W.) by dark andesite tuff. The Oklune mountains consist of an ancient tuff and calcareous shales with Aucella. Here, too, we see long and steeply-rising eruptive dykes. Towards the south-west much basalt occurs.

The folds in the cañon of Kuskokvim show great irregularities of strike; they maintain, however, as far as the sea, the principal direction to the south-south-west, and although they advance towards the sea, they possess, on the whole, according to Spurr, a synclinal structure.

The *Alaska range* contains the highest peak of North America, and forms the northern part of the largest arc of the Alaskides, that of the Aleutian islands. Spurr has established the continuity of this arc. It advances to a point a little south of the Tanana (lat. 64° N.), and its most southerly part reaches lat. 51° 25′ N. In order to describe the structure, we will divide it into three parts, the Alaska range, the peninsula of Alaska, and the Aleutian islands.

A number of rivers, radiately converging, are discharged at the head of Cook's inlet; their valleys correspond only in part with the strike, but they determine the form of the surface. From the west comes the river Skwentna, which receives the Yentna; at a little distance from the sea it joins the Sushitna, which flows down from the north. From the north-east comes the Matanuska; it is discharged into Knik bay; finally we may mention the Turnagain fjord, or arm of the sea, coming from the east; this is more correctly part of an eyde, which, with the exception of a low tract of land, 18 kilometers in breadth, and covered in part by a glacier, would separate the peninsula of Kenai from the mainland.

All the land between these rivers is occupied by lofty mountain ranges, which bear numerous glaciers. The part situated to the south of the Skwentna is the *Tordrillo* range. In the region north of the Skwentna, and extending to the Sushitna, rises the *Alaska* range, the highest and wildest of all. The interval between the Sushitna and Matanuska is occupied by the *Talkeetna* range, which descends on the east to the plateau of the Copper river. The range situated to the south of the Matanuska is not to be included in the Alaska arc.

Let us now turn our attention to the region of syntaxis.

On the north side of the Tanana, the end of the principal range of the rocky mountains is formed by a gneiss range known as the 'Yukon geanticline' of Canadian geologists. The termination is placed by Brooks in lat. 64° 20′ N., long. 147° W. While this gneiss of the Rocky mountains strikes away, first to the east and then to the south-east, a southern chain begins south of the Tanana, and quite close to the river, in about lat. 63° N., and long. 143° W. Its ancient schists form the north-east side of the Mentasta range, the south side of which consists of upper Carboniferous and Permian limestone, and slopes away towards the volcanos of the Wrangell group. The schists gain very rapidly in height towards the west. The peaks of the Rocky mountains to the north of the Tanana reach a height of 1,800 meters, but in this gneiss range mount Kimball rises above 3,000 meters, and west of it, in long. 147° W., mount Hayes exceeds 4,400 meters (fig. 33). These great heights form at the same time the north border of the plateau of the Copper river. The south side of mount Kimball is traversed on this side by a great trough-like subsidence in which lie Carboniferous and Permian limestones. To the south of it the ancient rocks crop out once more on the border of the plateau of the Copper river. Mendenhall and Schrader state that the dislocation is so recent that patches of coal-bearing Tertiary are wedged into it [1].

Brooks formed the impression that the axes of the great chains do not come together, but pass each other by [2]. *The Rocky mountains do not enter into direct syntaxis with the Alaska range,* like the southern zones in Chugatsk bay. The Alaska range seems rather, by means of an elongation extending across the meridian of syntaxis, to join the south side of the Rocky mountains, which terminate in long. 147° W. in the meridian of mount Hayes.

Mount Chisana, the last spur of the Alaska range, consists of highly contorted crystalline schists. Mendenhall crossed the chain situated to the east of mount Hayes, as he came from the south, that is, from the plateau of the Copper river. He observed at its south foot a comparatively recent granite, not dynamically altered, and then deformed gabbro and diabase, but within the chain only the same schists (here termed Tanana schists) as those which surround the gneiss on the other side of the river, and form many of the south-westerly striking chains of the west (Kaiyuh and others) [3]. According to Eldridge's observations, the same schists extend in a broad zone to

[1] W. C. Mendenhall and F. Schrader, The Mineral Resources of the Mount Wrangell District, Al., U.S. Geol. Surv. Prof. Papers, no. 15, 1903, 71 pp., maps, in particular pp. 46 and 66.

[2] A. H. Brooks, A Reconnaissance in the Tanana and White River Basins, U.S. Geol. Surv. Ann. Rep., 1900, XX, 7, pp. 425–509, maps, in particular p. 452.

[3] W. C. Mendenhall, A Reconnaissance from Resurrection Bay to the Tanana River, Ann. Rep. U.S. Geol. Surv., 1900, XX, 7, pp. 271–340, maps, in particular p. 313.

the west-south-west of this point (in long. 149° W.), where they reach the principal range, on the west side of which lies mount McKinley. They also include, to the east of this mountain, the valley of the Sushitna, and on the right bank of this river a long granite ridge rises out of them [1].

The structure of *mount McKinley* (20,300 feet = 6,187 meters), and of mount Foraker (17,100 feet = 5,212 meters), which lies 24 kilometers more to the south, is described by Brooks as follows.

The lowest member occurs on the north side, and is probably a true Archaean gneiss. We again encounter a metamorphic, often gneiss-like, conglomerate. Above these follows a series of schist and phyllite, above these again limestones, slates, and sandy beds with lower Silurian fossils, then Devonian limestone, which is widely distributed. Finally, a thick series of sandstone and shale, with Mesozoic fossils, follows on in the south. This last-named series completely wedges out towards the north-east. The highest peaks of mount McKinley and mount Foraker are probably formed by a band of comparatively recent intrusive granite or grano-diorite. We have already mentioned a second and similar granite range in the Sushitna valley [2].

Thus the sediments succeed one another in the order of their age, from north to south, while in the Romanzov range the succession is from south to north.—

The principal range of the Alaska mountains rises in lat. 62° N. to heights of 10,000 feet, and reaches lake Clark with a height of 5,000 to 6,000 feet. To the east of the lake the valley of the Sushitna opens out to a breadth of 140 kilometers above Cook inlet. The ancient schist range disappears beneath a belt of Kenai sediments, and we reach a broad, low-lying alluvial land which extends to Cook inlet.

To the west of this flat tract, on the left bank of the lower Yentna, rises the lonely peak of Yenlo mountain (lat. 62° 8′ N., long. 151° 15′ W., 3,000 to 4,000 feet). Pumice occurs at its foot; according to Spurr it is the most northerly of the Aleutian volcanos.

The interior of the wild *Talkeetna* range is unknown. On the west it is bounded by the valley of the Sushitna, to the south-east by the Matanuska valley. The river *Matanuska* rises on the summit of the Copper river plateau, and, following a south-westerly course, reaches Knik bay. It seemed to Martin to lie in a trough, 11–13 kilometers broad, bounded by fairly straight and parallel fractures. But it is possible that the trough-like appearance is due to the greater resistance of the bordering rocks.

[1] G. H. Eldridge, A Reconnaissance in the Sushitna Basin and adjacent Territory, ibid., pp. 7–29, maps.

[2] A. H. Brooke and D. L. Reaburn, Plan for Climbing Mount McKinley, Nat. Geogr. Mag., 1903, XIV, pp. 30–35, map; Brooks, Preliminary Report in U.S. Geol. Surv., 1902–1903, XIV, pp. 94–102; Geography and Geology, p. 34 et seq., map, pl. XI.

Mendenhall found *Aucella crassicollis* and Belemnites. Brown coal and anthracite coal-measures, which are probably Mesozoic, are also present [1].

The *Tordrillo* range, which has been crossed by Spurr, is a secondary ridge of the Alaska range with ill-defined boundaries. All its rocks are late Mesozoic. These are—basic lavas or tuffs, alternating with granitic arkose, upon these lie black shales, impure limestone, and arkose with plant-remains, the whole forming a syncline and traversed by numerous and diversified dykes (aplite to gabbro). Most of them run parallel with the strike. The middle crest of the range (Cathedral Peak, 5,500 feet, 1,676 meters) is a dyke of this kind, formed of quartziferous syenite, and some meters in breadth [2].

We must once more make a hasty survey of the flat country at the *head of Cook inlet*. The volcanic mountain of Yenlo has been mentioned already. The solitary mount Sushitna, rising to the west of the mouth of the Sushitna, consists of granite of unknown age. Although the valley of the Sushitna is the most important elongation of the flat land, yet we shall see directly that the valleys of the Knik and Matanuska form the tectonic continuation of Cook inlet.

The Alaskan peninsula (II, p. 196). Scarcely any part of the Pacific festoon is so well known as this peninsula, together with Shelikof strait and Cook inlet. Since the facts concerning this region are of an unexpected nature they demand close consideration.

The lofty chain of Alaska, as we have already seen, reaches lake Clark (between lats. 61° and 60° N.) on the south. A series of other great lakes—Iliamna, Kukaklek, Naknek, Besharof—extends down through the peninsula to the lakes of Ugashik, which reach lat. 57° 15′ N. They all discharge to the west, through a belt of flat land into Bristol bay.

A very long and narrow zone of granite, marked in places as syenite, extends through the peninsula, generally keeping close to the zone of the lakes. That it is the direct continuation of the Alaska range cannot be shown. It probably represents a coulisse situated a little further east, and the isolated granite mountain Sushitna may perhaps belong to it. In any case it makes its appearance as a continuous zone in lat. 60° N.; it becomes somewhat broader in mount Johnson, south of lake Naknek, strikes across the western ends of the succeeding lakes, and, according to the accounts by Purington (in Dall), extends along the west side of the peninsula into the neighbourhood of Port Möller (lat. 56° N.). Grewingk marks it at some points even further to the south.

Spurr was the first to show that this granite range, extending through

[1] W. C. Mendenhall, Ann. Rep. Geol. Surv., XX, 7, p. 307 et seq.; G. C. Martin, A Reconnaissance of the Matanuska Coal Field, U.S. Geol. Surv. Bull., no. 289, 1906, 36 pp., map, in particular p. 17.

[2] E. J. Spurr, Ann. Rep. U.S. Geol. Surv., XX, 7, pp. 149, 225, et passim.

four degrees of latitude, is of pre-Jurassic age [1]. This is apparent from the presence of Jurassic granite-conglomerate and Jurassic arkose.

Apart from the upturned schists in Woody island (Kadiak), the oldest sediments are the Trias beds with *Pseudomonotis subcircularis* at the entrance to Cold bay, lat. 57° 40′ N., and on a promontory situated further north [2]. Pompecki assigns the fossils of Kialagvit bay (lat. 57° 30′ N.) to the upper Lias [3].

The classification of the upper beds has been made by Martin and Stanton [4].

According to these investigators the oldest and most certainly known member of the Jurassic presents the following characters in the neighbourhood of lat. 60° N. It begins with a bed of granitic conglomerate, followed by about 3,000 feet of dark sandy shales, with bands of limestone and many fossils. In the lower beds bivalves chiefly occur; in the upper, Cadoceras, Macrocephalites, Stephanoceras, Phylloceras, and other genera; also numerous examples of Inoceramus, and isolated plant-remains, such as *Sagenopteris Goeppertiana* and others.

This is Martin's *Enochkin* (Inosskin) stage; according to Stanton it is equivalent to the Kelloway. Petroleum has been found in it, and borings have been made to a depth of over 1,000 feet. It corresponds to the beds of Katmai (lat. 58° N.), previously assigned by Pompecki to the Kelloway, and is known far towards the south at many localities on the east side of the granite range. It is also visible at Anchor point (Kenai) on the opposite shore of Cook inlet.

It is covered by Spurr's *Naknek* stage. According to Martin's account there are first 290 feet of a granite-conglomerate and ancient schist *with andesitic ash in the matrix*, and then frequently repeated layers of sandstone and andesite. On the coast of Chinitna bay (west side of Cook inlet) this alternating series reaches a thickness of over 5,000 feet. This is the horizon of *Aucella Pallasi*. Stanton also mentions forms allied to *Cardioceras alternans* and *Cardioceras cordatum*, and correlates the Naknek

[1] E. J. Spurr, ibid., pp. 145–147, 232, map. A list of the older works in Grewingk, p. 193.

[2] In vol. II, p. 197, the locality mentioned by Pinart is given as cape Nunakhalkak, situated about lat. 58° 20′ N. According to Dall (Ann. Rep. U.S. Geol. Surv., XVII, 1, p. 870) the point lies in Cold bay in lat. 57° 40′ N.; Martin (Bull. U.S. Geol. Surv., no. 250, p. 53) calls the same cape on the north-east side of Cold bay cape Kekurnoi.

[3] J. F. Pompecki, Jura-Fossilien aus Alaska, Verh. Russ. k. Min. Ges. St. Petersb., 1900, 2. Ser., XXXVIII, pp. 239-280; Hyatt (Ann. Rep. U.S. Geol. Surv. XVII, 1, p. 906) mentions doubtful Lias in Kamishak bay (lat. 59° – 59° 30′ N.); Dall (ibid.) assigns Kialagvit to the lower Oolite.

[4] G. C. Martin, The Petroleum Fields of the Pacific Coast of Alaska, U.S. Geol. Surv. Bull., no. 250, 1905, pp. 37–59, maps; T. W. Stanton and Martin, Mesozoic Section on Cook Inlet and Alaska Peninsula, Bull. Am. Geol. Soc., 1904, XVI, pp. 391–410, maps.

stage with the Volga stage of Russia. The Ammonites mentioned above suggest that somewhat lower stages are also present.

The two members of the Jurassic, Enochkin and Naknek, extend from 61° N. through at least five degrees of latitude. At a few localities they are associated with *Neocomian* containing *Aucella crassicollis*; near Port Möller (lat. 56° N.) the peninsula is only 9 kilometers broad, and consists only of the two Aucella beds.

The middle and upper *Cretaceous* are known at a few localities, both as plant-bearing beds and as beds containing Inoceramus.

The Tertiary series begins with the typical Eocene containing *Venericardia planicosta*, which Palache discovered in Stepovak bay (nearly opposite Port Möller)[1].

The coal-bearing *Kenai* stage occurs with regular bedding north of Cook inlet on the lower course of the Sushitna and in Knik bay, and attains a considerable development in its course through west Kenai down to Kachemak bay. It also occurs near Tyonek (north of lat. 61° N.) on the west coast of the inlet. Andesitic ashes and tuffs are often interbedded with it. Isolated patches are encountered far to the south.

The Kenai stage is followed on the south by conglomerates with driftwood, the *Unga* stage of Dall, which is well known to the inhabitants on account of the amber it contains. It is covered by marine beds, characterized by a great Crepidula[2].

The Enochkin (Kelloway) and Naknek (Volga) stage thus comprise a very considerable part of the east coast of the peninsula. On the west side of the Kenai peninsula, and probably of Kadiak island also, there are indications that these stages strike on beneath Cook inlet, and probably beneath Shelikof strait. As far as we can judge, all the lofty and recent volcanos are seated upon them, from Ujakushatsh (Burnt mountain or Redoubt volcano, lat. 60° 30′ N.) onwards. *The period of the andesitic eruptions here dates back at least as far as the Volga stage or the upper Jurassic.* We have already seen that in east Hokkaido the southern part of the volcanic zone of the Kuriles dates at least from the upper Cretaceous.

Proceeding from west to east in that part of the peninsula which lies south of lat. 60° N., we first meet, according to Martin's account, with the granite range; it forms here Grewingk's Chigmit mountains, of rugged aspect and with an average height of 3,500 feet (1,067 meters). Then follows, to all appearance, a considerable fault, and next to this a badly-crushed and narrow anticline of the Enochkin stage, then comes a narrow syncline, and finally a broad flat saddle (2,200 feet, 670 meters) of the same

[1] C. Palache, Geology about Chichagof Cove, Stepovak Bay, with Notes on Popof and Unga Islands, in Harriman, Alaska, IV, pp. 69–98; Dall, tom. cit., pp. 99–111.

[2] These were formerly known as the Nulato beds (II, p. 197).

stage; on its seaward flank this is vaulted over conformably by the Naknek stage[1].

From Naknek lake, Spurr travelled south-east to Katmai (lat. 58° N.) on the east coast. Here the peninsula is 135 kilometers broad. In the west the land is flat; then we reach the broad, lower part of the lake; its shores are formed of syenite and hornblende granite. Towards the east the lake becomes narrower. Then follows a green granitic arkose, in almost horizontal beds, with Jurassic fossils, and an augite-andesite which is probably contemporaneous. The arkose follows the ascent to a pass, 3,500 feet in height, which lies between two great volcanos; on the right glaciers descend. Below the pass quantities of very hot water break forth and form a rapidly flowing stream. Towards the east we now look down a broad valley in the direction of Shelikof strait. The arkose continues beyond the volcanos, and its bedding retains its almost horizontal position, only becoming slightly upturned in the direction of one of the volcanos. It is not until we reach the vicinity of the sea, near Katmai, that it again shows slight upturning. From this locality the specimens of Cadoceras and other fossils described by Pompecki are derived. Just to the north of it, in Amalik harbour, Dall observed coarse sandstone with some poor coal seams, dipping 30° N.E.; a little further north, near cape Douglas, this sandstone lies horizontal, alternating with flows of andesite, and here it contains *Sequoia Langsdorfi*[2].

Not far south of Katmai lies Cold bay. The section has been described by Martin. Here also the land to the west is flat. The granite range strikes past lake Besharof and the Ugashik lakes on the west; it includes the most westerly part of lake Besharof. Then come the Jurassic arkoses and sandstones. Upon these rises the volcano of *Peulik* (5,000 feet), separating the lakes. The Enochkin stage is thrown into broad folds parallel to the east coast; in the axis of an anticline which is incomplete in the direction of the sea, or, according to another account, in consequence of an overthrust, the Trias is exposed to the north-east of Cold bay. The Naknek stage prevails to the south-west of this bay, towards the interior and also in the direction of Katmai[3].

Let us now cross Cook inlet.

The eastern side of the *Kenai* peninsula is occupied by inhospitable ancient mountains, which we shall presently describe as the Kenai range. The greater part of the western side is formed by an extensive plateau of Kenai beds, unconformably superposed, partly on the ancient range mentioned above, and partly on the Mesozoic beds, as is shown by

[1] Martin, U.S. Geol. Surv. Bull., no. 250, 1905, p. 46, map.

[2] E. J. Spurr, Ann. Rep. U.S. Geol. Surv., XX, 7; Dall, Report on Coal and Lignite of Alaska, U.S. Geol. Surv. Ann. Rep., 1896, VII, 1, pp. 763–908, maps, in particular p. 798.

[3] G. C. Martin, U.S. Geol. Surv. Bull., no. 250, 1905, p. 50, map.

indications on the shore. We have already pointed out that it may be regarded as the continuation of the Kenai beds of the low-lying tract at the head of Cook inlet.

Furuhjelm and Oswald Heer have shown that in the south of the Kenai peninsula, lat. 59° 21′ N., the leaf-bearing beds rest unconformably on the irregular surface of crystalline rocks, and that they are characterized as a true freshwater deposit by Trapa, Unio, and Paludina[1]. From lat. 59° 30′ N. onwards, Kachemak bay, running towards the north-east, cuts deep into the main body of the peninsula. Its north side is formed by a declivity, as much as 550 meters in height, which exposes numerous coal seams lying undisturbed one above the other. As early as the eighteenth century this remarkable series was mentioned by Portlock and by Russian investigators. It has been described by Dall and Stone[2].

The declivity in the direction of Kachemak is the south side of a tableland, almost 130 kilometers in length and 40 kilometers in breadth, which sinks gradually on the north towards the Turnagain arm (lat. 61° N.). The bedding lies in broad and gentle undulations. Near cape Kussilof (lat. 60° 22′ N.) the coal-measures sink beneath the sea. On Turnagain creek the tableland is only 15 meters high, but north of Turnagain it reappears, and from this point, as we have seen, its continuations penetrate into the lower part of the river valleys.

Let us now return to Kachemak bay.

Beneath the Kenai beds folded tuff and sandstone containing Jurassic fossils occur, and beneath these Palache observed at several localities, notably in Halibut cove, red and green Radiolarian rocks, thinly bedded, intensely folded, and associated with diabase, or at one locality with gabbro. Emerson thinks they may correspond with the 'Franciscan series' of California. They rest on the ancient schist of the Kenai range[3].

In the *Shumagin group* (lat. 55° 30′ to 54° 30′ N.) the eastern islands are granitic; further west, metamorphic schists and quartzites prevail. The largest island, *Unga*, lies furthest west, and nearest to the east coast of the peninsula where, in the neighbouring bay of Stepovak, Eocene with *Venericardia planicosta* is said to occur. Unga, like the island of Popof which lies close to it, consists of gently undulating, coal-bearing Kenai beds, covered by the Unga conglomerates, upon which rest marine beds with Crepidula[4].

[1] O. Heer, Flora Foss. Alaskana, K. svenska Vet. Akad. Handl., 1869, VIII, no. 4.

[2] Dall, Ann. Rep. U.S. Geol. Surv., XVII, 1, p. 787 et seq.; R. W. Stone, Coal Fields of the Kachemak Bay Region, Bull. U.S. Geol. Surv., 1906, no. 277, pp. 53–73, maps.

[3] Emerson, in Harriman, Alaska, IV, p. 26; F. H. Moffit, Gold Fields of the Turnagain Arm Region, Bull. U.S. Geol. Surv., 1906, no. 277, pp. 1–52, map; in particular p. 16 et seq.

[4] Dall, Ann. Rep. U.S. Geol. Surv., XVII, 1, p. 867 et seq., map.

The following is a generalized section of Cook inlet: (1) granite; (2) Kelloway and Volga beds, and andesitic rocks, which were erupted during the deposition of a part of these beds; zone of the existing volcanos; (3) Cook inlet; (4) platform of the Kenai beds, resting first on (5) lower Jurassic and Radiolarian beds, and then on (6) the ancient Kenai range; (7) the foredeep; and (8) the Ocean.

The Kenai plateau shows that this region was once covered with fresh water for a great distance towards the south. A comparison with other regions, and in particular the disposition of the Kenai beds themselves, enable us *to recognize the existence here of a trough* produced by repeated subsidences along strike faults. This is confirmed by the fact that the group of the Wrangell volcanos certainly lies in a trough, as we shall be able to show later, and that Mesozoic beds strike away in the direction of Cook inlet through Matanuska towards the plateau of the Copper river and towards Wrangell Land. We have already seen that the valley of the Matanuska also gave Martin the impression of a trough.

The Aleutian islands. In spite of the general descriptions by Grewingk, Dall, and Becker, it is difficult to form any definite opinion as to the basement rock of the Aleutian islands. As yet it is known to us only at isolated localities, remote from one another. Diorite, resembling that of cape Karluk (north-west Kadiak), is mentioned as occurring in North Unalaska; the horneblende-andesite of the volcanos Bogosslovsk and Grewingk, which were newly formed to the north of Unalaska in 1790 and 1883, is said to contain boulders of a similar diorite [1]. Attu, far to the west, consists of ancient rocks, such as quartzite, diorite, and others.

Tertiary sediments frequently occur; both the Kenai beds and the marine stage are represented. Basaltic or andesitic lavas are often intercalated in them [2].

The great volcanic cones, with their broad base, play by far the most important part in the structure of the long arc. Not a few of them reach a height of 3,000 meters. The number of volcanos which have been active, or at least smoking, since the last century may be placed at forty-two, according to Becker's critical list, which includes all those situated between the Ujakushatsh in Cook inlet (long. 152° 45′ W.) and Little Sitkin (long. 178° 30′ E.). Yenlo rises on the other side of Ujakushatsh; Kiska, on the other side of Little Sitkin (long. 177° 30′ E.), consists of hornblende-andesite, and Buldir (long. 176° E.) is an ancient cone.

We cannot look through Grewingk's and Becker's lists without a feeling of astonishment at the uniform manner in which the smoking craters are

[1] Becker has described both the new volcanos in Reconnaissance of the Gold Fields of South Alaska, Ann. Rep. U.S. Geol. Surv. (1896–1897), 1898, XVIII, 3, p. 25 et seq.

[2] Dall and Harris, Correlation Papers, Neocene, Bull. U.S. Geol. Surv., 1892, no. 84, pl. III, p. 268.

distributed over this long tract. A considerable gap occurs only between the volcanos St. Augustine (long. 153° 51′ W.) and Venjaminov (long. 159° W.), that is, to just beyond the middle of the peninsula of Alaska; but from Pavlov (long. 161° W.) to Little Sitkin (long. 178° 30′ E.) there is scarcely any interval greater than 1½ to at most 2 degrees of longitude. Between these smoking volcanos lie a great number of hot springs; Venjaminov observed one of them (volcano of Sevidovski, long. 168° 12′ E., on Unimak) in the rhythmically active or geyser state [1]. Transverse fissures are not mentioned; the new volcanos of Bogosslovsk and Grewingk stand slightly inside the arc.

The volcano of *Bogosslovsk* (lat. 53° 56′ N., long. 167° 57′ W.) was formed, as already mentioned, in the year 1790. In the spring of 1883 volcanic phenomena were observed in its neighbourhood; a second new volcano, to which Dall has given the name of *Grewingk*, began to rise out of the sea. In October, 1883, it reached its maximum activity, and at the same time, far away from this locality, the volcano of St. Augustine, in Cook inlet (lat. 59° 23′ N., long. 153° 51′ W.), burst into eruption for the first time since it was known, that is for at least a century. Direct communication at so great a distance can scarcely be proved, but, quite apart from this occurrence, the Aleutian arc shows a degree of unity and continuity in the distribution of its eruptive centres which is hardly rivalled by any other volcanic series.

The *Commander islands*, situated far to the west, consist of two strips of land directed to the north-west, that is in the direction continuing the Aleutian arc. Bering island, the larger of the two (about 80 kilometers in length), is not so elevated as the other, Copper island. The presence of native copper on the latter has led to the conjecture that older rocks exist here in place. But we now know that the copper is cast up by the sea. Grebnitzky and Dawson have shown that these islands, or at least the greater part of them, are formed of basalt and Tertiary beds. Lignite is known in Bering island, and the table-mountains (Stolovoi) contain marine fossils. At one locality in Copper island beds are known standing almost vertical. Earthquakes are of frequent occurrence. In clear weather the summits of the volcanos of Kamchatka are visible [2].

Many problems present themselves in connexion with the foregoing facts. In the islands the line of active volcanos, according to Becker, produces andesitic lavas exclusively. In the Tertiary beds basalts pre-

[1] Grewingk, p. 132. A description of Unimak is given by F. Westdahl, Mountains on Unimak island, Nat. Geogr. Mag., 1903, XIV, pp. 92–99.

[2] N. A. Grebnitzky, Commander Islands, published by the Ministry of Agriculture and Dominions, 8vo, St. Petersburgh, 1902, 47 pp., in particular pp. 3–5; Dawson, Geological Notes, &c., Bull. Am. Geol. Soc., 1894, V, pp. 123–127; and Nordenskjöld, Die Umseglung Asiens, p. 276.

dominate. In general, the Tertiary eruptive rocks are distributed, not only here but over the whole of the lower course of the Yukon, and in the islands of Bering sea down to the Asiatic coasts, in such a way that the existing volcanic arc appears, exactly as in Kamchatka, to represent the restricted remains of *an eruptive activity which was originally much more extensive.*

Equally surprising is the lie of the Tertiary sediments. On the lower Yukon their folding is so considerable that Spurr described the 'Post-Kenai-Revolution' as one of the most important phases of mountain formation. In the peninsula of Kenai itself they form, on the other hand, in face of the great volcanos, a vast, downthrown, but scarcely folded platform. It is easy to see that the marine stage is continued far towards the west, and forms table-mountains, even in Bering island. But it is much harder to understand how the leaf-bearing Kenai stage could find the conditions necessary for its formation on the other side of Cook inlet. It is true that in the more westerly parts of the archipelago the presence of this stage is only based on the occurrence of driftwood and amber, but we have already mentioned that near Port Möller, on the west side of the peninsula, beds of coal are present next the open water of Bering sea (long. 160° 45′ W.), and this is also the case in Makushkin bay, Unalaska (long. 167° W.).

The Kenai range. Ancient rocks crop out in several of the Shumagin islands; we may leave it an open question whether or not they belong to the zone which we are about to discuss. Dark shales and sandstone, and more widely distributed older rocks which are not so exactly known, form Kadiak and Apognak, and the mountains of eastern and southern Kenai, 3,000 to 4,000 feet in height; at the end of Cook inlet they are separated from the Chugatsk range only by the Eyd of Turnagain. At the same time an archipelago here emerges from the sea next Chugatsk bay (Prince William sound), which is composed of not less than fifty rocky islands, of greater or less size, some as much as 3,000 feet in height, and generally elongated towards the north-west in the direction of the strike, like the island of Montague, 72 kilometers in length. The bay itself is surrounded by the Chugatsk range, deeply incised by a number of fjords, and the promontories between the fjords, 5,000 to 6,000 feet in height, partly correspond in position to the islands mentioned above. The range is here about 80 kilometers in breadth, and a few peaks exceed 8,000 feet. It is strongly glaciated and difficult of access.

The chief features in the structure of this great range have been determined by Schrader and his colleagues, whose self-sacrificing devotion to the task cannot be sufficiently acknowledged. The range surrounds the bay, and the strike is west-south-west to east and west. All the rocks are intensely folded, and inclined, as a rule, towards the north; but, since the oldest strata lie towards the interior, it follows that the range *is overfolded* *towards the south.* On its sharply defined northern border mica-schist, quartz-schist, and crystalline limestone (Klutina series) occur; they are followed towards the south by a thick series of altered, bluish-green quartzite, graphitic clay-slates, also drawn-out conglomerate (Valdes series); nearer to the sea a massive arkose predominates, with a great quantity of black schist and isolated beds of limestone (Orca series). In the lower part of the Orca series thick sheets of copper-bearing diabase are intercalated, especially in the islands of Chugatsk sound [1].

The Orca series is correlated by Emerson with the Yakutat series, distinguished by Russell in the region of the Elias range [2]. Fossils and other traces of organisms—which have been described by Ulrich from islands near the village of Kadiak—among them Inoceromya (very similar to Inoceramus), *Chondrites divaricatus* and others, bear a striking resemblance to the fauna of the upper Cretaceous Flysch of the Alps. In Europe we should simply describe these rocks as a Flysch zone on the outer border of the mountains.

Survey of the Alaskides. Three principal branches play the most important part in the structure of the virgation of the Alaskides, which opens out towards the west. These are: the Romanzov, Alaska, and Kenai mountains.

The *Romanzov* range makes its appearance in long. 147° W. on the shore of the Arctic Ocean, and thence its northern border extends in an arc to cape Lisburne. Where it is best known, a little to the west of the Flats, it is called the Endicott range, and consists of ancient gold-bearing schists, and further on, up to the north border, of Palaeozoic beds. On the other side of this region lies a Cretaceous and Tertiary belt which extends to the tundra. The ancient rocks of the south side reach Bering sea in Kotzebue sound.

The intrusive rocks of *Seward peninsula* extend across the Diomedes islands to Asia, and are repeated elsewhere in the Chukchi peninsula. A long range of granite and gneiss strikes apparently to the west-north-west, from cape Novosiltzev to Kolyutshin and Chaun bay. Chukchi peninsula is the continuation of Seward peninsula and of a part of the Romanzov range, but the great arc, concave to the north, which first trends south-south-west in the east, then west from long. 152° W. onwards, and still almost west at cape Lisburne, turns probably in Kotzebue sound to the west-north-west in Asia and to the north-north-west in the New Siberian islands.

[1] F. C. Schrader and A. C. Spencer, The Geology and Mineral Resources of a portion of the Copper River District, publ. by the U.S. Geol. Surv., 8vo, 1901, 94 pp., maps; also Schrader, A Reconnaissance of a part of Prince William Sound and the Copper River District, Ann. Rep. U.S. Geol. Surv. (1898), 1900, XX, 7, pp. 347–423, maps.

[2] Emerson, in Harriman, Alaska, IV, p. 46; E. O. Ulrich, Fossils and Age of the Yakutat formation, tom. cit., pp. 125–144.

The Yukon hills, the Gold mountains, as well as the Kaiyuh mountains, to the south of the Yukon, which reach the sea north of lat. 63° N., are intercalated secondary branches of the great virgation. The Kuskokwim mountains, terminating in cape Newenham, are, in all essential features, a Mesozoic syncline, and cannot be regarded as a secondary branch.

The *Alaska* range begins on the south side of the Tanana, and for a short distance it runs in contact with the south side of the gneiss range of the Rocky mountains. It ascends rapidly to great heights, forms McKinley peak, loses again in height, and reaches lake Clark.

In the Alaska range the zones of rock are arranged in an opposite manner to those of the Romanzov range. Gneiss appears as the foundation on the north side; schists form the main range; an intrusive ridge of granite probably forms the highest peaks; a second granite range occurs in the Sushitna valley. Palaeozoic sediments succeed, and an outer zone of Mesozoic slopes away towards the plateau of the Copper river.

The long Mesozoic range, which bears the great volcanos in the Aleutian archipelago and the peninsula of Alaska, is continued through the Matanuska valley into the western border of the plateau of the Copper river, and at the same time into the Mesozoic outer border of the Alaska range. Knik bay becomes the tectonic continuation of Cook inlet, and this inlet, along with Shelikof strait, assumes the characters of a fault-trough, owing to the presence of the Tertiary platform in Kenai.

Although traces of Tertiary, and even more recent, volcanic activity are scattered throughout the basin of the lower Yukon, and far and wide through Alaska, the islands of Bering sea and Chukchi land, yet no cone of any height, nor any active volcano, is anywhere to be seen, except along the arc of the Aleutian islands.

The rugged *Kenai* range includes east Kenai and, at the least, Kadiak also. It consists, so far as it is yet known, of ancient altered sediments, and a Flysch-like outer zone on the south; the order of the zones of rock corresponds with that of the Alaska range, that is, the younger belt lies in the south.

Then follows the foredeep.

In all essential characters the Alaskides correspond with the marginal arcs of Asia. They are a member of the same series. They enter into syntaxis with the Rocky mountains and the Elias range. To these we shall now turn our attention.

CHAPTER XI

THE END OF THE ISLAND FESTOONS

Introduction. 1. Rocky mountains, south and south-east. Wyoming and Montana. Mackenzie river. Entry of the Rocky mountains into the syntaxis. 2. Beginning of the Intermediate range. Wrangell volcanos. The Columbian grano-diorite. 3. Elias range. Alexander archipelago. 4. Continuation of the Intermediate range. Vancouver. Transverse section in lat. 49° N. Cascade range.

WHEN we previously attempted to give a general survey of North America (I, p. 553), scarcely anything was known of the structure of the Alaskides and of Mexico. The syntaxis of Chugatsk and the connexion of the Antilles with the mainland were, it is true, correctly conceived, as is shown by subsequent investigation, but of Central America our knowledge was so slight, that, following Humboldt, we still assumed a separation of the chains near Tehuantepec, while in fact no such separation exists.

Our studies in the north have now clearly exposed the Asiatic structure of the Alaskides.

In the preceding chapter we showed that the same structural plan and the same elements are repeated in the Okhotides, the Anadyrides, and the Alaskides, and that they are very nearly the same in all the peripheral structures of Asia. While, however, the Alaskides, though not situated on the periphery of Asia, reproduce these characters, yet in the syntaxis on the east they so closely resemble the south-easterly trending chains of western America that, as we have already seen, Brooks applied the names Rocky Mountains, Central Plateau Region, and Pacific Mountains System, on both sides of the syntaxis, thus following in the main the division into Rocky Mountains, Interior Plateau, and Coast Ranges, which Dawson has suggested for Canada in 1879.

We have already explained our reasons for making a change of name in passing from one side of a syntaxis to the other; but with the exception of the altered strike there is much resemblance on the two sides even with regard to the structure. For example, the Alaskides consist of an outer part folded towards the Pacific Ocean (Kenai, Alaska range), and an inner part, turned away from the Ocean and folded in the opposite direction (Romanzov); and in the chains running to the south-east the same opposition is to be found between a part turned towards the Ocean and folded in the same direction (Elias range), and another part (the Rocky mountains) folded towards the east.

The Asiatic elements are present, but they do not achieve the formation of another arc. To what extent this has been prevented by the position of Laurentia is difficult to determine. A peculiar, oblique division into coulisses, which distinguishes the whole range of the Rocky mountains, is repeated in New Mexico. The free ends of the Rocky mountains, resolved into coulisses, lie on the south-east side of the Colorado Plateau (Sangre de Cristo, among other ranges, I, pl. VI). *They form the eastern extremity of the Asiatic structure.*

The second element, the Interior Plateau Region, is not very clearly defined in Alaska, and there includes many intermediate members. The Central Plateau of Dawson, however, owes its name to a Tertiary platform beneath which folded chains continue their course. Orographically, it is a very striking part of the system, but its distinction rests on a secondary phenomenon only. Dawson himself subsequently recognized only the Rocky mountains and Coast ranges[1]. We shall adopt a slightly different conception of this part of the system. We will term it for the present the *Intermediate range.* The third, and western, elements will then be represented by the *Elias range.* It terminates fairly far in the north, while the Intermediate range, or features closely allied to it, are continued much further south.

In the south the rigid Colorado Plateau (I, p. 569), which extends from lat. 33°–34° to lat. 40° N., and from long. 114° to 106° W., stands opposed to the long chains which come from the syntaxis. The Colorado river has cut through the whole stratified succession down to the Archaean gneiss. This is covered unconformably by the Algonkian series. This series has also been folded and worn down. It is covered, also unconformably, by a flat-bedded series, which dates, according to Walcott, from the middle Cambrian period at least. Since that period the plateau has been subjected to fracture and flexure, but, in contrast to its surroundings, has remained exempt from folding[2].

Near long. 104° W. and lat. 36° 50′ N. lies the town of Folsom; 9 kilometers to the south of this locality the slender cone of mount *Capulin* (9,000 feet, 2,743 meters) rises 837 meters above a lava field with many small volcanos. North of Folsom the broad basaltic Mesa de Majo rises to a far greater height than the base of mount Capulin. Towards the west it lies up against the slopes of Sangre de Cristo. This chain terminates rather suddenly near lat. 35° 30′ N. The basalt platform, here known as

[1] G. M. Dawson, Physical Geography and Geology of Canada, reprinted from the Handbook of Canada issued by the British Association, 8vo, Toronto, 1897, 48 pp., in particular p. 38.

[2] C. D. Walcott, Pre-Cambrian Igneous Rocks of the Unkar Terrane, Grand Canyon, with Notes on the petrographical character of the Lavas, by J. P. Iddings, Rep. U.S. Geol. Surv., 1890, XIV, pp. 497–524, maps; also Davis, Bull. Mus. Comp. Zool. Harvard College, 1901, V.

the Mesa de Raton, and further away as the Plateau de las Vegas (1,800 meters), forms a belt around the southern end of Sangre de Cristo. The basalt covering is here 600 meters thick, and rests chiefly on folded Cretaceous, lying in front of the coulisses. It presents a long and narrow

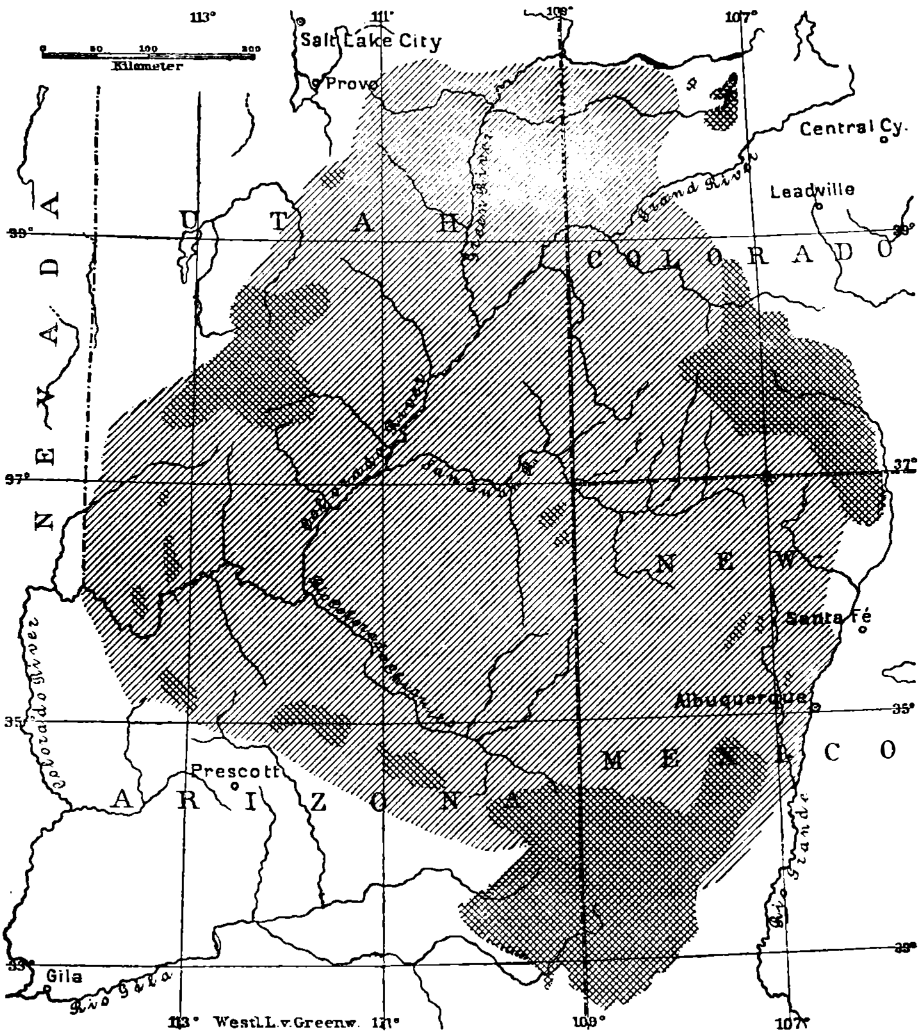


Fig. 29. *The Colorado Plateau* (after Dutton).
The darker parts are volcanic rocks. The Uinta mountains are included on the north.

continuation to the south, the Glorieta plateau (east of Santa Fé; further away, Galisteo Divide). Still further south, another long series of shorter horsts (Sandia, Manzano, Serra Oscura, Serra Andreas, and others) succeeds, cut up by more or less meridional faults. Since folding and overthrusting are still to be seen in the south (Caballos mountains, lat. 33° N.) the structure presents no small resemblance to that of the Basin Ranges. Volcanos, some of very recent date, accompany this system, the fractures of which are in part post-Tertiary. The stratified succession approaches that of Texas; crystalline rock is overlain by Carboniferous limestone, the Red series, and the Cretaceous from the Dakota stage upwards.

The troughs between the horsts are filled high with débris and pebbles. The largest and most southerly of these troughs, the once ill-famed Jornada del Muerto (Death ride), extends for a distance of 320 kilometers, to lat. 32° N. and beyond; it is a true 'bolson' [closed basin].

The course of the Rio Grande marks approximately the western border of this structure from lat. 35° 30′ onwards. Here we have the free ends of the Rocky mountains [1].

In our brief survey of the structure of the Rocky mountains we will start from these southern latitudes. Having reached the syntaxis in the extreme north, we will again turn to the south and consider the western chains. We take the chains in this unusual order because we are thus enabled to discuss the syntaxis as a whole, and also its relations to the Alaskides.

1. The Rocky Mountains (I, p. 561, pl. VI).

The south. The description already given of this part of the mountains enables us to deal briefly with it here. The Rocky mountains, approaching the Colorado plateau from the north like so many waves, are stowed against its northern border and propagated along its eastern side in the direction of their free ends.

The stowing of the first wave gives rise to the Uinta range, with its westerly trend. On the north-east border of the plateau this wave turns right round to the south, forming the Elk mountains, the great Sawatch and the southerly-trending Sangre de Cristo with its smaller outrunners. The second coulisse, dammed back at a considerable distance from the first, forms Park range and South park, and terminates in the Wet mountains (east of Sangre de Cristo). The third forms Medicine Bow range and Front range. On the continuation to the north-west of this or the preceding coulisse, lies Wind River range, which forms, together with the Grand Teton, the north-east side of the triangular area draining

[1] R. Hill, Volcanic Areas of Eastern New Mexico, Bull. Am. Geol. Soc., 1892, III, p. 98 et passim; for the foundation of the basalt, Sangre de Cristo, P. H. van Diest, Plication of the Coal Measures in south-eastern Colorado and north-eastern New Mexico, Proc. Colorado Sci. Soc., 1888–1890, III, pp. 185–190; for the south, W. T. Lee, Water Resources of the Rio Grande Valley in New Mexico, U.S. Geol. Surv. Water Supply and Irrigation Papers, 1907, no. 188, 59 pp., map; further, C. R. Keyes, Geology and Underground Water Conditions of the Jornado del Muerto, New Mexico, op. cit., 1905, no. 123, 42 pp., map.

into the upper course of the Green river. The south side is formed by the Uinta mountains, and the west side by the chains, striking north and south, which do not belong to the Rocky mountains. The fourth and last coulisse is the Laramie mountains, and in this the deflexion to the west is lost; it runs almost due north-north-west.

The free end of each of these coulisses is directed to the south or south-south-east and lies further to the north and east than the end preceding it. This arrangement gives rise to the re-entrant angles (parks or embayments) which open towards the south-south-east on the eastern border of the range.

The sedimentary covering of the great Archaean gneiss-masses not only forms a belt with upturned basset edges following these embayments of the mountain border, but it also runs deep into the high range, in the form of pinched-in coulisse-boundaries.

Thus, we have a plan resembling that produced by the flat-foldings at the ends of Mont Blanc and the Aar mass. But since great faults are present, which cut through the folds at an acute angle, we are left in doubt as to whether we are dealing with true horsts or a common arching-up of the longitudinal axes of anticlines, as in the Alps.

From Huerfano park onwards, a continuous strip of sediments separates the first from the second coulisse as far as the mines of Leadville and Ten Mile. Fig. 30 gives the plan of the range east of Leadville, according to Emmons. Emmons perceived that, later disturbances apart, these regions are dominated by a general folding which strikes N. 30°–40° W., that is, obliquely to this part of the range. At the point where the Mosquito fault reaches the north edge of the map its throw is estimated at 1,500 meters. Towards the north the throw becomes still greater and the fault turns towards the north-west, following the direction of the Sawatch range.

On the south follow the London and Weston faults; along all these lines the downthrow is to the west; the several fragments of the range thus cut up show traces of the ancient folding. A syncline has been preserved extending almost across the whole breadth of the Mosquito range, and the upper Carboniferous on Mosquito peak still reaches a height of 4,199 meters [1] (I, p. 565).

The same phenomenon, namely, the division of the great range into a number of oblique coulisses running across its main strike, occurs under the most diverse circumstances. To the north of lat. 40° N., where for

[1] F. S. Emmons, Geology and Mining Industry of Leadville, Colorado, U.S. Geol. Surv., Monograph XII, atlas, 1886, and Ten-Mile District, Colorado, Special-Folio, U.S. Geol. Surv., atlas, 1898. Another admirable example is afforded by Manitou-Embayment: W. O. Crosby, Archaean-Cambrian Contact near Manitou, Colorado, Bull. Am. Geol. Soc., 1899, X, pp. 141–164, maps.

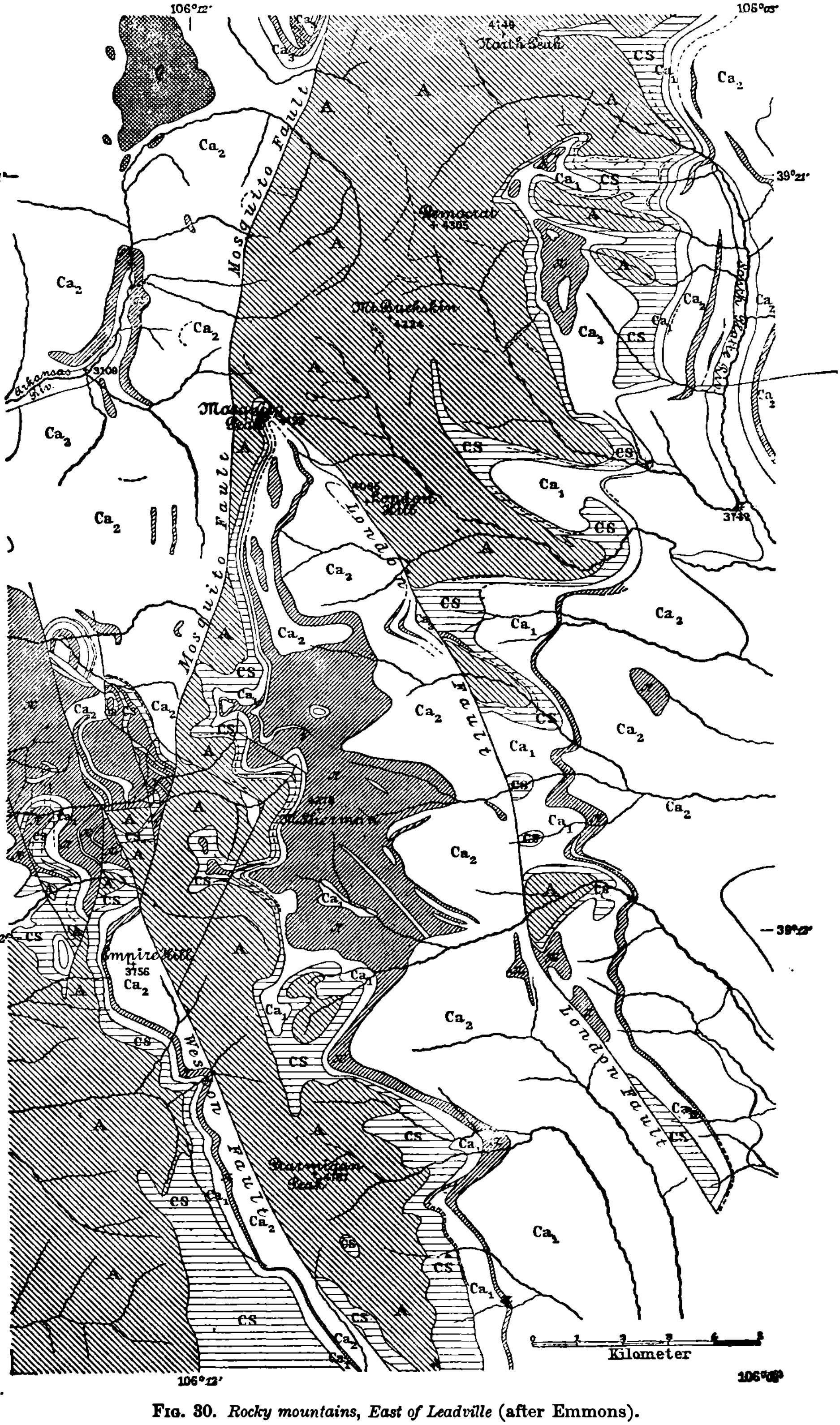


Fig. 30. *Rocky mountains, East of Leadville* (after Emmons).
A, Archaean; CS, Cambrian and Silurian; Ca_1, Lower Carboniferous; Ca_2, Upper Carboniferous; π, Porphyry; Q, Rhyolite. Heights in meters.

a certain distance no Palaeozoic sediments are visible, a number of embayments occur on the east border. Emmons and his colleagues interpret the ridges between them as true anticlines [1].

The strangest form on the outer border of the Rocky mountains is the almost circular range which cuts off the *Big Horn basin* from the prairie (lat. 43° 10′ to 45° 30′ N., Cloud Peak, 4,100 meters). But if we examine the map published by Eldridge, and the later map by Darton, we see that, although the flexures which bound the horsts have the most decided influence on the existing configuration, yet this structure also consists of oblique folds, separated by embayments. The Owl mountains, which complete the ring in the south, have the orographic direction N. 70° W., they consist, however, of at least four anticlines, ranged one after the other, with a strike of N. 50° to 60° W. [2].

Even the *Black Hills* of Dakota, which are cited as the type of an isolated dome-shaped elevation, are elongated in the same direction, and smaller secondary folds, which occur towards the west, lead us to conjecture a similar origin in this case also (I, p. 559).

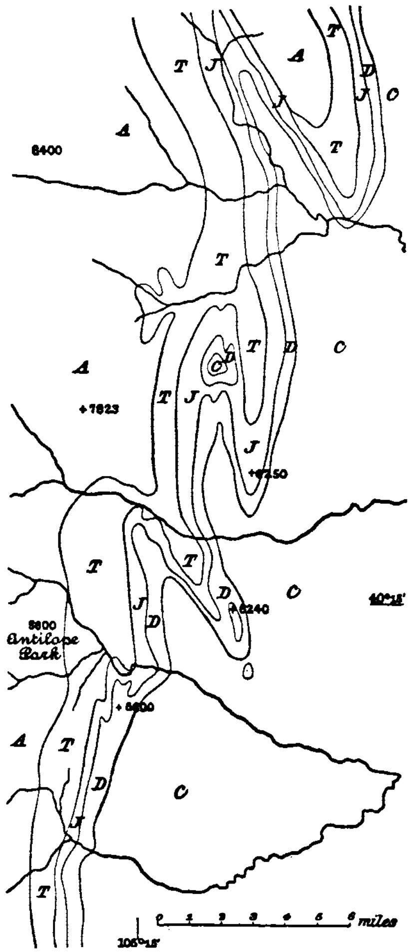


FIG. 31. '*Folds en échelon*' (Whitney) *on the outer edge of the Colorado range* (after Emmonds, Cross, and Eldridge). *A*, Archaean; *T*, Trias; *J*, Jurassic; *D*, Dakota Sandstone (Cenomanian); *c*, Higher stages of the Cretaceous. Heights in feet, some in round numbers.

In none of these regions is the folding markedly inclined either towards the east or towards the west, and the numerous oblique anticlines which follow one after the other are all fairly symmetrical.

North Wyoming and South Montana. We have now reached the latitude of the Yellowstone park. In the valley of the Snake river floods

[1] Emmons, Cross, and Eldridge, Geology of Denver Basin, Colorado, U.S. Geol. Surv., Monograph XXVII, 1896, p. 80, pl. IX.

[2] G. H. Eldridge, Geological Reconnaissance in north-west Wyoming, Bull. U.S. Geol. Surv., no. 119, 1894, 72 pp., map, in particular pp. 16 and 37; N. H. Darton, Geology of

of lava extend far towards the west; isolated ash cones rise above them. Between longs. 116° and 117° W., where the lavas diminish, a Tertiary lake-bottom occurs. In the east, about lat. 111° W., these lavas, which are chiefly basic, end close to the Yellowstone park, in which acid eruptive rocks predominate. A great volcanic zone thus cuts through both the western cordilleras and the Rocky mountains.

The folded chains, proceeding from the south, which form the west border of the plain of the upper Green river, disappear beneath these flows and ejectamenta on reaching the upper Snake river east and west of long. 111° W. East of this locality the situation is made clear by the instructive descriptions of the Yellowstone Park by Hague, Iddings, and Weed[1].

The *Grand Teton* trends north and south, and is thrown down on its east side, along a north and south fault, against Jackson lake. Its northern part penetrates like a spur into the volcanic ejectamenta of the Yellowstone park. It is accompanied by several meridional faults; one of these, on its west side, brings Cretaceous against Carboniferous, the next Carboniferous against Archaean gneiss; and another, on the east side, brings Cretaceous against Carboniferous. This last-named strip of Cretaceous reaches the south shore of the Yellowstone lake. It is thrown into folds, broken up, and partly buried beneath plateaux of effusive rocks (Huckleberry mountains, Big Game ridge, and others). Regarded as a whole, however, the north end of the Teton is a horst sinking on the north beneath the ashes and lavas.

Such is the situation in the south of the Yellowstone park. In the north-west it is very similar. Archaean rocks crop out from beneath the lavas between long. 110° 40′ and 110° 58′ W., almost in the meridian of the Archaean rocks of the Teton, the western scarp of which lies in long. 110° 49′ W. The rocks are also traversed by faults along which the sediments are downthrown. This is the beginning of the *Gallatin range*, which runs towards the north, and, owing to the volcanic accumulations piled upon it, attains a considerable height and breadth.

If we now join to the maps of the Yellowstone park those of the adjacent areas on the east and north, which we owe to Hague, we shall find on the north border, and adjoining the rocks of the Gallatin range, another Archaean formation traversed by faults, the *Buffalo plateau, upon*

the Bighorn Mountains, U.S. Geol. Surv. Professional Papers, no. 51, 1906, 129 pp., map. In particular Sheep Mountain Anticline and North and South Fork of the Powder River Syncline, Dry Fork Anticline, and others; also, for the breaking up of the coulisses, C. A. Fisher, Geology and Water Resources of the Bighorn Basin, op. cit., no. 53, 1906, 72 pp., map.

[1] A. Hague, Iddings, and Weed, Geology of the Yellowstone National Park, Part II, U.S. Geol. Surv., Monograph no. XXXII, 1899, p. 149 et seq., Geol. atlas, fol. no. 30.

which patches of Cambrian sediments are horizontally superposed; still further towards the east and north-east rises an inhospitable and lofty Archaean mass, which is known as *Snowy range*, and more to the east as *Beartooth*. It projects across the border of the Rocky mountains like an alien body, and is surrounded towards the south-west, that is, towards the Absaroka range (formed of volcanic ejectamenta) and the Yellowstone park, by a very long Palaeozoic border, which slopes regularly towards the south and south-west. The Cambrian sediments form a girdle of basset edges.[1]

The Yellowstone park is thus seen to be a region of subsidence or inbreak. In the south and north-west the faults run mostly north and south; several of them present a throw of over 1,000 meters. In the north-east, on the other hand, the Beartooth mass slopes with a gently inclined, regular surface beneath the lavas.

This mass marks the beginning of a mountainous region which starts south of lat. 45° N. and extends beyond lat. 47° N., thus including the boundary of Wyoming and Montana; it differs in structure from the rest of the Rocky mountains, and, owing to the comparatively trifling thickness of its volcanic covering, it exhibits even more clearly the signs of subsidence. The several parts of this range are horsts of gneiss, covered here and there with patches of flat-lying Cambrian or pre-Cambrian sediments, and broken up by fractures and troughs running in the most diverse directions, in which the sedimentary series up to and including the Laramie stage is let down in a shattered condition.

The most important of these horsts are: Beartooth (together with Snowy range); to the north-west of this and in continuation of the Gallatin mountains, *Bridger range*; to the west and north-west of this the *Great Belt mountains*, and to the east and north-east of these the *Little Belt mountains*, which extend across the common mountain border for a great distance towards the east and away in the prairie, still fairly far to the east, find an isolated continuation known as the *Snowy mountains* (not Snowy range). Within this region, west of the narrow Bridger range, and surrounded by these horsts, there lies a piece of level country in which (near lat. 45° 55′ N., long. 111° 30′ W.) the Missouri is formed by the confluence, near the Three Forks, of three rivers, the Jefferson, the Madison, and the Gallatin. In this region, also, the Palaeozoic series is completed by the occurrence of the Belt stage. Weed describes this stage as 12,000 feet thick, formed of quartzite and sandstone below (Neihart quartzite), and then of shales and limestone in repeated alternation. According to Walcott, it is covered unconformably by the lowest beds of the middle Cambrian, rests unconformably on Archaean rock, and contains organic remains, which occur somewhere near the middle in the Grayson

[1] A. Hague, Absaroka, fol. no. 52, 1899, and Livingston, fol. no. 1, 1894.

shales. Some of these fossils are supposed to be traces of Merostomes. The Belt stage is often regarded as a part of the Algonkian [1].

On the north side of the Beartooth mass, traces of the oblique coulisse folding may be seen in the narrow outer border which adjoins the prairie. The east border of the Bridger range is partly overfolded in the direction of the prairie. The fascicle of folds, distorted along the strike, which occurs at the Three Forks, and thus right between the horsts, is overfolded towards the south-east. It has been described by Peall [2].

Castle mountains, the southern foothills of the Belt mountains, are, according to Weed and Pirsson, a fragment of the Belt stage, broken through by a now denuded volcano [3].

The Little Belt mountains resemble in many respects the Beartooth mass. According to Weed's description, they form a very flat boss of gneiss, regularly surrounded by a border of stratified rocks ranging from the Belt stage into the Cretaceous, which flattens out as it passes into the Cretaceous of the prairie. From *Yogo peak* onwards, on the east side of these mountains, a syenite cicatrix of irregular outline, from 22 to 24 kilometers in length, and as much as one to six kilometers in breadth, extends towards the north-east. To all appearance it stands in some connexion, beneath the surface, with the numerous large laccolites which occur in the north and north-east part of the Little Belt mountains; these have forced their way for the most part through the least resistant Cambrian shales, and have given rise to boil-like intumescences [4].

Outside this region isolated volcanic intrusions are scattered far over the prairie, sometimes surrounded by arched beds, sometimes by flat-lying beds, and very often by a broad girdle of radiating dykes. Striking examples are furnished by the Highwood (lat. 44° 30′ N., long. 110° 30′ W.), Crazy (lat. 46° N., long. 110° 15′ W.), and Judith mountains (lat. 47° 3′ to 47° 18′ N., and long. 108° 57′ to 109° 25′ W.) [5].

It seems that a region exists in the north of the Yellowstone park in which the scarcely perceptible oblique folding is replaced by a general

[1] C. D. Walcott, Pre-Cambrian fossiliferous Formations, Bull. Am. Geol. Soc., 1899, X, pp. 199–244.

[2] A. C. Peale, Palaeozoic Section in the Vicinity of Three Forks, Montana, Bull. U.S. Geol. Surv., no. 110, 1893, 56 pp., map; and Three Forks, fol. no. 24, 1896.

[3] W. H. Weed and L. V. Pirsson, Geology of the Castle Mountain Mining District, Montana, Bull. U.S. Geol. Surv., no. 139, 1896, 164 pp., maps.

[4] W. H. Weed, Geology of the Little Belt Mountains, Montana, Ann. Rep. U.S. Geol. Surv., XX, 3, 1900, pp. 271–581, maps; Weed and Pirsson, Little Belt Mountains, fol. no. 56, 1899.

[5] W. H. Weed and L. V. Pirsson, Highwood Mountains, Montana, Bull. Am. Geol. Soc., 1895, VI, pp. 389-422; J. E. Wolff, Geology of the Crazy Mountains, Montana, op. cit., 1892, III, pp. 445-452, map; Weed and Pirsson, Geology and Mining Resources of the Judith Mountains, Montana, Ann. Rep. U.S. Geol. Surv., XVIII, 3, 1898, pp. 437–621, maps.

subsidence of the mountains along great faults striking in different directions; it resembles a fragment of foreland broken down and divided into horsts rather than the fragment of a mountain chain. If, however, we look further west for a possible continuation of the Rocky mountains, we reach, on the other side of long. 112° W., south of Helena, a granite mass about 64 kilometers in breadth and 112 kilometers in length, which includes the rich mining district of *Butte.* This granite is not old; it alters the Carboniferous limestone in contact with it, and is therefore younger than the Carboniferous, possibly very much younger [1].

The investigations of Weed on the north of the region in question have shown beyond dispute that the volcanic intrusions, especially the laccolites of the Little Belt mountains, have arisen simultaneously with the dislocations.

We thus arrive at the following results: from the middle Cambrian onwards, up to and including the Laramie stage, the beds, notwithstanding some gaps, lie to all appearance conformably. Towards the conclusion of the Laramie stage very great disturbances set in, the results of which are seen along the whole eastern border of the Rocky mountains, but from the Yellowstone park to a little beyond lat. 47° N. the sinking movement was so preponderant that folding is scarcely perceptible except in local pinched-in strips along faults.

The North. North of the Belt mountains the structure of the mountain border changes. Here again the strike is similar to that in the south, N. 10°–20° W.; coulisses also occur here, but as a rule they are very long and bulky; further to the north an isolated coulisse may occasionally extend in front of the mountains. Here commences a great overthrusting to the east upon the Cretaceous of the prairie, which is likewise folded.

The region between lat. 48° and 49° N. has been rendered familiar by Bailey Willis [2].

The border is formed by *Lewis range*, but this coulisse dies away a little north of lat. 49° N. The *Livingston range*, which follows towards the west, does not emerge to the south of it, as is the rule, but comes up further to the north and is again lost to view in lat. 48° 45′ N. Both these great ranges are formed by the Belt stage, and together they enclose a great syncline, from which rises a feeble anticline bearing the highest peak (mount Cleveland, 3,263 meters). Livingston range is cut off on the west by a strike fault, on the other side of which Carboniferous limestone makes its appearance. Lewis range terminates on the east, next the prairie, along an irregular line of steep cliffs, often more than 1,300 meters in

[1] S. F. Emmons and G. W. Tower, Butte, special fol., no. 38, 1897.

[2] Bailey Willis, Stratigraphy and Structure, Lewis and Livingston Ranges, Montana, Bull. Am. Geol. Soc., 1902, XIII, pp. 305–352, map; for the intermediate region to the south, R. H. Chapman, Structure of the Rocky Mountains in the Lewis and Clarke Timber Reserve, Montana, Trans. Am. Inst. M.E., 1899, 4 pp., map. For the region to the west of 116°, B. Willis, in Bull. U.S. Geol. Surv., no. 40, 1887, pl. I.

height, and composed for the most part of limestone belonging to the Belt stage. These cliffs form the border of the Palaeozoic formations, which are thrust over the Cretaceous; the inclination of the thrust-plane is very gentle, usually ranging from below 3° to 7° 45′, and directed towards the south-west; its breadth amounts to at least 11 kilometers. The irregularity and the steepness of the border are caused by the giving way of rocky masses of the Belt beds, which lie above the more destructible Cretaceous; *Chief mountain*, which stands isolated in front of the border in lat. 48° 56′ N., bears witness to this process; it consists in its upper part of Cambrian or pre-Cambrian Belt limestone, in its lower part of Cretaceous belonging to the Benton stage (pl. III).

To the west of these great overthrusts the Belt stage extends far into the range. It certainly reaches long. 117° W. Lindgren here distinguishes a chain, under the name of the *Cœur d'Alène* mountains, which extends from the Lolo pass (lat. 46° 35′ N., long. 114° 20′ W.) towards the north-west across the lake of Cœur d'Alène, and consists of the same rocks. Walcott has shown that the beds of the eastern border extend up to this point; their thickness here is surprisingly great, they are unconformably overlain by middle Cambrian sediments, and at the same time present astonishingly few signs of disturbance [1].

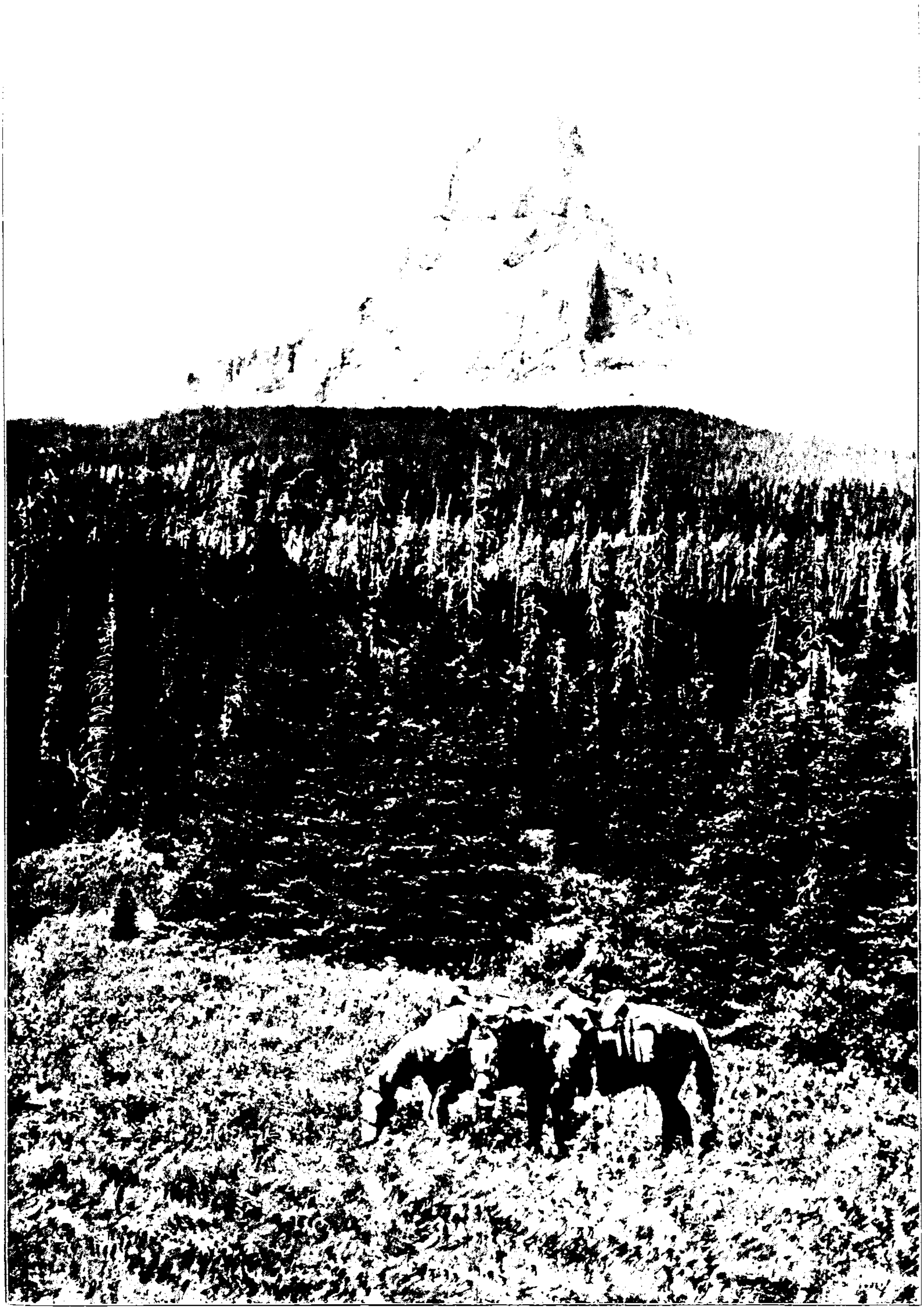
Near the Canadian frontier an extremely long and almost rectilinear furrow commences its course. It strikes to the north-north-east, parallel to the outer border, and crosses the 49th parallel near long. 115° W. Here it serves for some distance as the bed of the Kootenay river [2]; then it takes in part of Columbia river, and afterwards Canoe river and the upper course of the Fraser to some distance beyond lat. 54° N. Up to this point its waters discharge into the Pacific Ocean. In lat. 54° 30′ N. it forms the valley of the Parsnip, and then of the Finlay river as far as lat. 58° N. and beyond, but from the Parsnip river onwards the waters flow to the Arctic Ocean.

Daly has devoted particular attention to this line; he believed that it was continued as far as the Liard, and named it the 'Rocky-mountain Trench' [3]. The significance of this line of depression, which may be recognized through at least 9 degrees of latitude, is not known.—

[1] W. Lindgren, A geological Reconnaissance across the Bitterroot Range and Clearwater Mountains, U.S. Geol. Surv. Professional Papers, no. 27, 1904, 123 pp., maps, in particular pp. 16 and 81; Walcott, Algonkian Formation of north-western Montana, Bull. Am. Geol. Soc., 1906, XVII, pp. 1–28, map.

[2] J. McEvoy, Summary Report, in Geol. Surv. Canada, Ann. Rep. (new ser.), XII, 1902, p. 87 A.

[3] R. A. Daly, Nomenclature of the North American Cordillera between the 47th and 53rd Parallels of Latitude, Geogr. Journ., 1906, pp. 586–606, map on p. 588. The only features which might possibly be compared to these are the Scandinavian lines (III, p. 393).



After Bailey Willis

CHIEF MOUNTAIN (MONTANA), VIEW FROM THE NORTH-EAST

Algonkian (Belt Series) overthrust on to Upper Cretaceous Strata

We will first trace the outer border of the range. It is characterized by violent overthrusting towards the east, by a number of long coulisses which lie in front of it, and, above all, by the fact that towards the north the folding encroaches more and more on the stratified series of the foreland, which is formed exclusively of Devonian, middle and upper Cretaceous, and Tertiary.

Even in the south the Cretaceous of the foreland is included in the folding to a considerable extent. The overthrusting of Chief mountain near lat. 49° N. is followed towards the north, at least as far as lat. 53° N., by a zone in which the eastern part of the range is at first broken up into long flakes of Palaeozoic and Cretaceous beds, with a general dip towards the west and a strike to the north-north-west (Livingstone, High Rock Range, and others)[1]. Towards the west, that is, towards the interior of the range, the Cretaceous disappears.

A section has been drawn by G. M. Dawson from Revelstoke on the Columbia (lat. 51° N.) north-eastwards to Donald (lat. 51° 30′ N.), and

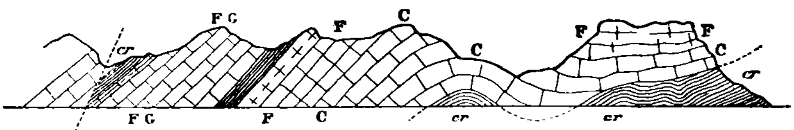


FIG. 32. *Outer border of the Rocky mountains on the Ghost River, South Canada* (after McConnell). *C*, Castle mountain group, Cambro-Silurian; *F*, Devonian; *G*, Banff limestone, Permo-Carboniferous; *cr*, Cretaceous.

McConnell has continued it in an easterly direction from this point to the outer border[2]. Let us follow this completed section. To the west, in the Selkirk range, and even still further west, gneiss predominates, then come ancient schists, next the equivalents of the Castle-mountain group (Cambro-Silurian), along with the older Bow-river series, and finally a great overthrust directed to the east. The succeeding rocks are probably Silurian.

Near Donald, on the Columbia river, a Cambrian anticline makes its appearance. From this point to the Sawback range, a distance of 60 kilometers, there extends a fairly regular succession of Cambrian and Silurian anticlines and synclines, the first of the synclines being, perhaps, overfolded towards the west. From the *Sawback range* onwards, 36 kilometers from

[1] Here we may mention the map by Leach in Ann. Rep. Geol. Surv. Can. (1902–1903) 1906, XV, and the sections by Dowling, tom. cit., AA, p. 86 et seq.; then D. D. Cairnes, Moose Mountain District, op. cit., 1907, 55 pp., maps. All the Cretaceous coal-measures are folded.

[2] G. M. Dawson, Geological Structure of the Selkirk Region, Bull. Am. Geol. Soc., 1891, II, pp. 165–176; R. G. McConnell, Geological Structure of a portion of the Rocky Mountains, accompanied by a section measured near lat. 51° N., Ann. Rep. Geol. Surv. Canada, 1887, part D, 41 pp. The same Archaean mass is described by A. Bowman in lat. 52° 50′, tom. cit., part C, 49 pp., map.

the eastern border of the Rocky mountains, we meet with the Castle-mountain group, Devonian, Carboniferous, and finally Cretaceous. From this point onwards the Palaeozoic series is divided into seven flakes, over-riding each other towards the east. On the outer border the Castle-mountain group overlies the Cretaceous for a distance of 3 kilometers. McConnell estimates the extent of this almost horizontal overthrusting at about 10.5 kilometers. In the interior of the range some of the flakes pass into overfolded anticlines.

On the upper Athabasca, north of lat. 52° 30′ N., McEvoy met with folded Archaean and Cambrian rocks, then, after a great fault, Devonian and Carboniferous, steeply upturned on the border of the range, but not overlying the Cretaceous [1].

Further north the flakes set in again.

In lat. 56° N., on the *Peace river*, McConnell marks six flakes of Palaeozoic beds overthrust towards the east, and the more easterly of these include pinched-in Trias; the dip is invariably to the west. This section is followed on the west by Archaean rocks, which have been traced as far as lat. 57° 40′ N. along the Parsnip and Finlay rivers. In this region the great longitudinal furrow lies in the strike of a strip of Palaeozoic, which is pinched-in between two Archaean flakes [2].

A little north of lat. 56° N. the lower Palaeozoic beds disappear in the foreland; on the border of the Canadian shield Middle Devonian rests directly on the Laurentian gneiss, and is followed by the Dakota stage (Cenomanian) (II, p. 232).

Let us follow further the guidance of McConnell along the border of the Rocky mountains [3].

The strike to north-north-west or north-west is maintained, and in lat. 59° 30′ N., long. 126° W., the outer border of the range, presenting peaks of from 900 to 1,200 meters in height, reaches the river *Liard*, close beneath what was once Fort Halkett. To the east of this point shorter ranges of Palaeozoic crinoidal-limestone and Trias are cut through by the Liard. In long. 124° 40′ W. these ranges terminate, and the river cuts its bed as much as 300 meters deep in horizontal Cretaceous beds. On the other side of lat. 60° N., between longs. 124° and 123° 30′ W., fresh Cambrian coulisses, striking to the north-north-west, crop out near Fort Liard, on the left bank of the river. Here there is still a distinct contrast between the foreland, in which the Liard exposes horizontal beds of Devonian and

[1] J. McEvoy, Geology and Natural Resources of the country traversed by the Yellow Head Pass, Ann. Rep. Geol. Soc. Can., 1901, new ser., XI, part D, 41 pp., map.

[2] R. G. McConnell, Report on an Exploration of the Rivers Finlay and Omenica, Ann. Rep. Geol. Surv. Can., 1894, new ser., VII, part C, 45 pp., map.

[3] R. G. McConnell, Exploration of the Basin of the Yukon and Mackenzie, Ann. Rep. Geol. Surv. Can., 1890, new ser., IV, part D, maps.

Cretaceous, and the bluff parallel ranges, which at once reach a height of 1,200 meters. While these ranges diverge from the meridian towards the north-north-west, a new coulisse, formed of Cambrian and Silurian, of equal height and equally striking in appearance, emerges beyond lat. 61° N. in long. 121° 30′ W. on the Nahanni butte, close to the left bank of the Liard; this coulisse strikes to the north, leaves the Liard, and in lat. 62° 15′ N. forms the left bank of the *Mackenzie*. Then it also turns towards the north-north-west.

In lat. 62° 45′ N. a very long coulisse, 1,200 meters in height, rises on the right bank of the Mackenzie, and from this point onwards this river flows in a coulisse valley of the Rocky mountains. At the same time the coulisse on its left bank diverges further and further from the river; the valley becomes 90 to 100 kilometers broad, and the river frequently exposes Devonian, lying as a rule horizontally, though here and there it is folded. Whiteaves assigns it to the Cuboides zone [1]. From lat. 64° N. onwards, the Cretaceous with Inoceramus makes its appearance in the valley, and the Devonian bears salt springs, which are also distributed far and wide in the foreland. Nevertheless, the coulisse on the right bank, which had begun in lat. 62° 45′ N., continues on and is cut through by the Great Bear river in lat. 65° 10′ N.; here Bell observed folded Silurian in the rapids. Mount Charles (1,500 feet) belongs to this range [2].

The isolated *Bear Rock* (1,400 feet), at the point where the Great Bear river enters the Mackenzie, is a Devonian anticline; even leaf-bearing Tertiary beds appear here to share in the folding.

From this point onwards the mountains diminish in height; their direction is north-west. The river flows through Devonian and Cretaceous. The rock of *Carcajou* (lat. 64° 40′ N., long. 128° 20′ W.) is an anticline formed of the same beds, and is regarded by McConnell as a continuation of the coulisse which begins in about lat. 61° N., long. 123° 30′ W.

At the rapids of *Sans-Sault* (lat. 63° 40′ N., long. 129° 10′ W.) the Mackenzie again cuts its way through an anticline of Devonian and Cretaceous; now, however, the coulisses disappear, and flat bedding prevails as far as the delta. This is also the case near the rapids of the *Ramparts* (lat. 66° 15′ N.), where *Stringocephalus Burtini* has been found. In lat. 67° 25′ N. the Devonian with *Atrypa reticularis* yields oil; a little further on, in long. 131° 40′ W., it disappears beneath the Cretaceous, which persists to the head of the delta. The lower course of the Mackenzie thus lies outside the chief range in the series of the foreland; the foreland,

[1] J. F. Whiteaves, Contribution to Canadian Palaeontology, 1891, I, pp. 197–253, part 3, The Fossils of the Devonian Rocks of the Mackenzie River Basin, in particular p. 249.

[2] J. Macintosh Bell, Report on the Topography and Geology of Great Bear Lake, Ann. Rep. Geol. Surv. Can., new ser., XII, 1902, part C, p. 25.

however, is traversed by long coulisses, which run parallel with the chief range. This is a very exceptional case [1].

McConnell's account is supplemented in an instructive manner by that of Camsell [2].

Let us return to the rapids of Sans-Sault. We have already mentioned that the Mackenzie leaves the mountains at this point (near lat. 63° 40′ N.) and enters a region in which the bedding is horizontal. The border of the mountains is fairly well marked, and follows an almost rectilinear course to the west-north-west, as far as the upper Wind river (right tributary of the Peel river) and beyond. Here, in about lat. 65° 15′ N., and not very far from long. 136° W., the mountain border describes a bend, and runs almost due north into the neighbourhood of Fort McPherson. Thus, not only the Mackenzie in its course below Sans-Sault, but almost the whole of the Peel river, remains outside the Rocky mountains. Both these rivers flow through a platform of horizontal or but slightly-folded Cretaceous and lignitiferous Tertiary beds. The Peel, in many parts of its course, has cut for itself a deep valley. The platform is 1,700 feet high in its southernmost part, is interrupted by short coulisses which lie in front of the range (Illtyd, 4,200 feet) and terminates on the Satah (right tributary of the Peel, lat. 66° 50′ N.) in a long and steep declivity. At the foot of this begins the plain of the Mackenzie in the last part of its course.

Below Fort McPherson, on the left bank of the Mackenzie, the platform meets the mountains, which here renew their advance. Mount Goodenough, 3,000 feet in height, in about lat. 68° N., ends on the east in a very steep slope only 3 kilometers away from one of the arms into which the river divides. This mountain consists of horizontal or only very gently folded beds. At its base lie black shales, then comes clay ironstone weathering red and containing ammonites, and over this sandstone. Towards the north and north-west the height decreases, and west of the mouth of the Mackenzie the mountain finally slopes beneath the sea. This concludes Camsell's account.

Somewhat to the west of this point the maps mark two hilly ranges trending north-west, and possibly connected, these are the Richardson and Buckland mountains. They probably reach the sea near long. 139° 30′ W., east of the Malcolm river. They are the most northerly ranges with which

[1] The delta is described by E. de Sainville, Bull. Soc. géogr. Paris, 1898, p. 291, map. The most detailed geological accounts are still those of Kennicott (II, pp. 38, 232, and 37, note 2). The Rev. Kirby appears to have collected Devonian fossils on the Porcupine river at a very early date.

[2] C. Camsell, Peel River and Tributaries, Ann. Rep. Geol. Surv. Can., 1906, XVI, CC, 49 pp. I must express my gratitude to Messrs. Camsell and Daly for giving me access to this valuable report before the appearance of this volume. The geology of north-west Canada is shown in the map of the Yukon Territories, no. 917 (compiled by J. Keele) in the Summary Report (1905) 1906.

the Rocky mountains enter into syntaxis. To the south of them lies the watershed; in this region, between lats. 69° and 68° N., long. 141° W., Turner, as already mentioned, encountered a lofty range; this must be the east-and-west-trending main chain of S. J. Marsh, which is sometimes named Davidson mountains on the maps; it is no doubt the veritable end of the Romanzov range. This range certainly terminates within a short distance. McConnell and Camsell both travelled from the Mackenzie, across the Rat river (lat. 67° 45′ N.), to the Porcupine river, and did not find any continuation of it.

McConnell has drawn two sections, 30–35 kilometers apart, from the head of the delta towards the west. The northern section, on the Rat, crosses mountains 2,800 feet in height, formed of Cretaceous sandstone with ammonites; the strike is northerly. The second section, near lat. 67° 26′ N., extends from the portage on the Peel river to the Lapierre house on the Bell river. The mountains are as much as 4,000 feet high, and appear to form a broad anticline striking to the north, but here also only Cretaceous has been met with: it seems to be of great thickness.

On the Bell river an exposure was seen at only one locality, it showed inclined Cretaceous strata, apparently with a north-north-west strike. On the *Porcupine*, where the great bend of the river begins, beds with Aucella crop out from beneath the Cretaceous sandstone (lat. 67° 30′ N., long. 137° 30′ W.), and beneath them lie Palaeozoic rocks. Further away, Tertiary beds occur on the Porcupine river; the *Old Crow* mountains (long. 140° W.) are Cretaceous. The *Upper Ramparts* of the Porcupine are rapids in a cañon of basalt, beneath which steeply upturned, probably Devonian, beds are visible; they strike almost north. The basalts continue on; near the Lower Ramparts (near lat. 67° N., long. 142° 30′ W.) Silurian crops out from beneath them[1]. Then comes Cretaceous once more. The Porcupine now enters the Yukon Flats.

All the land so far described, from the Mackenzie to the syntaxis, thus belongs to the coulisses lying in front of the Rocky mountains, in which a bend of the strike to the north is perceptible. We should not expect to find the continuation of the principal chain of the Rocky mountains before reaching the region situated to the south of the plain of the Peel.

In order to search for it let us return to the south.

It is true that large tracts of unknown land extend between the coulisses lying in front of the Rocky mountains and the series of gneiss masses which, with contours elongated in the direction of the strike, mark the western border of the range. But the zeal of Canadian geologists, supplemented by that of prospectors for gold, enables us to determine approximately the main features of this region. Our knowledge is based chiefly on G. M. Dawson's journey from the Stikine and the upper Liard across

[1] Kindle, Am. Journ. Sci., 1908, 4 ser., XXV, p. 125, Niagara stage.

Frances river to the upper Pelly, then to the ruins of Fort Selkirk on the Yukon, and his return journey across Lewis river towards the south[1]. His account, together with a number of more recent works, furnishes us with the following facts.

Archaean rock has already been mentioned as occurring on the Tochieca as far as lat. 57° 40′ N. The gneisses and ancient granites, which begin far to the south, are accompanied by highly altered schist, in places also by quartzite, marble, and serpentine. The schist is the principal source of the gold found here. It is sometimes interrupted by masses of granite or gneiss, and sometimes covered by Cretaceous or Tertiary beds, but it is continually cropping out along its course. It is regarded as pre-Cambrian; the prospector finds no gold in the Cambro-Silurian lying further to the east, and the completely divergent series of the intermediate range situated to the west is equally unproductive.

Dawson perceived that the biotite granites of these inner ranges of the Rocky mountains, with their not infrequent transitions into gneiss, are much older than the grey hornblende granites of the west coast, which we shall discuss directly. He thought they might form an alternating series of masses, arranged very much after the fashion of the coulisses of the Palaeozoic range.

We may mention, without entering into details, that in lat. 59° N. the Dease river cuts through a band of these ancient granite and 'granitoid' rocks, 20 kilometers in breadth, with a north-west trend, that a great part of the *Cassiar range* is formed of the same rocks, and that the Pelly river crosses the strike at an acute angle, somewhat north of the mass of the *Glenlyon mountains*. These mountains consist of a granite of a slightly different nature, the apophyses of which cross the river obliquely in a west-north-westerly direction.

The Pelly river flows, however, for the greater part of its course, in schist, with beds of hornstone. Near the mouth of the Macmillan, McConnell mentions sericitic schist with some gneiss, and then granite gneiss, which is a true ortho-gneiss, often described as the Pelly gneiss.

The ancient rocks, striking from the Pelly across the Stewart river, now reach the river Klondike, and their northern border crosses the Yukon a little below the town of Dawson. As they strike to the north-west their breadth decreases; towards the south they present a sharp boundary[2]. They next strike, north of the Tanana, further to the west-north-west. In this region Spurr named them many years ago the *Yukon-geanticline*;

[1] G. M. Dawson, Report on an Exploration in the Yukon District, N.W.T., Ann. Rep. Geol. Surv. Can., 1888, III. A new edition of this valuable report was prepared in 1898, with part of McConnell's report appended, 244 pp., maps.

[2] R. G. McConnell, Yukon, Preliminary Report, Ann. Rep. Geol. Surv. Can., 1902, new ser., XII, A, pp. 16–52, map.

this anticline terminates, as we have already seen, in lat. 64° 20′ N., long. 147° W.[1].

At this point, however, in the neighbourhood of the syntaxis, we can hardly speak of a true gneiss range. McConnell shows that by far the greater part of the range on the Klondike, and even further towards the south-east, is dynamically transformed into a pale-coloured sericite schist, which betrays its derivation from granite or porphyry only under the microscope, or by scattered, ill-defined masses of Pelly gneiss. This completely crushed, intrusive rock is regarded by McConnell as the true home of the gold [2].

In this fashion the range of gneiss-masses which commenced to the south of lat. 49° N. on the west side of the Cambro-Silurian zone comes to an end. From Kootenay on the south, through Cariboo, the valley of the Finlay, the upper Stikine, the upper Liard, the Cassiar range, and a number of other features as far as Klondike and beyond, these masses are literally united by a golden girdle.

To the east and north of this zone, even up to the vicinity of the syntaxis, a peculiar and lofty zone of Palaeozoic limestone and slate may be distinguished. In places Aucella beds are associated with it. On the north it forms the watershed next the Arctic Ocean. It probably includes Selwyn range (very little known), and Ogilvie range, the north border of which reaches the plain of the Peel between long. 135° and 136° W. and beyond lat. 65° N. To this range belong also the lofty Palaeozoic mountains which meet the Yukon, below the British boundary, near Eagle and at the mouth of the Tatundock; likewise the Ketchumstock mountains, north of the Tanana.

The manner in which the extreme north-easterly end of the Alaska range meets this extreme north-westerly end of the Rocky mountains in the valley of the Tanana has already been described.

2. The beginning of the Intermediate range.

The Wrangell volcanos. Between lat. 62° and 63° N., lying on the zone of syntaxis, is the downthrown plateau of the Copper river, which bears in the east the group of the Wrangell volcanos. Its length from north-west to south-east measures about 220 kilometers; its breadth, taken at right angles, somewhat less. The Copper river rises on the north side of the volcanos, curves round their western border and separates them from the

[1] J. E. Spurr, Geology of the Yukon Gold District, Al., U.S. Geol. Surv., 1898, XIII, 3, 392 pp., maps.

[2] R. G. McConnell, Klondike Gold Fields, Ann. Rep. Geol. Surv. Can. (1901), 1905, XIV, B, 71 pp., maps; p. 19 description of the sericitic schist by Barlow. MacMillan and Peele, op. cit. (1902–1903), 1906, XV, A, p. 22 et seq., map.

tundra which covers the surface of the plateau towards the north-west and west, up to the foot of the Alaska range. Having passed the volcanos the river enters, near Taral, on the south, a long and narrow transverse valley, 90 kilometers in length, which cuts from north to south right across

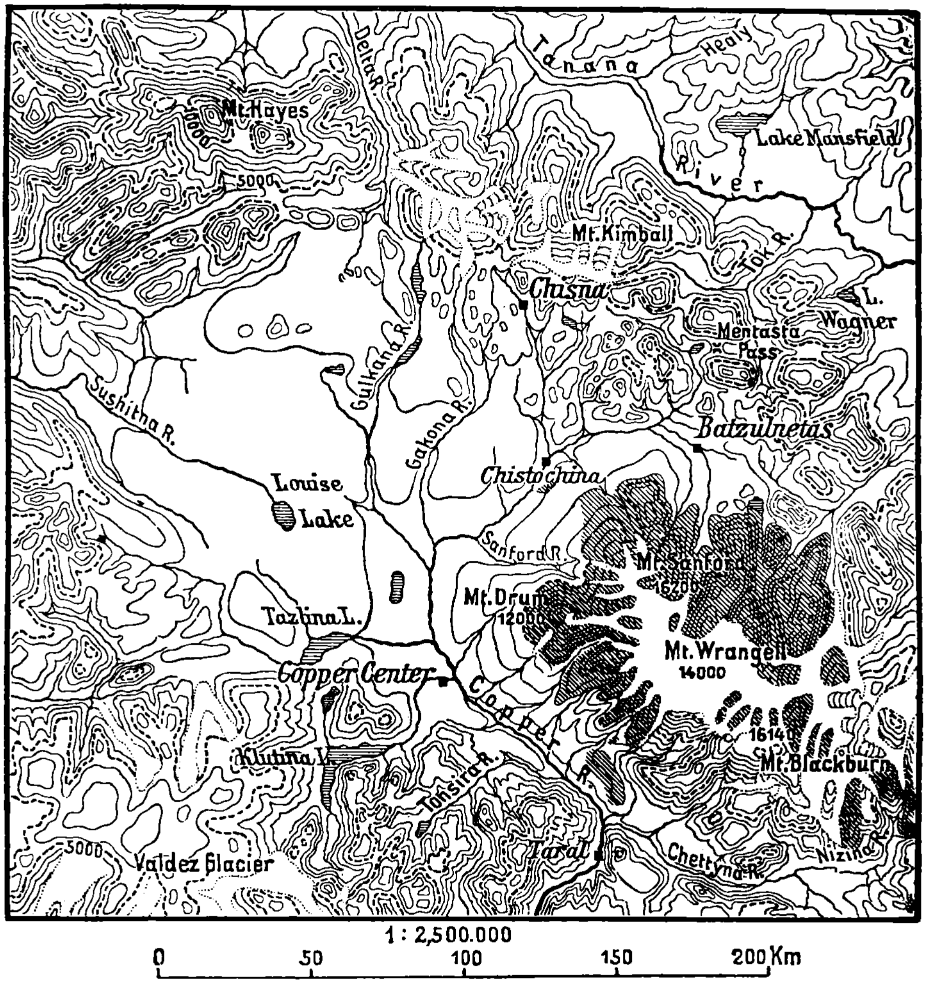


FIG. 33. *The Plateau of the Copper river* (after the map of R. U. Goode, in Brooks, Alaska; geological data according to Mendenhall, Schrader and Spencer; heights in English feet). The encroachment of the horst, which is in part mesozoic, is visible on the south slope of mount Blackburn. Mounts Hayes and Kimball belong to the Alaska range; Mentasta pass corresponds with the fault which strikes to the north-west beneath Mount Kimball, and the southern, downthrown mountains are formed of ancient eruptive rocks, upper Carboniferous, and Tertiary sediments. Tanana river is the boundary between these mountains and the Rocky mountains. The southern mountains surround the gulf of Chugatsk and strike south-east to mount Saint Elias.

the Chugatsk range. Before entering the first cañon it receives from the east-south-east the important river Chettyna, which flows in a broad valley, surrounding the south foot of the volcanos. The Rocky mountains do not enter the region which borders the plateau of the Copper river. The southern side is formed by the precipitous northern slope of the Chugatsk range, which is continued towards the south-east without interruption into the Saint Elias range. In the north-west of the plateau rises mount Hayes, which has already been mentioned as one of the most easterly peaks of the Alaska range. Its strike is east-north-east, and it is joined with an east-south-easterly strike (corresponding to the angle of syntaxis) by the Mentasta range and its continuation, the Nutzotin range, which runs past the volcanos on the north. The Nutzotin range itself is separated on the north from the gneiss of the Rocky mountains, which also strikes to the east-south-east, only by the broad and marshy valley of the Tanana.

The group of the Wrangell volcanos is a single mass of ash and lava, bearing several very lofty volcanos, but in the south, north of the river Chettyna, it includes older lavas and sedimentary beds. On the west also the basement of the volcanic structure is occasionally visible.

The broad cone of *Wrangell* volcano (4,269 meters, almost exactly in lat. 62° N., long. 144° W.) forms the centre of the mass; towards the north a lofty ridge connects it with *mount Sanford* (4,940 meters), the highest of these mountains; to the south-south-east of mount Wrangell, advancing a little in the direction of the Chettyna, rises *mount Blackburn* (4,919 meters). On the west *mount Drum* (over 3,600 meters) rises near the middle of the curve of the Copper river. The height of mount Drum is attained or exceeded, according to Mendenhall, by at least ten other peaks. Of late years mount Wrangell was the only one of these peaks over which a smoke cloud hung, but in the spring of 1907 violent eruptive activity occurred, in which mounts Wrangell, Blackburn, and Sanford seem to have shared [1].

This great assemblage of mountains, measured from the west-north-west, where it slopes down to the plateau of the Copper river, to the east-south-east, where it joins the *Skolai* range, is 160 kilometers across, and in a direction perpendicular to this 110 kilometers. On the heights of the Skolai range there is also a long series of accumulations of more recent ashes, lavas, and pumice. The glaciers carry this material down into the valleys, and fragments of it are known even as far as the Chilkat pass above the Lynn canal. Above the Klutlau glacier rises the mountain of Na-taz-hat (about lat. 61° 30′ N., long. 141° 30′ W.), the probable point of discharge of a white ash, which may be recognized over a wide area as an intercalated layer in the soil [2].

[1] A. Porter, Zeitschr. Ges. Erdk., 1907, p. 628 (from Science).

[2] C. W. Hayes, An Expedition through the Yukon District, Nat. Geogr. Mag. Washington, 1892, IV, pp. 117–152, maps; Brooks, Ann. Rep. U.S. Geol. Surv., XXI, 2, p. 365.

The Wrangell group itself lies a little to the east of the syntaxis; observations in the Skolai range show that the volcanic chain is continued from the Aleutian islands, through Cook inlet across the plateau of the Copper river, and through mounts Wrangell and Na-taz-hat further towards the east-south-east. No other case is known in which a line of active volcanos follows a syntaxis, and we will therefore enter somewhat into detail[1].

Mendenhall and Brooks have concordantly arrived at the conclusion that the Wrangell volcanos are situated upon a downthrown region, which is bounded on the north, next the Nutzotin range, by faults, and on the south, in the valley of the Chettyna, next the north border of the Chugatsk range, by flexures or fractures, that is, these volcanos are situated upon a *strike trough*[2].

To the north the principal chain of the Mentasta and Nutzotin range consists of schistose greywacke with numerous quartz veins (Tanana schist), cut off from the southern foothills by a great strike fault. South of the Wrangell volcanos highly altered amphibolite and mica schists, together with crystalline limestone (Klutina series), occur and represent the most northerly and ancient formation of the Chugatsk (Elias) mountains; they are covered by a thick series of schist and greywacke (Valdez series), which forms the greater part of these mountains.

In the meridian of the Wrangell volcanos the fault-trough is at least 170 to 180 kilometers broad.

The downthrown series thus comprises the following groups:—

1. *Nikolai diabase*; repeated flows, piled up to a height of 4,000 feet; the uppermost part copper-bearing.

2. *Upper Carboniferous limestone* with Fusulina and *Productus cora*; Schuchert remarks on its affinity with rocks of the same age in Asia[3].

3. A thick series of *Permian* shales and limestone[4].

[1] The principal sources of information are, for the west, W. C. Mendenhall, Geology of the Central Copper River Region, Alaska, U.S. Geol. Surv. Prof. Papers, no. 41, 1905, 133 pp., maps (also Mendenhall and Schrader, op. cit., no. 15); for the east and the Skolai range, A. H. Brooks, A Reconnaissance from Pyramid Harbour to Eagle City, Alaska, U.S. Geol. Surv. Ann. Rep., XXI, 2, 1900, pp. 331–391, maps; and O. Rohn, A Reconnaissance of the Chetina River and the Skolai Mountains, tom. cit., pp. 393–440, maps; further, for the whole region, Schrader and Spencer, Geology and Mining Resources of the Copper River District, 8vo, U.S. Geol. Surv., 1901, 94 pp., maps; and Brooks, Geology and Geography, passim.

[2] W. C. Mendenhall, U.S. Geol. Surv. Prof. Papers, no. 41, pp. 82–88; and almost identical as regards the facts, Brooks, Geology and Geography, p. 256.

[3] Schuchert, in Schrader and Spencer, Copper River District, p. 44, and in Ann. Rep. Geol. Surv., XXI, 2, pp. 359.

[4] Schuchert, in Mendenhall, Prof. Papers, no. 41, p. 42 et seq. Among other species Spirifers were found from the group of *Spirifer striatus*, *arcticus*, and *supramosquensis*, *Productus* resembling *semireticulatus*, *cora*, *Humboldti* and others, then Goniocladia, Ortho-

4. *Trias*; dark limestone, above it some 3,000 feet of shales with *Monotis subcircularis* and Daonella.

All these subdivisions lie conformably, and are folded with a strike to the north-west; their worn-down folds are covered unconformably by 5. *Neocomian* (Kennicott formation; *Aucella crassicollis*) corresponding to the Knoxville stage of California[1].

6. Isolated patches of plant-bearing *Tertiary* on the north border.

The middle Jurassic, so largely represented on the peninsula of Alaska, has not yet been met with. The most recent sediment is the Neocomian, which is covered by the lavas of Wrangell.

Coming from the Nutzotin range, i.e. from the north, and crossing the trough, we encounter, according to Mendenhall's map, first a fragment of dioritic rock wedged into the marginal fault, and then the thick Permian series, which along the fault is steeply upturned and traversed by basic sills, but further south lies flat and is without sills. Then we reach a broad boss of diorite, older andesite, and diabase. These rocks plunge beneath the alluvial land of the Copper river; and out of this rise the mighty volcanos. On their west side, emerging from the lava, are highly altered rocks, which possibly belong to the Klutina series of the adjacent Chugatsk range; further away we see diorite like that already mentioned. Finally, on the south side of the volcanos and beneath their ejectamenta, the whole series is exposed from the Nikolai diabase to the Neocomian. It extends up to considerable heights; the southern part of the volcanic accumulations thus rests on a horst, which once rose out of the trough.

This southern, sedimentary part of the Wrangell mass is simply the western end of the Skolai range, and this, along with its volcanos, is probably nothing else than a part of the trough, let down a little less deeply.

Brooks and Peters have travelled from the Lynn canal to the Nutzotin range, and thence to the Yukon. Rohn crossed the Skolai mountains, and reached the north side of the volcanos. There is no doubt that the upper Palaeozoic and Mesozoic sediments of the trough extend from the volcanos in an unbroken range, and with increasing breadth as far as British Columbia.

Brooks thinks that the volcanos of the Aleutian islands may be regarded

tichia and other genera; the most characteristic genera, such as Enteletes and all the Cephalopods, are absent.

[1] In California as in Russia two horizons have been distinguished in the Aucella-bearing beds. The Jurassic beds are termed the Mariposa, the Neocomian, the Knoxville stage; both in Russia and in this part of Alaska an unconformity occurs at the base of the Knoxville stage; P. Smith, Age of the Auriferous Slates of the Sierra Nevada, Bull. Am. Geol. Soc., 1894, V, pp. 243–258; A. Hyatt, Trias and Jura in the Western States, tom. cit., pp. 395–434; J. S. Diller and T. W. Stanton, The Shasta-Chico Series, tom. cit., pp. 435–464. In Alaska this distinction has not everywhere been carried out.

as a south-westerly continuation of the Wrangell volcanos, although they are not geographically connected[1]. If we compare what has been said above with regard to the structure of Cook inlet and Shelikof strait, which is probably that of a trough, as well as the description of Matanuska, we find this point of view confirmed. We may conclude that a strike trough or troughlike inbreak follows both directions of the syntaxis, extending between the Alaska and Nutzotin ranges in the north, and the Kenai and Elias (Chugatsk) range in the south.

The grano-diorite of Columbia. North of the volcanos lies the Nutzotin range. On the north border of this range, between it and the plain of the Tanana, where it is traversed by the river Nabesna, between longs. 143° and and 142° W., Brooks observed a small outcrop of grey granite[2]. Hayes and Brooks again met with the same granite on the upper White river, on lake Kluane, and on lake Dezadeash (long. 137° W.), i.e. in a zone striking to the south-east. In this direction it increases rapidly in breadth, assumes in places dioritic characters, and is also described as grano-diorite. Above the gold placers of the Porcupine river (long. 136° 15′ W., north-west of Chilkat inlet, Lynn canal), C. W. Wright describes it as a dioritic range, more than 120 kilometers in breadth, in front of which, and at a distance of 12–13 kilometers further south, lies a second dioritic range only 3·2 to 6·4 kilometers in breadth. The sediments, which are penetrated by the diorite, contain, on the south side, lower Carboniferous fossils, and are thrown into narrow folds, with a strike of N. 60° W., dip N.E. They are altered by contact; in places the diorite follows the bedding planes, and in others it cuts across the strike[3].

This marks the beginning of an intrusive mass, which is more recent than the Trias, according to Spencer and C. W. Wright even more recent than the Aucella beds, and older than the Cenomanian; it is of unsurpassed magnificence. Its most important features were first recognized by Dawson[4].

The western margin reaches the head of Lynn canal, and a very long, narrow belt of sediments, for the most part the contact zone, separates it from the sea for several degrees of latitude. The grano-diorite rises in steep cliffs above this zone; on an average it is 80 kilometers broad, but

[1] Brooks, Geography and Geology, p. 250.

[2] Brooks, Ann. Rep. U.S. Geol. Surv., XXI, 2, p. 361, map.

[3] C. W. Wright, The Porcupine Placer District, Al., U.S. Geol. Surv. Bull., no. 236, 1904, 35 pp., maps.

[4] G. M. Dawson, Exploration in the Yukon District and adjacent Northern Portion of British Columbia, 1887, with Extracts relating to the Yukon District, from Report on an Exploration in the Yukon and Mackenzie Basins, 1887–8, by R. G. McConnell, new ed., Geol. Surv. Can., 1898, 244 pp., maps, p. 28. The general map on the western half of the country published by the Geological Survey of Canada in 1901 marks the whole of the granite range along with the northern parts as far as the frontier in long. 141°.

on the Stikine over 100 kilometers; it is cut through by fjords, and reaches the mouth of the Fraser. At this point it recedes from the sea, and, growing narrower, comes to an end in the United States, beyond lat. 49° N. Throughout its length of *almost fourteen degrees of latitude* it is a lofty, rugged, and rocky range; it bears a large number of peaks over 7,000 feet in height, some even attain a height of 8,000–9,000 feet.

The expression 'grano-diorite' is employed in accordance with American usage. In general we associate this term with a rock allied to tonalite or monzonite. Sometimes the expression granite, quartz-diorite, or diorite is preferred. E. Wright states that the great intrusive mass includes the most diverse rocks, seldom granite, more frequently grano-diorite, and transitions to diorite or gabbro. Observations along the Behm canal and the Unuk river (lat. 55° 10′ to 56° 45′ N.) show on the west side alteration into mica schist, more rarely into hornfels and spotted schists, as well as the presence of numerous veins of pegmatite and aplite; on the east side, on the other hand, there is a sharply defined boundary at the zone of contact.

On the east Dawson met with upper Carboniferous at various points over a distance of 800 kilometers, and at isolated localities, as on the Stikine, Trias. This is the succession in the Skolai range. As early as 1887 Dawson concluded that the great igneous mass could only have acquired its present position by absorption of the adjacent rock [1]. On the Unuk a recent flow of lavas is to be seen close to the contact [2].

This batholite is known in Canada as the *Coast range.* It must not be confused with the Californian coast ranges. Its oblique course in the north has given rise to the statement that north of the Lynn canal the Coast range enters the interior of the country.

Brooks conjectures that a rock from the peaks of McKinlay must be referred to the grano-diorite [3].

To gain an acquaintance with the west side of the batholite we must once more turn our attention to the north.

3. The Elias range.

This great range, 1,800 to 2,400 meters in height and difficult of access, is cut through by the Copper river below Taral, and strikes away between the Chettyna river and the sea towards the south-east. It is the

[1] G. M. Dawson, Geological Examination of the North part of Vancouver island, Ann. Rep. Geol. Surv. Canada, 1887, new ser., II, B, 129 pp., map, in particular p. 11. I mention with gratitude that the late Mr. G. M. Dawson has frequently given me by letter detailed information with regard to the granite range and especially its continuation towards the north-west.

[2] F. E. Wright, Unuk Mining River Region, Summ. Rep. Geol. Surv. Canada (1905) 1906, pp. 46–53.

[3] A. H. Brooks, Geography and Geology, pp. 204, 250.

continuation of the Chugatsk range. Like that range it presents to view both the Valdez and the Orca series; in each case the younger rocks lie next the sea, and in each the tangential movement has been directed seawards, giving rise to unilateral folds. The outer border next the sea recalls in many respects the outer borders of the Eurasiatic region. A little to the east of the mouth of the Copper river, in Controller bay, and on the Continental coast of Bering sea, Martin has described variegated shales, possibly belonging to the Orca series, then dark carboniferous shales with petroleum and marine Tertiary shells (Katalla formation, Eocene), then the coal-bearing Kenai stage, and above this marine Miocene, corresponding with the Unga stage of the Aleutian islands.

All these sediments are folded, but an exact survey of the folds made for the purpose of tracing the petroleum shows that between longs. 144° 30′ and 143° W., that is, fairly far to the east of the syntaxis, a north-easterly strike still prevails in this belt of the mountains, only interrupted in places by the normal strike to the north-west, as though the movement west of the syntaxis had lasted longer than on the east[1]. At cape Yaktag (long. 142° W.) marine Miocene beds form, according to Eldridge, an anticline striking to east and west[2].

Up to this point the height of the range increases. It attains 5,514 meters in mount St. Elias, north of cape Yaktag, and 5,855 north-east of this in mount Logan. It reaches Cross sound as mount Fairweather (4,700 meters) and mount Crillon, and there separates Lynn canal from the Ocean, but it is divided into two parts by Glacier bay, which receives the great Muir glacier.

Our knowledge of St. Elias is chiefly derived from three sources—two expeditions by Israel Russell[3] and one by Prince Amadeus of Savoy[4]. The slopes and foothills are described in the first two; to the third we owe some knowledge of the summit.

This peak is formed of diorite, but at its very summit of hornblende

[1] Ann. Rep. U.S. Geol. Surv., 1898, XIX, 6 contin., p. 110; G. C. Martin, Petroleum Fields of the Pacific Coast of Alaska, U.S. Geol. Surv. Bull., no. 250, 1905, pp. 1–36, maps. At the southernmost extremity of Kayak island a rock of trachyte rises suddenly from the sea.

[2] Maps and Descriptions of Routes of Exploration in Alaska, U.S. Geol. Surv., 1899, 8vo, G. H. Eldridge, The Coast from Lynn Canal to Prince William Sound, p. 104. The little island of Middleton, which lies 88 kilometers from the land opposite the mouth of the Copper River, is probably an accumulation of boulder clay thrust out from the land; Dawson, Bull. Am. Geol. Soc., 1893, IV, pp. 427–431.

[3] I. C. Russell, Expedition to Mount St. Elias, Alaska, Nat. Geogr. Mag., Washington, 1891, III, pp. 53-204, maps, in particular p. 167 et seq.; Second Expedition to Mount St. Elias in 1891, U.S. Geol. Surv. Ann. Rep., 1892, XIII, 2, pp. 1–91, maps.

[4] Filippo de Filippi, Spedizione di S. A. R. il Principe Luigi Amadeo di Savoja, Duca di Abruzzi, al Monte S. Elia (Al.), 1897, large 8vo, Milano, 1900, 284 pp., maps, in particular App. E; V. Novarese, Roccie e minerali dell' Alaska meridionale, op. cit., pp. 261–268.

rock. These high-lying regions are covered with snow and ice; their rocks are only known from the moraines. Gabbro has been obtained from mount Cook [1]. In Disenchantment bay Russell observed white limestone and green schists, with great dykes of quartz mica diorite. Still further to the south-east, on the shores of Glacier bay and on the Muir glacier, Reid mentions widely distributed diorite and quartz-diorite, cutting through folded Palaeozoic rocks. These rocks cross over into the island of Tshitshagov, and are probably apophyses of the great batholite [2]. In Drake island (middle of Glacier bay, lat. 58° 40′ N.) the upper Silurian *Leperditia baltica* has been obtained, and, on the Dirt glacier (extreme south-east of the Muir glacier), a Palaeozoic coral [3].

Let us return to the precipitous southern cliff of the pyramid of St. Elias. It probably represents the basset edges of the principal range of Palaeozoic rocks. Its beds dip gently towards the north-east. Beneath the projecting spur of the cliff, brown sandstone and black shales crop out, Russell's Yakutat system, the resemblance of which to the Cretaceous Flysch has already been pointed out when discussing Kadiak (Aleutian islands). The Yakutat beds, violently folded and crushed, *plunge beneath the mass of St. Elias.* In fact, we must assume that the principal Palaeozoic range is pushed up from the north-east over the Yakutat system, in much the same way as the limestone zone of the Eastern Alps is pushed up over the Flysch zone.

Further away the Yakutat system occurs with the same north-easterly inclination on the southern slopes of mount St. Elias, beneath the peaks named Newton and Augusta. This is the only rock encountered as far as Yakutat bay (long. 140° W.). On the other side of the bay, the gentle inclination to the north-east still prevails, but in the most southerly belt (Blossom on the north-east side of the Malaspina glacier, Knight island in Yakutat bay) the beds are steeply upturned.

The Yakutat system is succeeded towards the south-west of the Elias range by the Pinnacle system. In his first account, Russell described on the Pinnacle pass a series of sandstone beds, 1,800 feet in thickness, with insignificant coal seams in its lowest part, and repeated intercalations of conglomerate, together with boulders of ancient rocks. The upper part of the series includes a dense grey limestone with great Pectens. So far this system might well be regarded as Tertiary; it occurs in a similar form

[1] Williams, Some Eruptive Rocks from Alaska, Nat. Geogr. Mag., 1892, IV, p. 68. The specimen is compared to the Forellenstein of Neurode (Silesia).

[2] H. F. Reid, Glacier Bay and its Glaciers, Ann. Rep. U.S. Geol. Surv., XVI, 1895, pp. 415–461, maps, in particular p. 433; also Williams, op. cit.; Reid, Muir Glacier, Nat. Geogr. Mag., 1892, IV, pp. 19–55, maps; H. P. Cushing, Geology of the Vicinity of Muir Glacier, tom. cit., pp. 56–62; and Notes on the areal Geology of Glacier Bay, Trans. N.Y. Acad. Sci., 1896, XV, pp. 24–34.

[3] Schuchert, in the report of Brooks on the Ketchikan District cited below, p. 19.

between the Chaix hills and the Yakutat beds beneath mount St. Elias. Perhaps we may even venture the conjecture that it is on the same horizon as the beds further to the south-east in Lituya bay (at the foot of mount Fairweather), about 400 meters above the sea, which contain the great Pectens that aroused, many years ago, the astonishment of La Peyrouse. The beds of Lituya bay dip 15° to 75° to the N.W., according to Dall; the little island Cenotaph is Miocene [1].

Russell also mentions deposits of more recent age. On the crest of Pinnacle pass, at a height of 5,000 feet (about 1,500 meters), *Mya arenaria, Cardium islandicum*, and other still-existing Arctic species were found in sandstone and shales [2].

The Chaix hills, 900 to 1,000 meters high, and 12 to 16 kilometers in length, extend towards the south-east; they descend precipitously to the south, and their beds dip 10° to 15° to the north-east. They consist entirely of stratified morainic material with glaciated boulders. *Cardium islandicum, Panopaea arctica*, and other species occur in intercalated beds of fine clay. The foothills of the Elias range, like the Samovar mountains, and probably the Robinson mountains also, present a similar structure; in these the beds dip towards the north [3].

These data show that fairly long rock-zones strike from the heights of St. Elias down to Yakutat bay; some are continued still further in a more or less south-easterly direction. Hornblende rock and diorite of unknown age form the summits; the Flysch-like Yakutat system dips gently beneath it; this is followed, with the same inclination, by the Pinnacle system, probably middle Tertiary, and this is followed towards the sea by glacial silt, which extends downwards from 1,500 meters. Further north (long. 145° W.), horizontal marine deposits of recent age occur at isolated localities up to a level of 30 feet above the strand.

The recent movement of the mountains, which carried glacial deposits up to such considerable heights, seems to have attained its maximum, according to the imperfect data so far at our disposal, somewhere near the origin of the great Malaspina glacier, which reaches the sea with a breadth of 100 kilometers west of Yakutat bay. The explanation at once suggests itself, that the whole of the principal range of the Elias mountains was pushed up from the north-east, in post-glacial times, over the Flysch-like Tertiary and glacial beds.

From an account given by Tarr and Martin it appears that *this range is still in process of formation.*

[1] Dall, Bull. U.S. Geol. Surv., no. 84, 1892, p. 235; Ann. Rep., XVII, 1, p. 783. Russell, in spite of grave doubts, has described the Pinnacle system as older than Yakutat; Novarese has pointed out this uncertainty. The statement is possibly based on the lie of the beds, which is to all appearance reversed.

[2] Russell, Nat. Geogr. Mag. Washington, 1891, III, first report, p. 170 et seq.

[3] Russell, Ann. Rep. U.S. Geol. Surv., 1892, XIII, 2, second report, p. 24 et seq.

There is evidence to show that during repeated earthquake shocks in September, 1899, an elevation of the land took place, about Yakutat bay, to an extent which exhibited great local variation. The greatest displacement affected the west coast of Disenchantment bay, and is not less than 14·4 meters. This case, and that of San Francisco, are probably the most thoroughly investigated cases of true tectonic movement in our own times [1]. In their irregularity they offer an instructive contrast to the eustatic strandlines.

The Alexander archipelago. As the great batholite approaches the sea the Elias range rapidly diminishes in height. In the archipelago, which lies on the same strike, Baranov island alone reaches a height of 1,000 to 1,200 meters. In Kreuzov island, west of Baranov island, rises the isolated volcano of Edgecumbe [2]; all the rest of the archipelago follows, in long lines, the south-easterly strike, which corresponds nearly, if not exactly, with the western boundary of the batholite. In the north, down to lat. 57° N., our knowledge of the batholite has been considerably advanced by Spencer's investigations of the gold region of Juneau, and by those of C. W. Wright in the Admiralty islands; in the south, from about lat. 56° to 55° N., by the description of the Ketchikan district, in Revillagigedo island, by Brooks [3]. The following conclusions may be regarded as making some approximation to the truth.

The batholite is believed by Spencer to have arisen by the coalescence of several bodies; its rocks are described by him sometimes as granite, sometimes as diorite (quartz-diorite and other species). Its western border is accompanied by contact phenomena and ore deposits. This zone is often traversed by sills, and some of these intercalations pass into bands of pure hornblende. In the north, still within this zone, Carboniferous fossils occur, very probably indeed upper Carboniferous [4]. The entire zone dips towards the north-

[1] R. S. Tarr and L. Martin, Recent Change of Level in Alaska, Geogr. Journ., 1906, XXVIII, pp. 30–43; and Bull. Am. Geol. Soc., 1906, XVII, pp. 29–64, maps. Tarr made an attempt to reach Russell's high-lying glacial beds, but was prevented by remarkable changes which had taken place in the glaciers in the summer of 1906, Bull. Geogr. Soc. Phil., Jan. 1907.

[2] Notwithstanding statements to the contrary, activity in the historic period (here very short) is not established. G. F. Becker, Reconnaissance of the Gold Fields of South Alaska, Ann. Rep. U.S. Geol. Surv., XVIII, 3, pp. 1–86, maps, in particular p. 12. The lavas of Mount Edgecumbe are described by Szachno, Trav. Soc. Nat. St. Pétersbourg, 1895, XXIII, pp. 97–100 (in Russian).

[3] A. C. Spencer, The Juneau Gold Belt, Alaska, and C. W. Wright, A Reconnaissance of Admiralty Island, Al., Bull. U.S. Geol. Surv., no. 287, 1906, 154 pp., maps; A. H. Brooks, Preliminary Report on the Ketchikan Mining District, Alaska, U.S. Geol. Surv. Profess. Papers, no. 1, 1902, 120 pp., maps, in particular p. 14 et seq.

[4] On the existence of a basic marginal zone, cf. F. E. Wright, Lode Mining in South-East Alaska; in Brooks' and other reports on the progress of the investigation of the mineral resources of Alaska in 1905, Bull. U.S. Geol. Surv., 1906, no. 284, pp. 30–54,

east *beneath the grano-diorite*, and the same is true of all the sediments in the north for a breadth of 16 to 22 kilometers; then, at a greater distance, folding occurs. In the folds of the southern part of Admiralty island upper or Permo-Carboniferous fossils have been found, and in several places lower Carboniferous also, while more to the west, along the west shore of Chatham strait, upper Silurian fossils as well as lower Carboniferous occur. Some limestones in the west of Baranov island also are believed to be Silurian. They probably represent the continuation of the Palaeozoic beds in Glacier bay (lat. 58° 40′ N.). Intrusive rocks traverse the islands in many long strips, and are particularly evident in Tshitshagov island, and some of the islands to the south.

This folded series, which strikes with great regularity to the south-east, is unconformably overlain by Neocomian with Aucella. The Neocomian is also folded into the older series, and a strip thus folded in occurs to the north-west of Juneau; it has been traced down to the south of Admiralty island.

The great constancy of the strike, notwithstanding all the differences in relief, shows that all the mountain-land from the lower course of the Copper river across the Elias range and down past lat. 55° N. must be regarded as a single element.

The overthrusting to the south-west, which characterizes the Elias range, is also to be seen in the batholite, at least in its northern part. This also explains the fact that it assumes in places a gneiss-like structure. But the Cenomanian here lies horizontal, and the folded, petroleum-bearing Tertiary outer border of the Elias range is so far unknown outside the Archipelago. This may indicate that the true continuation of the Elias range must be sought for out to the sea.

In the fault trough of Wrangell we found a definite series, beginning with the Nikolai greenstone and upper Carboniferous, followed by Mesozoic, with an unconformity at the base of the Neocomian, and completed by the volcanos and granodiorite. This we regarded as the succession of the Intermediate range. It is continued through the Skolai range into the Alexander archipelago, but the Elias range, its companion on the west, disappears, and it attains a very great breadth, while the Rocky mountains are continued much further to the south, and are folded towards the east, that is, in the opposite direction.

Thus, the last traces of Asiatic influence disappear in the west, and from the Queen Charlotte islands onwards we see that oblique arrangement of the chains in coulisses which gives its characteristic outline to the west coast of America.

map. For the distribution of Palaeozoic faunas, E. M. Kindle, Geol. Journ., 1907, XV, pp. 314–337. The European character is a striking feature.

4. Continuation of the Intermediate range.

The Vancouver range. Here Dawson's observations enable us to distinguish three regions which succeed each other towards the south. The first of these is Graham island, in the Queen Charlotte archipelago; the second is a very long zone of Cretaceous beds, which starts from Skidegate inlet; the third comprises the whole of the south of the archipelago, along with Vancouver, and forms a peculiar mountain system, known as the Vancouver range.

Some reefs of trachyte porphyry, accompanied by a Cretaceous belt with Inoceramus, form the north-western extremity of Graham island. Then follows a broad plain of Tertiary and still more recent sediments, with peaks of some elevation formed of Tertiary eruptive rock. On the north coast, as at so many points on the border of the North Pacific, we see marine Tertiary resting on lignitiferous beds.

This plain is bounded on the south by a strip of Cretaceous, which strikes obliquely through the archipelago towards the south-east, bounds the greater part of Skidegate inlet, and near lat. 53° N. reaches by its southern border the east coast. It forms the beginning of a long series of Cretaceous fragments which extend sometimes closely in-folded, sometimes let down into fault-troughs, with an almost constant strike to the south-east; they are known on the east coast of Vancouver, in Queen Charlotte sound, in the strait of Georgia, Juan de Fuca strait, and still further towards the south-east, or, altogether, through more than 6 degrees of latitude. Coal-seams frequently occur [1].

To the north, in Queen Charlotte archipelago, the series begins with the Knoxville stage (Neocomian); as in Alaska, it is separated from its basement by an unconformity. It reaches Vancouver, and traces of it have even been met with in Seattle (Washington). Further south, the younger stages of the Cretaceous occur in transgression, and exhibit litoral, and finally brackish-water characters. The coal-bearing series of Puget sound, part of which at least is of Laramie age, is much younger than that of the Queen Charlotte islands. As the transgression increases, Indian and European species make their appearance in the fossil faunas. The Knoxville stage, with Aucella, still bears a northern stamp. The Horsetown stage, which follows next, contains in its upper beds *Schloenbachia inflata* and *Lytoceras Sacya*; it is covered by the Nanaimo stage, which, according to

[1] G. M. Dawson, Queen Charlotte Islands, Geol. Surv. Can. Report of Progress (1878–1879) 1880, B, 239 pp., maps; Geological Examination of the North part of Vancouver Island and adjacent coasts, op. cit., new ser., II, 1887, B, 129 pp., maps; for Puget Sound, J. P. Kimball, Physiographical Geology of the Puget Sound Basin, Am. Geol., 1897, XIX, pp. 225–237, 304–322; Bailey Willis, Some Coal Fields of Puget Sound, Ann. Rep. U.S. Geol. Surv., XVIII, 3, 1898, pp. 399–444, map.

Whiteaves and Kossmat, contains species of the Indian Ariayalur group and the Senonian of Sachalin [1].

In the Queen Charlotte islands the beds containing *Schloenbachia inflata* are overlain by a thick conglomerate, followed by marl and sandstone with *Inoceramus labiatus*.

As the Cretaceous advances step by step from the north, so manifestly the marine Eocene enters Puget sound from the south, and there invades the region of the brackish upper Cretaceous. A similar example on a smaller scale occurs in Europe, where the strait of Brünn is first entered by the Bohemian Cretaceous coming from the north and then by the Viennese Second Mediterranean stage coming from the south.

To the south-west of the Cretaceous lies the Vancouver range. The southern part of the Queen Charlotte archipelago is mountainous (1,500 meters) like Vancouver. Here as there, only Trias fossils have so far been found, if we except some doubtful traces of Carboniferous. The mountains are formed of shales with layers of limestone, and accompanied by thick sheets of diabase or diorite. Thus this Trias presents the same composition as that which occurs far to the north, near the sources of the Indigirka. The Trias range seems to extend from Juan de Fuca strait as far as the latitude of Skidegate inlet, i. e. from lat. 48° 30′ N. nearly to 53° 30′ N.; it strikes regularly to N. 35° W., and then in the north somewhat more to the west. Indeed, in Skidegate inlet a strike to N. 67° W. prevails over a considerable distance, and it seems almost as though the bend of Chugatsk were about to be repeated thus far in the south.

The islands in the strait of Georgia, such as that of Texada and others, show that a close connexion exists between the border of the great batholite and rocks which are correlated, though with some uncertainty, with those of Vancouver. But even in the east of Vancouver itself Dawson observed a broad intrusive belt, which included innumerable fragments of the neighbouring rock, and, both to the south and along the west coast, comparatively recent intrusions of granitic rocks occur [2]. The interior of the great island is unknown.

If any conclusion is possible, it would seem that the Vancouver range is not a continuation of the Alexander archipelago, but a range lying to the west of the great batholite, similar to the Intermediate range. The only feature it has in common with the islands of the Alexander archipelago is the unconformable transgression of the Neocomian.

[1] F. Kossmat, Jahrb. k. k. geol. Reichsanst., 1895, XLIV, pp. 471 et sqq.; and J. F. Whiteaves, On some additional Fossils from the Vancouver Cretaceous, Geol. Surv. Canada, Mesozoic Fossils, I, pt. 5, 1903, pp. 309–415.

[2] A. Webster, Geology of the West Coast of Vancouver Island, Ann. Rep. Geol. Surv. Canada (1902–1903) 1906, XV, A, pp. 54–76, and E. Haycock, tom. cit., pp. 76–92, in particular p. 84.

The Interior Plateau. This region, lying to the east of the great batholite, extends, according to G. M. Dawson, for a distance of 800 kilometers towards the north-west; it possesses a mean breadth of 160 kilometers, and a mean height of 3,500 feet; it is higher in the south than in the north. In its middle part and almost up to both its borders it consists of broad fragments of tableland, separated by deep denudation valleys, and built up of two thick sheets of lava and ashes. In its southern part, up to some distance beyond lat. 51° 15′ N., where investigation has been carried furthest, Dawson distinguishes the upper volcanic platform, presenting a vast horizontal surface, from which rise, strewn far apart, isolated hills, the remnants of eruptive cones—beneath this a Miocene freshwater deposit—resting in turn on the lower volcanic platform, and beneath this again a freshwater deposit which is probably Oligocene[1].

This Tertiary structure rests as a flat and even covering on the folded series of the Intermediate range, which strikes to the north-north-west. On the west side, next the batholite, we meet, as already mentioned, with upper Carboniferous and Trias, as well as the unconformable Knoxville stage; on the east side, next the gneiss of the Golden ranges (Rocky mountains), only Trias is so far known; the lists of fossils leave it an open question as to whether Lias is also present. Very thick masses of volcanic rock, chiefly diabase, accompany the upper Carboniferous and Trias.

In this tableland, also, large areas remain unexplored, and the east boundary of the batholite in particular may have many unexpected facts to reveal. In the Telkwa valley (lat. 55° N.) Leach observed in the eastern part of the batholite very thick volcanic masses (Cretaceous?) overlain by coal-bearing beds; they are themselves traversed by dykes, and the whole, in contrast to the tableland, is intensely folded[2].

Transverse section in lat. 49° N. This line, the boundary of the United States and Canada, has been made the subject of special investigation by the geologists of both countries, with a view to determining the degree of correspondence between the north and south. Although the tectonic unity of the chief subdivisions has been placed beyond doubt, yet it is clearly apparent that the orographic and the tectonic classification frequently fail to correspond.

In Washington and Oregon the expression 'Coast range' has come into use for the recent volcanic Cascade range; it is as distinct from the Coast range of Columbia as from that of California. If we inquire into the application of the name 'Cascade range' we find that in following the

[1] G. M. Dawson, Presidential Address, Bull. Am. Geol. Soc., 1901, XII, pp. 57–92; for details, Camloops Sheet, Geol. Surv. Can. Report of Progress for 1894, new ser., VII, 1897, B, 451 pp., map.

[2] M. W. Leach, Telkwa Mining District, Geol. Surv. Canada Summ. Rep., 1906, pp. 35–42.

orographic range to the north this has been extended to ranges of the most diverse kind. The *Hozomeen* mountains, which in long. 121° 4′ W. form one side of the valley of the Skagit, are regarded in the north as the main body of the Cascade range, and the *Okanagan* mountains, situated to the east of it, as a secondary range. The former of these is a steeply-upturned series of Mesozoic beds, striking north and south; the second consists of a heterogeneous intrusive rock [1].

This is followed on the east by a region which is known as the Interior plateau; it is the natural continuation of the highland discussed above under this name, but Daly, who is best acquainted with these mountains, points out that no plateau exists here, and the designation is therefore incorrect.

The most important tectonic boundary, that of the Rocky mountains, has the least effect on the relief. —

From a tectonic point of view two chief groups may be distinguished, namely, the Intermediate range—characterized by a series ranging from the upper Carboniferous upwards, through grano-diorites and volcanos—and the Rocky mountains, with gneiss and a thick lower Palaeozoic series. According to Daly's orographic classification [2] we must include in the Intermediate range Vancouver, the Coast range, the Cascade range, the Interior plateau, and a part of the Columbian system; in the Rocky mountains, the remaining part of the Columbian system, Selkirk mountains, Cœur d'Alène mountains, Purcell range, and the Rocky mountains proper.

At this point, where the so-called Coast range crosses lat. 49°, south of the bend of the Fraser river, Daly's accounts [3] describe its basement as formed of thick, folded, Crinoidal limestone and highly altered rocks. In the region extending from this point to the Similkameen river and the Hozomeen range, both Daly and Camsell [4] mention altered rocks, which sometimes present an appearance of great age, and then grano-diorites accompanied by patches of lower Cretaceous, younger lavas, and Tertiary beds. The Hozomeen mountains, which we have already described as a range of steeply-upturned Mesozoic beds striking north and south, rise to their highest point (9,000 feet) immediately above the place where the Skagit crosses the boundary.

On the river Pasayten (right tributary of the Similkameen) a diversified group of intrusive rocks is visible beneath an unconformable covering of

[1] G. O. Smith and F. C. Calkins, Geological Reconnaissance across the Cascade Range near the 49th parallel, Bull. U.S. Geol. Surv., no. 235, 1904, 103 pp., maps.

[2] R. D. Daly, Nomenclature of the North American Cordillera between 47th and 53rd Parallels of Latitude, Geogr. Journ., 1906, pp. 586–606, map; and Bull. Am. Geol. Soc., 1906, XVII, p. 332.

[3] R. D. Daly, Ann. Rep. Geol. Surv. Canada (1901) 1905, XIV, A, pp. 39–51; op. cit. (1902–1903) 1906, XV, A, pp. 139–149, and AA, pp. 91–100.

[4] C. Camsell, Similkameen District, Summ. Rep. Geol. Surv. Canada, 1906, pp. 43–55.

lower Cretaceous. From this point it follows the 49th parallel towards the east as far as lake Ossoyous (long. 119° 30′ W.), that is, for a distance of 90 to 100 kilometers. It belongs to the *Okanagan* mountains. Daly has made it the subject of an instructive paper. Seven intrusions succeeding each other, from the Carboniferous (?) into a late stage of the Tertiary, have here formed a composite batholite; they decrease in density and increase in silica contents in serial order from below upwards (gabbro 2·959, and dunite 3·173, to granite 2·608). The intrusion was accomplished by absorption of the adjacent rock [1].

This gives us a clear insight into the nature of one of those great masses which are at present known under the general name of grano-diorite. The mining districts, which lie towards the east, on the Kettle river, and no doubt those near Rossland also, have been studied by Brock, and show that similar intrusions are repeated as far as Columbia [2]. At the same time, rocks which we may regard as Archaean begin to make their appearance in this region, and acquire more and more importance. They are not unknown further to the west, but observers express doubts as to whether they may not be sediments altered by contact. From about Christina lake onwards (long. 118° 15′ W.), granite of apparently greater age is associated with them, and then, according to our present knowledge of the facts, they give place on the north to a vast extent of gneiss, biotite schist, and the like. The range is of great height (mount Gladsheim in the Valhalla range, lat. 49° 46′ N., long. 117° 36′ W., 2,826 meters); it is known as the *Gold range*, and we may regard it as forming part of the Rocky mountains. It is not separated by any important fracture from the Intermediate range. We have already observed that intrusions are not absent, but masses of andesite also occur, and at some localities, as about the sources of the north fork of the Kettle river (lat. 49° 36′ N., long. 118° 20′ W.), they rest on sandstone and river pebbles, apparently of Tertiary age. Here, where they rest on the Gold range, they may be regarded as outliers of the Interior plateau. Whiteaves has shown that remains of Amyzon, a genus of fishes, described by Cope from Nevada and Colorado, also occur up to lat. 52° N. and beyond (Horsefly beds), and reveal the presence of an extensive freshwater region of Oligocene age [3].

Between long. 117° 30′ and 117° 15′ W., lat. 49° N., we encounter those thick sediments of pre-Cambrian and Cambrian age, which in these latitudes form the greater part of the Rocky mountains. These mountains are here

[1] R. D. Daly, Okanagan composite Batholith of the Cascade Mountain System, Bull. Am. Geol. Soc., 1906, XVII, pp. 329–376.

[2] R. W. Brock, Preliminary Report on the Boundary Creek District, Ann. Rep. Geol. Surv. Canada (1902–1903) 1906, XV, A, pp. 92–138; Operations in the Rossland Mining District, Summ. Rep., 1906, pp. 56–65.

[3] Whiteaves, Age of the Horsefly, Similkameen and Tranquille Tertiary Beds, Summ. Rep. Geol. Surv. Canada (1905) 1906, pp. 137–138.

generally more than 2,000 meters high, and of sharp, jagged outline; they are known as the *Selkirk range*[1].

The first zone crossed by Daly consisted of coarse conglomerate, arkose, volcanic breccias and flows, quartzites, sandstones, and slates, with a few thin intercalations of crystalline limestone. This zone forms the *Quartzite range,* and is *completely overturned towards the west*, with a north and south strike, and a dip to the east of 70° to 85°. The beds, of great thickness, are traversed by flaws and thrust-planes. On the Priest river (long. 116° 56′ W.) they rest unconformably on crystalline schist, with thick intercalations of amphibolite, and include a granite batholite. This older zone extends into the neighbourhood of the Kootenay river. It is cut off on the east by a fracture, along which another quartzite series, of great thickness and composed of gray, heavily-bedded quartzites, is let down.

This quartzite series forms the beginning of that stratified succession, described in the section (fig. 32) between lat. 51° and 51° 30′ N., which, after forming a syncline probably overfolded towards the west, passes into the great overfoldings turned towards the east, and dominating the whole eastern part of the Rocky mountains.

The fracture of Kootenay led Daly to inquire whether the elongated Kootenay lake is a fault-trough or the result of river excavation. Its depth (533 meters) renders the former supposition probable. Several others of the long, narrow lakes, lying more or less in the strike and running for the most part north and south, show similar depths (Locan lake, 536 meters; Lower Arrow lake, 420 meters; and others).

The Cascade range (I, p. 587). A part of the range known in the north under this name, the Okanagan mountains for example, is the exposed basement of a considerable chain of recent volcanos, which is designated in the south by the same name.

The *Olympian mountains,* with cape Flattery, in the west, are but little known. The reports of foresters on this thickly-wooded region assign a height of 2,484 meters to mount Olympus. Granite has only been observed in boulders, and neither schist nor porphyry is known to occur. But since gold and copper have been mined here, we may suppose that rocks are present of greater age than those revealed by Arnold's investigation along the coast, where only Jurassic (?), a thick Cretaceous sandstone, and Tertiary are mentioned as occurring[2].

[1] See on this subject Daly's Report of 1906, AA, pp. 91 et sqq.; and McConnell and Brock's map of West Kootenay, 1904.

[2] A. Dodwell and T. F. Rixon, Forest Conditions in the Olympian Forest Reserve, U.S. Geol. Surv., 1902, Profess. Papers, no. 7, 110 pp., map; R. Arnold, Geological Reconnaissance of the Coast of the Olympian Peninsula, Bull. Am. Geol. Soc., 1906, XVII, pp. 451–468.

Let us return to the point at which the Skagit river, following the western face of the Hozomeen range, crosses lat. 49° N. West of the river lie the *Skagit* mountains. This range broadens out south of lat. 49°, and is then cut across by the river Skagit. On the west it terminates suddenly in the direction of the plain near long. 122° W. It is diversified in form and composition. Granite, andesite, and Jurassic (Stephanoceras, Aucella) are known. On the north the strike is N. 30° W.; north of mount Shuksan it becomes N. 40° W., and in the south due north and south. At the place where the Columbia river again turns towards the south, near long. 120° W., and at the same time marks the boundary between the southern spurs of the Skagit range and the lava floods B. Willis and Otis Smith observed very recent folds which involve the young basaltic sheets; these are cut through by several rivers, of which the Yakima is one.

A little to the west, crossing a range which is still part of the Skagit mountains, begin the great volcanos of the Cascade mountains. They extend through nine degrees of latitude, from mount Baker in the north to Lassen peak in California. The principal direction is north and south; in the south it becomes south-south-east. Intercalated sediments lead us to suppose that some of the flows are of Eocene age. In the Miocene period there was great activity, and isolated craters are still smoking at the present day [1].

Many of the northern volcanos are seated on granite. *Mount Baker* (3,299 meters), mentioned above, which rises north of the Skagit river, is an andesitic volcano seated on light-coloured granite. South-east of this lies *Glacier peak* (3,172 meters), the remains of an andesite volcano, also on granite; mount *Stuart* (2,886 meters) is not a volcano, but is formed of granite. Further south, according to Russell and O. Smith, the cone of mount *Rainier* (4,327 meters) consists of white granite up to a height of 8,000 feet (2,438 meters) [2].

We may safely assert that this granite is not all of great age. Of the great batholite, which includes mount Stuart and forms the rugged Wenache range, it can only be said that it is older than the Eocene, but to the west of this batholite, on *Snoqualmie pass*, a little north of the point

[1] Bailey Willis, Changes in River Courses in Washington Territory due to Glaciation, Bull. U.S. Geol. Surv., no. 40, 1887, VI, pp. 477–480, maps; and in particular G. Otis Smith and B. Willis, Contribution to the Geology of Washington, Profess. Papers, no. 19, 1903, 101 pp., maps, and G. O. Smith, in Journ. Geol. Chicago, 1903, XI, pp. 166–177. I. C. Russell, Geological Reconnaissance in Central Washington, op. cit. Bull., no. 108, 1893, regards the hill ranges in question as segments unilaterally let down; Preliminary Paper on the Geology of the Cascade Mountains in Northern Washington, Ann. Rep. U.S. Geol. Surv., XX, 2, 1900, pp. 89–210, maps; J. E. Spurr, Ore Deposits of Monte Cristo, Washington, op. cit., XXII, 2, 1901, pp. 785-865, maps.

[2] I. C. Russell, Glaciers of Mount Rainier, with a paper on the Rocks of Mount Rainier, by G. Otis Smith, op. cit., XVIII, 2, pp. 349-423, maps.

where the railway running to Seattle crosses the Cascade range, Otis Smith and W. Mendenhall came on a great batholite of Miocene age. Shales with leaves of Acer, Platanus, and Cinnamomum are converted into a hornfels-like rock in the zone of contact. Epidote, garnet, and turmaline occur in this zone. The intrusive rock resembles granite, but diorite also occurs and cannot be separated from it. Granite veins, very rich in quartz, penetrate the adjacent rock, and *one of them invades an overlying andesitic lava* [1].

In the face of these facts *the distinction between the granite* or granodiorite *batholites and the andesite volcanos disappears.* The great batholite of Columbia becomes a cicatrix which may once have borne volcanic cones.

Towards the south, first the continuations of the Skagit range, and then the granites disappear. To the south of the Columbia river the high and continuous chain of lavas and ejectamenta extends throughout Oregon unbroken by a single transverse valley. Near lat. 43° N. it bears on its surface *Crater lake* (1,901 meters) 9·9 kilometers in length and 6·8 kilometers in breadth; this has been produced by the collapse of the volcano *Mazama,* the ruins of which still rise 600 meters above the lake [2].

Far away in the east, a vast region of effusion, one of the most extensive in the world, starts from the Yellowstone, and proceeding to the west extends right across the mountain land. At first it follows the Snake river, but soon spreads out, includes on the north the lava-fields of the Columbia river, on the south covers the greater part of Oregon and considerable areas in Idaho, and encroaches to the south on the extensive desert region of the Basin ranges (I, p. 577).

Russell's descriptions of the lava fields of Oregon are instructive in more respects than one. The *Stein mountains* (lat. 42° to 43° N., long. 118° to 119° W., 9,000 feet), situated in south-east Oregon, on the east boundary of the desert basin, form an oblique-lying block which extends for a distance of 160 kilometers towards the north-north-east, and exposes in a steep escarpment on its east side, 5,000 feet high, numerous lava-flows, separated by 17 intervening beds of sandstone. In some tracts volcanic centres are so numerous that we may count as many as fifty from one point of outlook [3].

[1] G. O. Smith and W. C. Mendenhall, Tertiary Granite in the North Cascades, Bull. Am. Geol. Soc., 1900, XI, pp. 223–230.

[2] J. S. Diller and H. B. Patton, Geology and Petrography of Crater Lake, National Park, U.S. Geol. Surv. Profess. Papers, no. 3, 1902, 167 pp., maps; for Miocene intercalations, Diller, Bohemia Mining Region of West Oregon, Ann. Rep. U.S. Geol. Surv., XX, 3, 1900, pp. 1–52, in particular Knowlton, ibid., p. 47 et seq.; also the works on the John Day and Payette Formations.

[3] I. C. Russell, Notes on the Geology of south-west Idaho and south-east Oregon, Bull. U.S. Geol. Survey, no. 217, 1903, 83 pp., maps; Preliminary Report on the Water Resources of Central Oregon, op. cit., no. 252, 1905, 133 pp., maps.

Idaho. In north-east Oregon the *Blue mountains*, with their irregular contours, rise out of the lavas. According to Lindgren's description they are not a chain lying in the bend of the Snake river, as they are represented on some maps, but a part of the mountains of West Idaho, cut off from them by the long cañon of the Snake river, but not tectonically distinct. They consist of several ranges which are united orographically by lavas. The most important are the *Elkhorn* and *Greenhorn* mountains, west of Baker city; further to the north-east rise the *Eagle Creek* mountains. The last-named possess rounded contours, attain a height of 9,000 feet, and are enveloped by lava up to a height of 4,000 or 5,000 feet. The heights of the Elkhorn and Greenhorn mountains present similar features. Smaller hills rise like islands out of the lava [1].

Within these folded ranges doubtful upper Carboniferous, marine Trias, in the west a trace of Lias also [2], and on the John Day river Cretaceous, have been determined on the evidence of fossils. At one locality in the Elkhorn mountains Lindgren believes he has recognized Archaean gneiss. The gloomy cañon of the Snake river is 5,000 feet deep. The upper half of the ravine consists of basalt, and the lower of dark Halobia shales, which, as usual, are accompanied by basic intercalations. On the west side of the river there are points at which the shore line of the lava floods reaches a height of 7,000 feet (2,133 meters). The height of the river above the cañon, near Weiser, is 646 meters.

The most remarkable of Lindgren's results is the evidence that in West Idaho the range is cut through by an intrusive batholite of granodiorite, which repeats the characters of the Columbian batholite; it runs to the north, is of post-Trias age, and attains in places a breadth of over 150 kilometers [3].

On the south this batholite first makes its appearance in the *South mountain* (8,000 feet, near lat. 42° 45′ N.). It is continued towards the north through Silver City into the *Owyhee* mountains, and its western border is crossed by the Snake river, near Boise (west of long. 116° W.) The east border lies at a great distance from the west, and its outskirts extend to Hailey (west of long. 114° W.) and beyond. Further north its eastern part forms the whole range of the *Bitterroot* mountains, as far as Lolo pass (lat. 46° 35′ N.), where it encounters the ancient sediments of the Cœur d'Alène mountains, which are included in the Rocky mountains. It has thus been traced through nearly four degrees of latitude. Towards the west its northern part disappears beneath the lavas of the Clearwater.

[1] W. Lindgren, Gold Belt of the Blue Mountains of Oregon, U.S. Geol. Surv., XXII, 2, 1901, pp. 551–782, maps.

[2] A. Hyatt, Bull. Am. Geol. Soc., 1894, V, p. 400.

[3] W. Lindgren, Gold and Silver Veins of Silver City, de Lamar and other Mining Districts in Idaho, Ann. Rep. U.S. Geol. Surv., XX, 3, 1900, pp. 65–256, maps; A Geological Reconnaissance across the Bitterroot Range and Clearwater Mountains, Profess. Papers, no. 27, 1904, 123 pp., maps; for the disturbance, pp. 26, 47, 51.

Wherever its boundaries can be seen this granodiorite proves to be intrusive. At Hailey, Carboniferous fossils have been found near the zone of contact. The cañon of the Salmon river cuts across its breadth. It includes several great fragments of gneiss.

On the east side of the Bitterroot mountains, which is also the east border of the Mesozoic granodiorite, Lindgren describes a fault, striking north and south, over 90 kilometers in length, of great vertical throw, yet outcropping on a fairly level plain. Over the whole of this area the granodiorite slopes uniformly towards the east at an angle of 15° to 26°; in the south it slopes to the south-east, and on this descent it has been transformed into gneiss by a shearing movement. This younger gneiss is distinguished from the ancient gneiss by its nature and the absence of folding. Lindgren believes that either the whole of the eastern range has subsided with a slight inclination (the slope just mentioned), or else the western (lying) limb has been elevated. Phenomena in an adjacent mine have even led to the conjecture that the movement still persists at the present day. Some small eruptions of rhyolite accompany the line of disturbance.

The resemblance between the mountain-group of north-east Oregon and West Idaho (Blue mountains to Bitterroot) and those parts of the Intermediate range mentioned above is thus very great. At the same time, the petrographical succession is the same as that of the Basin ranges, the northern part of which we have already examined. Over a tract marked out by the continuations of the Canadian part of the Intermediate range in the west, which disappear between lake Chelan and the Yakima (east of mount Stuart and mount Rainier), and next by the place where the Blue mountains disappear in the east and where the granodiorite range of Idaho disappears in the northern part of the Basin ranges, down to the place of disappearance of the Californian mountains to be discussed below, there exists, as we believe, a broad depression, an interruption of the Intermediate range, now concealed by lavas.

CHAPTER XII

THE APPEARANCE OF THE ANDES

Klamath. Californian Coast ranges. Lower California. South border of the Colorado plateau. Mexico. Stratified succession of the Intermediate range.

Klamath. The Intermediate chain, broken up into a sea of sub-meridional ranges, is represented in the United States chiefly by the Basin ranges, which occupy the region, 600–700 kilometers in breadth, between the western slope of the Wasatch and the eastern slope of the Sierra Nevada (I, p. 577). The Sierra Nevada may even be included in them. With the longitudinal valley of the Sacramento, however, a great change sets in, and we may regard the Californian Coast ranges on the western side of this valley as the beginning of the mighty structure of the Andes. It is impossible, it is true, to draw a perfectly sharp boundary; some members of the sedimentary series extend from one region to the other, and in the north observers are not completely in accord.

The sketch map by Diller (fig. 34) represents the topographical distribution of the most important tectonic members [1].

The most southerly volcanos of the Cascade range, mount Shasta (4,384 meters) and Lassen peak (3,181 meters), are included in this map. Beyond them the country descends to the Sacramento, and in lat. 39° 15′ N. the great longitudinal valley lies only 30–45 meters above the sea. From this depression rises the little volcano of Marysville; whether or not it is to be included in the Cascade range may remain an open question [2].

The lavas reach the Sierra Nevada on the south-east; to the west of them lies a group of mountains which appears on the maps under several distinct names (Siskiyou, Salmon, Trinity mountains, and others); it is known by American geologists as the Klamath range. On the north, in south-west Oregon, it emerges from a girdle of younger deposits; in lat. 41° 30′ N. it becomes detached from the Californian Coast ranges. Thus we have here an encounter of the Sierra Nevada, the Cascade, Klamath, and Coast ranges. The position of the beds and the strike show *that the Klamath range is the continuation of the Sierra Nevada.*

[1] J. S. Diller, Topographical Development of Klamath Mountains, Bull. U.S. Geol. Surv., 1902, no. 196, 69 pp., map; also Geology of Lassen's Peak District, op. cit., Ann. Rep., 1889, VIII, pp. 395-432, maps; also map, op. cit., XIV, 2, p. 414, pl. XLV, et passim.

[2] Turner and Lindgren, Marysville folio, 1895.

On the north, in south-west Oregon, the Klamath mountains are surrounded by a broad Jurassic belt, characterized by *Aucella Erringtoni*. Starting not far from where the boundary of California reaches the sea, it strikes far away to the north-east, and dips to the south-east, that is, beneath the older rocks of Klamath. Its most remarkable member is Diller's Dothan stage, composed of grey shales, which contain beds and lenticular

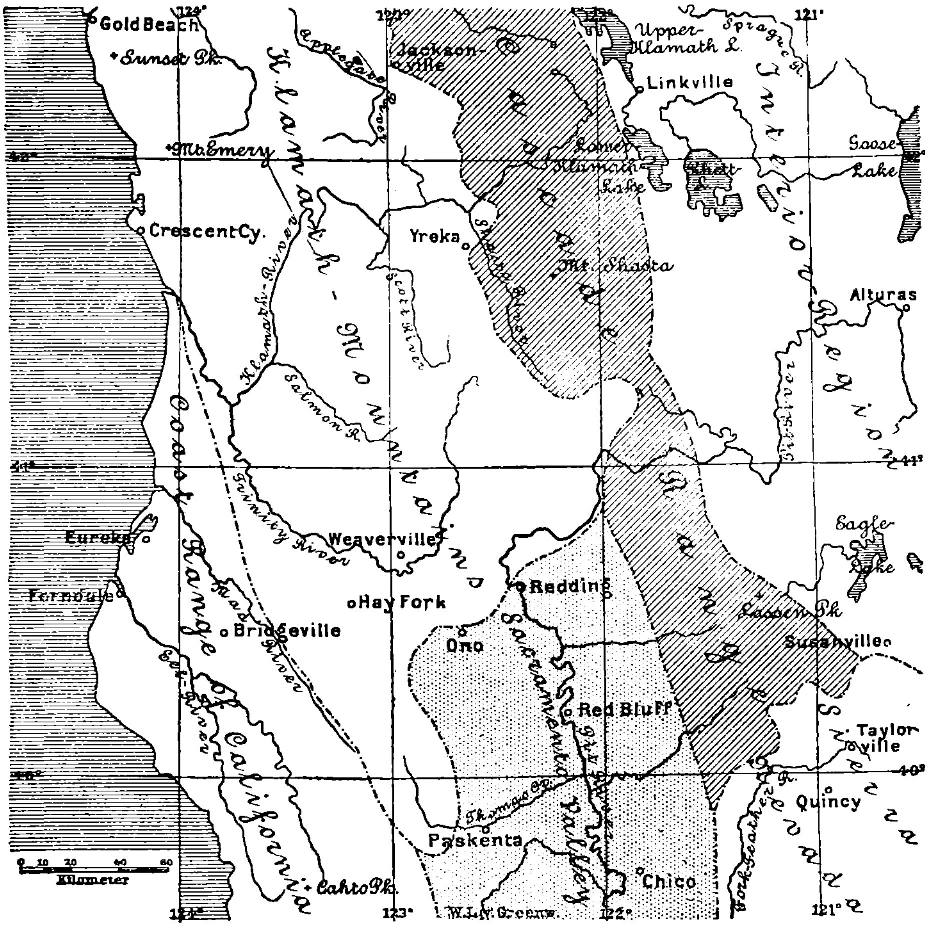


FIG. 34. *The Klamath mountains* (after Diller).

masses of red or green radiolarian chert[1]. Associated with these is the nickel-bearing peridotite ridge of Riddles, as well as many other intrusive

[1] J. S. Diller, Mesozoic Sediments of south-west Oregon, Am. Journ. Sci., 1907, 4 ser., XXIII, pp. 402–421; a somewhat divergent description by Louderback, Journ. Geol. Chicago, 1905, XIII, pp. 514–555. Plantbearing middle Jurassic also occurs; L. Ward, Status of Mesozoic Floras of the United States, 1905, Monograph XXXVIII, pp. 47–151. They are repeated near Oroville, California. As regards the lie I have no recent data.

ridges. Gold, platinum, and chromite occur in the basic intercalations: awaruite (nickel iron) has also been met with, as at Biella (near the range of Ivrea)[1]. The Jurassic rocks are folded, and the Neocomian (Knoxville stage) extends over them unconformably. There can scarcely be any doubt that this upper Jurassic belt, now interrupted by the sea, once surrounded the western side of the Klamath range.

Various accounts have been given of the Klamath range itself. Diller, starting from Redding in the south, observed a series extending to the Trinity river in the west, and for a great distance to the north and east, which consists of a pre-Devonian plutonic rock, Devonian and Carboniferous; to the east of this, with a more northerly strike, a pre-Trias intrusive zone, then, on the upper Pit river, Trias, followed by Jurassic. Hershey, coming from the west, divides the Klamath range into four flakes, dipping to the east and to some extent imbricate. The first line of overthrust would correspond with the western boundary of the Klamath mountains marked on fig. 34; here the radiolarian shales dip to the east beneath the older rocks of the Klamath mountains. The second line crosses the Klamath river (Orleans fault) near the mouth of the Salmon river; the third and fourth follow on as far as the Scott river. We will confine ourselves to the fact that the radiolarian series occurs on the Orleans fault also, where it is of great thickness, and still dips towards the east beneath older rocks. From this we may conclude that the overthrusting of the Klamath mountains upon the radiolarian series, which was observed in south-west Oregon, also occurs in the west, and that the radiolarian series enters into the structure of the Klamath mountains themselves[2].

This upper Jurassic series is represented in the Sierra Nevada by the Mariposa shales, which are also characterized by *Aucella Erringtoni* and intercalations of diabase and serpentine. Since our first description of this range (I, p. 581) it has been ascertained that the mass of granodiorite, which occupies the east of the Sierra, and from Mariposa onwards its whole breadth, is younger than the Mariposa shales. Its length extends over about 5 degrees of latitude, and its breadth in the south is more than 100 kilometers. South of the Kern river its southern extremity abandons

[1] G. F. Kay, Nickel Deposits of Nickel Mountain, Oregon, Bull. U.S. Geol. Surv., 1907, no. 315, pp. 120–127. Fragments of radiolarian rocks enclosed in serpentine and metagabbro are mentioned by Diller in the Roseburg folio, 1898; here blue amphibolite schist is mentioned as occurring in the Aucella-bearing Myrtle Formation. For awaruite, Jamieson, Am. Journ. Sci., 1905, 4 ser., XIX, pp. 413-415; for glaucophane, Nutter and Barber, Journ. Geol., 1902, X, pp. 738–744; also in particular Louderback, Journ. Geol., 1905, XIII, p. 534; and Carey and Miller, Journ. Geol., 1907, XV, pp. 152–169 (cf. Ransome, note 3, p. 423).

[2] J. S. Diller, Bragdon Formation, Am. Journ. Sci., 1905, 4 ser., XIX, pp. 379–387; O. H. Hershey, Some West Klamath Stratigraphy, op. cit., 1906, XXI, pp. 58–66. A part of Diller's pre-Trias intrusive zone would fall, if I am not mistaken, in that zone which is assigned in fig. 34 to the much more recent Cascade ranges.

the general direction to the south-east, and makes a bend south-west to the Tehachapi pass (lat. 35° 10′ N.).

The sediments which border the west side of its northern half are overfolded towards the west, and inclined beneath the batholite. One syncline was traced along the strike for almost 200 kilometers. Turner has given a section through the county of Amador, which shows the overfolding of the whole of this mighty series towards the west[1]. The beautiful maps of the Survey, for example Lindgren's map of Truckee, or Lindgren and Turner's maps of Smartsville, Jackson, and Placerville, show how frequently this series is penetrated by intrusive rock.

The correspondence of this granodiorite with that of Columbia was recognized by Lawson as early as 1893[2].

The Californian Coast ranges (I, p. 583). It has been shown, in opposition to early conjectures, that the granite of the Coast ranges is older than that of the Sierra Nevada. It is accompanied by gneissose schist, mica schists, crystalline limestone, and clay slates; and is of Carboniferous, or even greater age. The radiolarian rocks, alternating with sandstone, here form the *Franciscan series*, which rests, in the peninsula of San Francisco for instance, autochthonously upon the granite. It extends far to the south, and there, too, is accompanied by long intercalations of peridotite and other basic rocks. There also chromite, platinum, gold, and osmiridium are known to occur in them; they contain quicksilver. Fossils occur in the associated shales, but are rare (Aucella, Opis, Hoplites). This series is the equivalent of the Mariposa beds of the Sierra Nevada and the Dothan stage of Oregon. It was formerly regarded as Neocomian, by which it is covered unconformably. It extends southwards as far as Santa Barbara. With the exception of a few traces of upper Carboniferous species, Palaeozoic fossils have never yet been found beneath the Franciscan series; indeed this series seems to form, over large areas, the base of the normal succession. It is intensely folded. According to Ransome, the glaucophane schists which occur along with basic rocks have their origin in Radiolaria.

The Coast ranges, as we have already stated, strike obliquely out to sea in repeated coulisses directed to the north-west; some of the coulisses are bounded by long rectilinear dislocations.

One of these lines follows a direct course, running S. 35° E. from Punta Arena to mount Pinos, a distance of 600 kilometers. It enters the sea near the mouth of the Golden Gate of San Francisco, and, according to Lawson,

[1] Turner, Ann. Rep. U.S. Geol. Surv., 1894, XIV, 2, pp. 457, 486. A general map of the whole batholite is given by the same author in op. cit., 1896, XVII, 1, p. 532, pl. XVIII.

[2] A. C. Lawson, Cordilleran Mesozoic Revolution, Journ. Geol. Chicago, 1893, I, pp. 579–586.

its northern half was the starting-point of the devastating earthquake of April 18, 1906. This resulted from a horizontal displacement of the south-western part of the mountains, relatively to the north-eastern part, to the extent of about 10 feet in a north-west direction, and a simultaneous relative elevation of the same south-western part to a height which, in some places, reached 4 feet[1].

The other lines of dislocation have not been described in such detail, but we can distinguish without difficulty a series of coulisses, and also some recent volcanos which follow the strike fairly well and extend from Clear lake towards San Francisco bay[2].

The north is covered by a thick mantle of Tertiary beds, pierced through by the radiolarian beds of the Franciscan series, which stand out in sharp ridges. Granite first makes its appearance at Punta de los Reyes, north of San Francisco, and in the adjacent group of islands, the Farallones. This probably marks the beginning of the coulisse, which is cut off obliquely by the west coast of the peninsula of San Francisco. Lawson and Crandall's maps of this peninsula show how the several zones of rock, and the strike-faults by which they are accompanied, run out obliquely to the sea[3]. In the regions which succeed, the arrangement of the chains in coulisses has been described by Fairbanks. The granite of Punto de los Reyes and the peninsula of San Francisco runs towards the south-east through the sierras of *Santa Cruz* and *Gavilan* into the county of Monterey; its north-western extremity plunges into the sea, the south-western lies inland, east of the river Salinas.

East of this coulisse rises mount Diablo, as another independent range; it forms a regular anticline striking to the south-east, but along its axis only the Franciscan series and serpentine are exposed; its south-eastern continuation does not possess the orographic significance which many maps assign to it[4].

Of so much greater importance, however, is the chain of *Santa Lucia*, which lies west of the Salinas river, and rises steeply on the southern

[1] A. C. Lawson, Preliminary Report of the State Earthquake Commission, 8vo, 1906, 17 pp.

[2] G. F. Becker, Geology of the Quicksilver Deposits of the Pacific Slope, U.S. Geol. Surv., Monogr. XIII, 1888, passim.

[3] A. C. Lawson, Sketch of the Geology of the San Francisco Peninsula, Ann. Rep. U.S. Geol. Surv., XV, 1895, pp. 399–476, map; Leslie Ransome, Geology of Angel Island, Bull. Geol. Univ. Cal., 1894, I, pp. 193–240; G. H. Ashley, Neocene Stratigraphy of the Santa Cruz Mountains of California, Proc. Cal. Acad. Sci., 1895, 2 ser., V, pp. 273–376, map; Lawson and C. Palache, Berkeley Hills, a Detail of Coast Range Geology, Bull. Geol. Univ. Cal., 1902, II, pp. 349–450, map; R. Crandall, Geology of the San Francisco Peninsula, Proc. Am. Phil. Soc., 1907, XLVI, pp. 1–55, map.

[4] H. W. Turner, The Geology of Mount Diablo, California, Bull. Am. Geol. Soc., 1891, II, pp. 383–414, map; for the orography compare the little map in Eldridge, p. 366, pl. XLIV.

shore of the bay of Monterey. Its western flank, formed of crystalline limestone and of ancient, sometimes gneissose schist, descends sheer to the sea; its axis consists of granite; Fairbanks shows that this axis diverges at an acute angle from the line of the coast and runs towards the south-east, crossing obliquely the valley of the upper Salinas. Its further continuation lies east of San Luis Obispo, and in the direction of San Emidio and the Tejon pass. There it seems to form a junction with the chains striking towards the lower course of the Colorado river and Lower California [1].

Thus the Sierra Santa Lucia also extends far inland, but the coulisses which follow to the south of San Luis Obispo gradually change their direction. To the north of lat. 36° N., according to Fairbanks and Eldridge, the mean strike of the folds is N. 20°–40° W., near San Luis Obispo N. 50°–60° W., and near Point Concepcion N. 80°–90° W., so that only that part of the coast line which runs east and west near Santa Barbara follows to some extent the direction of the folds [2]. The coulisses which rise one after the other to the south of the continuation of Santa Lucia are largely formed of Miocene, but even in the Emidio chains this is folded, up to a considerable height. The Sierra *Santa Inez*, the most important of the east-and-west chains, at the foot of which lies the coast region of Santa Barbara, mentioned above, is formed entirely of Miocene; the Sierra *Santa Monica*, which also runs east and west, shows near Los Angeles a core of granite beneath the Miocene. It is continued in the islands of the Santa Barbara archipelago; they stand on a common base, elongated from east to west (San Miguel, Santa Rosa, Santa Cruz, Anacapa).

Fairbanks remarks, not without justice, that it seems as though a number of independent chains had been formed at different times, and as though the compressing and elevating forces had not always found expression along the existing axes, but had formed new axes beside them, or even in a divergent direction.

The east-and-west direction is not maintained, either towards the interior or towards the south.

The *Santa Anna chain*, which rises not far from Los Angeles, consists of several parallel anticlines, with a strike to N. 60° W., and runs a long

[1] H. W. Fairbanks, Review of our Knowledge of the Geology of the Californian Coast Ranges, Bull. Am. Geol. Soc., 1894, VI, pp. 71–102; also Lawson, Geology of the Carmelo Bay, Bull. Geol. Univ. Cal., 1893, I, pp. 1–59, map; Bailey Willis, Some Coast Migrations, Santa Lucia Range, California, Bull. Am. Geol. Soc., 1900, XI, pp. 417–432, map; E. F. Nutter, Sketch of the Geology of Salinas Valley, Journ. Geol., 1901, IX, pp. 330–336.

[2] The trendlines of this region are given in R. Arnold and R. Anderson, Preliminary Report on the Santa Maria Oil District, Bull. U.S. Geol. Surv., 1907, no. 317, 66 pp., map.

way towards the mouth of the Colorado river; Miocene, traces of Carboniferous or Trias, and crystalline schists are known in it.

The great Sierra *San Bernardino*, or *Sierra Madre*, which is the probable continuation of Santa Lucia, or else a new coulisse rising in close alternation, strikes parallel to the sierra of Santa Anna, and its northern border slopes away to the Mohave desert. The ancient basement crops out with increasing frequency; its covering is almost entirely of Tertiary age. Campbell crossed the Sierra Madre through the Cajon pass; a fault cuts across the strike of the chain at an acute angle and forms the southern margin, probably for a long distance, towards the south-east. South of the fault hornblende schist is observed, and north of it coarse grey granite, with a few patches of altered sediments. This is followed on the north by sandstone and conglomerate, thrown into gentle folds, and apparently of Eocene age, then towards the margin of a desert by a mighty belt of gravel. Here, at a height of 1,250 meters, lies the summit of the pass; Cajon cañon cuts completely across the ancient range [1].

Beyond the *Victor* and *Borate* ranges the desert land is covered by lacustrine deposits, containing at many places intercalations of borax-bearing beds, and here and there of younger lavas. These deposits are not of equal age; some are intensely folded, others undisturbed. Rubble formed by the disintegration of grey granite is present. There are short rocky ranges formed of the same granite or of highly altered sediments. Thus, we reach the region of the Basin ranges at the exit of *Death Valley*. This fault trough, according to S. Ball, is 190 kilometers in length, 8–16 kilometers in breadth, and sinks 123 meters below the sea-level; *Amargosa* chain and *Funeral* chain, on the east, are 1,500–2,000 meters high; *Paramint*, on the west, over 2,700 meters, and the fault trough appears to be one-sided, produced by a fracture on the east side of Paramint, and thus similar in structure to the Dead Sea in Syria. At the bottom lies a salt deposit [2].

We are now amidst the inbreaks of the Basin ranges. The ancient rocks occur here, but along with them mighty beds of Palaeozoic. At no great distance rise the *White mountains*, in which Walcott observed Cambrian fossils and overfolding towards the west [3]. The adjacent gneisses are certainly pre-Cambrian.

[1] M. R. Campbell, Reconnaissance of the Borax Deposits of Death Valley and Mohave Desert, Bull. U.S. Geol. Surv., no. 200, 1902, 23 pp., map; also E. W. Claypole, Sierra Madre near Pasadena; Bull. Am. Geol. Soc., 1901, XII, p. 494.

[2] S. H. Ball, Geological Reconnaissance in South-west Nevada and East California, Bull. U.S. Geol. Surv., 1907, no. 308, 218 pp., map.

[3] C. D. Walcott, Lower Cambrian Rocks in East California, Am. Journ. Sci., 1895, 3rd ser., XLIX, pp. 141–144; Appalachian Type of Folding in the White Mountain Range of Inyo County, tom. cit., pp. 169–174. The White Mountains form the east side of the trough of Owen Valley.

At El Paso peak, near the southern extremity of the Sierra Nevada, on the north-western margin of the desert, marine Eocene fossils have been found.

Lower California. The return to the north-westerly strike may be recognized in the contrast between the Santa Barbara islands, which run from east to west, and the more southerly islands, such as San Nicolas, San Clemente, and Santa Catalina, which are directed without exception to the north-west. They have been described by Lawson [1].

The mountain ranges lying east of San Diego exhibit rocks of granite and gneiss, bleached white by the weather. In front of these a platform

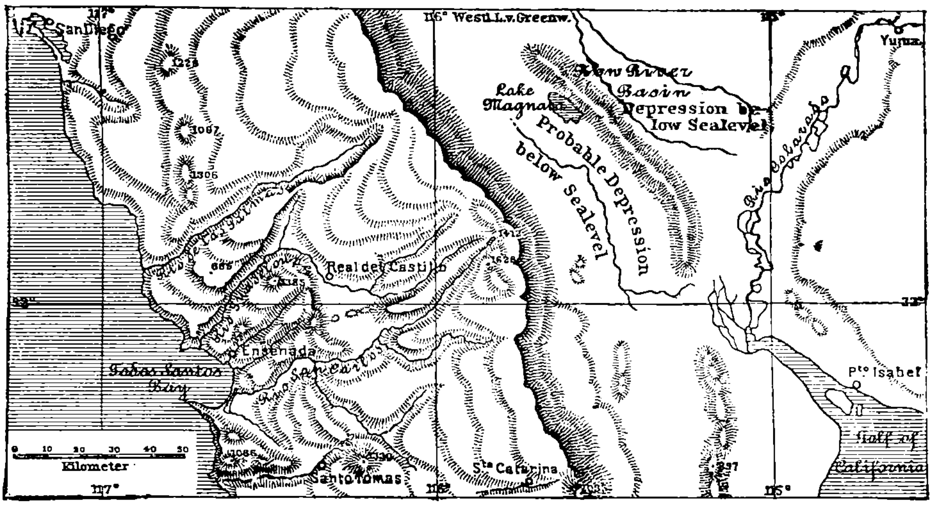


Fig. 35. *Mouth of the Colorado river* (heights in meters). (Approximate topography before the sea entered the depressions lying west of the Colorado river. After Lindgren.)

known as the San Diego mesa extends along the coast with a breadth of 19–20 kilometers, and a height above San Diego of 240 meters. It consists of marine Pliocene and a covering of river gravel; it is regarded as a Pliocene delta. Mount San Pedro (449 meters), south of Los Angeles, connected with the coast by a flat tongue of land, is formed of inclined Miocene; Santa Catalina (642 meters) consists of quartzite, diorite, and a much younger andesite; San Clemente (597 meters) for the greater part of the same andesite [2].

[1] A. C. Lawson, Post-Pliocene Diastrophism of the Coast of South California, Bull. Geol. Univ. Cal., 1893, I, pp. 115–160; W. S. Tangier-Smith, Geology of South Catalina Island, Proc. Cal. Acad. Sci., 1897, 3rd ser., I, pp. 1–71, map; Geological Sketch of San Clemente Island, Ann. Rep. U.S. Geol. Surv., XVIII, 2, 1898, pp. 461–496, map; Topographical Study of the Islands of South California, Bull. Geol. Univ. Cal., 1900, II, pp. 179–230, map; Smith and R. Arnold, Marine Pliocene and Pleistocene Stratigraphy of the Coast of South California, Geol. Journ. Chicago, 1902, X, pp. 117–138.

[2] San Pedro is divided into terraces up to a height of 366 meters, San Clemente up to

In our earlier attempt to represent the structure of lower California (I, p. 584) our information was restricted to one source, a memoir by Gabb. Since then observations have increased in number. With regard to the general structure Emmons and Merrill point out that the peninsula is directed to the north-north-west, while its mountain ranges run more to the north-west and give rise to bays on the west coast opening towards the north-west, so that the peninsula assumes a coulisse-like structure[1]. The mountains enter the peninsula from the region north of Los Angeles and east of San Diego, they occupy more than the western half of its breadth, reach a height of 1,500–2,000 meters near their eastern side, and, according to Lindgren's description, sink in a rapid descent to the depression of lake Magnata. Since that description was written engineering works have given the drainage of these mountains accidental access to the low-lying regions. A vast sheet of water has been formed, and much arable land flooded (Fig. 35)[2].

It was already known, from Gabb's account, that the peninsula consists of long granite ranges, separated from one another by flat mesas of sandstone, which partly covers them, both granite and mesas being frequently concealed by a flow of recent volcanic rock, and broken through, near lat. 27° 30′ N., by a recent group of volcanos (Tres Virgines and others).

On the coast near San Diego, Lawson and Fairbanks observed Cretaceous (Chico stage with *Coralliochama Orcutti* at the base) and Eocene (Tejon stage) underlying the Pliocene of the mesa; a patch of Cretaceous lies on the south side of Todos Santos bay. Between lats. 29° 30′ and 29° 20′, according to Emmons and Merrill, Cretaceous and Eocene still occur in the lower parts of the table mountains. White has remarked in connexion with the finds near San Diego that Cretaceous deposits with Atlantic (Texan) characters cross over to the west side of the Mexican Sierra Madre, while a very different Pacific type of Cretaceous predominates in California, and consequently the narrow hill range of lower California must have formed a dividing barrier in the Cretaceous seas[3].

402 meters; the fact that the intervening island of S. Catalina possesses no terraces or, according to T. Smith, only a few traces of them in the lower horizon, led Lawson to assume the existence of independent tectonic movements. Shaler (Bull. Am. Geol. Soc., 1895, VI, pp. 141–166) felt the inconsistency of this and assumed the existence of movements of the strand-line (somewhat as understood by Strabo or Chambers).

[1] S. F. Emmons and G. P. Merrill, Geological Sketch of Lower California, Bull. Am. Geol. Soc., 1894, XV, pp. 489–514, map, in particular p. 513; also Merrill, Notes on the Geology and Natural History of the Peninsula of Lower California, Rep. U.S. Nat. Mus. Washington (for 1895) 1897, pp. 969–994.

[2] W. Lindgren, Notes on the Geology of Baja, California, Proc. Cal. Acad. Sci., 1889, 2nd ser., I, pp. 173–196; McDougal, Delta of the Colorado, Bull. Am. Geogr. Soc., 1906, pp. 1–16, map; W. T. Lee, Geology of the Lower Colorado River, Bull. Am. Geol. Soc., 1906, XVII, pp. 275–284, map, et passim.

[3] C. A. White, Mesozoic and Cenozoic Palaeontology of California, Bull. U.S. Geol.

The northern part of the lower Californian range is formed on the west, along the coast, by a granite ridge, traversed by porphyry; this is followed by a series of depressions described as the 'interior valleys', and then, forming the eastern border, comes a very high and broad granite range. Gold-bearing river gravel occurs on the highest ridges. Towards the south the mountains become lower; on the east a new granite range rises from beneath the mesas. Thus the chains succeed each other in an alternating arrangement. Between the granite ranges zones of highly altered shales striking to the north-west are seen; jasper is also mentioned, but as frequent reference is also made to the radiolarian shales of the Franciscan series, said to occur in the coast ranges, it is possible that these rocks are of a similar kind.

The land at the head of the bay of *San Sebastian Viscaino* is a broad mesa, which runs obliquely through the peninsula.

The rocky island *Cedros* (Cerros, 1,205 meters, lat. 28° 20′ to 28° N.) consists of highly altered schist, amphibolite, and serpentine, together with granite porphyry. Basalt flows and fossil-bearing sandstones likewise occur. They are continued towards the south-east through the *Sierra de Santa Clara*, which stands completely isolated in a desert region, and extends as far as Punto Abrojos of Ballenas bay [1].

Inside of this coulisse the whole breadth of the peninsula consists of mesa and recent volcanic sheets. The remarkable copper-bearing sediments of *Boléo* (near the east coast) are, according to Fuchs, flat-lying Miocene [2].

South of lat. 25° N. the rocky cape of *San Lazaro* (395 meters), connected with the mainland by a littoral bar, runs out into the sea. This is joined by the islands *Magdalena* and *Santa Margarita* (578 meters), elongated towards the south-east and separated by lagoons from the flat mainland; these also consist of highly altered slates, serpentine, and other rocks, and Lindgren regards them as forming a second coulisse, similar to Santa Clara. Plain and mesa now extend along the east coast down to La Paz bay (lat. 24° 15′ N.), and on the west coast as far as Lobos point (lat. 22° 23′ N.)

The southernmost part of the peninsula is high land. The south-west as far as *cape San Lucas* consists, according to Gabb and Eisen, of granite; the peak of *Santa Genoveva* is said to reach a height of 8,000 feet. In the *Cacachilas* mountains the granite range runs to the north-north-west, east of the capital of *La Paz*, but the islands which lie in the same direction

Surv., no. 15, 1885, p. 30. Certainly the difference in Texas is great, but it is precisely the beds with *Coralliochama Orcutti* which show a certain resemblance to the upper Cretaceous of the Tethys, especially the Gosau beds, as is pointed out by White himself; New Cretaceous fossils from California, tom. cit., no. 22, p. 9.

[1] W. Lindgren, Proc. Cal. Acad. Sci., 1893, 2nd ser., III, pp. 25–33.

[2] E. Fuchs, Note sur les gîtes cuivreux de Boléo, Bull. Soc. géol. France, 1886, 3e sér., XIV; for the lavas of these regions, E. Ritter, Étude de quelques roches éruptives de la Basse-Californie, Arch. Sci. phys. et nat. Genève, 1895, 3e sér., XXXIII, pp. 330–344.

consist (at least for the greater part), like the east coast to the south of them, of volcanic tuff.

The valley of the San José bounds the great granite range on the south-east; here Gabb mentions crystalline schist. The extreme south-east of the peninsula, the *Sierra de Trinidad* (879 meters), is formed, according to Eisen's statement, of crystalline limestone [1].

Ordoñez and Aguilera, in accordance with the earlier view of Gabb, regard *the lofty southern part of the lower Californian peninsula as the continuation of the Mexican Sierra Madre del Sur through cape Corrientes and Las Tres Marias islands.* The coulisses of Santa Margarita and Santa Clara represent its further continuations [2].

As regards the islands of the gulf of California I possess no information, with the exception of some data on volcanic rocks. According to Gabb, *Carmen* is probably a fragment of the mesa *Giganta* of the peninsula. The eastern coast of the gulf is described as a long and mighty scarp, which lies nearly on the continuation of the eastern scarp of the Sierra Nevada. This, together with the fact that the granites near Todos Santos (lat. 31° 30′ to 32° N., west coast) are white, contain hornblende, and resemble the younger granite of the Sierra Nevada, has led eminent geologists to suppose that the peninsula may correspond with the Sierra Nevada, but the gulf with the depression of the Owen valley, and so on. The facts we have cited tend, however, to confirm another view, also put forward by Mexican geologists, according to which the peninsula is the continuation of the coast ranges, and the gulf corresponds to the longitudinal valley of the Sacramento (I, p. 586). It is true that the younger beds, though they are folded in the Sierra Santa Monica, near Los Angeles, and the other east-and-west trending parts of these upper Californian chains, are not folded in the peninsula.

The south border of the Colorado plateau. The Colorado plateau is like a blunt wedge, pointing south, and is inserted between the chains which, to use Dutton's simile, stream towards Mexico like an army of caterpillars crawling from the north-west and north-east.

This southern part of the plateau was certainly a continent during a great part of the Mesozoic aera. Overlying the upper Carboniferous, from the border of the lavas, which surround the great cone of the San Francisco (13,000 feet), to the Colorado Chiquito (Little Colorado), and far beyond this river, are first brownish-red clays with salt and gypsum, and then conglomerate, sandstone, and some limestone (Shina-rump formation),

[1] G. Eisen, Exploration in the Cape Region of Baja California in 1894, Proc. Cal. Acad. Sci., 1896, 2nd ser., V, pp. 732–778, in particular p. 754, maps; cf. an illustration in Diguet, Ann. de Géogr., 1900, IX, p. 246, pl. XI.

[2] Bosquejo geológico de México, Bol. Inst. geol. Mexico, nos. 4, 5, 6, 1897; Ordoñez, p. 51; Aguilera, p. 189.

which contain the frequently-mentioned fossil woods of Arizona. Remains of Belodons and Labyrinthodons have also been found. Then follows, chiefly on the east and north-east, the red sandstone of the 'Painted Desert', which extends to New Mexico, and is finally surmounted by transgressive patches of Cretaceous [1].

New Mexico also furnishes a Trias flora (*Cheirolepis Münsteri* and other plants), which is found at Abiqui, 80 kilometers north-west of Santa Fé. This locality is situated in the Chama valley, on the border region of the plateau.

On the south-west, from the Great Cañon almost as far as Fort Apache, a distance of nearly 400 kilometers, the plateau ends in the Aubray cliffs, a scarp formed by the basset edges of the upper Carboniferous, which has just been mentioned as the basement of the Trias. It is flat-bedded and overlooks, especially where it forms the Mogollon mesa, the country lying towards the south-west. From Fort Apache onwards, lavas of increasingly recent age advance to the border. From the most southerly point the boundary turns towards the north-east, and reaches the Rio Grande, which, for more than 300 kilometers, separates the plateau from the sierras; and then, south of Albuquerque, the outrunners of the Rocky mountains make their appearance [2].

In front of the steep south-western border lies, according to Ransome and Leslie, a zone of mountains, 110–200 kilometers in breadth, which strike, between the plateau in the east and the Gila desert in the west, first to the south-east and then to the south. Their western boundary is marked by Fort Mohave on the Colorado river, and the towns of Phoenix and Tucson. They reach a height of 8,000 feet, and are often assigned to the Basin range, yet no folds, only fractures, are to be seen. The mining district of Globe (lat. 33° 15′ to 33° 30′ N., long. 110° 45′ to long. 111° W.) presents, apart from various eruptive rocks, a Palaeozoic series, including the upper Carboniferous, which is only traversed by normal subsidence faults, so that we might almost suppose we had before us a downthrown belt of the plateau itself. Further east also, in the Clifton Morenci district (lat. 33° to 33° 15′ N., long. 109° 15′ to 109° 30′ W.), folding is scarcely

[1] Lester F. Ward, Status of the Mesozoic Floras of the United States, Ann. Rep. U.S. Geol. Surv., 1900, XX, 2, pp. 211–430, in particular p. 320 et seq.; and Monograph XLVIII, 1905, pp. 13–46.

[2] W. M. Fontaine and F. H. Knowlton, Notes on Triassic Plants from New Mexico, Proc. U.S. Nat. Mus. for 1890, XIII, pp. 281–285; C. E. Dutton, Tertiary History of the Grand Cañon District, U.S. Geol. Surv., Monograph II, 1882, pp. 14–15; Mount Taylor and the Zuñi Plateau, Ann. Rep., 1886, VI, pp. 109–198, maps, in particular p. 118, pl. XII; C. L. Herrick, The Geology of the Environs of Albuquerque, New Mexico, Am. Geol., 1898, XII, pp. 26–43; and Report on a geological Reconnaissance in West Socorro and Valencia Cities, New Mexico, op. cit., 1900, XXV, pp. 331–346, maps. A peculiar description of the south-western chains is given by J. E. Spurr, Origin and Structure of the Basin Ranges, Bull. Am. Geol. Soc., 1901, XII, pp. 217–270, map.

perceptible. Here Cretaceous sets in; its discordant overlie is ascribed not to tectonic processes, but to erosion; it is disturbed, however, by a recent intrusion of diorite porphyry. Recent flows of lava occur in both districts; and spread out in both, as the most recent formation, is the mighty Gila conglomerate. This is a fluviatile deposit, formed along the lines of the existing valleys, but at a time when the mountains were much higher. A few patches occur up to a height of 5,000 feet [1].

This conglomerate slopes away on the south-west to the desert, from which rise a few short and little-known chains. Nowhere but in these can we possibly suspect a continuation of the Mesozoic series of the Basin ranges. Further towards the north-west, east of Cadiz, is a height which exposes Cambrian beds [2].

Then follows the lower course of the Colorado, which lies in a depression.

The south-eastern border of the Colorado plateau presents a different character. South of Albuquerque the Rocky mountains come to an end. The region between the upper Pecos (down to lat. 31° N.) and the south-eastern border of the plateau possesses a structure of purely Mexican type.

Two series of sierras striking to the south-east fill the space between the Rio Pecos and the Rio Grande. They are folded, and after the folding were cut through by considerable faults, striking south-east, which have determined their existing form [3]. The stratified succession shows that approaching completion of the series which may so often be observed at the entrance to a folded land. Thick upper Carboniferous limestone is overlain by the red gypsiferous clays of the Permian (and the Trias?) of Texas; in the Malone mountains (lat. 31° 15′ N., right bank of the Rio Grande), according to Cragin's accounts, Jurassic with Perisphinctes also occurs, belonging to the Kimmeridge stage or Tithonian, and corresponding with the Mexican Alamitos stage; then follows, with subordinate modifications, the Texan Cretaceous series [4].

The first series of sierras begins with the Jacarille mountains (lat. 34° N.), which lie near the end of the Rocky mountains. They are continued without interruption into the Sierra Sacramento and Sierra Guadelupe. Then from lat. 31° N. onwards the Cretaceous plateau of Stockton crosses over to the west side of the Rio Pecos; the sierras pass by the last out-

[1] F. L. Ransome, Geology of the Globe Copper District, Ar., U.S. Geol. Surv., Profess. Papers, no. 12, 1903, 168 pp., maps, in particular pp. 10, 14–16; W. Lindgren, The Copper Deposits of the Clifton-Morenci District, Ar., op. cit., no. 43, 1905, 375 pp., maps, in particular p. 51 et seq.

[2] Darton, Iron Mountain near Siam, Journ. Geol., 1907, XV, pp. 470–473.

[3] C. R. Keyes (Structures of Basin Ranges, Journ. Geol., 1905, XIII, pp. 63–70) states that the folding is pre-Cretaceous; I follow Stanton's data in Cragin's work on Malone.

[4] F. W. Cragin, Palaeontology of the Malone Jurassic Formation of Texas, Bull. U.S. Geol. Surv., no. 266, 1905, 109 pp., map.

runners of the western Altaides (IV, fig. 12, p. 79), and are cut through in the San Jago chain by the Rio Grande.

The second series begins further north. It is particularly high (3,900 meters, valleys at a level of 1,100 meters), and formed for the greater part of upper Carboniferous limestone and recent volcanic rocks. But it also includes the Jurassic Malone mountains, and south-east of these the Quitman mountains, in which, according to Stanton, the whole Cretaceous succession is overthrown towards the east.

The 'bolson', that is, the depression, devoid of outflow, which lies between the Sierra Sacramento of the eastern series and the Sierra San Andrea of the western series, is covered by salt and gypsum, derived from springs in the red Permian[1]. The bolson, 75 kilometers in length, in the west of the Guadelupe chain (lat. 32° 15′ to lat. 32° 31′ N.), is a fault-trough, according to Hill. Between the Organ and Hueco mountains (lat. 32° 10′ N.) we come upon a recent lava stream, which has flowed down for 50 kilometers from the north, and now forms a 'mal pais' not easy to cross[2]. In the Sierra Vieja on the Rio Grande, Cretaceous coal makes its appearance[3]. Without much change in character these sierras reach the Rio Grande, which runs athwart them between lats. 29° 45′ and 29° N. Beyond the river they are continued through Coahuila into western Tamaulipas.

Mexico. The southern outrunners of the Rocky mountains have disappeared. The Colorado plateau terminates in Arizona and New Mexico. Troops of chains, of the same tectonic type as the Basin ranges, and with a prevalent strike to the south-east, cover the land, and form the continuation of the sierras described on the other side of the Rio Grande. On the Pacific side, the coast range is continued from the north-west through lower California and the Marias into the Sierra Madre del Sur, which forms a great arc concave towards the north-east, embracing all the sierras of the interior.

Up to twenty years ago three orographic zones were supposed to cross the breadth of the country, namely, a Sierra Madre Occidental, a Central Meseta, and a Sierra Madre Oriental. In 1890, Heilprin showed that the whole land is folded, and that its inequalities have been levelled up in the case of the Central Meseta by volcanic ejectamenta[4]. The important results of the Geological Survey, and in particular the comprehensive descriptions of Aguilera, have established the fact that

[1] C. L. Herrick, Geology of the White Sands of New Mexico, Journ. Geol., 1900, VIII, pp. 112–126, map.

[2] R. S. Tarr, Recent Lava-flow in New Mexico, Am. Nat., 1891, pp. 524–527.

[3] T. W. Vaughan, Reconnaissance in the Rio Grande Coal-fields of Texas, Bull. U.S. Geol. Surv., 1900, no. 164, 100 pp., map.

[4] A. Heilprin, Geology and Palaeontology of the Cretaceous Deposits of Mexico, Proc. Acad. Nat. Sci. Phil., 1890, pp. 445–469.

there is no Sierra Madre Oriental, but that the sierras of the interior decrease in height towards the Atlantic coast and run out in free ends. It has also been shown that an arcuate marginal fracture next the gulf of Mexico does not exist [1].

Let us first consider the stratified succession.

Marine Palaeozoic beds are seldom visible. Dumble mentions, as occurring in the river basin of the Yaqui, Sonora, and on the road to Hermosillo, upturned quartzites, and also granular limestone and schist; on their basset edges upper Silurian with Cyathophyllum and Heliolites rest unconformably [2], but, apart from these occurrences in the north-west, no Palaeozoic fossils are known, until upper Carboniferous limestone once more crops out very far to the south.

In Sonora, especially at Los Bronces (east of Tecoripa), in the coal-field of Santa Clara, and further towards Hermosillo, conglomerate and sandstone with workable coal seams and a Mesozoic flora (Dumble's Barranca stage) rest on a basement which is sometimes Palaeozoic, probably, and sometimes pre-Cambrian [3]. Further south they rest on the denuded Archaean. Aguilera mentions them at numerous localities in Sonora, Puebla, and Oaxaca [4].

It seems as though this stage followed the strike of the ancient rocks of the west and south. Similar plant-bearing beds are also known in Honduras; there they possibly rest on upper Carboniferous limestone [5].

Their flora is often described as Rhaetic, but since stress is laid on its affinity with that of Abiqui, North Carolina, and Richmond, and no exact descriptions exist, it is uncertain whether it should not rather be correlated with the flora of the Keuper. In any case, it appears that the areas indicated were dry land during a part of the Trias epoch. The traces of shells, which Gabb described from Los Bronces, are of too doubtful a nature to overthrow this conclusion [6].

[1] J. G. Aguilera, Bosquejo Geológico de México, Bol. Inst. geol. México, nos. 4, 5, 6, 1897, 207 pp., map, and Sobre las condiciones tectónicas de la Republica Mexicana, 8vo, Mexico, 1901, 34 pp.

[2] E. T. Dumble, Notes on the Geology of Sonora, Mexico, Trans. Am. Inst. M. E., 1899, 31 pp.

[3] E. T. Dumble, op. cit., and Triassic Coal and Coke of Sonora, Bull. Am. Geol. Soc., 1900, XI, pp. 10–14.

[4] J. G. Aguilera, Bosquejo Geológico de México, Bol. Inst. geol. México, nos. 4, 5, 6, 1897, p. 202.

[5] J. S. Newberry, Rhaetic Plants from Honduras, Am. Journ. Sci., 1888, 3rd ser., XXXVI, pp. 342–351; *Taeniopteris glossopteroides* Newb. and *Nilssonia polymorpha* Nath. A marked generic correspondence unites this flora with that of Los Bronces in Sonora.

[6] Gabb, in Geology of California, I, p. 28, Panopaea? Above the Barranca stage Dumble describes in Sonora andesitic lavas which are older than the Cretaceous, and terms them the Lista Blanca stage. I have no further confirmation of andesitic eruptions in this period.

The case is different further inland. Here Burckhardt and Scalia have made us familiar with a Carnic fauna from Zacatecas; some species (Sirenites, Juvavites) are allied to those of the Californian Trias[1].

Lias forms the next stage. Böse's accounts give several localities for it in the east and south-east (Mexico, Querétaro, Hidalgo, Puebla, and Veracruz)[2].

With regard to middle Jurassic there is an almost complete dearth of information.

Nikitin was the first to mention the occurrence of Aucella in Mexico. In the Sierra de Catorce, Castillo and Aguilera have distinguished a lower (Alamitos) stage with numerous Perisphinctes, and an upper (Ceneguita) stage with Aucella[3]. Burckhardt has furnished very detailed information concerning the Kimeridge, Portland, and Neocomian in the Sierra de Mazapil. Many species occur which in Europe belong to the Tethys. Amidst the series thus characterized, a bed with *Aucella Pallasi* makes its appearance as an Arcto-Russian intercalation above the horizon of *Idoceras Balderum*, and beneath that of *Haploceras Fialar*. Virgatites are mentioned as occurring somewhat higher up[4].

The upper Jurassic of Malone on the Rio Grande, with its European characters, has been already mentioned. Beds of the same European type are also seen at Oaxaca, in the south[5].

Neocomian with Holcostephanus, next comes on, near Mazapil, then thick limestone, a zone with Parahoplites, and finally, in a vast transgression and of great thickness, the middle and upper Cretaceous. This is in the main an extension of the Texan Cretaceous, and forms a considerable part of the folded sierras of central Mexico.

Marine Eocene and Miocene nowhere advance far into the interior.

The Cretaceous limestone mountains were covered, probably after the middle Tertiary epoch, by ashes and lava ejected from hundreds of eruptive centres, of which only a very few are now recognizable. On the west in particular they support a great mass of acid ejectamenta.

The series of rocks concludes with the volcanos of the present day, which include some of the most stupendous in the world. The Pic of

[1] C. Burckhardt and S. Scalia, Faune marine du Trias supérieur de Zacatecas, Bol. Inst. geol. Mexico, 1905, no. 21, 41 pp.

[2] E. Böse, Lias in Mexico, Zeitschr. deutsch. geol. Ges., 1898, pp. 168–175.

[3] Nikitin, N. J. f. Min., 1890, II, p. 273; A. del Castillo y J. G. Aguilera, Fauna fosil de la Sierra de Catorce, Bol. Com. geol. Mex., 1895, I; Felix, in J. Felix and H. Lenk, Beitrag zur Geologie und Palaeontologie der Republik Mexico, 3 parts, 1889–1899, II, 1899, p. 164.

[4] C. Burckhardt, Géologie de la Sierra de Mazapil, Guide X^e Congr. géol., 1906, no. 26, 40 pp., maps; and La Faune Jurassique de Mazapil, Bol. Inst. geol. Mex., 1906, no. 23, 216 pp.

[5] Felix, op. cit., III, 1891 (Palaeontographica, vol. XXXVII), p. 140 et seq.

Orizaba measures 5,549 meters in height, Popocatepetl 5,450 meters, Ixtaccihuatl 5,280 meters; Nevada de Toluca and others exceed 4,000 meters in height. Some, such as Colima, have been very active in recent times. Jorullo, with its four cones [1] rising on a line running to the north-north-east, first came into existence in September, 1759, or at least was further developed at that time.

In Sonora the west side of the *Sierra Madre Occidental* presents, as we have seen above, ancient rocks, Silurian, and the Barranca stage of the Trias, with its coal-beds; patches of Cretaceous limestone and volcanic ejectamenta cover a great part of this substructure. Towards the south the volcanic accumulations rapidly increase in importance. The transverse section drawn by Weed from Parral (south-west Chihuahua), west-south-west, to the lower course of the river Sinaloa, shows the intensely folded sediments as occurring for short distances in the western foothills and the lower part of the eastern border only. In place of a mountain chain we have a dissected plateau, 2,500 meters in height, in its highest parts even 3,200 meters, which towards the east sinks gradually to the lofty inner plateau; but towards the west, a little west of Guadelupe y Calvo, it presents a high and steep cliff. This cliff, however, does not represent a fracture. It is the result solely of denudation, and the zone of foothills, about 24 kilometers in breadth, which separates it from the low-lying coast region is formed by the basement beds of the great plateau. The plateau itself once extended further towards the west.

The history of these table-mountains is as follows: Upon the folded sediments a great quantity of flat-lying, coarsely stratified, andesitic breccias, tuffs, and lavas was piled up. Local eruptions of monzonitic rocks occurred. Then the whole andesitic land was cut through, much in the same way as the existing surface, by a number of valleys, some of them very deep. Then all these valleys and the whole andesite mass were covered up by rhyolitic and dacitic flows and ejectamenta, which produced new plateaux over the old furrowed plateaux of andesitic rocks. Upon these, finally, plateaux of basalt occur here and there and represent the most recent formation. The existing configuration has been produced by denudation, and from Weed's description we understand how it is that only andesites and not rhyolites are mapped in the western foothills [2].

[1] E. Ordoñez, Le Jorullo, Guide X^e Congr. géol., 1906, no. XI, 54 pp., map.

[2] W. H. Weed, Notes on a Section across the Sierra Madre Occidental of Chihuahua and Sinoloa, Mexico, Bull. Am. Geol. Soc., 1902, 15 pp.; and Notes on certain Mines of Chihuahua, Sinoloa and Sonora, Mexico, op. cit., 1902, 48 pp. Details relating to Parral are given by P. Waitz, Guide X^e Congr. géol., 1906, no XXI, 21 pp., map, and Robles, op. cit., XXII; in a corresponding manner Hovey describes the mining district of Guaynopita (West Chihuahua) in Festschrift auf H. Rosenbusch, 8vo, Stuttgart, 1906, pp. 77–95; a survey of Chihuahua is given by the same writer in Bull. Nat. Mus. N.Y., 1907, XXIII, pp. 401-442, map.

These data confirm the excellent description of the great Sierra and its rhyolites, which was published a little earlier by Ordoñez [1]. It is obvious that the Sierra Madre Occidental is for the greater part of subaerial origin. The northernmost parts of Sonora present a certain resemblance to the jagged hill ranges on the margin of the Gila desert of Arizona. Further south the several ranges press more closely together, and then follows the volcanic covering.

In Durango and Tepic, as in Sinaloa, an older eroded andesite formation may be perceived beneath the rhyolites. The rhyolites extend for the most part over the Sierra Madre Occidental; towards the east, on the Meseta Central, they are less widely distributed. On the Sierra they seem to have proceeded from great fissures, running as a rule with the strike, but on the Meseta from isolated centres of eruption. The *Bufas*, massive blunt pillars formed of rhyolitic groundmass reduced to fine dust, are in no small part, according to Ordoñez, the hardened contents of the funnels. The great Bufa of Guanajuato, which contains large blocks of biotite granite and other rocks brought up from below, and is surrounded by a zone of *Locero*, i.e. of hornfels produced by the contact alteration of a red conglomerate, may be regarded as a typical example.

Towards the south part of Jalisco, according to the sketch map by Ordoñez, the rhyolites disappear; they are concealed by the basic lavas of the existing volcanos, but still crop out between them, as, for example, in the *Navajas*, south of Pachuca, which include fragments of a meseta more than 3,500 meters in height.

The volcano of Ceboruco and other recent cones conceal any orographic boundary which might delimit the hills on the side next cape Corrientes. Those who have sought for a boundary to the Sierra Madre Occidental in the configuration of the country have fixed upon the Rio de las Balsas, which lies much further south. But its valley is merely a superficial feature, due to erosion.

It is a fact of importance that the rhyolitic eruptions, which extend only a short distance towards the east into the Meseta Central, turn towards the south-east from Tepic and Jalisco onwards, and even in the direction of Jalapa remain visible beneath and between the existing volcanos, nearly up to the east coast. *The map by Ordoñez clearly indicates that the older volcanic range of the Sierra Madre Occidental bends round into the zone of the existing volcanos.*

The *Meseta Central* is higher in the south, in the direction of the recent great volcanic mountains, and loses in height towards the north, reaching its lowest point (1,700 meters) in the *Bolson de Mapimi.*

[1] E. Ordoñez, Las Rhyolitas de México, Bol. Inst. geol. Mex., nos. 14, 15, 1900 and 1901, 75 and 76 pp., map.

Here its resemblance to the Basin ranges, as shown by the repeated trough-like subsidence of the folded mountains along extensive faults, the numerous but less considerable volcanic accumulations, and the closed drainage system, is most manifest. The drawings and written communications which I owe to the kindness of Herr Edmund Naumann, supplemented by the accounts of other observers, are my authority for the following account.

In the State of Parral, as well as in Carmen (on the boundary between Durango and Chihuahua), we are still within the region of the volcanic sheets of the Sierra Madre Occidental, which are here about 800 meters in thickness. Further towards the east lie regions where long folded Cretaceous ranges, striking towards the north-west, are separated by broad level plains, which are diversified by volcanic hills and walls.

The folding of the Cretaceous limestone is here carried to an extraordinary degree. Robert Hill states that in the Sierra Almoloya (Chihuahua, between Parral and Ximenes) it even goes as far as the formation of plunging sheets, with marmorization or foliation of the limestone. Were it not for the 'recumbent folds', visible in the steeply upturned ends of the sheets, we should regard the sierra as a long quaquaversal dome. Intense overfolding towards the north-east is also mentioned by Naumann as occurring in the Sierra Cadena (north Durango), a range 60 kilometers in length. This direction of the folds, together with a constant strike of the numerous chains and fractures towards the north-west, prevails over the whole of this region. The folding is everywhere older than the volcanic accumulations of the Sierra Madre Occidental.

To the north-east of the Sierra Cadena we reach a plain, 25 kilometers in breadth, and then the *Bufa de Mapimi* (2,400 meters). This is a repetition of the Sierra Cadena, but of less length. Like this range it slopes gently towards the south-west and steeply towards the north-east; the descent towards the north-east amounts to 700 meters, and at the bottom of a trough-like inbreak lies the rich ore deposit of the *Ojuela*. This is a vertical pipe, about 30 meters in diameter, which has been opened up by mining to a depth of 500 meters; it is in pipes of this kind that the auriferous and argentiferous lead ores of this region occur. All the pipes are connected with great fissures. According to Naumann they appear to be the final expression of eruptive activity, and it seems as though the eruptive dykes were cut off by the processes involved in their formation. To the north-west of the Ojuela we meet with volcanic rock in the same fault-trough.

On the other side of the Ojuela a short horst forms the *Cambio* chain; it is possible that towards the north-east sediments older than the Cretaceous take part in its formation. Then we again reach a depression, 20 kilometers in breadth, hilly towards the north, and presenting a chain-like arrangement; finally we cross another sierra, precipitous on that side, however, which faces south-west, and beyond this is the station of Besmejillo, on the Central Mexican railway.

The volcanic rocks in this part of eastern Durango are associated with strike fissures and make their appearance sometimes as dykes, sometimes as volcanic cones [1].

In the south of the Bolson de Mapimi, at Parras, and nearly as far as Mazapil, the folds strike not to the south-east, but to the east-south-east and nearly east and west; at Parras, and in the direction of Monterey, there is a tendency to form oval brachyanticlines. The ore-bearing sierras near Mazapil, formed of Jurassic and Cretaceous, owe their richness to igneous intrusions, which while forcing their way up have absorbed the adjacent rock [2].

The famous ore-deposits of Zacatecas and Guanajuato have originated in similar intrusions, but at both localities sericitic schists crop out, representing a basement not elsewhere visible in this part of Mexico. From the account of Burckhardt and Scalia it appears that the Carnic Trias met with here is intimately associated with spilite (*Roca verde*), thus recalling similar occurrences in the Alps [3].

Let us now turn our attention to the so-called *Sierra Madre Oriental*. It does not form a tectonic unit. The behaviour of the Cretaceous is instructive here. Further south, at Cardenas, between San Luis Potosi and Tampico, Böse has shown that the lower Senonian, besides containing *Exogyra costata* and some other North American species, presents the Gosau facies, which is continued here from Jamaica [4]. Traces of it have also been discovered between Monterey and Saltillo, and here in the north it is covered by coal, which, according to Aguilera, forms the base of the Laramie stage [5]. Robert Hill, who is intimately acquainted with Texas, has shown

[1] An abstract was given by E. Naumann in a communication to the Zeitschr. deutsch. geol. Ges., 1898, pp. 106–108, and Ber. Senckenb. naturf. Ges., 1901, p. 88; also J. D. Villarello, Le Minéral de Mapimi, Guide X[e] Congr. géol., 1906, XVIII, 18 pp., and E. Böse, Mines de soufre de la Sierra de Banderas, op. cit., XIX, 11 pp. For the recumbent sheets of the Sierra Almoloya, R. Hill in Science, May 3, 1907, new ser., XXV, pp. 710–712; for the bufa, E. Angermann, Parerga Inst. geol. Mex., 1907, II, pp. 17–25.

[2] Not by penetrating hollow spaces, as I once thought, nor by active participation in the folding. The folding is here an independent process, older than the intrusion; faults were subsequently formed; this is shown with particular clearness by the Sierra de Concepcion del Oro overfolded towards the north; Burckhardt, Géologie de la Sierra de Mazapil, Guide X[e] Congr. géol., 1906, no. XXVI, 40 pp., maps, in particular p. 36; and Sierra de Concepcion del Oro, op. cit., XXIV, 24 pp., maps.

[3] Burckhardt et Scalia, Géologie des environs de Zacatecas, Guide X[e] Congr. géol., 1906, no. XVI, 26 pp., maps; and Villarello, Hores, et Robles, Étude de la Sierra de Guanajuato, op. cit., no. 15, 23 pp., maps.

[4] E. Böse, La Fauna de Moll. del Senon. de Cardenas, Bol. Inst. geol. Mex., no. 24, 1906, 95 pp.

[5] J. G. Aguilera, Guide X[e] Congr. géol., 1906, no. XXVII, Gisements carbonifères de Coahuila, 17 pp.

that the brackish-water Laramie stage of the United States occurs with unaltered character in the sierras between the Rio Pecos and Rio Grande, and from Presidio del Norte to Tampico, so that it shares the folding of the eastern sierras of Mexico almost as far as lat. 22° N. We know from Aguilera that it extends into northern Coahuila.

Here, as in the Rocky mountains (and also in a great part of the Intermediate range), according to R. Hill, the last folding occurred after the Laramie and before the Eocene. According to Hill's sketch, taken near Lampazos (west of Laredo on the Rio Grande), it was directed towards the east. The Eocene of Laredo contains the characteristic species *Venericardia planicosta* [1].

The detailed sections drawn by Böse, from Veracruz westwards, beneath the outrunners of the Pic of Orizaba, show various sub-divisions of the Cretaceous overthrust in imbricate fashion towards the sea [2].

The whole of the Sierra Madre Oriental consists, so far as it is known, of the echeloned free ends of numerous chains folded towards the east and north-east.

A completely different structure is presented by the *Sierra Madre del Sur*. Beginning in cape Corrientes it runs to the east-south-east, through Michoacan, Guerrero, Oaxaca, Tehuantepec, and Chiapas, as a broad range, slightly concave towards the north, formed of very ancient rocks. It is, without doubt, the most important trend-line of Mexico.

A section drawn from Acapulco to Veracruz, which Böse and Aguilera laid before the Geological Congress of Paris in 1900, showed, near Acapulco, a zone of gneiss and mica-schist, about 70 kilometers in breadth, then Cretaceous, a second zone of gneiss, then lacustrine Tertiary, again Cretaceous, and again mica-schist; next follow, on the plateau (2,000 meters in height), great deposits of gypsum, recent eruptive rocks, in particular andesite, traces of plant-bearing Trias, then once more gneisses, some of them, perhaps, fairly recent; beyond these, near Ocatlan, granite, and again, finally, Cretaceous.

The section drawn by Felix and Lenk from Puerto Angel, in Oaxaca, northwards across the Sierra de Cimaltepec and Sierra de Ejutla, gives a very great breadth to the southern and most important range; the height exceeds 3,000 meters [3].

The Sierra Madre Occidental is thus a volcanic tabular range which covers almost completely a folded range lying beneath it; it makes a bend

[1] R. Hill, Science, May 3, 1907, new ser., XXV, pp. 710–712, Am. Journ. Sci., 1893, 3rd ser., XLV, pp. 307–324.

[2] E. Böse, Geologia de los Alrededores de Orizaba, Bol. Inst. geol. Mex., no. 13, 1899, 52 pp.; Ein Profil durch den Ostabfall der Sierra Madre Oriental von Mexico, Zeitschr. deutsch. geol. Ges., 1901, pp. 173–201.

[3] Felix und Lenk, Beitrag zur Geologie und Palaeontologie der Republik Mexico, 3 parts, 1889–1899, II, p. 1 et seq., pl. V.

towards the Sierra Madre del Sur. The Meseta Central is a broken-in folded land, of much the same type as the Basin ranges. The Sierra Madre Oriental is formed by the ends of the folded ranges of the Meseta Central. The Sierra Madre del Sur, on the other hand, is a broad, gently curved range of gneiss and other ancient rocks.

In front of the Sierra Madre del Sur the zone of recent volcanos, 70-100 kilometers in breadth, runs obliquely across Mexico. Its lavas are andesites and basalts. Its ejectamenta have greatly increased the height of the surrounding country.

Humboldt believed that these volcanos had been built up over a transverse fissure. Felix and Lenk, who travelled through Mexico in 1888 and 1889, differ from Humboldt in so far as they assigned to a cliff which bounds the plateau on the south, from the west almost to Popocatepetl, the significance of a fracture or fault; they also assumed the existence of a principal line of volcanic activity running to the east-south-east, almost corresponding with this cliff, and of numerous secondary fissures, which approaching from the north joined it more or less at right angles. Of these secondary fissures two are more important than the rest, one running through Tlamacos, Tlaxcala, Ixtaccihuatl, and Popocatepetl, and the other from Cofre de Perote to Pico de Orizaba [1].

It has been objected to this view that it leaves out of account several great volcanos of the plateau such as Malinche, and the more remote volcano of Tuxtla, or refers them to secondary fissures; while Colima, Tancitaro, Jorullo and others lie wholly south of the cliff. Consequently Sapper, in 1893, assumed the existence of only two principal lines, a longer one on the north running from the volcano de San Juan in Tepic to the volcano of Tuxtla, and a shorter one on the south running from the Bufa to Jorullo; transverse lines he dispensed with altogether [2].

Heilprin discovered in 1890 that near Orizaba on the east, past Tehuacan to the south-east, and in the state of Morelos on the west, the folded Cretaceous limestones underly the volcanic ejectamenta, and in particular the spurs of the Pico de Orizaba and Popocatepetl; and he came to the conclusion that no fault-scarp exists, but that the volcanos are seated on the folded Cretaceous formation, which strikes away beneath them [3]. Böse arrived at a similar result; according to his representation the great volcanos should correspond rather with the strike of the folded Cretaceous

[1] Felix und Lenk, op. cit., I, passim; also Ueber die tektonischen Verhältnisse der Republik Mexico, Zeitschr. deutsch. geol. Ges., 1892, pp. 303-323, map; Ueber die mexicanische Vulcanspalte, op. cit., 1894, pp. 678-681; and Bemerkungen zur Topographie und Geologie von Mexico, op. cit., 1902, pp. 426-446.

[2] C. Sapper, Ueber die räumliche Anordnung der mexicanischen Vulcane, Zeitschr. deutsch. geol. Ges., 1893, pp. 574-577, map.

[3] Heilprin, Geology and Palaeontology of the Cretaceous Deposits of Mexico, Proc. Acad. Nat. Sci. Phil., 1890, pp. 463 et seq.

ranges which approach the Sierra Madre at right angles. The steepness of the slopes has usually been overestimated.

Isolated maare occur, in connexion with which no fractures are visible. Nevertheless, the possibility of the existence of fissures is not denied. In particular the transverse line which terminates in Popocatepetl is cited as an example, and Böse supposes that the eruptive activity has *wandered southwards* along this line from Ixtaccihuatl (4,800 meters) through an intermediate crater to Popocatepetl (5,425 meters). 'It might well be described,' says Böse, 'as a volcano with a travelling crater [1].'

Many circumstances combine to obscure the problem. As a volcano increases in height, so does the extension of the base, and with this the concealment of the substructure. A zone, 100 kilometers in breadth, and covered out of sight, affords too much room for conjecture. We may be content for the present with the general fact that a broad zone of lofty volcanos runs across Mexico.

The term 'across' is certainly correct in a topographic sense, but it would be more difficult to show that it also holds in a tectonic sense. The volcanic zone runs fairly parallel with the Sierra Madre del Sur. Böse has also observed this fact. The gneiss of this zone strikes to the west-north-west; if we regard cape Corrientes as belonging to the north-east border, then the direction lies between west and north. The prevailing strike of the Cretaceous folds is only exceptionally, as at Parras and Mazapil, west-north-west to west, elsewhere it is approximately N. 30°–40° W. Böse has also traced these folds with a strike to N. 30° W. beneath the spurs of the Pico de Orizaba.

Aguilera and Ordoñez conjectured that the encounter of these two directions of strike in the folding was one cause of the appearance of the volcanos [2]. These distinguished investigators regard, as we have seen, the Sierra Madre del Sur as the continuation of lower California, and the gulf of California as the continuation of the valley of the Sacramento, and they justly bring into comparison this encounter of the two directions of strike, and an encounter of the coast ranges with the Sierra Nevada and the Basin ranges.

This strike to N. 30° W. is indeed continued into the southern Cretaceous mountains near Tehuacan, as may be seen, for example, at Cuernavaca in Morelos. At the same time, however, there are unexpected exceptions. Böse observed an anticline with a strike of N. 70° W. south of Orizaba, and there is no lack of further examples [3]. We may therefore ask whether the

[1] E. Böse, Geologia de los Alrededores de Orizaba, Bol. Inst. geol. Mex., no. 13, 1899, pp. 1–53; and Sobre la independencia de los volcanes de grietas preexistentes, Mem. Soc. cient. Ant. Alzate, 1899, XIV, pp. 199–231, in particular p. 219.

[2] Aguilera and Ordoñez, Bosquejo Geológico de México, Bol. Inst. geol. Mex., nos. 4, 5, 6, 1897, p. 63; Ordoñez, Rhyolithas de México, op. cit., nos. 14, 15, 1900 and 1901, I, p. 56.

[3] E. Böse, Orizaba, etc., Boll. Inst. geol. Mex., no. 13, 1899, p. 22; Coapa, south of Tehuacan, N. 70° W., Aguilera, Bosquejo, op. cit., nos. 4, 5, 6, 1897, p. 84; Zapo-

ends of the Cretaceous sierras do not make a bend in the direction of the Sierra Madre del Sur, and Aguilera's description of the neighbourhood of Tehuacan, where Cretaceous and mica schist meet together with the same strike, appears to show that they do. In general, however, the fact cannot be overlooked that the ancient rocks of Mexico are covered far and wide by autochthonous plant-bearing Trias and various stages of the Cretaceous, and that they therefore represent a very old structure.

However this may be, it must be borne in mind that, from the interior *down to the Atlantic coast, nowhere does a boundary exist between the volcanic masses of the Sierra Madre Occidental and the recent volcanic zone.* The ancient rocks of lower California and the Sierra Madre del Sur describe an arc concave to the north-east, and the volcanos describe a similar arc from Sonora onwards, with this difference, that those of the west are extinct. In the direction of the Sierra Madre del Sur and the most ancient rocks, the volcanic zone is thus not a transverse but a longitudinal line. Whether the same is true for the Cretaceous sierras must be left to further investigation to decide.

It is a striking fact, opposed to the observations made in Hokkaido, and the Aleutian islands, and others made in South America to which we shall refer later, that in Mexico no intercalations of tuffs are mentioned as occurring in the older sediments, such as the adjacent Cretaceous, for example.

Stratified succession of the Intermediate range. It has been repeatedly observed that parts of the Rocky mountains run out in coulisses directed towards the south-south-east, and that, in the west, coulisse-like spurs advance towards the north-west into the Pacific Ocean. The tectonic element, which we have provisionally designated the Intermediate range, first makes its appearance on the borders of the Copper river plateau, beneath the lavas of the south side of the Wrangell volcanos and in the Scolai range. In the Alexander archipelago the characters of the forelying Elias range disappear and the Intermediate range then includes the Columbian granodiorite and the Interior plateau. It sinks to no inconsiderable extent beneath the lavas of Washington and Oregon, makes its appearance again, with the same characters, on the boundary of Oregon and Idaho, embraces in Nevada and Utah the whole of the desert region from the Sierra Nevada to the Wahsatch, and in

titlan in a similar position, N. 60° W., op. cit., p. 89. Even in the Cerro de la Virgen south of Tlaxiaco, Orizaba, already, it is true, in the region of the gneiss mountains, Neocomian occurs with a strike to N. 54° E.; Felix und Lenk, Beitrag zur Geologie und Palaeontologie der Republik Mexico, III, p. 141; also a north-east strike in the first foothills near Jalapa; Heilprin, Proc. Acad. Nat. Sci. Phil., 1890, p. 460; also a north-east strike near Totimehuacan, a little south of Pueblo, and an east-and-west strike to the north of this locality; Aguilera, Bosquejo, etc., p. 80; and Böse, Guide X^e Congr. géol., no. II, passim.

Arizona and southern California is hemmed in between the Colorado plateau and the Pacific coast chain, possibly indeed interrupted by them. South of the Colorado plateau it again reappears and is very broad, extending eastwards even as far as the Pecos. Its folded sierras are here sharply separated from the tablelands of Texas, although the Cretaceous limestone is the same in both. It then occupies the whole centre of Mexico up to the Sierra Madre del Sur, and finally, after the strike has turned out of the south and south-south-east into the south-east, reaches the Atlantic coast between lats. 19° and 26° N.

The Intermediate range has this character, in common with the Caledonides and the Saharides, that its long folds are not collected into a main chain. In the north, so far as any direction of folding is perceptible, they are driven towards west or south-west, and in lat. 49° N. this movement may apparently be recognized even in the most westerly parts of the Rocky mountains. In the Sierra Nevada, overfolding towards the west-south-west still occurs; from the north of Mexico onwards the opposite direction to the east and north-east prevails with equal clearness. Strike-faults cut through the structure, which is thus often divided into long strips, or often also let down to form deep troughs (Owen's valley, Death valley, Bolson de Mapimi). Eruptive rocks crop out along these faults. The Intermediate range includes the batholites of Idaho and the Sierra Nevada, in addition to the granodioritic batholites of Columbia, among which we may reckon the whole series of the Cascade range. Its stratified succession is more complete between the upper Carboniferous and Cretaceous than in the boundary regions.

The eastern boundary seems to be defined in the north by the gneiss masses on the west side of the Rocky mountains. Further south it is marked by the scarp of the Wahsatch range and the western border of the Colorado plateau.

The western boundary is defined, from lat. 41° 39′ N. onwards, by the crystalline rocks of the Pacific coast ranges (Californian coast ranges, Lower California, Maria islands, Sierra Madre del Sur).

The Intermediate range stretches obliquely across the whole continent, from the Pacific to the Atlantic coast, and thus affords us an opportunity of studying the relations which existed at a comparatively early date between the two Oceans.

Even in the extreme north, as in the Nutzotin range, north of the Wrangell group, the Nikolai diabase is overlain by Fusulina limestone with *Productus cora*, and then by marine Permian, and the upper Carboniferous limestone is probably present throughout the whole region of the Intermediate range. Nor is it absent from the constriction of Arizona. It is developed to a great thickness in the southern part of the Central plateau, and also in the sierras of the Rio Grande.

In Texas the window of the Cretaceous table-mountains exposes the upper Carboniferous and the Pacific Permian, in part marine, which dip gently towards the west, beneath the European Cretaceous, which dips gently towards the east. The red beds of the Permian form by their broad 'Plazas' the flat watershed between the Canadian river and the Pecos, and enter, charged with gypsum, the stratified series of the adjacent sierras of New Mexico.

We can hardly suppose that the Permian of Texas has received its fauna from the east; but it cannot be shown that a connexion existed by way of the Intermediate range.

The marine Trias enters this region from the north as a very broad belt, reaches the Rocky mountains, and even extends to their eastern border. In the United States its subdivision and distribution have been investigated by Perrin Smith. Here it extends from the sea towards the interior as far as Idaho, and then advances with a wedge-shaped outline towards the south. Its most southerly point is represented by a doubtful outcrop in the Santa Anna chain, California (lat. 33°–34° N.), which may indicate an encroachment on the Coast ranges; well-developed Trias is known to extend as far as Inyo city (lat. 36° 30′–37° 30′ N.). The fauna of the lower Trias shows an affinity with that of the Arcto-Pacific regions, the middle Trias contains Arctic and Indo-European forms. The fauna of the upper Trias, containing numerous European species of the Carnic stage (zone of *Tropites subbullatus*), seems to indicate an Alpine-Indian and, in particular, an Alpine origin. Nevertheless, Perrin Smith maintains that, in view of our less complete knowledge of the Indian fauna, an Indian origin is the more probable. This receives some support from the fact that a large part of the western Mediterranean is surrounded by Trias of Germanic type [1].

In Zacatecas, south of the constriction of Arizona, upper Trias makes its appearance.

Marine deposits of Rhaetic age are not known either in the north or south of the Intermediate range.

Lias is mentioned from several localities; in Mexico it extends from the coast inland at least as far as Querétaro.

Of the Jurassic, the Kelloway stage with Macrocephalites and Cadoceras is mentioned as occurring in Alaska, and indeed in Cook inlet and Shelikov strait. An isolated stage, which may be correlated with the *Cardioceras cordatum* zone of the Oxfordian, accomplishes an independent transgression. W. N. Logan has prepared a map showing its distribution [2]. It extends

[1] J. P. Smith, The Comparative Stratigraphy of the Marine Trias of West America, Proc. Cal. Acad. Sci., 1904, 3rd ser., Geol., I, no. 10, pp. 323–412, in particular pl. XL; also Festschrift für A. von Koenen, 8vo, Stuttgart, 1907, pp. 377–434 (Cretaceous and Jurassic are also discussed here).

[2] W. N. Logan, A North American Epicontinental Sea of Jurassic age, Journ. Geol., 1900, VIII, pp. 241–273, in particular p. 245.

from the Pacific Ocean inland down Fuca strait, and occupies an area not wholly unlike that of the Trias, but lying further towards the east and stretching across the Rocky mountains. This region extends from the middle of Oregon eastwards into the Black Hills of Dakota, and to the south as far as the Santa Clara river (south-west Utah, near lat. 37° N.). At both these latter localities we see the transgression beginning to thin out between gypsiferous and other sediments; here the boundary is not far off. In the Wahsatch, gastropods and bivalves characteristic of this zone are still to be found[1]. It is a remarkable fact that this independent transgression has evidently come from the north-north-west, and that the Rocky mountains as little afforded a limit to it as to the Trias.

The most important and peculiar member of the Jurassic is formed by the radiolarian beds, which in the Californian coast ranges lie on much older rock, and by the Mariposa beds of the Sierra Nevada, which are generally correlated with them. The latter are the equivalents of the upper Jurassic Aucella beds of Russia.

Let us now turn our attention to the Jurassic in Mexico.

Middle Jurassic is not mentioned, but from Oaxaca to the Rio Grande upper Jurassic, belonging to the Kimeridge and Portland stages, borders the Atlantic coast. It extends to Durango, and on the Rio Grande (Malone) crosses the 105th meridian.

Burckhardt's studies in Mexico and the Andes have shown that near Mazapil (San Luis de Potosi) a bed with the Russian Aucella (probably the continuation of the Mariposa beds of California) is inserted between the Kimeridge beds of West European type, and that a Virgatites is still met with at the base of the Portland—and further, that even east of the pass of Tinguiririca in the Andes, i. e. *about 62 degrees of latitude further south*, the Russian types (Virgatites) are intercalated in homotaxial horizons of the uppermost part of the Jurassic.

In the Cretaceous of Mexico it is possible to distinguish a Pacific from an Atlantic region even still more clearly than in the upper Jurassic.

The Pacific region does not depart very far from the coast. It presents itself in Alaska, Queen Charlotte islands, Vancouver, and the adjacent part of the continent, in South Oregon, and California. The stratified succession begins with the Neocomian (Knoxville stage, *Aucella crassicollis*). Where the lie of the beds is known in detail (south side of the Wrangell volcanos, Queen Charlotte islands, Californian coast ranges[2]) an unconformity separates the Neocomian from the underlying rocks.

The succeeding stages (Horsetown and Chico) extend in transgression (except in Alaska, where they are so far only known as plant-bearing beds)

[1] Boutwell and Stanton, Journ. Geol., 1907, XV, p. 454.

[2] For Knoxwell in the Californian Coast Ranges, see T. R. Crandall, The Cretaceous Stratigraphy of the Santa Clara Valley, Am. Journ. Sci., 1907, 4th ser., XXIV, pp. 33–54.

across and beyond the Neocomian, the Chico (Senonian) travelling the farthest. Starting from the Queen Charlotte islands and Vancouver, the Cretaceous advances southwards in the direction of Puget sound, and as it does so the Japanese, Indian, and European species of the upper beds increase in number.

Diller and Stanton have given a map showing the distribution of these two stages in the southern regions [1]. The Horsetown group makes its first encroachment from the sea into Puget sound, the next from the mouth of the Columbia river nearly up to cape Blanco, and the last from the Klamath river across the whole length of the Californian Coast ranges to Santa Barbara. The Chico stage extends over and beyond all these three regions of the Horsetown stage. The boundary runs from Fuca strait inland to the middle of Oregon and beyond, and then recedes to the western foot of the Sierra Nevada, which it then follows towards the south.

The Atlantic region of the Cretaceous is characterized in like manner by the transgression of the younger stages. The series is most complete in Mexico; the Neocomian appears to extend across the whole breadth of the land as far as Sonora. Then follows the thick mantle of middle and upper Cretaceous, stretching from the Atlantic to the Pacific Ocean. In Coahuila the Rudistes and Actaeonella facies of the Gosau occur in the lower Senonian from Jamaica onwards. The brackish-water Laramie stage coming from the north-east extends over Tamaulipas, and rests in North Coahuila on the Gosau beds.

In Texas the lower horizons are only represented by the Trinity sands with the Wealden flora, and by traces of the Aptian stage. The limestone plateaux corrrespond to the middle and upper Cretaceous. From this point onwards, the Cretaceous transgression extends through the prairie land towards the north into the region of the Mackenzie, but at its base the Neocomian and Gault are absent. After the sea had advanced thus far it began to recede, and the concentric zones of Tertiary sediments on the lowermost course of the Mississippi mark in succession the stages of its retreat.

The lower Potomac flora, which has been traced along the Atlantic litoral from Maryland into western Canada—its traces possibly accompanying the Cretaceous coal series even beyond cape Lisburne on the Arctic Ocean—is contemporaneous with the negative phase indicated by the Cyrena marls and the flora of the Wealden, from the Vistula out to the Atlantic coasts of Europe.

Of all the stages of the Cretaceous, only the Senonian reaches this coastal belt in Maryland, and in the same way it alone reaches Greenland, and in the far east it alone extends across the sea of Aral and beyond.

This picture of the way in which the two processes mentioned above,

[1] Diller and Stanton, Bull. Am. Geol. Soc., 1894, V, p. 454.

and the ancient shores in general, ultimately encroach on one another, incomplete as it is, enables us to form some conception of the manner in which a continent gradually acquires continuity. At the same time the Intermediate range appears as a tectonic element of a peculiar kind, it seems rather a region of subsidence and repeated submergence than a simple chain. We might attempt a comparison with the Tethys; the Mesozoic faunas of that sea extend with wonderful uniformity from southern and central Europe to the Sunda islands, while the Intermediate range, uniting Arcto-Pacific and sub-tropical-Atlantic regions, brings together alien elements, and was probably interrupted for a time in the constriction of Arizona.

Many years ago, the great botanist Asa Gray pointed out that the migrations of floras and land-faunas due to climate are more easily observed in North America than in Europe, because the mountains and rivers of that continent, and with them the paths of migration, maintain a north and south direction, while the Alps run east and west. The case is not unlike, and we may hope for further light on the true nature of the Mesozoic stages.

Finally, it may be pointed out that from the beginning of the Californian coast ranges onwards, through all their continuations and through the whole of the Sierra Madre del Sur down to the Atlantic coast, there is no recorded instance, save for a statement referring to Sonora, of the occurrence of thick Palaeozoic sediments on the east. From its commencement to its close the Palaeozoic aera is only represented by the rare occurrence of the upper Carboniferous, and in many cases only Mesozoic sediments abut against the crystalline rocks. The significance of this character, although merely negative, is enhanced by the fact that the beds sometimes occur in autochthonous superposition—the Bronces stage for example, which lies autochthonous on crystalline rocks.

The data so far at our disposal show that the thick lower Palaeozoic series of the east terminates suddenly in the midst of the Basin ranges near long. 117° W. (I, p. 579). It then advances towards the Mohave desert, and Devonian is said to occur even in the Klamath mountains.

CHAPTER XIII

THE SYSTEM OF THE ANDES; ITS TWOFOLD ADVANCE

Chiapas, Guatemala, Honduras. The volcanos. Panama. First advance. Backward bend towards South America. Ecuador, Peru. Cordillera Real, Argentine Chains. Cordillera de los Andes and Cordillera de la Costa. Sierra de la Ventana. Patagonia. Second advance. Summary.

Chiapas, Guatemala, Honduras. The States of Chiapas, Tabasco, and Yucatan, as defined by their political boundary, still belong to Mexico; but the continuity in structure of Central America will be more plainly exhibited if we consider these regions in connexion with the south.

We have already seen that a mountain chain runs through Guatemala in the direction of the Rio Motagua, reaches the sea on the golfe Dolce, as well as near Omoa, and proceeds into the Antilles. We have also recognized a three-fold division of the Antilles into an inner volcanic arc; a middle arc, mountainous and rocky, and an outer arc, formed of Tertiary or still younger sediments. In our first account we were led, however, to conclude from the data then at our disposal that the mountain land of Mexico ended in Oaxaca and that a new order of things began south of the isthmus of Tehuantepec (I, p. 542).

The interruption caused by Tehuantepec is only an interruption in an orographic sense. Only a few years after the appearance of our first account, Herr Sapper, who has since done such excellent work in the investigation of Central America, was able to send me information from Coban that the ancient rocks of the Mexican Sierra Madre del Sur extend from Oaxaca through Tehuantepec and Chiapas into the mountains of Guatemala [1].

From Böse's description of *Tehuantepec* we obtain the following [2]:—

The lowest pass across the isthmus lies at 244 meters. From the west, i. e. from Oaxaca, and from the east, i.e. from Chiapas, the Sierra Madre

[1] A detailed account was published in C. Sapper, Sobre la geografia física y la geologia de la Península de Yucatán, de Chiapas y Tabasco, Bol. Inst. geol. Mex., 1896, no. 3, 57 pp., maps.

[2] M. Böse, Reseña de la geologia de Chiapas y Tabasco, Bol. Inst. geol. Mex., 1905, no. 20, 116 pp., maps, and Guide X^{e} Congr. géol., 1906, XXXI; Excursion à l'Isthme de Tehuantepec, 40 pp.; also G. W. von Zahn, Isthmus von Tehuantepec, Zeitschr. Ges. Erdk., 1907, pp. 321-333 and 361-373, map.

gradually sinks from considerable heights down to this side. Mountains rising to 600 or 700 meters form the highest parts of the isthmus. Gneiss, ancient schists, crystalline limestone, granite, and porphyry form, from the south coast onwards, a more elevated strip of land, about 90 kilometers in breadth. It is accompanied by folded Rudistes limestone. Towards the north follow slightly-folded Tertiary beds, and then we reach the Atlantic plain.

The same Sierra Madre, which forms a hilly region in Tehuantepec, accompanies the south coast of *Chiapas* with a strike to east-south-east, and before it reaches the boundary of Guatemala its granite summits have already reached heights of 2,200 meters. The structure of Chiapas presents, according to Sapper and Böse, the following features :—

Lying, in the south-east, against the north side of the ancient rocks of the Sierra Madre is a large segment of folded red sandstone and upper Carboniferous. This is followed throughout the length of the range by a zone of sandstone and conglomerate (Sapper's stage of Todos Santos), resting in some places on upper Carboniferous, in others directly on pre-Cambrian rocks. It is probably the equivalent of the plant-bearing series of the Trias, which occurs, similarly superposed, both in Mexico (Dumble's Barranca stage) and in Honduras. The beds dip towards the north, but are not folded.

We now reach, towards the north, a broad and lofty range of Cretaceous limestone, the Meseta central, the southern part of which has been affected by a considerable longitudinal disturbance, the Depresión central. According to the admirable description of Böse, it resembles a strike-trough. The southern part of the limestone range, together with the 'Depresión', lies not far above the sea-level, and Tertiary beds now make their appearance. On its northern border the Meseta attains a height of over 2,000 meters, rising in steep steps, which might be regarded as so many step-faults. The north border of the Meseta is also steep, and in front of it blocks of Cretaceous limestone project out of folded Tertiary land. The fact that this is folded, while the Cretaceous limestone is horizontal, is ascribed by Böse, and no doubt correctly, to the comparatively yielding nature of the Tertiary beds. Towards the sea they lie flat; in their southern part Nummulite-bearing Eocene occurs.

Both Sapper and Böse have observed isolated patches of marine upper Tertiary beds up to the astonishing height of 2,400 meters. We must therefore suppose that the whole of this limestone range was arched up at a comparatively late period and then let down along step-faults.

To the east, a second limestone range, which extends to Petén in Guatemala, makes its appearance north of the folded Tertiary land, between this and the Atlantic plain.

On this substructure of Chiapas volcanos are seated. The volcano of

Soconusco, said to be situated in lat. 15° 54′ N., long. 93° 39′ W., does not exist.

Zontehuitz (long. 92° 42′ W., 2,858 meters) is the ruins of an andesitic volcano, superposed on the lofty Cretaceous mesa; beside it and similar to it rises the *Cerro de Hueytepec*, and other andesitic extrusions occur. Böse makes the interesting suggestion that the Depresión central corresponds to the lake of Nicaragua, that Zontehuitz and Hueytepec stood on its north-west border, and that the once existent volcanos of San Bartolomé and Mispilla arose out of the lake [1].

The volcano of *Tacaná*, on the south-eastern boundary (long. 92° 6′ W., 4,057 meters), is seated on the Sierra Madre; up to a height of 2,200 meters the mountain consists of ancient granite, and the magnitude of its cone has therefore been overstated, and the same is the case with some of the most northerly volcanos of the Cascade range. Tacaná is supposed to be the most north-westerly member of the long line of Central American volcanos.

It would further appear from Sapper's works that the whole of this region, as far at least as Costa Rica, is occupied by a virgation, or a serial succession of concave chains, along which or in which the volcanic lines of Central America range themselves in more or less the same direction [2].

Before a general survey of these chains is attempted two localities must be discussed separately; the first of these certainly conforms to the general structure, while the second is of an alien character.

The first comprises the *Cockscomb mountains* in British Honduras, a wooded hill-land, surrounded on the east by the sea, and elsewhere by a plain, as much as 1,000 meters in height, rhomboid in outline, 70 kilometers broad, and 90 kilometers long. The range consists of granite and quartz-porphyry, clay-slate, quartzite, and crinoidal Carboniferous limestone, with a strike between north-east and east. Sapper regards it as a horst [3].

The second locality is the *Isla de Pinos*, lying south of western Cuba. Granular marble and garnetiferous mica-schist occur with a north-and-south strike. According to W. Hayes and his fellow-workers the rocks are

[1] Böse, Reseña, etc., p. 62.

[2] The conception of the general structure on which this description is based, is not in accord with that which Sapper has represented in Bericht über den VIII. Geogr. Congress, 1904, pp. 231–238 (with map of the trend-lines). Guided by the Eurasiatic examples, Sapper supposes that the mountain arcs of Central America must also be convex towards the exterior. Thus the brow of the Sierra Madre would be turned towards the Pacific side. We have assumed that these arcs have a concave structure somewhat like the southern Appalachians. This is supported in particular by the arrangement of the rocks. The ancient rocks lie in Chiapas, for example, on the Pacific side.

[3] Sapper, Peterm. Mitth., 1899, Ergänzungsheft no. 127, pp. 23–33 and 73; also Bellamy, Proc. Geogr. Soc., 1889, p. 542 et seq.

thrown into sharp folds, inclined to the east, and repeated by imbricate structure (possibly also by north-and-south step-faults). Both the strike and the nature of the rocks stand in contrast to the adjacent parts of Cuba [1].

If we disregard these two localities, and endeavour to discover the principal lines on the basis of Sapper's observations, we are led to results which agree very well as regards the region east of Tehuantepec with the earlier conjectures of Seebach (I, p. 543) [2].

The Sierra Madre runs from the south of Chiapas to the east-south-east and east into the region between the towns of Guatemala and Coban. It is known there as the Sierra de las Minas, and attains a height of about 3,000 meters. Thence it bends round towards the east-north-east, becomes narrower, and is now known as the Sierra del Mico. It disappears north of the mouth of the Rio Motagua.

On the north side of the Sierra de las Minas lies a zone of folded sediments; the presence of upper Carboniferous, Cretaceous, and several stages of the Tertiary is shown by fossils. The range appears to be let down along longitudinal faults against the foreland. The foreland also is traversed by long step-faults, particularly towards Petén (west of the Cockscomb mountains). Only a part of the Tertiary deposits is involved in the folding; the rest forms, along with more recent sediments, the plain of Tabasco, Campeche, and Yucatan.

On the north side of the Sierra de las Minas and the Sierra del Mico, Sapper observed a band of serpentine which reaches the Golfo Dolce; the south side of the range is also accompanied by a band of serpentine which extends in the longitudinal valley of the Motagua for a distance of 225 kilometers. It is regarded as younger than the upper Carboniferous and older than the middle Cretaceous.

South of the Motagua, a parallel chain of pre-Cambrian rocks, the *Sierra del Espiritu Santo,* rises gradually in its course from the town of Guatemala onwards. On the sea coast it is known as the Sierra Ocoa. It passes

[1] C. Willard Hayes, T. W. Vaughan, and A. C. Spencer, Geological Reconnaissance of Cuba, 8vo, Washington, 1902, 123 pp., maps. Some data certainly lead us to conjecture the presence of similar rocks in the extreme west of Cuba; cf. R. A. de Yarza, Bol. Mapa geol. España, 1895, XX, p. 72.

[2] For Guatemala: Sapper, Grundzüge der physischen Geographie von Guatemala, Peterm. Mitth., 1894, Ergänzungsheft no. 113, 59 pp., maps; Geografia física . . . de Guatemala, small 8vo, Biblioteca del 'Progreso Nacional' de Guatemala, 1897, 88 pp., and Die Alta Verapaz, Mitth. geogr. Ges. Hamburg, 1902, XVII, 146 pp., maps. For Honduras, Beiträge zur physischen Geographie von Honduras, Zeitschr. Ges. Erdk. Berlin, 1902, pp. 33-241, maps; for the entire region and for more southerly tracts, Gebirgsbau und Boden des nördlichen Mittel-America, Peterm. Mitth., 1899, Erg.-Heft no. 127, 199 pp., maps, and Gebirgsbau und Boden des südlichen Mittel-America, op. cit., 1905, Erg.-Heft no. 151, 82 pp., maps; also Verh. Ges. Erdk. Berlin, 1900, pp. 417-426 (with a map of the trend-lines as far as Panama).

through Puerto Cortez and is continued in the elongated islands of Utila (only Quaternary and basalt), Ruatan (mica-schist, strike east-north-east) and Bonaca (phyllite, serpentine)[1].

Serpentine is known to form a considerable part of the mountains of Cuba, and it occurs also in Haiti (I, p. 543).

The whole of the south and south-east of Guatemala and the whole of Salvador, as far as the Terra caliente of the coastal belt, are occupied by the recent volcanos and their accumulations; towards the east, however, in *Honduras*, more or less continuous fragments of folded chains crop out, which present an arcuate form like those of Guatemala, but trend more to the east.

A conspicuous line of depression divides Honduras, in the meridian of 87° 45′ W., into an eastern and a western half; it does not, however, seem to be connected with the strike of the chains. Among the latter the *Sierra de Píja* (Congrehoy Peak or Cerro Cangrejal, 2,450 meters) is especially prominent; it borders the coast, south of the island of Ruatan, as far as long. 86° W. and beyond. It is formed in great part of ancient eruptive rock. South of this locality we meet continually with granite, ancient schist, quartzite, and Cretaceous limestone striking east with a little north or due east. In the ore-bearing *Sierra de Juancito* (north of Tegucigalpa), Carboniferous limestone is recorded, and from this range the oft-mentioned Rhaetic (or Keuper) flora is derived[2].

Traces of a more considerable sierra appear to strike from the neighbourhood of Ocotal towards Gracias á Dios. All these sierras, however, are much lower than the Sierra de Píja or the chains of Guatemala, and disappear in Nicaragua before reaching the Mosquito coast[3].

The volcanos. In Mexico the older volcanic coverings of the Sierra Madre Occidental meet the broad belt of recent volcanos, which accompany the northern part of the Sierra Madre del Sur. Then the volcano of Tuxtla stands forth towards the east-south-east, and thus we have the rare case of a volcano on the east coast of America. Still further to the east-south-east, but in the interior of the land, the little series of extinct volcanos, such as Zontehuitz, rises like a connecting link in central Chiapas. Further

[1] Sapper, Peterm. Mitth., Erg.-Heft no. 151, p. 17.

[2] Newberry, Am. Journ. Sci., 1888, 3rd ser., XXXVI, pp. 342–351; A. J. Bourdariat, Esquisse géologique et minérale du district aurifère de S. Cruz, Honduras, Bull. Soc. géol. Belge, 1893, VII, Mémoires, pp. 35–40.

[3] This brief description differs somewhat from that which Mierisch has given of Nicaragua; it is based on Sapper's publications, and letters which he has kindly sent me. B. Mierisch, Goldgebiete im Osten von Nicaragua, Peterm. Mitth., 1893, pp. 25–39, map; and Reise quer durch Nicaragua vom Managua-See bis Cabo Gracias á Dios, op. cit., 1895, pp. 57–66, map. Still greater is the difference from that of Crawford, Geology of Nicaragua, Proc. Am. Assoc. for the Advancement of Science, held at Washington 1891, Salem, 1892, pp. 261–270.

again to the south-east, and still more remote from the Atlantic coast, the granite of the Sierra Madre supports the cone of Tacaná, already mentioned, which marks the commencement of the long zone of Central American volcanos.

This zone follows the Pacific coast, without any marked deviation from the strike of the sierras, as far as Fonseca bay, and then enters, with a slight change of direction, the great area of depression, marked by the lake of Nicaragua, which cuts obliquely through the whole continent. Then, further towards the south-east and also further inland, volcanos again appear up to the isolated volcano of Chiriquí.

Our earlier views as to the distribution of these volcanos (I, p. 86), founded on the work of Dollfuss and Montserrat, must, in the light of more recent investigation, and especially that of Sapper, undergo a change [1].

From Tacaná onwards Sapper enumerates 81 considerable cones in this zone, 44 of which have been active in recent times.

This zone of fire, narrow as we see it, is surrounded by andesitic rocks. Between lats. 89° 30′ and 90° N., where we previously (I, p. 93, fig. 5) marked the transverse fissure of Chiquimula, there stand, as we now know, numerous eruptive centres irregularly disposed; the active volcano of Jalapa rises one degree to the north of the main line, elsewhere so sharply marked. Cerro Errapuca (2,500 meters), and Cerro Selaque (2,800 meters), two extinct cones, which dominate the scene in south-west Honduras, lie equally far north of the main line. In the andesite region of the upper Vulvul, on the south-east side of the Cerro del Trapiche (east of Matagalpa, lat. 13° N., long. 85° 15′ W.), Mierisch thought he perceived still other craters [2]. Tertiary lavas are known at not a few localities. Extinct eruptive centres will certainly be discovered to the north of the existing belt of fire, and this preliminary survey leads us, as in Kamchatka and Alaska, to the conclusion that the existing line of igneous manifestation is but the hemmed-in remainder of a once much more widely distributed eruptive activity.

Sapper thinks that the existing line should be divided into several

[1] Sapper, Räumliche Anordnung der mittelamerikanischen Vulcane, Zeitschr. deutsch. geol. Ges., 1897, pp. 672–682, pl. XXIV (here another lateral line is marked running south-east from San Diego towards San Vicente. I have not included it in the enumeration given above, because it is precisely here, and as far as lat. 89°, that the series appears to me to be less clearly marked). Numerous descriptions by the same author in Zeitschr. deutsch. geol. Ges., 1896, pp. 14–26 (San Salvador); 1899, pp. 578–587 (Las Pilas); 1901 (southernmost volcanos); in Centralbl. f. Min., 1903, pp. 33–52 (Santa Maria) and pp. 103–130 (Izalco); Peterm. Mitth., 1894, pp. 82–85 (types of crater); 1895, pp. 105–109, Guatemala; 1897, pp. 1–7 (Salvador and south-east Guatemala); also, In den Vulcangebieten Mittel-Americas und West-Indiens, 8vo, Stuttgart, 1905, 334 pp.

[2] Mierisch, Goldgebiete im Osten von Nicaragua, Peterm. Mitth., 1895, p. 62.

alternating segments, each of which, as it follows on the south-east, is displaced over a certain distance towards the one in front of it.

The first segment extends, according to this view, from Tacaná (long. 92° 6′ W.) to Tajamulco (long. 91° 54′ W.); the second from Lacandon (long. 91° 42′ 50″ W.) to Pacaja (long. 90° 36′ W.); the third from Tecuamburo (long. 90° 26′ W.) to Conchagua (long. 87° 50′ W.); the fourth extends towards a short transverse fissure in the interior of Fonseca bay, from Coseguina (long. 87° 35′ W.) to the island of Madera in the lake of Nicaragua (long. 85° 27′ 30″ W.); the fifth from Orosí (long. 85° 29′ W.) to Turrialba (long. 83° 49′ W.), and after a considerable interruption to Chiriquí (long. 82° 30′ W.).

Although this division, like any other of the same kind, is to a certain extent a matter of personal judgment, yet it cannot be denied that, with the exception of the region between long. 89° 30′ and 90° W., the arrangement of the active volcanos in series is much more marked than—for example—in Mexico.

The volcanos of the first, second, and third segments, that is those occurring as far as Fonseca bay, are seated on a lofty substructure, formed chiefly of andesite, in which parts of a folded sierra are visible here and there. All that was previously said as to the tendency of the eruptive centre to move towards the Pacific Ocean holds true in reference to these volcanos, and in particular to those on the north. A more exact knowledge of the alleged transverse fissure of Chiquimulu necessarily gave rise to doubt. Nevertheless, the statements previously made with regard to the shorter lines still hold good; the line from Santa Maria to Cerro Quemado, which was then regarded as the sole exception—since the crater active upon it was the one more remote from the sea—has now conformed to the rule, for in October, 1902, an eruption occurred from the other crater, that of Santa Maria, which lies next the sea. During this eruption numerous boulders of amphibolite were ejected, showing that the chimney in the mountains beneath had been enlarged or otherwise altered [1].

The fourth segment, extending from Coseguina to Madera, is supposed by Sapper and Mierisch to lie in a fault-trough. These distinguished investigators have been led to give renewed expression to this view, owing to the growing belief that the volcano of *Momotombo,* situated at the north-western extremity of the lake of Managua, was the cause of the earthquake of the 29th April, 1898; they showed that the earthquake was, on the contrary, of tectonic origin [2].

Willard Hayes, in making investigations preliminary to the construction of an inter-Oceanic canal through lake Nicaragua, ascertained that

[1] Sapper, Centralbl. f. Min., 1903, p. 39; Bergeat says amphibolite.

[2] K. Sapper, Das nicaraguische Erdbeben vom 29. April 1898 und die Maribios-Vulcane, Globus, 1899, LXXV, pp. 201–208 and 222–227, in particular p. 226.

a part of the isthmus which closes the lake on the west consists of the Orbitoides (Lepidocyclina) beds, which are so widely distributed in the West Indies. They are known here as the Brito formation. Thus, the existence of a connexion between the Atlantic and Pacific region in the Tertiary aera is placed beyond doubt. The Brito beds are moderately folded; their strike is directed a little more to the west than the trend of the coast. They are covered by recent lavas, and these, according to Hayes, have built up the rest of the great dam throughout its whole extent towards the north-west as far as mount Coseguina, thus cutting off from the Pacific Ocean a gulf which once extended from Fonseca bay into the existing lakes of Managua and Nicaragua. When the inland seas were closed in, their waters rose to such a height that they overflowed the lip next the San Juan and opened up a passage to the Atlantic [1].

In support of this view Hayes mentions that a Megalops, a shark, and a sawfish live in lake Nicaragua; they belong, it is true, to groups known to ascend into fresh water, but the cataracts of the San Juan would oppose so insurmountable an obstacle to their passage, that they must be regarded as relics [2].

The fifth segment, beginning with the volcano of Orosí, occupies for a short distance, south of lake Nicaragua, the whole breadth of the isthmus. The ejectamenta of Orosí reach the Pacific coast, and the succeeding volcanos, Rincón de la Vieja, Miravalles, and Tenorio, slope towards the west to the depression which unites the peninsula of Nicoya with the mainland. On the east, however, their base, like that of all the succeeding volcanos as far as Turrialba, lies in the fluvial region of the San Juan, the valley of which opens wide towards the Caribbean sea.

Panama. The Brito stage of the west side of the lake of Nicaragua is continued round the south border of the lake, and in the upper course of the San Juan, according to Hayes, calcareous sandstone is encountered, which must be regarded as the Atlantic continuation of the same stage. On the

[1] C. W. Hayes, Physiography and Geology of the Region adjacent to the Nicaragua Canal Route, Bull. Am. Geol. Soc., 1899, X, pp. 285–348, map. The danger of constructing a canal in the neighbourhood of the lines of volcanic activity has been pointed out in particular by A. Heilprin, Shrinkage of Lake Nicaragua, Bull. Geogr. Soc. Phil., 1900, II, pp. 115–124, map.

[2] The fish fauna of lake Nicaragua has been described by Gill and Bransford in Proc. Acad. Nat. Sci. Phil., 1877, pp. 175–191. Gill's statement that the sharks of the lake are identical with the Pacific and different from the Atlantic species is to be found in Hayes, Bull. Am. Geol. Soc., 1899, X, p. 344. Since our knowledge of the distribution of fish has made considerable advances since 1877, I have laid the question before Herr Steindachner. This distinguished investigator informs me that, beside the endemic species in the lake of Nicaragua, only cosmopolitan species are known; in particular, Megalops is found in great quantity in the lower Amazon, and *Pristis antiquorum* occurs in the east and west. Thus a decisive argument disappears, but we do not wish to deny the probability of the theory in question.

east side of Turrialba (lat. 10° N.) the Tertiary beds are exposed in a long section, which has been described by Hill and Sjögren[1]. Here they are folded and contain volcanic intercalations; the Guallava sandstone of Hayes, which Dall correlates with the horizon of Vicksburg[2], is the continuation of the Brito stage. Younger Tertiary beds extend towards the Caribbean sea; at Limon, on the east coast, Guppy has observed Pliocene lying unconformably and horizontal[3]. Towards the west the folded Tertiary beds extend far inland and reach considerable heights. Even beyond the volcanos, still south of San José, coal is found, and Gabb states that Tertiary beds form a large part of the Sierra Candella, which extends from the volcanos Irazu and Turrialba towards the gulf of Nicoya[4]. Folded Tertiary beds have been observed by Hayes north of the Pico Blanco (long. 83° W.). Coal is also known on the shores of the Chiriquí lagoon.

We thus see that the Caribbean slope of the isthmus, from lake Nicaragua and the Rio San Juan to the line of the canal from Colon to Panama, is bordered by a Tertiary belt of varying breadth. On lake Nicaragua it encroaches on the Pacific side, and possibly extends, in the Sierra Candella, towards the entrance to the bay of Nicoya; on the line from *Colon* to *Panama* it occupies the whole breadth of the isthmus.

The studies of Zürcher, Douvillé, and Marcel Bertrand, based on numerous borings made along this line, afford the most important data for forming an opinion on the structure of the isthmus[5].

Marcel Bertrand writes somewhat as follows:—

The highest point is formed by a superposed dome of andesite, the *Cerro Culebra*. The canal cuts through a broad saddle of Tertiary beds, the axis of which lies a little to the north of the Culebra. The middle of the saddle, which is at the same time the oldest visible horizon of the Tertiary formation, is an accumulation of basic volcanic flows and breccias (Roche de Gamboa), assigned, on account of an intercalated bed of small Nummulites and Orbitoides, to the Tongrian or Aquitanian stage. It is

[1] R. Hill, Geological History of the Isthmus of Panama and portions of Costa Rica, Bull. Mus. Comp. Zool. Harvard College, 1898, XXVIII, no. 5, 285 pp., maps; in particular p. 232, and App., p. 281, Notes by A. Sjögren on the East Section of Costa Rica.

[2] Dall, Bull. Mus. Comp. Zool., 1898, XXVIII, no. 5, App., p. 275.

[3] R. J. Guppy and W. H. Dall, Description of Tertiary Fossils from the Antillean Region, Proc. U.S. Nat. Mus., 1897, XIX, pp. 303-331.

[4] W. M. Gabb, Notes on Costa Rica Geology, Am. Journ. Sci., 1875, 3rd ser., X, pp. 198-204 and 320.

[5] P. Zürcher, Communication préliminaire relative aux observations faites dans une mission récemment exécutée dans l'Isthme de Panama, Bull. Soc. géol. France, 1898, 3e sér., XXVI, pp. 425, 426; D. Douvillé, Sur l'âge des couches traversées par le canal de Panama, tom. cit., pp. 587-600; I, M. Bertrand et P. Zürcher, Étude géologique sur l'Isthme de Panama; II, M. Bertrand, Phénomènes volcaniques et tremblements de terre de l'Amérique Centrale, 4°, Paris, 1898, 38 pp., map.

not sharply separated from the glauconitic clays which follow it on the Atlantic side and are covered by the Orbitoides limestone of the Peña blanca. This is followed on the north by true Miocene (couches de Gatun and other beds) containing *Turritella tornata, Pecten subpleuronectes*, and Clypeaster, and also trachytic tuff. Thus we reach the Atlantic plain.

On the Pacific side we see more eruptive rocks and an increase of littoral characters. In particular, the volcanic series of Gamboa is followed, not by the Orbitoides limestone, but by laminated marl with plant-remains and a little Congeria, and towards the upper part some lignite. Of the marine fossils of the Atlantic side only traces are found here. The next beds, here as there, are Miocene with *Pecten subpleuronectes*.

The most recent rock is the andesite of the Culebra.

Here Douvillé's studies on the classification of the Tertiary sediments acquire significance. Two important horizons must be distinguished: the Orbitoides limestone of the Peña blanca and the stage of Gatun.

The first of these, the Orbitoides limestone (Brito stage, couche de Vamos-Vamos, Vicksburg beds), is correlated with the upper part of the Aquitanian stage. In the investigations preliminary to the construction of the canal it was traced by the engineer, M. Canelle, for a distance of 350 kilometers towards the west to Chiriquí, and for 300 kilometers towards the east to the Rio Thuyra. We shall meet with the series under another name in the Antilles, and it is possible that a girdle of these sediments will one day be found to extend around the globe [1].

The stage of Gatun with *Turritella tornata* is contemporaneous, according to Douvillé, with the Burdigalian (first Mediterranean stage). It occurs both on the Atlantic and the Pacific side, but all the investigators who have turned their attention to this series conclude, with more or less positiveness, that a continent formerly existed to the west of the existing Pacific coast.

The rocky islands in the gulf of Panama consist, according to Wagner, Hill, and Bergt, of a dark eruptive rock [2]. Joukowsky penetrated for a certain distance inland up the river Sambu, which runs parallel with the south-east of the gulf, and has also visited the eastern part of the peninsula of Azuero in the south-west. In both these regions also, dark eruptive rock (Labradorite) was encountered. In connexion with it Tertiary deposits occur, similar to those on the isthmus, but in the south-east, on the mountain of Sapo (near cape Garachiné), steeply-folded, blue-gray limestone, and siliceous shales, possibly of Cretaceous age, crop out with

[1] H. Douvillé, C. R. Acad. Sci. Paris, 2 mars 1891, p. 499; and Les Foraminifères dans le Tertiaire de Bornéo, Bull. Soc. géol. France, 1905, 4e sér., V, pp. 435–464; also Joukowski, C. R. Acad. Sci., 23 avril 1906, p. 964.

[2] W. Bergt, in Reiss und Stübel, Geologische Studien in der Republik Columbien, II, Petrographie der älteren Massengesteine, 4to, Berlin, 1899, pp. 219-223.

a north-westerly strike, and leave no room for doubt that we have here the remains of a cordillera [1].

The shallow gulf of Panama terminates in a steep submarine cliff, descending for more than 3,000 meters.

The higher mountains have been little explored, are difficult of access, and largely covered with volcanic ejectamenta; even where granite and syenite were encountered, the observer was often in doubt as to whether they might not be comparatively young intrusive rocks.

Within the Atlantic Tertiary belt, and running parallel to the coast, the *Sierra de Talamanca* rises to a height of over 3,000 meters. Its eastern and less lofty continuation is the *Sierra Veragua*; it consists, so far as it is known, of syenite and granite. The lofty peaks of mount Lyon and mount Ujum have been regarded as volcanos, but Pittier and Sapper share the doubts of Gabb on this question. On the highest part of the sierra, the *Buena Vista,* Pittier found a peak of basalt, and on the western spurs dioritic rocks [2]. That *Pico Blanco* is a granite boss traversed by dykes of porphyry, has been mentioned above. Gabb concluded that this granite is younger than the upturned Tertiary beds; he states that these are altered in its vicinity, but there are no granitic veins. This question is not yet decided, but Gabb's observations seem to refer to a lateral branch of the sierra which runs from the Pico Blanco to the east. Sapper crossed the sierra, going from the Lajuna di Chiriquí towards David (long. 82° to 82° 30′ W.). Diorite and recent eruptive rocks crop out on the lagoon; then follow basalt, and on the other side of the divide diorite, syenite, and granite, then again recent eruptive rock, and finally, near David, some Tertiary land. Still further towards the east (long. 81° 10′ W.) the sierra was crossed by Hershey; here it is about 1,500 meters in height and 40 kilometers in breadth. In this traverse also, massive eruptive rocks were alone encountered.

This sierra disappears fifty kilometers to the west of the line from Colon to Panama and thus affords room for the low-lying land of the ship-canal. To the north-east of this plain, however, the asserted recent granites again make their appearance, occurring in the *Sierra de San Blas*, which trends to east-south-east along the Atlantic coast.

With this structure it is doubtful whether or not the Sierra de Talamanca, Sierra Veragua, and Sierra de San Blas should be regarded as branches of the virgation of Honduras and Nicaragua.

[1] Joukowsky, Sur quelques affleurements nouveaux de roches tertiaires dans l'Isthme de Panama, Mém. Soc. Phys. et Hist. Nat. Genève, 1906, XXXV, pp. 155–178, map. In Azuero indications of this kind are not known to occur with equal clearness; see also O. H. Hershey, Geology of the central portion of the Isthmus of Panama, Bull. Geol. Univ. Cal., 1901, II, pp. 231–267, map.

[2] H. Pittier, Peterm. Mitth., 1892, p. 162.

The western part of these sierras meets the continuation of the volcanos of Costa Rica. The volcanos of Poas, Barba, Irazu, and Turrialba, are ranged close beside one another[1]. The pass of Ochomoga (1,530 meters) separates the volcanos, according to Pittier, from the beginning of the sierra[2]. The *Cordillera de Dota,* situated to the south of Turrialba, is also, probably, a volcano; it is followed by a long break in the mountains, extending to the *volcano of Chiriquí,* which also joins on to the west side of the Sierra de Talamanca.

The broad Sierra of *Aguacate,* which runs north of San José from the volcanos of Barba and Irazu towards Nicoya bay, has been investigated by Attwood[3] and Hayes; it is entirely volcanic. On the other hand, Hayes has found Rudistes limestone at the north foot of the Sierra Candella which follows it on the south; the Tertiary beds of this sierra have been already mentioned. The isolated peak of *Herradura* near the western end of the Sierra Candella, which is often cited as a volcano, cannot be regarded as such; it seems rather as though a series of Miocene folds bordered the Pacific coast for a considerable distance even to the west of the Sierra[4].

There are a number of characters which indicate that the promontories of Nicoya, Salsipuedes, Burica, the island of Coiba, and then Azuero and Garachiné, are fragments of one or several cordilleras; but, unfortunately, these parts are but little known. The Rudistes limestone of the Sierra Candella has been referred to above, and mention has also been made of traces occurring in Garachiné. Sapper's map marks several ranges of limestone, probably Cretaceous, extending from Nicoya to about long. 82° 30′ W.; they lie south-west of a folded Tertiary zone, which might be the border of one of these cordilleras[5].

Hill, who also suspects the existence of some connexion between the peninsulas, cites from Nicoya granite, serpentine, and jadeite, also a green quartzite, which is regarded as the oldest rock, and the 'Panama formation', a greenish white rhyolitic or pumiceous tuff, which is said to be older than the Tertiary sediments[6].

These peninsulas still offer an admirable field for investigation.

[1] K. Sapper, Zeitschr. deutsch. geol. Ges., 1901, pp. 24–51.

[2] H. Pittier, Sur l'orographie de l'Amérique Centrale et les volcans de Costa Rica, Arch. Soc. Phys. et Hist. Nat. Genève, 1889, 3e sér., XXII, pp. 466–472.

[3] G. Attwood, Geology of a part of Costa Rica, Quart. Journ. Geol. Soc., 1882, XXXVIII, pp. 328-340, map.

[4] A. von Frantzius, Beitrag zur Kenntniss der Vulcane Costa Ricas, Peterm. Mitth., 1861, p. 329; H. Pittier, op. cit., 1892, p. 162.

[5] H. Sapper, Peterm. Mitth., Erg.-Heft no. 151, pl. I.

[6] R. Hill, Bull. Mus. Comp. Zool., 1898, XXVIII, no. 5, pp. 206 and 221, 222. The older map by M. Wagner marks in the interior of Nicoya 'trachy-doleritic hills and tuff-formations of trifling height', Peterm. Mitth., 1863, pl. II.

First advance. Backward bend towards South America. The abysses of the gulf of Mexico do not reach 4,000 meters. The greatest depth of the Caribbean sea is 5,201 meters. Between the two basins the sea bottom sinks rapidly, south of the great Cayman, to 6,269 meters, in the Bartlett abyss. Just outside Amatique bay a depth of 3,075 meters has been sounded, then the depth rapidly increases up to the Great Cayman, and reaches 5,260 meters between Jamaica and Cuba. The Sierras which reach Amatique Bay with a course concave towards the north (Sierra del Mico, Sierra del Espiritu Santo) turn their convexity towards the north as they pass through Roatan towards Jamaica, and the *Bartlett abyss is their foredeep.* The serpentine ranges of these sierras are not continued into the serpentines of Cuba.

The Great Cayman is part of a submarine ridge, which runs from the Sierra Maestra of Cuba past the Little Cayman into the Mysteriosa bank. It borders Bartlett abyss on the north, and possibly corresponds to the Coxcomb mountains.

To the north of this ridge lies the Yucatan abyss (– 4,709 meters) extending in the same direction towards the east-north-east; a little to the south of the Sierra de Pinos it is still very deep (– 4,519 meters). It may be regarded as the foredeep of the Cayman ridge.

To the north of Cuba such considerable depths are not known.

It is only where the flat islands off the coast become more rare, on the other side of Great Inagua, that the sea-bottom again descends, north of Haiti, to –4,186 meters, and still further east, north of Puerto Rico and the Virgin islands, it attains the extraordinary depth of 8,341 meters. The abyss runs towards the east; north of Sombrero its depth amounts to more than 6,000 meters. It is *a portion of the foredeep of the cordillera of the Antilles, which advances here into the Atlantic.*

Nowhere in the Atlantic region is so considerable a deep known to exist. In lat. 0° 11′ S., long. 18° 15′ W., – 7,370 meters is reached in the Romanche abyss, but this is exceptional, and the place is remote from a coast or a visible folded range. The foredeeps of the Pacific alone are comparable. Here, as there, the foredeeps do not coincide with the volcanic lines.

On the mainland there seem to be indications of a virgation, but in the islands the branches converge. In the gulf of Guacanoyabo the Sierra Maestra meets the principal range of Cuba, at Port-au-Prince the line from Jamaica to Jacmel (Haiti) unites with the Cibao range.

We may now pass rapidly over some further details relating to our earlier account (I, p. 542) [1].

[1] Cuba: P. Frazer, Archaean nucleus of the Antilles, Rep. Brit. Ass. Adv. Sci., Bath, 1888, p. 654; Hayes, Vaughan, and A. C. Spencer, Geological Reconnaissance of Cuba, 8vo, Washington, 1901, 123 pp., maps, cf. p. 451, note 1; R. A. de Yarza (Rocas hypogén. de la

In 1887 Molengraaff subjected that account to an instructive criticism, with the following results. For the region beginning in the west and extending up to and including Saint Bartholomew, the data are undoubtedly correct. With regard to Antigua, Purves has since shown that its eruptive rocks are recent, and consequently it does not represent the cordillera. In Grande Terre (east Guadeloupe) only Tertiary beds are met with; Barbados is little known; Trinidad does not conform to the bend. These facts, however, are not incompatible with the existence of an arcuate Antillean cordillera, which would explain the corresponding sequence of the rocks in Venezuela and Trinidad on the one hand, and Jamaica and the remaining Antilles on the other [1].

Robert Hill, another investigator intimately acquainted with the facts, has shown that the – 1,000 fathom line indicates, in its course from South America, three long ridges. The first of these bounds, at its northern extremity, the little island of Aves (Bird Island). The second is formed by the arc of the Antilles, from Grenada to Puerto Rico, and includes

Isla de Cuba, Bol. Com. Mapa España, 1895, XX, pp. 71–88) describes the wide distribution of the diorites and serpentines and their intimate association; V. Pellitero, Apuntes geológicos referentes al itinerario de Sagua de Tánamo á Santa Catalina de Guantánamo, en la Isla de Cuba, tom. cit., pp. 89–98, map, section through the south-east part of Cuba; the Sierra de Tahagua strikes to the east-south-east to the Punta de Maisi; it consists of anticlines and synclines of Cretaceous and Eocene; on the anticlines diorite occurs as a basement; R. Hill, Notes on the Geology of the Island of Cuba, Bull. Mus. Comp. Zool., 1895, XVI, pp. 243–288, maps; J. W. Spencer, Geographical Evolution of Cuba, Bull. Am. Geol. Soc., 1895, VII, pp. 67–94.—Jamaica: R. Hill, The Geology and Physical Geography of Jamaica, Study of a Type of Antillean Development, Bull. Mus. Comp. Zool., 1899, XXXIV, 256 pp., map. The eruptive rocks are of Cretaceous and middle Tertiary age; to the latter belongs the so-called extinct volcano of Low Layton (p. 113). —Haiti: L. G. Tippenhauer, Die Insel Haiti, 8vo, Leipzig, 1893, 693 pp., maps; Geologische Studien in Haiti, Peterm. Mitth., 1899, pp. 25, 153, 201, maps. In west Haiti (with the possible exception of Jacmel peninsula) the east-south-easterly direction is probably more frequent in comparison with the due easterly than has hitherto been supposed, and doubtless corresponds to that of the Sierra de Tahagua in Cuba; Bergt, Zur Geologie von San Domingo, Isis, 1897, pp. 61–64; W. Sievers, R. Ludwig's Reisen auf San Domingo, Zeitschr. Ges. Erdk. Berlin, 1898, XXXIII, pp. 302–354, map. Basalts begin to occur in the west more frequently than had been supposed; the little island of Alta Vela lying to the south (150 meters, augite andesite and trachyte) may be a continuation, according to Sievers, of the volcanos of the Lesser Antilles. Bergt has described hornblende gneiss, and other Archaean rocks of the main chain. The attempt to claim a larger distribution for Archaean rocks in the Antilles has been opposed by Hill (in particular Jamaica, p. 226); Sievers, Zur Kenntniss Puerto-Ricos, Mitth. geogr. Ges. Hamburg (1891–1892), 1895, pp. 217–244, map. Proceeding from north to south we meet with a hill-range of Tertiary limestone, dipping gently towards the north, then at a lower level diabase-porphyrite, which also forms the north side of the southern ridge, then limestone dipping towards the north and apparently Cretaceous.

[1] G. A. F. Molengraaff, Het geol. Verband tusschen de W. Indische Eilanden, Hand. Nat. Geneeskund. Congres, Amsterdam, 1887, 10 pp., map; De Geologie van het Eiland St. Eustatius, Inaug.-Dissert., 8vo, Leiden, 1886, 62 pp., map; Purves, Esquisse géologique de l'île d'Antigua, Bull. Mus. Hist. Nat. Belg., 1884–1885, III, pp. 273–318.

a very deep embayment between Sombrero and Anegada. The third is very much constricted north of Tobago, and extends to the north past Barbados. A tectonic connexion with South America is denied[1].

The eruption of Mount Pelée in 1902 attracted general attention to the volcanic arc of the Antilles, and led to important investigations.

The work of Lacroix not only advanced our knowledge of volcanic phenomena in general, but also dealt with the special problems we are now considering. Lacroix shows that some of the volcanos have ejected fragments of gabbro, mica-schist, vein-quartz, and other rocks, thus showing that the arc of the cordillera is present underneath the volcanic arc. The volcanos are seated, above these ancient rocks, on a substructure of fairly old lavas and tuffs, and Tertiary sediments; Lepidocyclina occurs in the ancient tuffs of Martinique. This substructure becomes visible, together with the ancient rocks, on some of the islands (Anguilla, St. Martin, St. Bartholomew), which are consequently assigned to the cordillera (I, p. 549). But since Molengraaff and Cleeve have found andesites and basalts in this substructure, Lacroix infers the existence of two lines of volcanic islands, an outer and older line, and an inner line which bears the active volcanos. The former would comprise Anguilla, St. Martin, St. Bartholomew, Antigua, Grande Terre of Guadeloupe, and Desiderade; the second, St. Saba, St. Eustace, St. Christopher, Nevis, Redonda, Montserrat, Basse Terre of Guadeloupe, Dominica, Martinique, Santa Lucia, St. Vincent, the Grenadines, and Grenada.

In the same year Sapper arrived independently at a similar conclusion. The older line advances for a distance of 50 kilometers towards the younger inner line. 'We may say that this is mere chance,' writes Sapper, 'or idle speculation set forth on the map, but the fact remains that all the volcanic formations of the Lesser Antilles assemble in the neighbourhood of these curves, and do not occur anywhere outside them.'[2]

The resemblance of these curves with those of the Aleutian islands and the Kuriles is unmistakable.

Högbom draws attention to the trifling amount of potash present in almost all the acid rocks of the Lesser Antilles, and finds that the plagioclase granites pass imperceptibly into the quartz-diorites, and the latter into the olivine gabbro, completely resembling in this respect the granites and

[1] R. Hill, Jamaica, p. 211; Pelée and the Evolution of the Windward Archipelago, Bull. Am. Geol. Soc., 1905, XVI, pp. 243–288, in particular p. 279. The work by J. W. Spencer, Reconstruction of the Antillean Continent, Bull. Am. Geol. Soc., 1895, VI, pp. 103–140, deals less with these questions than with displacements of the strand-line.

[2] A. Lacroix, La Montagne Pelée et ses Éruptions, ouvrage publié par l'Académie des Sciences, 4to, Paris, 1904, 662 pp., maps, in particular p. 3; Sapper, N. J. f. Min., 1904, Beilage-Band II, pp. 37, 38.

diorites (granodiorite) of the Andes[1]. This is another point of resemblance between the Antilles and the Andes.

The mode of union with South America has given rise to doubt, and must now be considered.

Barbados (336 meters) has been described by Harrison and Jukes-Browne. On the long north-eastern coast the lowest rocks, known as the Scotland beds, are exposed. Gregory has correlated them with the Vicksburg stage (Brito or Vamos-Vamos stage of Nicaragua and Panama). They contain petroleum, and are intensely folded and overfolded, but cut through by numerous faults, which show that the island forms part of a field of fracture.

The folded Scotland beds are overlain unconformably by siliceous radiolarian beds, over these lies a sheet of white coral limestone; and then, lying at a trifling height, comes a still more recent coral limestone [2].

A fossil *Cystechinus crassus*, from the radiolarian beds, has been described by Gregory; it is a species characteristic of great depths[3]. The question arises *whether the foredeep may not be absent here, since its sediments have been raised up some thousands of meters.*

In any case, a folding movement occurred here after the upper Aquitanian (Scotland) period, and after this a very considerable folding or elevation again occurred.

Traces of such movements are also found in some of the other islands, e.g. in Jamaica. Under similar conditions radiolarian rocks make their appearance, according to Gregory, on the north side of the eastern extremity of Cuba.

With regard to *Tobago* I have only very scanty information. The north-eastern part of the island, according to Eggers, is rugged and mountainous (700 meters); yellow and red slates, basalt, and diabase are said to occur; the south-western part is flat and consists of coral limestone [4].

We may supplement our earlier account of *Trinidad* (I, p. 535) by adding that the Scotland beds (here termed the Naparima stage) contain petroleum, as in Barbados, and are similarly overlain in discordance by radiolarian beds. Although the east-and-west direction is clearly expressed

[1] Högbom, Petrographie der Kleinen Antillen, Bull. geol. Inst. Univ. Upsala, 1905, VI, pp. 214–232.

[2] J. B. Harrison and A. J. Jukes-Browne, Geology of Barbados, Salisbury, 1890, 8vo, 64 pp., map; Geology of Barbados, Geol. Mag., 1902, pp. 550–554; and Quart. Journ. Geol. Soc., 1891, XLVII, pp. 197–250, and 1892, XLVIII, pp. 170–226; J. W. Gregory, Contribution to the Palaeontology and Physical Geology of the West Indies, op. cit., 1895, LI, pp. 255–310, in particular pp. 297 and 309. Recently Harrison has distinguished folded lower, and unfolded, unconformably superposed, upper Scotland beds, Quart. Journ. Geol. Soc., 1907, LXIII, p. 336.

[3] Gregory, Quart. Journ. Geol. Soc., 1889, XLV, p. 640.

[4] Baron H. Eggers, Insel Tobago, Deutsche geographische Blätter, Bremen, 1893, XVI, pp. 1–20, map.

in the contour of the island, yet Wall observes that the strike of the rocks is almost constantly E. 20° N.; thus the island conforms more closely with the arc of the Antilles than its outline would lead us to suspect [1].

In the northern part of *Venezuela*, adjacent to Trinidad, Cortese observed a range of Archaean schist, already well known, which is accompanied in the south by Cretaceous limestone. Here the general strike is east, or east and a little north. Cortese found that the ancient schist dips to the north, but the Cretaceous limestone to the south, and that they are separated by a fault. The petroleum-bearing beds lie at their southern foot. Petroleum occurs on the western shore of the gulf of Paria, on the northern shore of the gulf of Cariaco, and further away along the sea-coast. A line of hot springs runs east and west through the Tertiary land. One of these, near Providencia, is an intermittent geyser.

In the south the Cretaceous limestone follows the inner cordillera. According to Cortese, faults running east and west determine the structure of the land and stand in some causal relation with the earthquakes, which are of frequent occurrence. We may therefore infer that the coulisse valley between Cumaná and the gulf of Paria is a fault-trough.

A lower Silurian trilobite, *Calymene senaria*, and a great Orthoceras were found by a traveller on the route from Caracas through Valencia to Puerto Caballo. They have been described by Drevermann. These are the only traces of lower Palaeozoic fossils known over this very considerable interval. Confirmation of these finds would, therefore, be of no small importance [2].

The islands of *Bonaire*, *Curaçao*, and *Aruba* have been described by Martin; they everywhere present the same rocks as the mainland; among them are radiolarian shales, some of which correspond with the radiolarian beds of Barbados and Trinidad; but it appears that similar shales also occur beneath the Cretaceous formation [3].

The peninsula of *Goajira*, which projects far out to sea, according to Simons, is mountainous and formed of three series of volcanic hills (up to 850 meters). The *Teta Goajira* (366 meters), which rises solitary out of the broad plain lying between these ranges and the north border of the Sierra de Santa Marta, consists, according to the same authority, of trachyte. Casas and Codazzi, officers on the frontier of Columbia and Venezuela,

[1] Harrison and Jukes-Browne, Quart. Journ. Geol. Soc., 1892, p. 217; Gregory, op. cit., 1895, p. 299; Wall, op. cit., 1860, p. 465.

[2] E. Cortese, Excursione geológica al Venezuela, Boll. Soc. geol. ital., 1901, XX, pp. 447–469; F. Drevermann, Ueber Unter-Silur in Venezuela, N. J. f. Min., 1904, 1, pp. 91–93.

[3] K. Martin, Geologische Studien über Niederländisches West-Indien (in his Reise nach Niederländischem West-Indien, II), 8vo, Leiden, 1888, 238 pp., maps; also J. Lorié, Fossile Mollusken von Curaçao, Aruba und der Küste von Venezuela, Samml. geol. Reichsmus. Leiden, 1887–1889, 2. Ser., vol. I, pp. 111–149.

mention the occurrence on the east coast of Tertiary beds and Cretaceous limestone, which they regard as the continuation of the Sierra de Perijá, which comes from the south. Its northernmost part, the Sierra Macuira, should also consist of limestone, according to this account; it is said to be united by a submarine ridge with the Monges reefs, and also with the Aruba chain of islands [1].

Thus the Sierra de Perijá, and therefore a branch of the Colombian Andes themselves, seems to swerve from the north-and-south into the east-and-west direction. Sievers had previously arrived at the same conclusion when investigating the *Sierra Nevada de Santa Marta.* In general, this is a very lofty mountain fragment formed of pre-Cambrian rock, and presenting much the same strike as the Sierra de Perijá [2].

On a map of the trend-lines, published by Sievers after very extensive investigations, we see how the several branches of the Andes, approaching the Caribbean coast from the south, swerve more and more to the north-east, east-north-east, and even east, all trending towards the arc of the Antilles [3]. These branches proceed (I, p. 535) from a great virgation in south Ecuador. Their four off-shoots, the Cordilleras de Choco, Occidental, Central, and Oriental, are separated by the valleys of the Atrato, Cauca, and Magdalena. The Cordillera Oriental, which runs furthest to the north and north-east, is the first to come to an end towards the south. The Sierra de Bogotá is one of its coulisses; it has been studied by Hettner [4]. The Sierra de Merida, described by Sievers, is one of the succeeding coulisses [5]. The ridge often marked on the maps east of lake Maracaibo does not exist. Here again, the dominant strike is to the north-east. The Serrania on the coast of Caracas and the Serrania interior, which lies to the south of it, are further coulisses, and the Caribbean range, together with Trinidad, is also a coulisse.

New light is thrown on this representation, in itself so consistent, by the studies of Stille on the Rio Magdalena. According to Stille, the valley of this river is a fault-trough, at least as far as lat. 3° 45′ N.; the east

[1] F. A. Simons, Exploration of the Goajira Peninsula, Proc. Geogr. Soc., 1885, new ser., VII, pp. 781–796, map; Casas und Codazzi, Vorläufiger Bericht der columbisch-venezuelischen Grenz-Commission, Ann. Géogr., 1902, XI, pp. 271–273.

[2] W. Sievers, Sierra Nevada de S. Marta und die Sierra de Perijá, Zeitschr. Ges. Erdk. Berlin, 1888, XXIII, pp. 1-158, map, in particular p. 67; W. Bergt, Beitrag zur Petrographie der Sierra Nevada de S. Marta, etc., Tschermak, Min. Mitth., 1889, X, pp. 271–386.

[3] W. Sievers, Karten zur physikalischen Geographie von Venezuela, Peterm. Mitth., 1896, pp. 125–129, pl. X.

[4] A. Hettner, Kordillere von Bogotá, Peterm. Mitth., Erg.-Heft no. 104, 1892, 131 pp., maps; Anden des westlichen Columbien, Peterm. Mitth., 1893, pp. 129–136.

[5] W. Sievers, Cordillere von Mérida, Penck, Geogr. Abh., 1888, III, Heft 1, 238 pp., map. F. von Wolff thought that the crystalline East Cordillera might be altered Trias and Jurassic, Zeitschr. deutsch. geol. Ges., 1904, XVI, Protok., p. 96.

border of the trough forms at the same time the west border of the Cordillera Oriental and the Sierra de Perijá, so that the lower-lying region between the latter and the Sierra de Santa Marta is, in all probability, the continuation of the trough of the Rio Magdalena, and the Sierra Nevada of the cordillera Central [1].

We have seen above that, according to Cortese, the structure of north Venezuela is determined by fractures, and that a fault-trough probably extends from Cumana to the gulf of Paria. These fractures are regarded by Cortese as connected with the earthquakes of Venezuela, and by Stille with those of Bogotá and Cucuta. The folding is anterior to the fractures. The fractures on the Rio Magdalena are, according to Stille, younger than a great part of the Tertiary formation and than certain andesitic ashes and lavas. The Cordillera Oriental bears no active volcanos.

The rocks mentioned as occurring in the Colombian Andes and the adjacent parts of Ecuador are chiefly pre-Cambrian and Cretaceous; eruptive rocks of various age are also present. Bergt also distinguishes on the west side of the Cordillera Central, from lat. 4° 15′ N. southwards, diorite porphyrites of tonalitic habit; he compares them with the Mesozoic eruptive rocks which attain such great importance further south [2]. Further, a highly altered series of rocks, which occur chiefly on the west side of the Cordillera Central between lats. 2° and 1° N., must be regarded, according to Bergt, as Palaeozoic.

Cretaceous sediments are very widely distributed and of great thickness. On the Rio Magdalena Stille estimates their thickness in round numbers at 6,000 meters [3]. The lower Cretaceous, the European character of which was already recognized by Karsten, includes the Hauterivian, Barrêmian, Aptian, and Albian stages [4]. It is followed by the upper Cretaceous (*Ananchytes ovata, Micraster coranguinum*), then red marl with gypsum (Guaduas beds, which Stille refers to the Cretaceous), then gravel, and finely clastic sediments, which are regarded as Tertiary.

Thus, in Western America, from Alaska down to Ecuador, the unconformity and transgression of the Cretaceous begins not with the Cenomanian but the Neocomian. From Wrangell to California we have the Russo-

[1] H. Stille, Geologische Studien im Gebiete der Rio Magdalena, Festschrift für A. von Koenen, 8vo, Stuttgart, 1907, pp. 277–358, map.

[2] W. Reiss und A. Stübel, Reisen in Süd-Amerika, Geologische Studien in der Republik Colombia, II; W. Bergt, Petrographie, 2. Die älteren Massengesteine, etc., 4to, Berlin. 1899, 239 pp., map, in particular p. 213; several details also in J. M. Zujovic, Les Roches des Cordillères, 4to, Paris, 1884, 75 pp., containing the description of Boussingault's collection.

[3] It is true that these figures include the Guaduas beds, which with equal justice might be regarded as Tertiary. The presence of traces of Lias (I, 535) has not been confirmed.

[4] G. Steinmann, Beitrag zur Geologie und Palaeontologie von Süd-America, VI; K. Gerhardt, Beitrag zur Kenntniss der Kreideformation in Columbien, N. J. f. Min., 1897, Beil.-Bd. XI, pp. 118–208; Stille, Geologische Studien, etc., p. 288 et passim.

boreal facies of the Knoxville stage, and in Colombia the Mediterranean-European facies.

The continuity of North and South America is clearly seen if we add the trend-lines of Central America, as they are sketched out by Sapper, to Sievers' map of the trend-lines more to the south [1]. We then perceive two virgations of opposite curvature, which unite in the arc of the Antilles.

This arc indicates *the advance of the Pacific folds into the unfolded region of the Atlantic*, and into that part of it in particular which lies between Laurentia and Brazilia. The movement dominates the whole of this region, and determines all the trend-lines of the west coast from lat. 43° N. down to lat. 4° S.

Ecuador, *Peru*. (I, p. 533.) Towards the sea the Cordillera Occidental is bordered by a plain, but isolated bosses of syenite and diorite emerge from the Inoceramus limestone of Guayaquil (I, p. 533), and on the east coast of the island of Puña (lat. 2° 48′ S.) Wolf observed a breccia of andesitic lava [2].

Mud volcanos rise here and there in the Tertiary coast region, which extends through Piura and the desert of Sechura down to lat. 7° S. Grzybowski finds that they must be assigned, along with the beds containing petroleum, to the lower Miocene or the boundary of the Oligocene, that is, they are approximately the same age as the petroleum beds of Trinidad. Here, however, granite occurs on the Rio Tumbez near lat. 4° S., and phyllite, with a north strike, near Payta (lat. 5° 5′ S.) [3]. They probably form offshoots of the little-known *Cordillera de Amotape*.

The great range of Ecuador consists of a western chain, the continuation of the Cordillera Occidental, formed chiefly of intrusive and effusive rocks of Mesozoic age, and an eastern chain, corresponding to the Cordillera Central, which is composed chiefly of pre-Cambrian rocks. These are separated by the Interandine region, which is bordered on both sides by recent volcanos and cumbered by their ejectamenta [4].

[1] Sapper, Verh. Ges. Erdk. Berlin, 1900, pl. VII; and Geogr. Congress, 1904, p. 238. Jukes-Brown and Harrison, basing their arguments on the uniform girdle of strand-lines, that is, a phenomenon which is independent of the mountain structure and not decisive in this case, had already conjectured that the Antilles were a branch of the Andes, Quart. Journ. Geol. Soc., 1891, XLVII, p. 239, 'an extension or offshoot of the Andes.'

[2] T. Wolf, Geografía y Geología del Ecuador, 8vo, Leipzig, 1892, 671 pp., map, pp. 237, 238, 333. Further traces of recent lavas on the west coast were mentioned in vol. I, p. 532; see also J. Siemiradzki, Geologische Reisenotizen aus Ecuador, N. J. f. Min., 1886, Beilage-Band IV, pp. 195–227.

[3] F. Moreno, Yacimientos de petroleo en el Departamento de Piura, Bol. Soc. Geogr. Lima, 1894, III, pp. 283–343; G. Grzybowski, Tertiärablagerungen des nördlichen Peru und ihre Molluskenfauna (Steinmann, Beiträge, VIII), N. J. f. Min., 1899, Beilage-Band XII, pp. 610–664, map.

[4] Whether Wolf's 'Interandine region' (I, p. 533, near long. 79° E., not between longs. 81° and 82°), and in particular the segment of Cuença, indicates the presence of a trough requires further investigation.

South of lat. 4° 30′ S. the range becomes broader, and in north Peru more diversified.

The structure of this region, which includes the low mountains formed of ancient rocks extending along the coast, the lofty Mesozoic chains and the ancient rocks on the Marañon in the east (I, p. 530), has more than once been represented by transverse sections, but that drawn by Steinmann through a distance of 220 kilometers, from Lima across the first lofty chain of the Andes, is the first to show that here the great cicatrice already makes its appearance, and is already developed on a gigantic scale. From this, as from a repeatedly reopening wound, molten rocks have been discharged ever since the Rhaetic or the Lias down to the present day.

Its products as determined by Steinmann are the following :—

1. *Basic porphyrites* (basic felspar, augite, magnetite, titaniferous iron): porphyritic breccia or tuff also occurs, frequently containing Jurassic fossils or wholly represented by normal Jurassic sediments; 2. *Andes diorite* (also Andes granite), with veins of aplite and pegmatite; 3. *Quartz-andesite*: this is more characteristic of the east; in the zone of contact lie the ores of Cerro del Pasco. Active volcanos are absent.

Six zones have been distinguished: 1. The granitic and Tertiary zone of the coast (not in the section); 2. A zone of normal lower Cretaceous, not very broad, and not extending far beyond Lima; 3. The zone of the diorites; 4. A porphyritic, Mesozoic zone; 5. A normal calcareous, Mesozoic zone; 6. In the east a zone of ancient schist and granite.

In order not to lose sight of the magnitude of the scale we may bear in mind the fact that the section across this foremost chain of the Andes is equal in length to the distance from the outer border of the Jura mountains, south of Bâle, to the southern shore of lake Maggiore. Nearly half of this distance is comprised in zones 3 and 4. The quartz-andesites in particular are still richly represented in zone 5.

At the end of this section, near the town of Lima and on the adjacent island of San Lorenzo, G. Neumann has discovered a Wealden flora with some European species lying beneath marine Neocomian; this affords fresh evidence that the coast chains, or at least certain parts of them, were dry land during various stages of the Mesozoic aera [1].

Cordillera Real (I, p. 518), *Argentine chains* (I, p. 512). From Peru onwards the mountains are divided into three principal zones. The first of these, on the east, is the Cordillera Real, extending along the east side of lake Titicaca; the second is the Cordillera de los Andes, on which the volcanos are seated; the third is the Cordillera de la Costa. The observations collected since the first discussion of this range show that the Cordillera

[1] Steinmann, Observaciones geológicas de Lima á Chanchamayo, Bol. de l. Ing. Minas Peru, Lima, 1904, no. 12, 27 pp.; R. Neumann, Beitrag zur Kenntniss der Kreideformation in S. Peru (Steinmann, Beitr., XIII), N. J. f. Min., 1907, Beilage-Band XXIV, pp. 69–132.

Real, the Bolivian Altaplanicie which lies in front of it on the west, and also the Argentine chains in the south, are formed of the same stratified series as that which covers a considerable part of the Brazilian mass, while the Cordillera de los Andes and the Cordillera de la Costa present a divergent series, marked by the diminished development of the Palaeozoic and the increased development of the Mesozoic marine beds. This fact has an important bearing on the nature of the continent itself and also on its relations to North America.

Let us approach the range from the north-east. Here the whole sedimentary covering, with the exception of some insignificant patches, has been removed. Evans met with some exposures on the Madeira in lat. 9° S., and observed that the strike of the ancient rocks was already directed parallel with the Cordillera. In this district alkali granites, granulites, and other crystalline rocks occur; and then, on the Beni, in rapids situated at great distances from one another, come gneiss, aplite, and a siliceous rock with sponge-remains. The plain lies surprisingly low, over large areas in Caupolicán it is only 250 to 300 meters above the sea.

The Cordillera Real increases very rapidly in height; towards the north-west, across the Nudo de Apollobamba and beyond, its free ends disappear [1]. It is followed by the giant mountains to the east and south-east of lake Titicaca (Illimani, Illampu, and others). The Nevados de Araca form its continuation to the south-south-east, and this direction is maintained to the north of Cochabamba, where an east-and-west strike unexpectedly sets in, and is followed by a sudden bend to the south, as though the bay of Arica really indicated a syntaxis in the interior of the land, although, as we shall see directly, the folding, at least in the south, does not bear out this suggestion. Here begin the long Argentine sierras, which likewise disappear far to the south in free ends.

From the summits of the Illimani, Conway has brought back gneiss and coarse-grained granite [2]. The slopes are formed of Palaeozoic sediments. Steinmann and his colleagues Hoek and von Bistram have given an interesting account of the structure of the chains from the Illimani (lat. 16° 40′ S.) past the bend at Cochabamba to lat. 22° 30′ S. The gneiss soon disappears and the mountains are formed of Cambrian, Silurian, and Devonian sediments overlain by a red Cretaceous sandstone (Steinmann's Puca sandstone) all thrown into long folds. The movement of folding, as far as can be discovered, is directed towards the east and must be younger than the Puca

[1] J. W. Evans, Expedition to Caupolicán, Geogr. Journ., 1903, XXII, pp. 601–646, map; The Rocks of the Cataracts of the River Madeira and the adjoining portion of the Beni and Marmoré, Quart. Journ. Geol. Soc., 1906, LXII, pp. 88–124, map.

[2] M. Conway, Exploration in the Bolivian Andes, Geogr. Journ., 1899, XIV, pp. 14–34, map, in particular Bonney, pp. 18 and 31; P. Lake, Trilobites from Bolivia, Quart. Journ. Geol. Soc., 1906, LXII, pp. 425–430; E. Wood, Graptolites from Bolivia, op. cit., pp. 431–432.

sandstone. This sandstone extends over so wide an area that its transgression does not seem reconcilable with the previous existence of a great range [1].

These facts are supplemented by important and more recent observations made by the Argentine geologists, which have been communicated to me through the kindness of Messrs. Hermitte, Keidel, and Schiller.

The folding towards the east is still perceptible in the extreme east of the range; on the east side of the Sierra de Zenta (about lat. 23° S., long. 65° 10′ W.) Keidel observed flakes of phyllite, and Cambrian and lower Silurian sediments, which have been thrust towards the east; even the upper Cretaceous is included in the overthrust flakes. In many places the eastern border of the pre-Cordillera appears, says Keidel, to be the margin of a segment which has been thrust up on to an invisible mass; it marks approximately the limit up to which the effect of the horizontal movement is directly visible towards the east. Similar flakes had previously been observed by Valentine on the upper Bermejo in the same region [2].

From this point to Mendoza, through twelve degrees of latitude, the southern border of the range reveals long fractures, horsts, and trough-faults, which cut through the folds. Brackebusch distinguished in this region no less than nine mountain ranges or coulisses, proceeding towards the south; the eastern ranges rise more or less isolated from the plain, the western are longer and more closely crowded together. Owing to this arrangement the isohypses drawn by this observer present us with a picture which resembles, though on a larger scale, that of the outer border of the Rocky mountains (p. 385, fig. 31) [3].

These coulisses are free ends, which emerge from a network of fractures. Stappenbeck found this to be the case in Rioja, and Keidel in Mendoza. Transverse disturbances also set in, and, as a consequence of the persistence of the folding, torsions have been produced near Mendoza, as well as overthrusts of the Cambrian on to plant-bearing Rhaetic beds.

In about the latitude of the bay of Arica *the western part of the promontory of Brazilia was overwhelmed by the folding movement directed towards the east, and at the same time broken in along sub-meridional lines.* This process gave rise to the Argentine praecordilleras, *but the movement decreases in force towards the south and dies away south of*

[1] H. Hoek und G. Steinmann, Erläuterung zur Routenkarte der Expedition in die Anden von Bolivien, Peterm. Mitth., 1906, pp. 1–12, maps.

[2] H. Keidel, Ueber den Bau der argentinischen Anden, Sitzb. k. Akad. Wiss. Wien, 1907, CXVI, pp. 649–674; J. Valentin, Bosquejo geológico de la Argentina (from the 3rd edition of F. Latzina, Diccion. geogr. Arg.), 8vo, Buenos Aires, 1897, 50 pp.

[3] L. Brackebusch, Mapa geológico del Interior de la República Argentina, 5 sheets, folio, Gotha, 1892; Höhenschichten-Karte, in Peterm. Mitth., 1893, pl. 10. A summary of the petrographical work is given by Romberg in N. J. f. Min., 1893, Beilage-Band VIII, p. 276.

Mendoza; possibly it has not come to an end even at the present day. The very considerable quantities of post-Cretaceous gravel and conglomerate which occur on many mountain-sides show inclinations up to 60° and marked unconformities. The network of faults in Mendoza sometimes forms the starting point of earthquakes.

Although the isolated *Sierra de Cordoba* (2,530 meters) presents divergent inclinations, yet its origin may be ascribed to the same general process. This sierra consists almost exclusively of pre-Cambrian rocks. Its folds strike, according to Bodenbender, through four degrees of latitude, chiefly to N. 25° W. (with variations to N. 25° E.), and are cut through by younger fractures; the sub-meridional western border possibly corresponds throughout its length with a fracture of this kind. Considerable subsidences also reveal a covering of what is probably Permo-triassic sandstone [1].

This extensive folding of the foreland is unique of its kind; a closer comparison between the Andes and Brazil thus suggests itself. On the lower Amazon, Katzer describes transgressive Devonian represented by the Hamilton stage (according to Schuchert, Oriskany) of the United States. In Matto Grosso, according to Ammon's statement, we again meet with the Hamilton stage, characterized by the widely-distributed *Vitulina pustulosa*, and also the next oldest stage, the upper Helderberg (and Oriskany sandstone), containing a great quantity of *Leptocoelia* (*Anoplotheca*) *flabellites*. Both the Leptocoelia and the Vitulina stages were observed by Bodenbender in the pre-Cordilleras, separated only by a bed with a lower Silurian Meristella; Kayser has inferred from this the presence of a transgression. Both stages reach lake Titicaca [2].

On the Amazon these stages are followed by the marine upper Carboniferous. On lake Titicaca, and then for a great distance towards the north-east, as well as towards the south-east, nearly as far as Cochabamba, Carboniferous (upper?) also occurs (I, p. 518) [3].

[1] G. Bodenbender, La Sierra de Córdoba, Anal. Minist. Agric., Secc. Geol., 1905, I, no. 2, 147 pp., map.

[2] F. Katzer, Das Amazonas-Devon; Sitzb. böhm. Ges. Wiss., 1897, 50 pp., map, in particular p. 41; Grundzüge der Geologie des unteren Amazonas-Gebietes, 8vo, Leipzig, 1903, 296 pp., map, in particular p. 244 et seq.; also C. Schuchert, Geology of the Lower Amazon Region, Journ. Geol. Chicago, 1906, XIV, pp. 722–746; L. von Ammon, Devonische Versteinerungen von Lagoinho in Mato Grosso (Brasil), Zeitschr. Ges. Erdk., 1893, XXVIII, pp. 352–366; G. Bodenbender, Devono y Gondwana en la República Argentina, Bol. Acad. Córdoba, 1897, XV, pp. 201–255, map; Contribución ál conocimiento de la Precordillera de San Juan de Mendoza, etc., op. cit., 1902, XVII, pp. 203–264, in particular pp. 221 and 232; E. Kayser, Beiträge zur Kenntniss einiger palaeozoischer Faunen Süd-Americas, Zeitschr. deutsch. geol. Ges., 1897, XLIX, pp. 274–317; for all details, A. Ulrich, N. J. f. Min., 1892, Beilage-Band VIII, 116 pp., in particular p. 90 et seq.; and J. Thomas, Zeitschr. deutsch. geol. Ges., 1905, LVII, pp. 233–270.

[3] On the upper Pachitea (left tributary of the Ucayali lat. 10–11°) lies upper Carboniferous with *Spirifer Condor* and other species; these were found by Orton and determined by Derby; Katzer, Grundzüge der Geologie des unteren Amazonas-Gebietes, p. 246.

In North Brazil and in this part of the Andes all marine formations come to an end with the Carboniferous, and they do not recommence until the deposition of the upper Cretaceous covering; this covering occurs in both regions, but in Brazil it presents the character of a partly marine transgression, and is restricted to sublitoral areas. Marine beds of Tertiary age are entirely absent. In South Brazil the marine beds in general are little developed, until, proceeding from the La Plata in the south, a great Tertiary transgression sets in.

We now reach the non-marine deposits. In the pre-Cordilleras, between San Juan and Mendoza, Szajnocha has established the presence of the European culm flora; it is not yet known in Brazil [1].

Zeiller has shown that the coal-measures of the Rio Grande do Sul and the southern part of Santa Caterina (lat. 28°–32° S., long. 48°–54° W.) contain the Khaharbári flora of the Indian lower Gondwána.

Kurtz discovered the same flora in Bajo de Velis (Sierra San Luis, lat. 32° 20′ S., long. 65° 30′ W.), and Bodenbender found it in the sandstone which occurs in the so-called Pampas sierras and the pre-Cordilleras, resting sometimes on an Archaean, sometimes on a Palaeozoic foundation. The typical species, *Glossopteris Browniana*, does not fail, and Lepidodendron here accompanies this flora, as in South Africa and on the lower Tunguska (III, p. 36) [2].

Rhaetic plant-remains are known in the pre-Cordilleras. Then follow the Puca sandstones, which are certainly in part extramarine; and freshwater Cretaceous marls, containing here and there freshwater shells and Dinosaurs, are recorded at a height of 4,000 meters. Above these beds, especially in certain parts of the Argentine sierras, there lie, precisely as in Colombia, astonishing thicknesses of gravel, sand, and argillaceous sediment, devoid of organic remains, which have been affected by tectonic movements from the time of the upper Cretaceous down to the present day.

From this it appears that nowhere between lats. 14° and 35° S., at least in the whole of that region of the Andes which lies east of lake Titicaca and the volcano of Tinguirica, does a Mesozoic completion of the marine series set in. In the Argentine pre-Cordilleras we have, in fact, a foreland series. It corresponds in the closest manner with that of Brazil; from the Carboniferous to the upper Cretaceous no marine bed makes its appearance, and successive floras (Culm, Gondwána, Rhaetic) show that through long periods no sea existed here. Active volcanos are absent throughout this eastern part of the Andes. It is true, however, that indications exist of former volcanic activity.

[1] L. Szajnocha, Carbonische Pflanzenreste aus der Argentinischen Republik, Sitzb. k. Akad. Wiss. Wien, 1891, C, pp. 199–209.

[2] R. Zeiller, Flore fossile des gisements houillers du Rio grande do Sul (Brésil méridional), Bull. Soc. géol. France, 1895, 3e sér., XXIII, pp. 601–628; F. Kurtz, Contribuciones á la Palaeophytología Argentina, Rev. del Museo de la Plata, 1895, VI, pp. 119–139.

Stelzner has shown that a long series of silver-tin veins extends from the northern end of lake Titicaca, along the lofty Cordillera Real through Oruro and the famous Potosi, nearly up to Argentina, i.e. from lat. 15° 10′ to lat. 21° S. It corresponds with a range of quartz-trachyte and dacite[1] which is at most of Cretaceous age. This range, occurring outside the zone of the existing volcanos, shows that here also the volcanic activity has been restricted or displaced. At other places also andesites cross over into the eastern region.

In the west of this part of the Andes, an elongated, narrow plateau, the Bolivian *Altaplanicie,* makes its appearance as a fairly independent element. It stands out very plainly in about lat. 16° S.; beyond lat. 23° S. the plateau of Atacama may be regarded as its continuation. It probably attains its greatest breadth in the latitude of the bay of Arica and the bend of Cochabamba, where the problematical indications of a syntaxis, diverging from the easterly direction of the folding, make their appearance. Dereims estimates the height at 3,700 to 3,800 meters (Titicaca, 3,812 meters; in the east, Illampu 6,684 meters, and Illimani 6,458 meters, according to Conway; in the west, Sajama over 6,500 meters [2]).

According to a transverse section by Steinmann the Altaplanicie consists (in lat. 17°) of gently undulating beds. To the east the predominant rocks are the Palaeozoic series of the Cordillera Real, traversed by trachyte, further to the west the very thick Cretaceous Puca-sandstone and the equally thick post-Cretaceous sediments [3].

The Cordillera Real, the Argentine cordilleras, and the Altaplanicie form a mountain-land with the stratified sequence of the Brazilian foreland, Andine structure, and no active volcanos.

The Cordillera de los Andes and Cordillera de la Costa. These two chains must be regarded as forming a single structure. The Cordillera de la Costa is the natural foundation of the Mesozoic series, which rests autochthonously against and upon its eastern side; it is this series which bears the volcanos.

In Peru marine Trias is present. In south Peru and for a long distance down into Chile the series ranges from the Lias into the Cretaceous; the Tertiary is represented by leaf-bearing beds. The thick Palaeozoic series of the near East has not yet been observed, only at La Ligua (lat. 32° 27′ S., north of Valparaiso) shales with Productus are recorded by R. A. Philippi [4].

To the west of this Mesozoic series the Archaean rocks of the coast

[1] A. W. Stelzner, Silber-Zinnerzlagerstätten Bolivias (edited by A. Bergeat), Zeitschr. deutsch. geol. Ges., 1897, XLIX, pp. 51–142, map.

[2] A. Dereims, Le Haut Plateau de Bolivie, Ann. de Géogr., 1907, XVI, pp. 350–359.

[3] G. Steinmann, Entstehung der Kupfererzlagerstätte von Corocoro, Festschrift für H. Rosenbusch, 8vo, Stuttgart, 1906, pp. 335–367.

[4] R. A. Philippi, Palaeozoische Schichten in Chile, Zeitschr. deutsch. geol. Ges., 1898, L, p. 435.

cordilleras first make their appearance in the north as isolated ridges (I, p. 523); further south they form long continuous ranges. Where they are absent, as for example near Iquique (lat. 20° 10′ S.), the Mesozoic rocks reach the sea. Ascending from the ancient granite of the coast at Copiapó (lat. 27° 15′ S.), towards the east, Steinmann met with Mesozoic porphyrites, then siliceous Neocomian limestone, and afterwards conglomerates and tuff, with dykes of porphyrite. At La Ternera he reached coal-measures resting on a conglomerate of Archaean rocks; they are overlain by Lias with Arietes [1]. At Caracoles gypsum makes its appearance in the Oolites and affords an easily recognized horizon.

On this diversified Mesozoic series, generally beginning with the lower Oolites, the great volcanos are seated. As regards their distribution we may refer to what has been said above, and to the lists of Hauthal (I, p. 519 et passim). There can be no doubt that volcanic activity has manifested itself over this long line from very remote times, since the lower Oolites, at least, and perhaps since the Rhaetic or the Lias. Many of the Mesozoic sediments are true tuffs. The whole series is invaded by sills and bosses. In the region between lats. 27° and 30° 40′ S., as would appear from Möricke's observations, diabases and augite porphyrites first made their appearance, chiefly as outpoured sheets, with beds of tuff and breccias, and these were predominant throughout the whole of the Jurassic and a part of the Cretaceous period. Then more acid rocks followed, quartz-diorites, hornblende porphyrites, and granites accompanied by quartz-porphyry. Somewhere near the beginning of the Tertiary times plagioclase-augite rocks made their appearance and were followed by andesites and liparites. The volcanos in Chile, not yet extinct, which were visited by Möricke, are formed of basic rocks, varying between olivine-bearing pyroxene andesite and basalt [2].

This succession of Möricke's is valid as a single instance only. The quartz-diorites, the granites, and the whole group of the so-called Andes granites may be regarded as the equivalent of the North American grano-

[1] H. Graf zu Solms-Laubach and G. Steinmann, Das Auftreten der Flora der rhätischen Kohlenschichten von La Ternera (Chile) (Steinmann, Beiträge, VII), N. J. f. Min., 1899, Beilage-Band XII, pp. 581–609. At Jorquera, south of Ternera, the ancient hornblende gneiss of the Coast cordillera crops out from the midst of the Mesozoic porphyrites; F. von Wolff, Zeitschr. deutsch. geol. Ges., 1899, LI, p. 478. A survey of the Mesozoic zone of North Chile is given by W. Möricke, Versteinerungen des Lias und Unteren Oolith von Chile (Steinmann, Beiträge, II), N. J. f. Min., 1894, Beilage-Band IX, pp. 69–76; for the physical structure of the north, also L. Darapsky, Das Departement Taltal, 8vo, Berlin, 1900, 229 pp., atlas.

[2] R. Hauthal, Die Vulkangebiete in Chile und Argentinien, Peterm. Mitth., 1903, pp. 97–102, map; and Distribución de los centros volcánicos, Riv. del Museo de La Plata, 1903, 16 pp., map; a small supplement is given by Steffen, Verh. deutsch. wiss. Ver. Santiago, 1904, V, p. 53, note; W. Möricke, Geologisch-petrologische Studien in den chilenischen Anden, Sitzb. k. Akad. Wiss. Berlin, 1896, XLIV, pp. 1161–1171.

diorites. These are of various age, some of them very recent. They are repeated towards the south; Nordenskjöld mentions them, e.g. in the island of Calbuco (north of Chiloe), and even much further south [1].

Tracts of extraordinary length here come under observation. Burckhardt points out that thick conglomerates formed of well-rounded pebbles of Jurassic porphyrite are known to extend, unchanged in character, from Bolivia to lake Nahuel-huapi, that is for not less than 25 degrees of latitude. These facts show how small a part of the volcanic history of these regions is represented by the existing volcanos.

The works of Hauthal, previously cited, still remain our principal source of information, although the area they include only begins at lat. 22° S. The most important results obtained by this observer are: the scarcity or complete absence of volcanic mountains in the Patagonian cordillera, their almost exclusive occurrence in the principal cordillera, their arrangement in series, often parallel to one another and the trend-lines of the Andes, and finally their most frequent occurrence in those places where the mountains consist of parallel folds running north and south, as between lats. 22°–27° S., where also the rectilinear arrangement is most clearly seen.

To this we may add that we as yet possess no evidence which might indicate a migration of the volcanos, but on the other hand fault-troughs are known in the volcanic zone, as for example the trough of Antofagasta, mentioned by Hauthal, which is 150 kilometers long and only 5 to 8 kilometers broad.

We have already observed that andesites extend into the region of the eastern series, but no active volcanos: a few, such as the twin volcanos at Poma (Jujuy, Hauthal's no. 28), may stand within the boundary, but they are not recorded as active.

On the north, the western border of the Altaplanicie may be taken as marking the eastern boundary: but I can find no precise accounts of this boundary in its course further to the south; the older stratified series of the east may sink normally beneath the Mesozoic series of the Cordillera de los Andes or it may be thrown down along a fracture, but in the absence of information we cannot decide between these alternatives. A boundary between a thick Palaeozoic series and a Mesozoic series which is without a Palaeozoic foundation occurs, as we know, in the Basin ranges near the 117th meridian (I, p. 579).

In the south, W. Schiller has travelled from the Pic de Palo (east of San Juan), which consists of pre-Cambrian and Palaeozoic rocks, towards the west across the lower Silurian Sierra del Tigre and thence into the Mesozoic region of mount Aconcagua. His account of mount *Aconcagua* has already

[1] O. Nordenskjöld, Krystallinische Gesteine der Magellansländer, Wissenschaftliche Ergebnisse der schwedischen Expedition nach den Magellansländern, 1901, I, pp. 175–240, in particular p. 202.

been published[1]. From letters written later I extract the following: Towards the boundary the structure is extremely complicated; the Pic de Palo is overfolded towards the west; west of the Sierra del Tigre the Mesozoic quartz-porphyries come in. Further south the fault-trough of Uspallata marks the boundary. The Cordillera (not the Sierra) del Tigre, which is continued towards the south into mount Aconcagua, consists of quartz-porphyry; the Jurassic and Cretaceous beds which are superposed on its western side dip towards the west, and are cut off next the Espinacito pass by a great fault; this fault is followed by the same series of rocks, from the quartz-porphyry upwards, similarly dipping towards the west. The volcanic rock has here caught up mighty fragments of Mesozoic formations, and also gypsum, and carried them to a great height. Aconcagua is not a volcano, but an accumulation of Mesozoic rocks, and to the south of this great mountain (near the Penitentes) a great overthrust occurs in Mesozoic beds.

Here the distinguished geologists who are occupied with this region find difficult problems confronting them.

Towards the south the eastern Palaeozoic series completely disappears; and the eastern chains of the Cordillera de los Andes are thrown into long open folds[2].

Not far from lat. 35° S. the *Sierra Pintada* leaves the border of the Cordillera, and strikes out to the south-east into the Pampas; according to Wehrli it consists of dykes and long veins of porphyry and diabase which crop out from tuff and sandstone. This sierra is cut through by the Rio Diamante and the Atuel; its southern extremity is 60 kilometers distant from the border of the principal range. A plain which narrows away like a wedge towards the north separates it from the border of the high mountains. In the United States this plain would probably be described as a Park. On entering the great range Burckhardt encountered a broad syncline striking north and south, which forms the outermost part of the east border of the mountains along the Atuel (lat. 35° S.) and the Rio Malarguë (lat. 35° 30′ S.), but probably extends far beyond this. This syncline

[1] W. Schiller, Geologische Untersuchung bei Puente del Inca (Aconcagua), N. J. f. Min., etc., 1907, Beilage-Band XXIV, pp. 716-736, map. The specimens which Fitzgerald brought back from the summit of Aconcagua are, according to Bonney, hornblende andesite; Fitzgerald, The highest Andes, 8vo, London, 1899, p. 321.

[2] G. Bodenbender, Terreno jurássico y cretácico en los Andes Argentinos entre el Rio Diamante y Rio Limay, Bol. Acad. Córdoba, 1892, XIII, pp. 5–47, map; Lange, Hauthal y Wolff, Examen topográfico y geológico de los Departamentos de S. Carlos, S. Rafael, y Villa Beltran (Provincia de Mendoza), Rev. del Museo de La Plata, 1895, VII, pp. 13-93, maps; C. Burckhardt, Profils géologiques transversaux de la Cordillère Argentine, Ann. Mus. de La Plata, 1900, fol., 136 pp., maps; for the stratigraphy of the Mesozoic foothills between lats. 35° and 40° S. valuable information (based on Bodenbender's collections) is given by O. Behrendsen, Zur Geologie des Ost-Abhanges der argentinischen Cordillere, Zeitschr. deutsch. geol. Ges., 1891, XLIII, pp. 369–420, and 1892, XLIV, pp. 1–42.

comprises, in conformable succession, the Mesozoic series from the lower Jurassic upwards, including the Senonian and the Danian. It is overlain unconformably by lavas which are younger than the folding.

In this region the porphyrite conglomerates on the Rio Colorado become so extremely thick that they form the greater part of the valley slopes. Gypsum is intercalated with the Jurassic [1].

Between lats. 38° and 39° S. Burckhardt is again our guide. The open folding, the porphyrite conglomerates, the gypsum and the recent lavas reappear here. The upper stages of the Cretaceous are not to be seen, but in the interior of the mountains a freshwater deposit occurs, believed to be Eocene; it is true that it lies unconformably, but its bedding is disturbed. In this region the cordillera maintains its original direction, but the strike of the folds varies, probably owing to the presence of large granite masses, and the whole cordillera is broken up into three branches by the insertion of two elongated plains. Burckhardt enumerates the following, taken in order from east to west: 1. The *eastern zone*, cropping out from the Pampas; simple Mesozoic folds; 2. The *plateau de las Lajas*; gravel and recent lavas; 3. The chain of *Peiro Hachado*, Mesozoic folds; porphyry and porphyrite, recent volcanic cone; 4. Plateau of the *Aluminé*, recent lavas, beneath which granite is exposed; 5. Eastern part of the chain of *Lonquimay*, folded Jurassic, broken through by a more recent granite boss; 6. Western part of the same chain, folded porphyrite conglomerates, and porphyrite, above them recent volcanos and lavas sloping away to the longitudinal valley of Chile. The structure of the margins of the inserted plains leads Burckhardt to the conclusion that they are sunken areas, and that a virgation of the Andes occurs here, produced by subsidences [2]. The occurrence of gypsum at a definite horizon in the Jurassic is itself an indication of local subsidence at an earlier period; we shall recur later to this peculiar structure, which so strongly recalls that of the Basin ranges.

In the east, near Roca on the Rio Negro (lat. 39° 5′ S., long. 67° 30′ W.), the *Guaranitic stage*, consisting of red sand and containing remains of Dinosaurs, may be seen beneath the general covering of younger formations; it forms the foundation of the plain. S. Roth has found lenticular marine intercalations in this sand, and Burckhardt has shown that its fauna corresponds with the upper Senonian and Danian, the same uppermost horizons of the Cretaceous which have just been mentioned as occurring in the syncline of the Rio Malargüe (lat. 35° 30′ S.). It is the

[1] Wehrli, in the introduction to Burckhardt, Profils géologiques, p. 7.

[2] C. Burckhardt, Coupe géologique de la Cordillère entre las Lajas et Curucautin, Ann. del Museo de La Plata, 1900, 100 pp., maps, in particular pp. 64 and 65; for the stratigraphy of the whole range between lats. 33° and 39° S., Beiträge zur Kenntniss der Jura- und Kreideformation der Cordilleren, Palaeontographica, 1903, L, 144 pp., maps.

same stage as that which was made known, about 32 degrees of latitude further north, by Derby and White, on the little river Maria Farinha north of Pernambuco (lat. 8° S.); its correspondence with the uppermost horizon of the Cretaceous of Ninnyur in India was recognized by Kossmat [1].

The Guaranitic sand with Dinosaurs is continued, according to Roth's observations, towards the west, and is visible on the lower Pichi Leufu (left tributary of the Limay, lat. 40° S., long. 70° W). A lower horizon is formed of grey quartzite. Still further towards the west, porphyry tuff occurs, and a tuff of vivid red and yellow colour gives its name to the Piedra Pintada. In this red tuffaceous sandstone, which passes below into marly limestone, Roth found marine Lias fossils and an intercalated bed with land-plants, which belong, according to Kurtz, to the flora of Ráj-mahál (upper Gondwána of India).

The beds, which have hitherto lain horizontally, now present an increasing number of disturbances, and in the ravine of the neighbouring Sierra de la *Angostura*, which is about 1,000 meters in height, gneiss and granite crop out [2]. Porphyries and granite, accompanied by recent volcanic rocks, follow and continue as far as the river Collon Cura.

The Lias fossils of the Piedra Pintada are the most southerly pre-Cretaceous marine fossils so far known in Patagonia. Their occurrence outside the border of the great cordillera shows that the Mesozoic zone spreads out towards the east beneath the Patagonian plain; the occurrence of gneiss and a land flora shows, however, that the foundation of this zone is already visible here, and the superposition of the land flora is probably just as autochthonous as in the Cordillera de la Costa. At the same time Archaean rock acquires an increased development in the high mountains.

[1] Santiago Roth, Apuntes sobre la geología y la paleontología de los territorios del Rio Negro y Neuquen, Rev. del Museo de La Plata, 1899, IX, pp. 141–196, map; Burckhardt, Le gisement supercrétacé de Roca, op. cit., 1902, X, pp. 206–222; A. C. White, Contribution to the Palaeontology of Brazil, Arch. Mus. Nac., Rio de Janeiro, 1888, IX, 273 pp.; F. Kossmat, Bedeutung der südindischen Kreideformation, Jahrb. k. k. geol. Reichsanst., 1894, LIV, pp. 459-478, in particular p. 467. The description of the regions to the south of lat. 39° S. is based on the beautiful edition of Moreno's map (1 : 1,500,000), which appeared as a supplement to L. Gallois, Les Andes de Patagonie, Ann. Géogr., 1901, X.

[2] Roth, Kurtz, et Burckhardt, Lias de la Piedra Pintada (Neuquen), Rev. del Museo de La Plata, 1902, X, pp. 225–250, map. According to Roth the gneiss would rest upon the Lias, but the observer states that he had no opportunity to make sure of this. This lie of the beds would indicate a considerable movement towards the east. For the geographical position see H. Zapalowicz, Rio Negro-Gebiet in Patagonien; Denkschr. k. Akad. Wiss. Wien, 1893, LX, pp. 531–564, map. According to the maps of the Padrón Minero (An. Ministr. Agric., Secc. Geol., 1906, I, no. 3, maps) two rivers situated somewhat further south bear the name of Pichi Leufu. The same work mentions numerous dykes of gold-bearing quartz in the district of Teca (Territory of Chubut, lats. 42° 45′ and 43° 30′ S., and longs. 70° 30′ to 71° W.).

Our knowledge of the range, and indeed of the whole of Patagonia, has been greatly increased by the dispute between Chile and Argentina with respect to their boundary.

On the partition of Patagonia the political boundary was determined in a manner which to some extent recalls the ancient disputes between the Russians and Chinese (III, p. 109), the unknown watershed of the Andes being adopted, on the supposition that this watershed nearly coincided with the crest of the Andes. But this range, as is common in arctic regions, is cut across by eydes, so that south of lat. 41° S. the watershed is almost completely displaced towards the east side. The violence of the western storms, the heavy rainfall on the Pacific slope, and the considerable fall of many of these transverse valleys cause the rivers, even at the present day, to cut their beds backwards, which is equivalent to a further displacement of the watershed towards the east, and many of the great lakes on the east side of the Andes have thus acquired an outflow towards the west in comparatively recent times. The reports of Steffen on behalf of Chile and the extensive travels of Moreno and his colleagues on behalf of Argentina have not only led to the discovery of these facts, but have furnished an instructive, though still incomplete, survey of the Southern Andes [1].

In lats. 38°–39° S. the cordillera to the east of the longitudinal valley consists, as we have seen, of three folded zones, which are separated by two downthrown plains (fault-troughs) extending from north to south. In the western plain (Plateau of the Aluminé) granite occurs beneath volcanic coverings; the granite plateau, which Moreno mentions on the Pitchin-Nahuel-Huapi (lat. 39° 35′ S., left tributary of the Aluminé), is probably its continuation [2], and only a little to the south of it, according to Hauthal, this range must possess considerable breadth towards the west; lake Huechu Lafquen lies in it; the volcano of Lanin and others are seated on it. Beside the granite, a gneiss range [3] running north and south makes its appearance on lakes Lolog and Lacar (lat. 40° 10′ S.). These ancient rocks also surround the whole of the western side of the Nahuel-Huapi: the great Tronador (3,400 meters, lat. 41° 10′ S.) is an extinct volcano on a granite base.

Folded ranges of Mesozoic, however, are seen again to the east of the

[1] From a number of works we will only mention: H. Steffen, Reisen in den Patagonischen Anden, Verh. Ges. Erdk. Berlin, 1900, XXVII, pp. 194–220, maps; Reisenotizen aus West Patagonien, Zeitschr. Ges. Erdk. Berlin, 1903, pp. 167–207; The Patagonian Cordillera and its main rivers between lats. 41° and 48° S., Geogr. Journ., 1900, XVI, pp. 14–38, maps; F. P. Moreno, Apuntes preliminares sobre una excursión á los territorios del Neuquen, Rio Negro, Chubut y Santa Cruz, Rev. del Museo de La Plata, 1898, VIII, pp. 198–372, map; Exploration in Patagonia, Geogr. Journ., 1899, XIV, pp. 241–269 and 353–378, map.

[2] F. P. Moreno, Geogr. Journ., 1899, XIV, p. 366.

[3] Hauthal, in Moreno, Rev. del Museo de La Plata, 1898, VIII, p. 338 et seq.

Cordillera. On the south-east border of the Nahuel-Huapi, near Punto Moreno, Wehrli observed a zone of quartz-porphyry and porphyrite extending towards the south-east. It is followed on the east by coarse, breccia-like tuffs, and still further to the east by sandstone; then near San Carlos by a broad anticline of beds which, judging from their plant-remains, cannot be younger than the upper Cretaceous. Similar folds are visible on the east border of the cordillera even to the south of lat. 40° S., where they disappear beneath the lofty basalt mountains which accompany this eastern border [1].

The rocks of the south-eastern part of the Nahuel-Huapi are continued at least as far as the Rio Manso (lat. 41° 40′ S.); east of the river, towards the border of the cordillera, Moreno arrived at a Cretaceous chain, which reaches 7,000 feet, and observed peaks of a porphyritic rock [2].

The result of these observations is as follows:—

The ancient rocks of the Cordillera de la Costa proceed further and further inland, always accompanied on the east by Mesozoic sediments; they are already visible in lat. 40° S., long. 70° W., covered, as in the north, by Mesozoic plant-bearing beds; and in lats. 38°–39° S. two long plains (fault-troughs) divide the Andes lengthwise, east of the longitudinal valley.

Porphyrites, with their variegated tuffs, occur at many localities. They may be traced into the Pampas, and far to the south, beneath the basalts which accompany the east border of the range, the porphyry boss of mount Kochaik (lat. 49° 6′ S., long. 72° W.) is still visible [3]. Moreno mentions a depression which strikes towards the south-east nearly parallel to the Rio Negro, and to the south of this a fairly extensive mountain-mass, the *Balcheta* (about lat. 40° 30′–40′ S., and long. 66°–66° 30′ W.), which rises to a height of 1,700 meters [4]. A porphyry has already been mentioned (I, p. 516) as occurring to the south of the mouth of the Rio Negro in the Sierra San Antonio at the head of the gulf of San Matias (lat. 41° 40′ S.). To the south of this locality porphyritic rocks are not infrequent. If we

[1] L. Wehrli, Rapport préliminaire sur mon expédition géologique dans la Cordillère argentine du 40° et 41° lat. S. (Région du Nahuel-Huapi), Rev. del Museo de La Plata, 1899, IX, pp. 221–242, map. The isolated Cerro del Perro formed of Liparite or trachyte rises from the folds of the east border without any disturbance of the surrounding country. For the part which borders it on the west, see Steffen, Beiträge zur Topographie und Geologie der andinen Region von Llanquihue, Festschrift für F. von Richthofen, large 8vo, Berlin, 1893, pp. 307–344, maps; in this work also a petrographical description of the ancient rocks by Pöhlmann.

[2] Moreno, Geogr. Journ., 1899, XIV, p. 363; Steffen, ibid., p. 36, and Mesozoic traces near lat. 43° 30′.

[3] Steffen, loc. cit., p. 263.

[4] Steffen, Rev. del Museo de La Plata, VIII, p. 302. Thus the commencement appears to lie not far from the Sierra de la Angostura and the Punta Pintada.

add to the facts recorded by Darwin those observed by Scrivenor[1], the case stands as follows:—

To the south of San Antonio (lat. 41° 40′ S.) no outcrop is so far known as far as Trelew on the lower Chubut (lat. 43° 15′ S.); there an acid eruptive rock crops out. Then, from lat. 44° S. to the heights of the Tetas de Pinedo (lat. 45° 3′ S.), porphyry, porphyrite, and porphyrite breccia occur at a number of places along the coast, as at St. Elena (lat. 44° 35′ S.) where a dyke of quartz-porphyrite, 11 kilometers in length, is exposed. Near Malespina (lat. 44° 30′ S.) on the Chico Chubut quartz-porphyry occurs and a closely folded porphyritic mass, the folds of which strike to the south-east. I think we may assume that these outcrops on the Chico Chubut and on the coast between lats. 44° and 45° S. are outliers of the ridge which, according to Moreno, strikes from the north-north-west to lake Musters. The next locality known is Port Desire (Deseado; lat. 47° 50′ S.), where Darwin mentions a ridge of claystone porphyry and stratified breccia, 134 meters in height, and extending at least 40 kilometers inland.

Finally, eruptive rocks occur in Bird island (lat. 48° 56′ S.).

Sheets of porphyry pebbles, the *Tehuelche* pebbles, extend through many degrees of latitude. Siemiradzki and Scrivenor believe that they are derived from isolated masses of porphyry within the Pampas[2].

A general consideration of these facts, in particular the advance of the ancient rocks from the west into the interior, the local occurrence of isolated Mesozoic ridges, and more especially the structure of the mountains which bound this region on the north and south, has led to the view (I, p. 516) that here the branches of the Andes diverge from one another towards the south and south-east in virgation. This opinion is not shared

[1] C. Darwin, Geological observations on the volcanic islands and parts of South America, 2nd ed., 1876, p. 435 et passim; J. B. Scrivenor, Notes on the Geology of Patagonia, Quart. Journ. Geol. Soc., 1903, LIX, pp. 160–179, map.

[2] Darwin, Geological observations, &c., p. 219; J. von Siemiradzki, Zur Geologie von Nord-Patagonien, N. J. f. Min., 1893, I, pp. 22–32, in particular p. 25; Scrivenor, Quart. Journ. Geol. Soc., 1903, LIX, p. 169. As early as 1892 Herr von Siemiradzki wrote me as follows in a long and instructive letter: 'The Sierra *Lihue-Calel* (lat. 38° S., long. 66° W.) consists of five very short anticlines of red granite-porphyry striking to the south-east and separated from one another by broad synclinal valleys. The dry river-bed of the Cura-Có (which once connected the Rio Salado and Rio Colorado), the entrance to which is stopped up by sand-dunes near the lagoon of Urre-Lafquen, is cut deep in red granite. The so-called Patagonian pebbles are not derived, as Darwin believed, from the remote cordillera, but from these local ranges which seem to form the whole foundation of the central Pampas, to the west of the confluence of the Cura-Có with the Colorado. The whole range of *Choique Mahuida* which extends along the Cura-Có . . . must be referred here. We also cross small porphyry chains in the region between the upper Colorado and Rio Negro.' This region corresponds approximately to the north boundary of the porphyry pebbles. Siemiradzki did not share the view that the Andes separate in virgation, but believed that there was an independent and older folding with a south-easterly strike.

by experienced Argentine explorers. The objection is raised that Roth observed gabbro on Lago Musters, also effusive rocks, probably quartz-porphyry and amygdaloidal rocks. None of these, however, have anything to do with the Jurassic porphyrites of the Andes, and all are younger than the lower Tertiary. Evidence in favour of a divergence of the cordilleras is not forthcoming. Folding does not occur, only local disturbances produced by eruptions [1].

It may first be observed that the whole region presents, not the rock sequence of Brazil, nor that of the Argentine praecordilleras, but rather one approaching, through its numerous eruptive rocks, of whatever age these may be, that of the Western Andes; and from these mountains it is not separated by any sharp boundary, as is shown, for example, by the Sierra Pintada and the Pietra Pintada.

Sierra de la Ventana. (I, p. 515.) The difference of opinion just mentioned extends also to the interpretation of the chains which terminate in the east near cape Corrientes and Bahia Blanca. No doubt exists with regard to the facts, especially after the detailed description by Hauthal and Schiller.

A northern, less-elevated series of chains strikes towards the south-east from the other side of Olavarria through *Tandil* to cape Corrientes. Granite and gneiss crop out on the north side. These are covered unconformably by dolomite, quartzite, and sometimes dark limestone, which are not strongly folded, though traversed by faults. The quartzite contains fossils which are believed to be *Arthrophycus Harlani*, Hall (upper limit of the lower Silurian of North America).

Opposite to these chains in the south and separated from them by a plain about 150 kilometers wide, rises a second group diverging towards the south-east, and named from its highest part the *Sierra de la Ventana* (according to recent measurements 1,280 meters in height). To the south-west of the Sierra Ventana (F, fig. 36) ancient granite crops out; then, forming the highest part of the sierra, a quartzite precisely similar to that of the Sierra Tandil, but intensely overfolded from the south-west to the north-east. At the north foot of the Sierra de la Ventana the quartzite dips to the south and is underlain by clay slate; then on the slopes of the Sierra de Pillahuinco (D, fig. 36), which lies beyond this range, conglomerate makes its appearance, and then again clay slate.

Hauthal regarded the northern (Tandil) group as an opposing buttress, and the southern (Ventana) chains as folded against it from the south-west. Schiller and Keidel regarded F and C (fig. 36) as the two limbs of a syncline overfolded from south-west to north-east [2].

[1] Keidel, Sitzb. k. Akad. Wiss. Wien, 1907, CXVI, p. 650.

[2] R. Hauthal, La Sierra de la Ventana, Rev. del Museo de La Plata, 1892, III, pp. 3–11; Las Sierras entre Cabo Corrientes é Hinojo, op. cit., 1896, VII, pp. 477–490; I. Excursión

Burmeister believed that the sierras Tandil and de la Ventana were members of an older mountain system; Hauthal and the observers who followed him maintain that they stand outside the complex of the Andes. Stelzner, on the contrary, regarded them as branches of the Andes. I believe that Stelzner's view is correct as regards the Sierra de la Ventana, but not as regards the Sierra Tandil.

Near the mouth of the La Plata, on the island of *Martin Garcia,* a basic, intrusive, and probably ancient rock crops out. In Buenos Ayres gneiss has been bored at a depth of 300 meters [1]. These are traces of the ancient Brazilian mass, and to this, forming part of the border, the Sierra Tandil belongs.

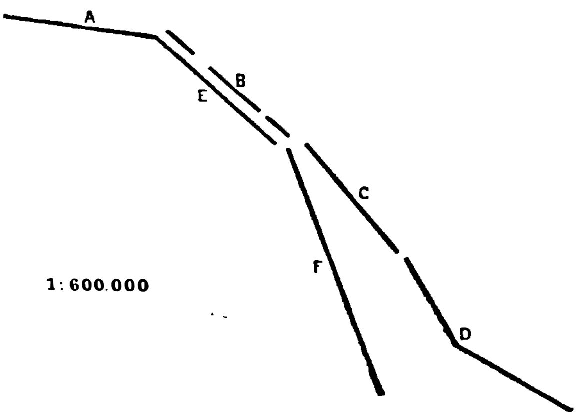


FIG. 36. *Trend lines of the Sierra de la Ventana* (after Hauthal). A., Sierra de Puán; B., S. de Bravard; C., S. de las Tunas; D., S. de Pillahuinco; E., S. de Curumalal; F., S. de Ventana.

We regard the Sierra de la Ventana as part of the Palaeozoic series, which has been folded by the advance of the Andine movement into the region of the foreland. The direction of the foldings to the north-east is that which the general eastward folding of the Argentine chains would lead us to expect at this place. This view also accords with what has been said regarding the structure of the east coast of Patagonia, and relieves us from the necessity of assuming that the Sierra de la Ventana is an independent element within the otherwise uniform structure of South America.

Patagonia. The broad plateaux of the plain increase in height

á la Sierra de la Ventana; II. Apuntes geológicos de las Sierras de Olavarria, Public. de la Univ. de La Plata, 1901, no. 1, pp. 1–30, map; and Beiträge zur Geologie der argentinischen Provinz Buenos-Ayres, Peterm. Mitth., 1904, pp. 83–92 and 112–117, map (here a third line directed to the south-south-east, that of the Sierra del Chaco, west of the Sierra de la Ventana, is added to the virgation); Schiller, in Keidel, Sitzb. k. Akad. Wiss. Wien, 1907, CXVI, pp. 650–652; also J. Valentin, Rápido estudio sobre las Sierras de los Partidos de Olavarria y del Azul, Rev. del Museo de La Plata, 1894, VI, pp. 1–24. J. von Siemiradzki mentions Devonian fossils from the north-westerly continuations of the Sierra Tandil, but the statement has raised doubt; Peterm. Mitth., 1893, pp. 49–62, map; for a divergent interpretation of the facts see Sievers, op. cit., Litterat.-Bericht, 1902, p. 78.

[1] Valentin, Bosquejo geológico, p. 12, has collected the data on this point.

towards the west. Basalt sheets and cones, extensive lakes, and mighty moraines accompany the eastern borders of the mountains. In their neighbourhood rather steeply inclined Cretaceous beds occur. At some distance from the mountains, Cretaceous and Tertiary lie flat. The Cretaceous also reaches the Atlantic coast, as, for example, near Port San Julian (lat. 49° 20′ S.).

At Roca, on the Rio Negro (lat. 39° 5′ S.), red sand with Dinosaurs, the Guarantian stage, and a marine deposit of upper Senonian or Danian make their appearance. On the upper Limay (lat. 40° S.), east of the Sierra Pintada, Roth found the same Dinosaurian sand, resting there on quartzitic sandstone [1].

Much further to the south, east of lake Pueyrredon (lat. 47° 30′ S.), Hatcher observed greensand with large oysters, above this conglomerate with fossil wood perforated by marine boring shells, then the fossiliferous Belgrano-beds, the fauna of which, according to Stanton, is not younger than Gault. The Trigonia recall those of Uitenhage [2].

On the Cerro Belgrano porphyry-tuff underlies the Cretaceous.

On the Mayer river (lat. 48° 15′ to 48° 30′ S.) we meet with the Dinosaur sands of the north. A clear idea of the region between the Lago Argentino and the Seno de la Ultima Esperanza (lat. 50° 10′ to 51° 55′ S.) is given by Hauthal's geological map and the description by Wilckens. The high mountains are covered with glaciers and unexplored. On the east they are joined by a zone which consists of quartz-sandstone, and above this thick beds of a compressed splintery clay-slate containing Algae like those of the Flysch, and also numerous Inoceramus, Pachydiscus, and Cardiaster. After what has been stated previously with regard to the East Alpine Flysch and the Yakutat series in Alaska, the recurrence of this facies at such remote points must arouse surprise. Wilckens terms this horizon the stage of *Inoceramus Steinmanni*; Paulcke believes it is of Senonian, probably upper Senonian age. Above it follow marine beds, and others which, from the similarity of their plant-remains, are correlated by Kurtz with the Dakota stage, but referred by Wilckens to the upper Senonian. The stage of *Lahillia Luisae* contains Baculites, and likewise belongs to the upper Senonian [3].

[1] S. Roth, Rev. del Museo de La Plata, X, p. 231.

[2] J. B. Hatcher, Geology of South Patagonia, Am. Journ. Sci., 1897, 4th ser., IV, pp. 327–354; and Sedimentary Rocks of South Patagonia, op. cit., 1900, 4th ser., IX, pp. 85–108, map; also Report of the Princeton University Expedition to Patagonia, 1896–1899, ed. by W. Scott, I, Marine cretaceous Invertebrates, by T. W. Stanton, 4to, Stuttgart, 1901, 43 pp.

[3] R. Hauthal, in F. Kurtz, Contribution à la Paléophytologie Argentine, III, Rev. del Museo de La Plata, 1899, X, pp. 43–61; O. Wilckens, Die Lamellibranchen, Gastropoden, etc., der Oberen Kreide Süd-Patagoniens, Ber. nat. Ges. Freiburg i. B., 1906, XV, pp. 91–156; W. Paulcke, Die Cephalopoden der Oberen Kreide Süd-Patagoniens, op. cit.,

The beds described as Neocomian in Brunswick peninsula (mount Tarn near Port Famine, lat. 53° 30′ S.) also belong to the border of the mountains. The problematical species *Helicoceras fuegense* comes from some place further inland; Dana gives Nassau bay as its locality (I, p. 526) [1].

As in the prairies of North America, so on the outer border of these high mountains, recent granite bosses, resembling laccolites, protrude here and there. Hauthal mentions several examples, in particular the *Cerro Payne* (lat. 50° 55′ S., long. 73° W., 2,500 meters), surrounded, as with a mantle, by Cretaceous beds, into which it sends off apophyses. *Chalten* (Fitzroy, lat. 49° 15′ S., long. 70° W.) is also a granite laccolite; like Cerro Payne, it was originally regarded as a volcano [2]. The Cretaceous marls appear to have played the same part with regard to these intrusions as in front of the Rocky mountains.

The subdivision of the Tertiary beds cannot be discussed here. On the *Mayer river*, according to Hatcher, inclined marine beds of Tertiary age rest against horizontal freshwater beds of the same age [3]. In Tierra del Fuego, Otto Nordenskjöld observed near *lake Solier* (lat. 54° 25′ S., long. 67° 45′ W.) vertical beds, probably Tertiary, in the northern foothills of the cordillera; they probably strike away to the extreme point of *cape San Diego*, on the strait of Le Maire. For details we must refer to the comprehensive work of Wilckens on this subject [4].

In the plain extending from Rio Negro to Terra del Fuego volcanic formations occur over a considerable area and offer a marked contrast to the lofty cones of the Andes. These are broad plateaux of basaltic lavas which when poured out must have been very fluid. A map showing their distribution has been published by Hauthal; according to his description the flows issued quietly from fissures, which though sometimes scarcely a meter in breadth extend for many miles. Here and there craters may be seen, and these often stand in closely crowded groups, as, for example, on the lower course of the Rio Gallego. As a rule the cones are only a few hundred meters in height [5].

1906, XV, pp. 167–244, and, in particular, O. Wilckens, Erläuterung zu R. Hauthal's Geologische Skizze des Gebirges zwischen dem Lago Argentino und dem Seno de la Ultima Esperanza, tom. cit., pp. 75–96, map.

[1] From islands in Magellan strait, C. A. White describes some upper Cretaceous fossils in Proc. U.S. Nat. Mus., 1890, XIII, pp. 13, 14.

[2] Hauthal, Ueber patagonischen Tertiär, etc., Zeitschr. deutsch. geol. Ges., 1898, L, pp. 436–440; and Ber. IX. Intern. Congr. Wien, 1904, pp. 649–656.

[3] Hatcher, Geology of South Patagonia, Am. Journ. Sci., 1897, 4th ser., IV, p. 338.

[4] O. Nordenskjöld, Geological Map of the Magellan Territories, Wissenschaftliche Ergebnisse der schwedischen Expedition nach den Magellansländern, 1899, I, no. 3, pp. 81-85. The assumption of Tertiary age is based in this case on petrographical correspondence.—O. Wilckens, Die Meeresablagerungen der Kreide und Tertiär-Formation in Patagonien, N. J. f. Min., Beilage-Band XXI, 1905, pp. 98–195, map.

[5] R. Hauthal, Distribución de los centros volcánicos, Rev. del Museo de La Plata, 1903, 16 pp., map.

In the neighbourhood of the Andes, between lats. 40° 15′ and 41° 10′ S., these flows attain a very remarkable thickness; the cones rise here, as an independent meridional series, in front of the Andes, with which they are connected by a volcanic plateau. Wehrli terms them 'a sort of *Prae-Andes*'[1].

This arrangement is repeated between lats. 47° and 48° S.; the heights here are still more considerable (Cerro Zeballos, 2,670 meters). The basaltic nature of these volcanos is not completely established.

We will now leave the border of the mountains and turn our attention to the mountains themselves.

The ancient rocks of the Cordillera de la Costa have already been described, though far from continuously, down to about lat. 46° 30′ S., and we have stated (I, p. 526) that according to Darwin and Steinmann a zone of slate and sandstone extending along the east side of the mountains reaches Brunswick peninsula, Admiralty sound, and finally Le Maire strait.

This is the course of the great trend-line, concave towards the north, which repeats the curves of the Sierra Madre of Mexico[2].

Our knowledge of the most southerly part of these mountains has been considerably increased by Lovisato's report on the Italian expedition under Lieutenant Bove (1882)[3], then by Hyades, who accompanied the French Mission to Cape Horn (1882–3)[4], and finally by the Swedish expedition under Otto Nordenskjöld. We owe to the last-named a geological map,

[1] Wehrli, Rev. del Museo de La Plata, IX, p. 239.

[2] King's excellent description gives Obstruction bay (lat. 52° 10′ to 52° 30′) as the end of the Cordillera de los Andes; H. Steffen (Verh. Ges. Erdk. Berlin, 1900, p. 212) regards the fact that the elongated ranges terminate in Chiloë as an argument against the connexion of the Patagonian Andes with the Coast chain. O. Nordenskjöld (Geological Map of the Magellan Territories, p. 25), on the other hand, thinks that the western part of Magellan strait along with Admiralty sound and lake Fagnano may be regarded as the continuation of the longitudinal valley of Chile which begins more than 25 degrees of latitude to the north of lake Fagnano. Fonck, who is one of those best acquainted with this country, regards the peaks of Sarmiento and Darwin to the south of this line as representing the coast cordillera as opposed to the principal cordillera, which is becoming extinct (see his Introducción á la Orografía y Geología de la Región Austral de S. America, Entr. I, 8vo, Valparaiso, 1893, 98 pp., in particular pp. 60 and 61). Fonck gives reasons and quotes older authorities in support of the view that cape Froward (758 meters, lat. 53° 55′ S.) is to be considered as the termination of the South American continent and of the principal cordillera (Cordillera de los Andes) (Examen crítico de la obra d. seň. perito argentin. F. P. Moreno, 8vo, Valparaiso, 1902, 146 pp., maps, in particular p. 49).

[3] D. Lovisato, Una escursione geologica nella Patagonia e nella Terra del Fuoco, Boll. Soc. geogr. ital., 1883, XX, pp. 333–347 and 420–443, also pp. 31–35 and 114–120, maps.

[4] Mission scientifique du Cap Horn, 1882–1883, t. IV: Géologie, par le Dr. Hyades, 8vo, Paris, 1887, 242 pp., maps. This work also contains the description of the rocks collected by Lovisato.

covering the region from the south up to lat. 50° S. [1]. If we add to these works the earlier accounts, especially those of King and Darwin, we obtain the following result:—

In *Staten island* (about 72 kilometers in length) sandstone, quartzite, and clay slate predominate, with a strike to east, or east with a little north. At cape Conway, about the middle of the north coast, some fossils were found in the clay slate which were at first regarded as Palaeozoic. Steinmann, however, has found fragments of Inoceramus in the same specimens, and regards the clay slate of cape Conway as the continuation of the Cretaceous rocks of mount Tarn on the mainland. At the same time Steinmann observed much secondary mica, and recognized a resemblance to the Bündner schist; it would thus seem as if dynamic action had produced its effects in the sediments of Staten island [2].

Proceeding inland from cape Conway, we reach the peak of mount Sebastian Cabot, which consists of hornblende schist. Both the Cretaceous clay slate and the hornblende schist are continued across Le Maire strait.

Schists of diverse kinds, but in particular hornblende schists, form the greater part of the mountains from this point onwards as far as Brunswick and Otway water, i.e. for a distance of 500 to 600 kilometers. The same rocks probably penetrate much more deeply into the structure of the mountains to the west of the upper course of the river Gallegos. Hornblende schist predominates in *Beagle canal*, and forms the high mountains as far as *mount Sarmiento*, then parts of Clarence and Dawson island, cape Froward, and other points. On the north side of the island of Hoste the rock passes into hornblende gneiss; in other places quartz-schist with garnets was found, also porphyritic felspar schist, chlorite schist, and at two places andalusite schist. All these schists are accompanied in the north by the Cretaceous zone of mount Tarn. Some foraminifera found by Hyades in the roofing-slate of the island of Button, which lies to the south (west coast of Navarin, Ponsonby bay), are doubtful. All the older schists have been subjected to pressure [3].

To the south and west of this range a long, and, as we may infer from

[1] O. Nordenskjöld, Geological map of the Magellan Territories, Wissenschaftliche Ergebnisse der schwedischen Expedition nach den Magellansländern, 1899, I, no. 3.

[2] G. Steinmann, Das Alter der Schieferformation im Feuerlande, Centralbl. für Min., 1908, pp. 193, 194.

[3] Ross mentions close-grained greenstone and hornblende rock in Hermite island, Voy. South. Seas, II, p. 287; syenitic greenstone on a basis of granite, according to McCormick, op. cit., p. 418. Steffen has also observed granitic rocks in Baker fjord (Estero Calén, lats. 47° 50′ to 48° 15′ S.); whether they belong to the same range I am not in a position to decide. Here, too, black schist follows in the direction of the eastern mountain border; Der Baker-Fjord in West-Patagonien, Peterm. Mitth., 1904, pp. 140–144, map. Hyades states that there is a transition from hornblende granite into horneblende schist.

Nordenskjöld's map, but little interrupted zone of a comparatively recent granitic rock extends from the extreme south far to the north. It begins at cape Horn and Hermite island and is met with again on many islands along the south and west coast. The rock is also known in Trinidad canal (lat. 50° S.); and it resembles so closely the granodiorite of the Andes and western North America that Nordenskjöld expressed the belief that a great granite range extends along the Pacific coast of Patagonia, like that which occurs, for example, in Alaska [1].

Andesite rocks are mentioned only at a few points (e.g. in the midst of Beagle canal). The neighbourhood of *Nassau* bay forms an exception. Andesites, andesite tuffs and breccias, columnar basalt and labradorite, occur in Hardy peninsula and the islands lying off it to the east, south of Navarin and north of Grévy. They mark the position of later eruptions. In the north of the island of Grévy, Hyades observed comparatively small basaltic cones, one of which appears in Hauthal's list of volcanos as *mount Oreille* (213 meters, lat. 55° 33′ S.).

Mount Oreille is separated by no less than 12 degrees of latitude from the most southerly volcano so far known, but the range is still to a great extent unexplored; small mountains of this kind may easily pass unnoticed, and andesite rocks indeed are known to occur here and there. Mount Oreille lies at a spot where a divergence from the general direction of the strike is indicated, proceeding from Hardy peninsula through the Wollaston islands towards cape Horn. It is precisely here, in Nassau bay, that two branches appear to separate, one of them striking through Staten island towards the east, and finally even to east and a little north, the other through cape Horn towards the south-east. It is true that the latter is only indicated by the position of the islands, and in the island of Grévy, just beneath mount Oreille, amphibolites still occur [2]. Thus, it remains uncertain whether a coulisse really branches off here. In support of this supposition we may mention that Andersson came upon a strongly-folded series with marine shells and driftwood in Tekenika sound, at the western extremity of Nassau bay, where the divergence appears to take place. *Helicoceras fuegense* also comes from the neighbourhood of Tekenika [3].

Second advance. Bellinghausen, after a visit to the south Sandwich islands in 1819, during which he witnessed a volcanic eruption in Sawadowskij, the most northerly of these islands, wrote as follows:—'The Sandwich islands and the Traversey islands appear to form the summits

[1] O. Nordenskjöld, Die krystallinischen Gesteine der Magellansländer, Wissenschaftliche Ergebnisse, etc., 1901, I, p. 193 et passim.

[2] Near cape Hall, Mission scientifique du Cap Horn, 1882–1883, t. IV: Géologie, par le Dr. Hyades, p. 173.

[3] G. Andersson, Geogr. Journ., 1904, p. 215. Dana says, half-way between Orange harbour and the head of Nassau bay in clay slate; Dana, in C. Wilkes, U.S. Explor. Expedition, 1849, X, pp. 604, 720.

of a mountain ridge which is connected through Clerk's reef with south Georgia, and from there on by the Aurora reef with the Falkland islands' [1].

The existence of the Aurora reef has since been found to be extremely doubtful, but the notion that there is some connexion between Patagonia and the Antarctic ranges has been frequently held, and was expressed by Barrow, for instance, in 1831 [2].

As early as 1886, H. Reiter, in a remarkable memoir, propounded the theory *that the contrast between the Atlantic and Pacific regions is manifested even in these southern regions.* The arc-like structure of Graham land, the South Shetland and South Orkney islands, and the Patagonian arc curved in the opposite direction were marked, with their trend-lines, on a map which enables us to recognize the peculiarly harmonious relations of the two arcs (II, p. 204) [3].

In 1895 Petersen thought it probable that the volcanos of the southern regions just mentioned represented the continuation of a series of Patagonian volcanos bent round to the south-east [4].

In the same year Arctowski drew a continuous arcuate trend-line from Staten island through the south Orkney islands towards Graham Land, and propounded the hypothesis—not, he thinks, too bold—*that the Andes are to be seen again in Graham Land* [5].

This view has been accepted by almost all modern investigators, including in particular J. Gunnar Andersson, who has contributed so much to our knowledge of these regions [6].

In a detailed examination of this question, we must first mark off the *Falkland* islands, which have been described on an earlier page (I, p. 527) as an alien and divergent fragment of folded Palaeozoic beds. The Devonian of these islands is wholly unknown in the western Andes, and accords completely with that of Matto Grosso and the Bolivian Andes. Darwin says they are formed of steeply inclined clay slates and sandstones, presenting on the east an east and-west strike, further west a strike to west-north-west, and still further west to the north [7]. At cape Meredith, the most southerly

[1] F. Lowe, Bellinghausen's Reise nach der Südsee und Entdeckungen im südlichen Eismeer, Erman's Arch. f. wiss. Kunde v. Russland, 1842, II, pp. 125–174, in particular p. 137.

[2] J. Barrow, Note in Journ. Geogr. Soc., 1830–1831, I, p. 62.

[3] H. Reiter, Die Südpolarfrage, Habilitations-Schrift, 8vo, Weimar, 1886, 34 pp., map.

[4] J. Petersen, Reisen des 'Jason' und der 'Hertha' in das antarktische Meer, 1893–1894, Mitth. geogr. Ges. Hamburg (for 1891–1892), Heft II, 1895, 61 pp., map, in particular p. 31.

[5] H. Arctowski, Observations sur l'intérêt que présente l'exploration géologique des Terres Australes, Bull. Soc. géol. France, 1895, 3e sér., XXIII, pp. 589–591.

[6] J. G. Andersson, On the Geology of Graham Land, Bull. Geol. Inst. Upsala, 1906, VII, pp. 19–71, maps; also Wilckens, Zur Geologie der Südpolarländer, Centralbl. für Min., 1906, pp. 173–180.

[7] C. Darwin, Geological Observations on the Volcanic Islands and part of South America, 2nd ed., 1876, pp. 440, 441.

part of West Falkland, the Devonian, according to Andersson, rests directly upon gneiss. These observations seem to indicate an arc of Devonian open towards the north-east. Added to this, Arber and Nathorst have been able to show that traces of the South African Glossopteris flora are present among the plant-remains brought home by Andersson from the little Speedwell island (south of East Falkland), and Halle has subsequently found Glossopteris at numerous localities in East Falkland [1]. According to information which Herr Nathorst has kindly communicated to me by letter, Halle has discovered beneath this horizon the glacial Talchír conglomerate.

The Falkland islands are thus a fragment of an ancient continent, comparable with Brazil and South Africa, and at the same time completely different from the Cordillera de los Andes, as well as from the east coast of Patagonia, south of the Sierra de la Ventana, so far as this coast is at present known.

Burdwood Bank stretches out, some hundred kilometers long, from Staten island. It is not broad, and runs first to east-north-east, then to east, and finally, with a slight bend, to south-east. From the way it lies it might easily be taken for a continuation of Staten island. In lat. 54° 18′ S., long. 60° W., not far from the spot at which the Admiralty charts mark Burdwood Rock as a 'danger', the younger Ross sounded in – 44 meters a narrow ridge of volcanic rock, stretching from east to west, and descending rapidly towards the north and south; further east, in lat. 54° 41′ S., long. 55° 12′ W., he came on black sand and volcanic rocks at – 489 meters. Moreno observes that in South Patagonia blocks of basaltic lava, and in their neighbourhood ashes also, possibly derived from submarine eruptions, have been observed on the Atlantic coast [2].

It has been ascertained that the direction of cape Horn departs from that of Staten island in Nassau bay, where also the volcanic mount Oreille is situated.

Diego Ramirez is said to consist perhaps of diorite; another account mentions porphyry lavas [3]. The isolated *Shag rocks* (lat. 53° 49′ S., long. 43° 26′ W.) do not lie on the continuation of Burdwood bank, but to the

[1] J. G. Andersson, Antarctics expedition arbeten på Falklandsöarne och Eldslandet 1902, Ymer, 1902, XXII, pp. 515–528; Contribution to the Geology of the Falkland Isles, Wiss. Ergeb. Schwed. Süd-Polar-Expedition (Nordenskjöld), 1907, Bd. III, 2, 38 pp., maps, in particular p. 13; A. G. Nathorst, Phyllotheca-Reste aus den Falkland-Inseln, Bull. Geol. Inst. Upsala, 1906, VII, pp. 72–76; and Geol. Fören. Stockh. Förh., 1908, XXX, pp. 202–204. Arber, who has traced the same flora in Argentina as far as lat. 40°, recognized this resemblance.

[2] J. C. Ross, Voyage of Discovery and Research in the Southern and Antarctic Regions, 8vo, 1847, II, pp. 281, 315; Moreno, Geogr. Journ., 1899, XIV, pp. 253, 369.

[3] Hyades has collected the reports; Mission scientifique du Cap Horn, 1882–1883, t. IV, pp. 8 and 15.

north-east of it, and must belong to another coulisse. The Swedish expedition of 1902 approached them, but they still remain untrodden by the foot of man [1].

South Georgia has been described by Thürach as a fragment of a chain, 2,000 meters in height, steep and violently folded. Phyllite gneiss, clay slate and quartzite, diabase and schalstein, have been observed. They strike to the north-west in the direction of the island, and this, as well as its outline and position, renders the island so similar to the fragments of the cordillera of the Antilles that Fricker has compared it with Puerto Rico and Haiti. Andersson's collections contained, according to O. Nordenskjöld, phyllite, porphyritic rocks (probably tuffs), and porphyrites altered by pressure.

South Georgia does not lie in the continuation of Burdwood bank; an arcuate connexion through the Shag rocks would seem far more probable [2].

No recent information on the *South Sandwich* islands is at my disposal; Cook and Bellinghausen imagined from the form of the islands that they were of a volcanic nature; as regards Sawadowskij this has been shown to be the case, but there is no direct evidence as regards the other islands [3]. Certainly the impression produced by the map given by Dumont d'Urville does not in the least suggest that of great and lofty fragments of cordilleras, cut through by fjords. On a long arc, slightly bent towards the east, islands of fairly equal size rise at intervals, also nearly equal, somewhat after the fashion of the Antilles, between Montserrat and St. Vincent. The island of Ljeskow alone stands out of line. In the *South Orkneys* (some of them over 1,600 meters in height) Pirie has found greywacke, quartzite, conglomerate, and black slate. In the eastern part of the group, near cape Dundas, the slate has furnished a graptolite and traces of Phyllocarides (Graptolite island). The beds are folded and strike to north-west or north-north-west. Pirie also conjectures that we have here a fragment of considerable folded range which may have connected Patagonia with Graham Land. Bruce's map of Laurie island shows long peninsulas running at right angles to the direction of the island; they lie probably in the strike [4].

[1] Andersson, Ymer, 1902, p. 410; O. Nordenskjöld, Petrographische Untersuchung aus dem westlichen antarktischen Gebiete, Bull. Geol. Inst. Upsala, 1905, VI, pp. 234–246, map, in particular p. 245.

[2] H. Thürach, Geognostische Beschreibung der Insel Süd-Georgien, Ergeb. d. deutsch. Polar-Exped., 1882, II, 7, 58 pp.; K. Fricker, Antarktis, Bibliothek der Landeskunde von Kirchhoff und Fitzner, I, 1898, p. 110; Andersson, Antarctics vinterexpedition till Syd-Georgien, Ymer, 1902, XXII, pp. 409–421.

[3] F. v. Bellinghausen's Forschungsfahrten im südlichen Eismeer, 1819–1821; based on the original Russian work published by the Verein für Erdkunde in Dresden (by H. Gravelius), 8vo, 1902, p. 57 et seq. (also Lowe, see note 1, p. 489).

[4] J. H. Pirie, Note on the Geology of the South Orkneys, Scot. Geogr. Mag., 1904, XX,

These data do not seem to accord with the general plan, which we are about to discuss. Nevertheless Andersson believes that some connexion with the South Shetland group may possibly exist. At the most easterly extremity of this group a bend to the east-south-east is actually visible[1].

Let us now approach the larger masses of land in the south.

This region extends in an arc slightly convex to the north-west through more than 7 degrees of latitude towards the south-south-west, and in this direction it also increases in breadth. The whole country is covered with snow and ice, with the exception of those tracts which are excessively steep and a few isolated active volcanos. Very long stretches of coast are unapproachable on account of the bordering ice, but so different are the outlines of the cordilleras, cut through by fjords and eydes, from those of the isolated conical volcanos that many conjectures made in advance of actual observation have since been confirmed. The existence of two distinct ranges of volcanos as supposed by H. Reiter is a case in point.

The *South Shetland* islands are a lofty, narrow rocky range, concerning which I have only a few data, but they are generally regarded as a fragment of the cordillera. Nordenskjöld reports greenish porphyrite from Nelson island. Larsen's description of the passage between Greenwich island and Livingston island suggests the presence of sheets of columnar basalt. Geikie mentions thick flows of basalt both in the South Shetlands and in Graham Land, similar to those of Greenland and the Faeröes[2]. South-east of this chain lie volcanos. The lofty conical island of *Clarence* is believed to be a volcano. *Bridgman* island has been observed in eruption. *Deception* island is a single gigantic crater; its oval basin, filled by the sea, measures, according to Kendal's map, more than 11 kilometers in length and 5–6 kilometers in breadth[3]. *Hoseason* island has also been supposed to be of volcanic origin.

All these points lie in the direction of Bransfield strait, and south-east of this strait lie the most extensive traces of Antarctic mountain chains. It is possible that the mountains already commence in Wedell island, others extend across the islands of *Joinville* and *Dundee* to *Louis Philippe Land*,

pp. 130, 131; On the Graptolite-bearing Rocks of the South Orkneys, Proc. Roy. Soc. Edinburgh, 1905, XXV, pp. 463-470; and Bruce, Outline Map of Laurie Island, Scot. Geogr. Mag., June, 1905.

[1] J. G. Andersson, Geology of Graham Land, Bull. Geol. Inst. Upsala, 1906, VII, p. 32.

[2] J. Petersen, Reisen des 'Jason', Mitth. geogr. Ges. Hamburg, Heft II, 1895, p. 24; A. Geikie, Proc. Roy. Soc., 1898, LXII, p. 448. It is not clear why Miers has conjectured the presence of hornblende schist in the most northerly part of South Shetland, Phil. Journ. Edinb., 1820, III, p. 379.

[3] Kendal, Journ. Geogr. Soc., 1830-1831, I, pp. 62–66, map. Webster describes alternating layers of ash and ice as well as the appearance of hot vapour on the strand near Ebbe; Voyage to the South Atlantic Ocean, 8vo, 1834, I, pp. 144–165, and II, pp. 300–306. Kendal and Webster took part in the voyage of the *Chanticleer* under Captain Foster's leadership; Foster was drowned on the return journey in Chagres river.

which, as we now know, is connected through *Danco Land* and *Foyn's Land* with *Graham Land*, and represents the north-eastern extremity of this elongated mountain tract.

Captain Robertson has brought back granite from Dundee island, and a pebble of red jasper with radiolaria [1]. Of particular interest is Antarctic strait between Joinville and Louis Philippe Land. J. G. Andersson passed eight months on the west shore of *Hope bay* and made a geological map of the coast. Here O. Nordenskjöld has described the reappearance of the Andine group of granodiorites of southernmost Patagonia, and Nathorst has described a Jurassic flora, situated in lat. 63° 15′ S., which resembles that of Europe and the East Indies, and reveals no climatic difference as compared, say, with that of Yorkshire. Freshwater ferns also occur here (Sagenopteris). Above lie light-coloured volcanic tuffs. The moraines reveal the presence of quartz-diorite, gabbro, and augite porphyrite [2].

The islands which lie off the east coast between lats. 63° 30′ and 64° 30′ S. are formed, in contrast to the mountainous Louis Philippe Land, of a sedimentary plateau, upon which recent volcanos are seated. According to Nordenskjöld and Andersson these islands include the great *Ross* island, with mount *Haddington* (2,150 meters), to the north of it *Vega*, then to the south-east of Ross, on the other side of Admiralty sound, the *Seymour* and *Snow Hill* islands, and in the sound itself the little Cockburn and Lockyer islands. Mount Haddington rises, according to Ross, in three great volcanic terraces. All around, the flat-lying sediments crop out from beneath the lavas, and form the whole of Seymour island, and probably of Snow Hill also. They contain marine shells of Senonian age (in particular Holcodiscus); Weller points out their affinity with the Indian Arialur stage and the Senonian of Magellan strait. Kilian arrives at similar results and suggests that the Indian and Atlantic faunas are connected in the south, thus agreeing with Kossmat, and also with Paulcke and Wilckens [3].

Larsen and Donald long ago brought back Tertiary shells from Seymour island; Sharman and Newton consider that it is of Eocene age; as likewise does Wiman, who described the vertebrae of Zeuglodonts and a remarkable variety of bird-remains, resembling those of penguins, which had been obtained in the island [4].

[1] A. Geikie, Notes on some Specimens of Rocks from the Antarctic Regions, with Petrographical Notes by J. J. H. Teall, Proc. Roy. Soc. Edinburgh, 1897–1898, pp. 60–70.

[2] O. Nordenskjöld and G. Andersson, The Swedish Antarctic Expedition, Geogr. Journ., 1904, XXIII, pp. 207–220, map; O. Nordenskjöld, Petrographische Untersuchung aus dem westlichen antarktischen Gebiete, Bull. Geol. Inst. Upsala, 1905, VI, pp. 234–246, map; A. C. Nathorst, Sur la flore fossile des régions antarctiques, C. R. Acad. Sci. Paris, 6 juin 1904.

[3] Stuart Weller, The Stokes Collection of Antarctic Fossils, Journ. Geol. Chicago, 1903, XI, pp. 413–419; W. Kilian, Sur une faune d'Ammonites néocrétacées recueillie par l'Expédition antarctique suédoise, C. R. Acad. Sci. Paris, 29 janv. 1906.

[4] Donald, Geogr. Journ., 1893, II, p. 438; and A. Geikie, Ann. Rep. Geol. Surv. for the

The conical mountain *Percy*, in Joinville island (1,128 meters), is supposed to be of volcanic origin; *Paulet* island (south-east of Dundee) is a crater with olivine basalt [1]. *Cockburn* island in Admiralty sound is probably a volcano, but recent sediments with Pecten are known to occur on it: mount Haddington also is regarded by Nordenskjöld as a great crater-bearing volcano. *Christensen* has been ascended by Larsen; this island is a volcano, its rocks, according to Petersen, are felspar basalt. *Lindenberg* was in eruption when Larsen saw it; the little *Robben islands* are likewise regarded as volcanic [2].

This volcanic zone lies to the east of Graham Land, which, as shown in so striking a manner by its outlines, is a repetition of the Patagonian Andes. The expedition of Charcot brought back from Gerlache strait, that is from the west side of Graham Land between lat. 64° 5′ to 65° 5′ S., only granite, quartz-diorite, and volcanic rocks [3].

These data are, on the whole, very scanty, yet several important conclusions may be drawn from them.

Andersson mentions three reasons in support of Barrow's earlier conjectures and Reiter's more comprehensive views on the relations of Graham Land to South America. 1. The outline and orography of the southernmost part of South America and of Graham Land resemble each other so closely that one continent may be said to be the reflection of the other. 2. The geological structure is strictly symmetrical. 3. The succession of the marine upper Cretaceous and Tertiary beds is the same in Patagonia and in Graham Land; in particular, the upper Cretaceous horizon of *Labillia Luisa* is repeated in the two regions.

Passing to details, we may extend our comparisons as follows :—

year 1893, p. 273; G. Sharman and E. T. Newton, Notes on some additional Fossils collected at Seymour Island, Graham's Land, by Dr. Donald and Captain Larsen, Proc. Roy. Soc. Edinb., 1897-1898, pp. 58-61; C. Wiman, Vorläufige Mittheilung über die alttertiären Vertebraten der Seymour-Insel, Bull. Geol. Inst. Upsala, 1905, VI, pp. 247-252.

[1] Robertson, in Geikie, Proc. Roy. Soc. Edinb., 1897-1898, p. 66.

[2] Petersen, Reisen des 'Jason', etc., Mitth. geogr. Ges. Hamburg, Heft II, 1895, pp. 18 and 31; Friedrichsen, op. cit., p. 59.

[3] E. Gourdon, C. R. Acad. Sci. Paris, 11 déc. 1905, 16 juillet 1906, maps, in La Géographie, 1906, p. 245 et seq. Unfortunately the principal work did not reach me until the first sheets were already printed. We may mention as an important point that granite allied to monzonite and quartz-diorite form a considerable part of the west. The latter in particular prevails almost universally from Hoseason (lat. 63° 45′ S.) to a point south of the island of Lund (lat. 65° 25′ S.), and probably forms the greater part of Palmer archipelago, the islands of Wiencke and Wandel, and the coast of Graham Land. Gourdon concludes from this that the dioritic rocks of Alaska, California, and the Andes are allied (Expédition Antarctique Française [1903-1905] commandée par le Dr. Charcot), E. Gourdon, Géographie physique, Glaciologie, Pétrographie, 4°, Paris, 1908, in particular pp. 149, 152, 204. This is the so-called granodiorite girdle which is continued in a long cicatrice through the Intermediate range towards the extreme south.

(*a*) The *Falkland islands* present the same succession of rocks as the Argentine and Brazil; whether they most resemble Brazil or the praecordilleras of the Argentine can only be determined when we know whether the Gondwána beds are also folded. The succession is certainly not that of the Cordillera de los Andes.

(*b*) Towards the interior of Patagonia is the upper Cretaceous and Tertiary plain. This corresponds to *Snow Hill* and *Seymour island* in the south.

(*c*) The volcanos of the *Ross group* (Paulet, Haddington, Christensen, and others) may be compared with those situated in front of the Andes, in particular between lats. 47° and 48° S. (Cerro Colorado, mount Belgrano and others), which further north have been termed the prae-Andes.

(*d*) In the north of *Graham Land* two principal features of the western Andes make their appearance, namely, the diversified eruptive rocks of the Andes and a Mesozoic land flora. In lats. 27° 15′ S. (la Ternera) and 40° S. (Piedra Pintada) the flora is that of the Lias; here it is middle Jurassic.

(*e*) No connexion can be shown to exist between the widely remote volcanic indications of *Burdwood bank*, the volcanic arc of the *South Sandwich islands*, and the *Bransfield volcanos* (Bridgman, Deception, and others). The resemblance between the South Sandwich islands and the volcanos of the Lesser Antilles has often been remarked upon.

Existing observations scarcely permit us to carry comparisons further. It must not be overlooked that Staten island and cape Horn do not present a completely concordant strike, and that mount Oreille may mark perhaps the beginning of a new volcanic arc, resembling the South Sandwich islands more closely than Burdwood bank. Arctowski marks — 4,040 meters a little to the south of Staten island. The connexion of the other groups, such as South Georgia, the South Orkneys and South Shetland islands, must remain an open question.

Bruce's deep-sea chart represents all the islands mentioned above, along with Patagonia and Graham Land, as standing on a common arcuate ridge, and all enclosed by the curve of — 1,500 fathoms (2,743 meters); while deeper water enters the interior of the arc from the west, and extends even to the north of the South Orkneys, where — 4,219 meters has been sounded. Similar depths extend to a point south of Staten island. It had already occurred to Grange that the South Shetland islands and the smaller islands as far as Elephant island form part of a common mountain range, running parallel to the curve of Graham Land. This is confirmed by the deep-sea chart, according to which the South Orkneys, along with the whole of Graham Land, are also included by the curve of 1,000 fathoms [1].

[1] W. J. Bruce, Bathymetric Survey of the South Atlantic Ocean and Wedell Sea, Scot. Geogr. Mag., August, 1905, XXI, pp. 402–412, map; J. Grange, Voyage au Pôle Sud

Immediately to the east of the South Sandwich islands no soundings have been made. We might, perhaps, expect to find a foredeep there similar to that which occurs outside a part of the Antilles.

We may now regard it as established that in the interval we have just discussed *the Pacific structure advances for the second time into the Atlantic region.* On the south-east, towards Coats Land, we may conjecture the existence of a foreland occupying a similar tectonic position to Brasilia.

Summary. We have stated on an earlier page (II, p. 204) that, with the exception of the coast of Guatemala where it wheels round to the Antilles, all the boundary regions of the Pacific, known in any detail, are folded in the direction of that Ocean. This was in accordance with the observations which had been made up to that time. We now know, however, that the case which was then held to be exceptional must now be regarded rather as the rule.

In the north the Elias range is folded in the Pacific direction; this is still true of the northern part of the Sierra Nevada of California, and certain parts of the Basin ranges.

As soon as we reach the Californian coast ranges nothing similar is to be seen. In the Mexican sierras the folding is clearly directed towards the Atlantic Ocean, and this is also the case further south, wherever it is clearly expressed, especially in the Andes of Argentina.

Right down into the Antarctic regions the mountain ranges lying next the Pacific coast are characterized by a trifling development of the Palaeozoic series. Upper Carboniferous alone occurs at certain places in the Andes; it is only from the promontories of Venezuela and the South Orkneys that Silurian fossils have been obtained. This, it is true, is a negative character, which may be brushed aside by future discoveries, but it is certain that in Mexico, Honduras, Chile, and the antarctic Andes, plant-bearing beds, ranging from the Keuper to the middle Jurassic, occur in these chains, and show that they formed dry land during a part of the Mesozoic aera.

It is not till we pass to the east of these chains in South America that the long zone of marine Mesozoic beds, recalling the Intermediate range of North America, makes its appearance, and with it the zone of the giant volcanos; to the east of these lies the Palaeozoic series of the Altaplanicie, the Cordillera Real, and the Bolivian and Argentine Andes, in which, upwards from the Gondwána stage, and in places from the Culm, only plant-bearing beds are known as far as the upper Cretaceous transgression.

We might now speak of *two groups of Antilles,* and place the northern Antilles beside the southern (South Sandwich islands), with Patagonia and Graham Land repeating the structure of Guatemala and of Colombia-Venezuela. These two groups of Antilles, and in particular the northern

sous le commandement de M. J. Dumont d'Urville, Géologie, Minéralogie et Géographie physicale, 2 vols., 8vo, Paris, 1848-1854, I, p. 40.

group, clearly present some of the tectonic characters of the Asiatic island-festoons, and we are tempted to regard the Andes as an imperfect repetition of the Asiatic plan; the foreland between these two groups of Antilles (Argentine, Brazil), overwhelmed in an easterly direction, might have been the cause of this defective development.

Two objections may be raised to this assumption.

The first of these lies in the structure of the chains situated further to the west, which correspond rather to a continent of Trias and Jurassic times, since marine upper Cretaceous lies unconformably superposed upon their west coast, as in Quiriquina, for example.

Further, considerable depths exist along a great part of the west side, which we might be inclined to regard as foredeeps situated, in contrast to all Asiatic foredeeps, on the west side of a range folded towards the east.

Agassiz has given a very clear description of these depths.

Even far to the north, where the mean depth of the Ocean is about 2,000 fathoms (3,658 meters), we observe near the west coast of America isolated pits of greater depth, as for example in lat. 20° N. −4,380 meters, near Manzanilla −5,120 meters, near Acapulco −5,341 meters, to the west, off the coast of Guatemala, −4,572 meters. Then the depths decrease in the direction of the broad plateau which rises into Cocos island and the Galapagos. In the south the depths recur near the west coast. Off Callao they already reach −5,869 meters, further south −6,867, then −6,542 meters, and the U.S. ship *Relay* observed between Antofagasta and Copiapó an elongated depression with −7,626, −7,635 and −7,507 meters. Even off Valparaiso the depth still reaches −5,651 meters [1].

To the west of these abysses lie the two ancient volcanic islands of San Felix and San Ambrosio; to the south of these the Chilian cruiser *Presidente Pinto* sounded such trifling depths for a distance of 760 kilometers that the existence of a submarine ridge running almost north and south in the direction of Juan Fernandez seems to be indicated [2].

It may suffice for the present to have mentioned these facts, which are not in accordance with those observed in connexion with Asia.

Since Victoria Land, with the Terror volcano, Auckland, and the south of New Zealand are assigned to the Atlantic region (IV, p. 294), it seems as though the boundary between the Atlantic and Pacific systems struck across the Antarctic just as it does across the Arctic region [3].

[1] A. Agassiz, Report on the Scientific Results of the Expedition to the East Tropical Pacific, Mem. Mus. Comp. Zool. Harvard Coll., 1906, XXXIII, pl. I. These deeps form the most important part of Van de Wiele's 'Bassin Préandin'; Van de Wiele, La Méditerranée des Antilles et le Bassin Préandin considérés comme régions d'affaissement, Bull. Soc. géol. Belge, 1906, XX, mém., pp. 83–161, map.

[2] Some doubts have been expressed with regard to this result; cf. Supan, Peterm. Mitth., 1899, p. 183.

[3] On this point Gregory, in Nature, April 25, 1901, p. 611, and April 16, 1908, p. 561.

CHAPTER XIV

ANALYSES

Analysis of the plan. Linking and syntaxis. Significance of the foredeeps. Folding. Backfolding and disappearance of the folds in the Asiatic structure. Analysis of the arcs. Analysis of certain transverse sections.

Analysis of the plan. The series of details we have cited is very long, and yet it is full of gaps.

One of the greatest ranges of the earth, that of New Guinea, is very little known. With regard to the principal range of the Oceanides, to which it belongs, connected observations are lacking to such an extent that conflicting statements exist even as to the direction of the folds, and it is not certain whether Timor belongs to the range or not. It is particularly to be regretted that notwithstanding the praiseworthy efforts of many investigators the structure of the South American Andes still diverges in many respects, not yet explained, from that of other chains. This and very many other questions must be left to future investigation.

On the other hand there are many extensive regions in which the fundamental features of the structure are well known. Definite units may be distinguished. Comparisons become possible. Contrasts and correspondences appear. We will now make an attempt to define some of these units. We will first enumerate them—although they differ in kind and are of unequal value—according to their arrangement in space.

1. The western half of *Laurentia* is bounded by the Rocky mountains, the Appalachians and the United States chain; it also includes Greenland, possibly the whole of the North Atlantic field of fracture, upon which stand the islands of Iceland and Jan Mayen, and even the western Hebrides and some of the western promontories of Scotland. Wherever Cambrian beds occur, they lie horizontal. Younger folding is entirely absent, except on the Mackenzie, on the right side of which the foreland (Devonian and middle Cretaceous, extreme western border of the Canadian shield) has been overwhelmed by the folds of the Rocky mountains and thrown into long coulisses.

The entire marine Mesozoic series is absent up to the transgression of the middle and upper Cretaceous. Marine Tertiary beds are confined to the neighbourhood of the Atlantic Ocean.

In the south, the Colorado Plateau and a small area in Burnet County above Austin (Texas) must be referred here.

2. *The Caledonides*, a pre-Devonian folded range, striking towards the south-south-west, may be regarded for the present as forming the eastern boundary of Laurentia. Traces of it are possibly to be seen even in northern Spitzbergen. It occupies the west of the Scandinavian peninsula, then the Shetland and Orkney islands, Scotland, almost the whole of Wales, and a very considerable part of Ireland. It lies between the supposed Laurentian gneisses of the western Hebrides in the west and the Baltic shield in the east, and according to existing data its folds are overturned and overthrust in the east towards the east, and in the west towards the west. They form a uniform zone, but not a uniform mountain chain.

3. *The Asiatic* (or Eurasiatic) *system*. The boundaries of this system, which encircles the globe, are defined by a number of folded arcs; free-branching folds extend beyond the arcs. It includes the following parts of northern and western North America: the United States chain, the Rocky mountains, the Elias mountains, and the Alaskides. It claims almost the whole of Asia along with the eastern island festoons as far as the Bonin islands and as far as the foredeeps of Palau and the Talauer islands, the Burman arc and all the mountain ranges which are sharply defined towards the south from the mouth of the Ganges to the western extremity of the Great Atlas. The whole of Europe belongs to it, with the exception of the Caledonides and the supposed Laurentian portion of north-western Scotland. One long free branch extends across the Atlantic Ocean and forms Newfoundland and the Appalachians. It dies away in Texas and Oklahoma. Thus Laurentia is surrounded by the Asiatic folds. In north-east Siberia (most clearly on the upper Annabar and Olenek), and also on the right tributaries of the Chatanga, this great folded structure with its numerous arcs surrounds a gneiss region across which a horizontal Cambrian covering is spread. This region, therefore, has not shared in the folding movements. It extends on the east to the Lena, on the west to the Yenisei, and on the south into the amphitheatre of Irkutsk. It is probably continued beneath the recent alluvial land of West Siberia. We have named it *Angara Land.*

In addition, great not-folded regions occur between the Asiatic folds, e. g. in northern China, in Cambodia, and Borneo. Here, too, we refer the Russian platform and the Baltic shield.

In Europe the Altaides, which are pre-Permian branches of this structure, are distinguished by a remarkable peculiarity; they have sunk in over large areas and determined the origin of posthumous chains within the frame. These are: (*a*) the Alpides (from the Balkans to the Balearic isles); (*b*) the folds of Provençal and the Pyrenees; (*c*) the folds of the London and Paris basin; (*d*) some smaller disturbances in western Portugal.

The Caledonides, which seem to be inserted between the remains of Laurentia and the western part of the Asiatic structure, date, as we have seen, from the pre-Devonian period. Thus, even at this remote time, the two largest elements of the northern hemisphere, Laurentia and Angara land, were already welded together. Indeed the Devonian continent of *Eria* extends across both.

The *Tethys* extends throughout the southern part of the Asiatic structure.

4. The *Bohemian mass* is an independent, alien and very ancient fragment; it includes the south of Bohemia, parts of Bavaria, upper and lower Austria and Moravia.

5. *Gondwána land*. This comprises: South America from the Andes to the east coast between the Orinoco and cape Corrientes, the Falkland islands, Africa from the southern offshoots of the Great Atlas to the Cape mountains, also Syria, Arabia, Madagascar, the Indian peninsula, and Ceylon. Here, as in Laurentia, there is no recent folding, except on the extreme western border. Just as the folding on the Mackenzie extends from the west, out of the Rocky Mountains, into the stratified series of the otherwise rigid Laurentian foreland, so the folding of the Andes likewise extends from the west into the stratified series of Bolivia and the Argentine, that is, parts of the otherwise rigid Gondwána land.

As in Laurentia, so again here, the marine Mesozoic series is almost entirely absent up to the middle Cretaceous transgression. The latter covers with its horizontal plateaux great parts of the Sahara, Syria, and Arabia, and thus renders the north of Gondwána land different in appearance from the south.

The *Saharides*, a zone of folds striking towards the south or south-south-west, extend in considerable breadth from Tidikelt to South Dahomey, that is between lats. 19° to 20° N. and right through the midst of the Sahara.

This zone is older than the horizontally transgressive upper Silurian and consequently older than the Caledonides. Nevertheless there seems reason to believe that it may represent a tectonic delimitation of ancient date, similar to that of the Caledonides: nor must the fact be overlooked that in the north-west of Scotland, the typical region of the Caledonides, a considerable gap exists between the folded Cambrian beds and the unfolded Devonian, so that the greater age of the Saharides can only be deduced from other regions. Africa is cut through by long fissures upon which active volcanos are seated. The Cameroon line runs nearly north-east; the lines more to the east are meridional or sub-meridional; one of them is continued through the Red sea and the Dead sea far to the north.

6. The *Cape range* consists of three fragments, the foreland of which is formed on three sides by the Karoo. These fragments are: in the west

the Cedar range, in the south the Zwarte range, in the east the Pondo range, which is represented by only a few and little-known remains. The Cape range represents a large folded system, resembling in many respects the Asiatic structure, and now submerged beneath the waters of the south Atlantic and south Indian oceans.

7. *Australia and the Oceanides.* The present state of our knowledge, which leaves much to be desired as regards the islands, is best in accord with the view that Australia, which is folded only on its eastern border, but also bears several Mesozoic transgressions, might occupy a position somewhat similar to that of north-eastern Angara land. At the same time it is surrounded on the north and east by folded arcs, which extend to the Carolines, Raroia, and probably to Hawaii. It is possible that the insertion of these arcs begins with Soemba, Rotti, and Timor, and that they mark at the same time the line of separation between Australia and the Asiatic system.

It is not wholly improbable that in the peninsula of Beru, New Guinea, and in some of the Sunda islands, a narrow strip of comparatively ancient land projects between the folds of Asia and Oceania. While considerable parts of the Oceanic arcs are without doubt recent folded ranges, it is uncertain whether the islands of Yap and Viti Levu should be regarded as such or as older formations.

8. The *Andine system* rises from the sea on the west coast of America between lats. 42° and 41° N., borders this coast and extends beyond it at least to lat. 68° S. Its folds penetrate, as we have seen, into the western part of Gondwána land, and they advance to the north and south of it far into the Atlantic region. This is the origin of the northern and southern Antilles.

The *Intermediate range*, which forms the transition, and is characterized by a greater diversity of Mesozoic sediments, by long folds, fault-troughs and recent volcanos, advances in the north from the Alaskides in a trough-like subsidence near the Wrangell group, extends as a broad zone through the west of Canada, forms the Basin ranges (which include a closed drainage system), lies in front of the most northerly range of the Andes, is possibly interrupted in west Arizona, reappears in Mexico, and reaches the Atlantic coast, where it covers a wide area. The cordilleras, which represent the Intermediate range in Mexico, can scarcely be distinguished tectonically from the Sierra Madre del Sur, the principal range of the Andine system.

In South America the Cordillera de los Andes itself assumes the characters of an intermediate range in those regions of Bolivia and Argentina which are known in greatest detail. Here, too, Mesozoic marine beds, recent volcanos, and long fault-troughs occur.

Graham Land is a repetition of Patagonia and must be assigned to the Andine system.

9. *Antarctis*, that is Victoria Land and Wilkes Land as far as the Gauss mountains, and on the other side Coats Land, are probably continuations of South Victoria. The volcanos which occur there—the Terror series—seem to be comparable with the volcanic series of Africa.

A glance at these nine units of such unequal value shows us that it is only in the Pacific region that the outlines of the continents and islands throw some light on the arrangement of the trend-lines. If the Atlantic region as it existed during, say, the Permian period, could be restored to our view, we should see a mountain chain striking across the existing Ocean from Armorica to Newfoundland. To the north of this chain we should still see perhaps the Erian foreland. Europe itself, especially the Iberian peninsula, would extend further towards the west, and the Cape mountains would possibly extend far into the region which is at present covered by the Ocean. But all this has disappeared. On none of the Atlantic or Indian coasts (with the exception of the Antilles) is any mountain-making activity now to be found. In the Pacific Ocean it is widely distributed. *This is the essential difference between the Atlantic and Pacific part of the globe.* Of the nine units, two, Laurentia and Gondwána land, are well known, they possess many characters in common, and may be recognized by the absence of any post-Cambrian folding (with the possible exception of the Saharides, and of the encroachment of younger folding on the Mackenzie and in Bolivia and Argentina) as parts of the earth which had become rigid early. It is probable that Antarctis occupies a similar position. If so, then the Atlantic half of the globe would present a northern, an equatorial, and a southern region of ancient rigefaction.

The Caledonides, the Cape mountains, and the Andine system are folded fragments of various age.

The Asiatic system is a folded structure which has been greatly checked in its development by the rigid forelands of Laurentia and Gondwána land. At the same time, however, this system itself encloses a pre-Cambrian plateau, i. e. Angara land. It seems likely that Australia stands in a similar relationship to the Oceanides, but here, as we have seen, observations are wanting, in particular as regards the principal chain, that of New Guinea. For these reasons our attention is directed first to the vast Asiatic system when considering the relations between the folded regions and those which last became rigid.

Linking and Syntaxis (pl. IV). The frequently recurring arcuate form of the mountain chains is the most striking feature of the Asiatic system. The manner in which the arcs encounter each other is twofold, either they enter into syntaxis, or one arc cuts across the direction of the other. We have termed this second case intersection (e. g. III, p. 375); Richthofen has employed the term *linking* (Kettung), which we shall adopt.

Richthofen regarded linking (in contrast to syntaxis) as a characteristic feature of eastern Asia, and has discussed this question with his customary power in a series of memoirs [1].

We now know that linkings have not all the same significance, and that both linking and syntaxis are present in the island-festoons. The islands from Kamchatka to the Kuriles strike in linking across the direction of the Alaskides, Hokkaido across that of the Kuriles, and so on, while the Alaskides enter into syntaxis towards the east, and so on.

We must now attempt to distinguish between the different kinds of linking, and to determine what it is that gives rise in one place to linking, in another to syntaxis.

The *Carpathians* strike across the direction of the Sudetes and the Sandomir mountains. Both the latter are of greater age, and there is no doubt that they dip beneath the Carpathian arc. This is linking by overwhelming.

The western side of the *Himálaya* enters into syntaxis with the Iranian folds, whereas in the east the Burman direction cuts across that of the Himálaya; here too, on the Brahmaputra, linking sets in. The situation, however, is not the same as in the Carpathians. If we term the chain which maintains its direction unchanged the dominant chain, then in the first case the dominant (Carpathians) is the younger, in the second case it is the older chain. Here Assam, an alien wedge-shaped fragment, is inserted. Maclaren states that in about lat. 95° 45′ E. the Himálaya encounters the Miju chains striking transversely to the south-south-east; they are the older and form part of the Burman arc. Again, near Tezpur, in about long. 92° 45′ E., crystalline rocks crop out at the bottom of the valley of the Brahmaputra, between the Himálaya in the north-west and the Patkai mountains in the south-east. Both ranges, the Himálaya and Patkai, are accompanied by a belt of Gondwána and Tertiary beds overturned in the direction of the Brahmaputra [2]. The older Miju chains were first on the spot; consequently here the Himálaya ends. The advancing strike of the Patkai mountains probably indicates a subsequent welling-forth of the Burman fold. It is certain that movements have occurred during a long period on both sides; this is shown by the overfolded Sewalik beds. For the present, however, we will bear in mind that the Miju chains were the first on the spot.

The asphalt pavement of our streets not infrequently presents fissures of a peculiar kind, and also a series of arcs. If the curbstone sinks, these are bent backwards from it (pl. IV, fig. 1); if the middle part sinks and the curbstone retains its position, they are turned towards it (fig. 2). In

[1] F. von Richthofen, Sitzb. k. Akad. Wiss. Berlin, 1900, pp. 888–925; 1901, pp. 782–808; 1902, pp. 944–975, map; and 1903, pp. 867–918.

[2] Maclaren, Rec. Geol. Surv. India, 1904, XXXI, pp. 179–232, map; and 1905, XXXII, p. 150.

both cases the tension produced by subsidence is resolved into arcs, not of the same but often of similar magnitude. The fissure arises in or near the middle (*g*, fig. 1) and then elongates itself towards the two sides. If it meets at the same time with a neighbouring fissure, as for example at the point *a* in fig. 7, then the trend-line of a syntaxis is produced; if it stops, or if its starting point was not in the middle of the asphalt (*b*), then linking takes place (*c*). If fig. 2 were a map, we should say that there was syntaxis in the north, and linking further south, and in every case the northern would be the dominant arc.

If after some lapse of time we again visit the same spot in the asphalt we sometimes find that the continued tension has affected the whole of the broken line *f*, *a*, *e*, and that any faint continuations which may exist on the inner side of *a* have not been subjected to this further dragging. In addition, secondary fissures frequently arise within the arcs. At last the asphalt becomes broken up and useless.

Three arcuate and concentric elements occur in the Asiatic island festoons, namely, the foredeeps, the folded chains (cordilleras), and the volcanic lines. The last-named are particularly adapted for comparison.

A hook-shaped fracture or fissure accompanies the hook-shaped bend of the strike in the syntaxis of Karoo Port (IV, p. 288). In the Aleutian islands a similar fissure has developed, under continued tension, into the fault-trough of Cook inlet; the fault-trough bends with the syntaxis, and near the place at which the bend is made (*a*, fig. 2) stands the Wrangell group of volcanos. Other arcuate fragments have also become fault-troughs by the same process—for example, the Fusiyama-Bonin line in the Fossa magna—and in the same way fault-troughs are formed in the strike of the great volcanic line which starts from the Ho-shue-shan and follows the Burman trend-line through 31 degrees of latitude, to the volcanos of Java and beyond [1].

That the volcanic arcs actually stand upon fissures is also evident from the fact that they are able to cross over into the arcs of an alien cordillera. Thus the arc of the Kuriles cuts across the cordillera of Hidaka in Hokkaido, and, while here the intersection is only continued to the volcano of Optateshike (III, p. 140, fig. 7), the map of the Japanese survey continues it to the west coast of Hokkaido. Another example is afforded by the caldron-fracture of Kago-shima bay, the volcano of Sakura and others, which mark the entrance of the Liu-Kiu line into the cordillera of south Kiu-Shiu. Here, however, transverse folds of Tertiary age also occur.

The long fissures or faults which cut through Korea in a virgation open towards the south, form the greater part of the east coast, and convert

[1] W. Volz, Zur Geologie von Sumatra; Koken, Geologische und paläontologische Abhandlungen, 1904, new ser., VI, 112 pp., maps; also Vorläufiger Bericht, in Sitzb. k. Akad. Wiss. Berlin, 1907, pp. 27–140.

Fig.1

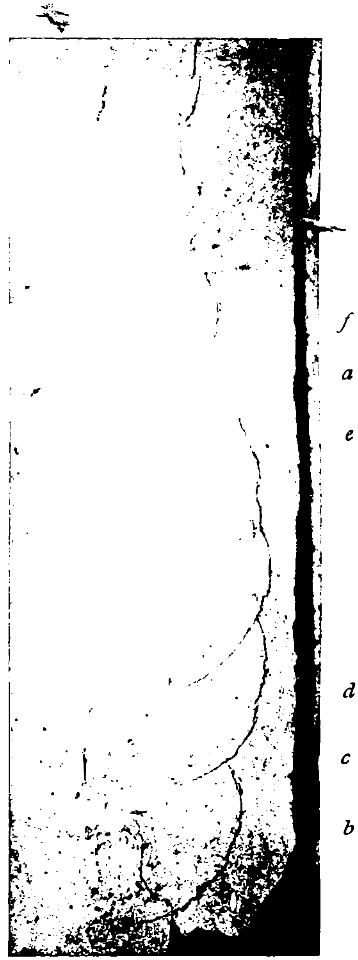


Fig.2

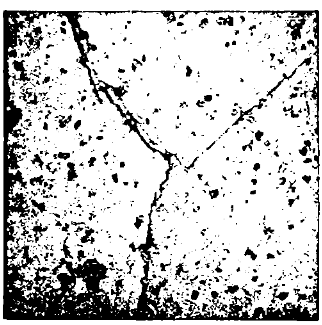


Fig.1a

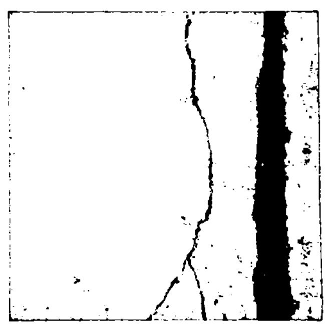


Fig.2a

CRACKS IN ASPHALT

the south into a rias coast, are possibly disjunctive lines which belong to Liu-Kiu.

This throws some light on the fact that in Mindanao the volcanos stand principally on lines of depression (III, p. 247) and not on the cordilleras.

We shall soon see, however, that in spite of many points of resemblance comparison with the fissures in the asphalt must be made with some reserve. For the present we only conclude that linking arises either when an older chain is overwhelmed (Sudetes), whereby the younger chain (Carpathians) becomes the dominant, or else when the chain which first reached the point of encounter maintains its position as dominant, this case being the most frequent in the island-groups of Asia. The Aleutian islands afford an example in which linking with the dominant (Kamchatka) has not yet been attained.

Significance of the foredeeps. Let us refer to what has already been said on pp. 294 and 328. With the exception of a depression of over 7,000 meters, near the middle of the Atlantic Ocean, of almost unknown outline, which owing to its position can scarcely be termed a foredeep, and with the exception of the long depression bordering parts of the west coast of America, the significance of which cannot be discussed here, all the foredeeps lie either close in front of the Asiatic arcs, or within the Oceanides. The foredeeps of the northern Antilles occupy a position similar to that of the foredeeps of Asia, and we must include them, as we have seen, among the Pacific structures. From analogy we may conclude that a similar foredeep will one day be discovered outside the South Sandwich islands.

The subsidences of the asphalt pavement take place on the concave side of each of the several arcuate fragments. During the process of draining the quicksand beneath the town of Brüx the subsidence began on the periphery, and was continued towards the interior. On renewed drainage subsidence began outside the area which had already sunk and narrowed away towards the interior. A similar process seems to have occurred in the north-west of Iceland (IV, p. 265, fig. 23), and may also be assumed here.

At the beginning of these studies attention was drawn to the analogy which exists between the North Pacific Ocean and the Indian peninsula, and the comparison may be extended to the Karoo. Folded mountains advance on three sides; the fourth side is open. On one side are Kamchatka, the Aleutian islands, and the Elias range; on the second the Sind chains, Himálaya, and the chains of Arakan; on the third the three Cape ranges. The Indian peninsula is a foreland, the Karoo also, and we must assume that another foreland lies beneath the North Pacific Ocean. In considering these main features of the structure we must not allow ourselves to be deceived by the hydrosphere. If we could remove it a vast land would lie before us at a depth of 3,600–4,000 meters below the existing sea-level, but in front of the folded arcs we should see elongated strips of land, no doubt not completely regular, which would lie 2,000, 3,000 or even 5,000 meters lower than the rest of the vast tract of newly exposed land [1]. This great tract of land is the foreland. *The outer border of the foredeep is the arcuate border of a subsidence of the lithosphere, and the inner border of the foredeep is the outer border of the folded range* which has advanced from the direction of the land over this deep. Asia is surrounded on the east and south by subsidences of this kind. We have termed them *vertices.* The peninsula of India is a horst which has been preserved at a spot where the foredeeps were probably less deep, and where they are now indicated by great river-valleys only. Africa is a horst which has been preserved throughout its whole breadth, from the folded system in the north (Atlas) to that in the south (Cape mountains).

The arcuate outer margins of the foredeeps have probably been produced by the breaking-up of an extensive sinking movement, which includes the whole of that part of the Pacific Ocean lying in the direction of Asia.

That the Cambrian beds lie just as undisturbed in the backland as in the foreland now becomes intelligible, as well as the fact that there are neither arcuate chains nor foredeeps (excepting the brow of the two Antilles) in the Atlantic and Indian Oceans. A foredeep makes its appearance as soon as we reach the Burman arc.

It is assumed, as we have seen above, that the two margins of the foredeep are of different character; the outer margin is a subsidence-margin of the foreland, which is covered by the sea, the other belongs to the advancing folded range.

In the foredeep volcanic rocks are but seldom encountered; they have been found in front of the Philippines, but in this case they may have been rained down from above. The volcanos which accompany the island festoons *never* stand in the foredeep, but belong entirely to the folded cordillera.

Folding. The simplest form in which the folds are distributed occurs when concentric arcs arise, closed at both ends, within a foreland which

[1] With regard to the deepest foredeep, that of Guam (9,636 meters), G. Scholl writes: 'The characteristic feature of this foredeep consists in the fact that the little furrow, both deep and narrow, which borders the east side of the islands of Guam, Tinian Saipan, and others in a north-and-south direction, is followed by a series of clearly marked elevations or ridges running from west-south-west to east-north-east (1,977, 1,260, 1,317 meters) as though a great fault-trough were present here, lying between horsts (islands in the west, submarine ridges in the east)'; Ann. d. Hydrogr., 1906, XXXIV, pp. 23–27. De Lapparent was one of the first to draw the attention of geologists (as early as 1879) to the remarkable distribution of the great deeps (Note sur la disposition générale des reliefs du globe terrestre, Bull. Soc. géol. France, 1879, 3e sér., VII, pp. 346–352), but the most important facts have only become known subsequently. The part played by Supan in obtaining recognition of their true significance has already been mentioned (IV 294).

is let down in a more or less arcuate form. In Asia a large part of the arcs of its vertex and of its margin either belong to or approach this type. Frequently, however, the arcs are not closed, and an open virgation is produced with free ends. The arcs may also be resolved into oblique coulisses, as in the Rocky mountains.

The virgation may show a tendency to elongate and join the arc, as on the Helmund or in the Aleutian islands, or it may extend far beyond the arc, as in the Thian-shan. Finally, cases are known in which folds advance independently for a great distance beyond the region of their origin, until they die away at last in free ends. We have termed these *branch-folds*. Their formation bears witness to a powerful and extensive lateral pressure, which finds expression in a projecture on the outer envelope of the planet. In this way the Appalachians and Hindu-Kush were formed, as well as the Burman arc, which advances far beyond the marginal arcs; possibly also the main bulk of the Ural, although it is here regarded, on account of its position, as a posthumous line of the Asiatic vertex.

These free folds, which strike away beyond the frame of a vertex, present independent deflexions. Where they meet with a local obstacle secondary *forced virgation* may arise, which is different from the primary virgation of the Alaskides or the Philippines. Secondary virgation of this kind is produced by the Adirondacks in front of the Appalachians, and the plateau of Ufa in front of the Ural. It is obvious that the opening of the forced virgation lies in the direction of the free ends. In the case of the Appalachians these are the isolated fragments of coulisses which lie far beyond the Mississippi, in the case of the Ural the much younger Yergeni.

The greatest deflexions are exhibited by the Alpides, which have arisen within the subsidences of the western Altaides as posthumous folding of the frame. In this way, continued development towards both ends has given rise to the bends at the Iron Gate, of the south-eastern Carpathians, at the union of the Alps and Apennines, and from Sicily towards Tunis, and, finally, the arc of Gibraltar; it has thus produced an almost vermiform trend-line, with free ends in both directions, namely 'running backwards' (towards the Altaides) in the east Balkans, the spur of Valeni and the spur of the Lägern (Jura mountains), and 'advancing' in the Balearic isles (as far as Majorca), although directed there towards the east.

Especially instructive are those cases in which a continued development of the free ends seems to have occurred. An example is afforded by the two folded ranges of upper Tertiary age, which advance out of the north border of the Caucasus and strive to surround the Cimmerian fragment in the Crimea. As other examples we may mention the ends of the Ghissar range, those of the Amu-darya at and below Kelîf, and those of the Mogul-tau, which are cut through by the Sir-darya below Chodjent (III, p. 299, pl. IV). These cases are particularly clear, since both rivers must be regarded as antecedent.

While the Dinarides exert pressure upon the Alps in the direction of the porphyry mass of Botzen, two fascicles of folds, caused by the avoidance of obstacles, arise in the Dinarides themselves, one running in the direction of lake Garda and the fault of Schio, the other in an east-south-easterly direction through South Styria and Croatia. The latter date (like the spur of Valeni in the Carpathians) from the post-Levantine period; but only a part of their long free ends are formed by folds, the remainder consisting of steeply upturned strips defined by faults (IV, p. 378).

Let us once more return to the long free branching folds.

A little board moves slowly on a surface of water. In front, in its wake, steeper waves are formed. At the sides they flow away in long free-branching waves, separating in virgation, as the distance increases, owing to intercalations and divergence, possibly too, like the Appalachians in Alabama, passing from convex into concave trend-lines, at the same time constantly decreasing in height and elongating beneath our very eyes. The comparison is more exact if we imagine the little board, or the source of the movement, just below the surface of the water. Then we may also discover a resemblance between the waves of Krakatoa which encircle the earth and the long arms of the Altaides.

Backfolding and dying-out of folds in the Asiatic system. Let us attempt, at the danger of repeating ourselves, to analyse the elements which form the Asiatic system. In the north of the Canadian shield the United States chain makes its appearance as part of the periphery. To the north of this chain the Arctic Ocean extends. Then Angara land is reached, which includes all the land between the Yenisei and Lena along with the fluvial region of the Aldan, and is probably continued beneath the plain of West Siberia. It is beneath this Cambrian platform that gneiss is exposed along several of the rivers of North Siberia. It has been called Angara land on account of the diversified late Palaeozoic floras of its southern part; in the north it is overlain by the flat-lying marine beds of Mesozoic transgressions.

The platform extends from Bennett Land into the horseshoe-shaped amphitheatre of Irkutsk (up to lat. 52° N.), which is the inner border of the ancient vertex on lake Baikal. This is followed towards the west by the pre-Devonian vertex of Minuzinsk, and this again by the Carboniferous vertex of the Altai. We now approach the periphery. We may regard the United States chain as the *first* member of the periphery. The *second* member, which is, more correctly speaking, a series, extends in the east from the Rocky mountains and the Elias range through the Alaskides and the east Asiatic island festoons to Halmahera and Celebes. The Uralides in the west correspond to these as a *third* member. The Urals which form their main stem recall the Great Khingan; their continuations reach the north of Norway, but the peripheral structure is there so little developed that horizontal Cambrian beds extend from the east up to and beneath the Caledonides.

To the south of the Philippines and the Uralides a change sets in. This begins on the Altai. Long straight lines mark the southern boundary of the succeeding parts of the periphery. The eastern part is prolonged towards the south into the Burman arc. The western part reaches the horst of Azov, extends towards Europe, is prolonged across the Ocean, and does not terminate until it reaches the other side of the Mississippi. These are the eastern and western Altaides, which form the *fourth* and *fifth* members of the periphery.

Within these long branches the southern marginal arcs represent the *sixth* and last member. They comprise: the Himálaya, the Iranian arc, and the Tauro-Dinaric arc. The arc which surrounds the western Mediterranean has undergone posthumous alteration.

Thus the Asiatic system terminates, and we return to the *amphitheatre of Irkutsk* (III, p. 10, fig. 2).

Here, in the middle of the Asiatic system, which all around strives towards the exterior, undoubted backfolding occurs next the interior, that is, over the concave side of the arc. The syncline of the peninsula of Olchon, overfolded towards the interior (III, p. 62, fig. 4), and the Silurian beds of the Onot range, also overfolded towards the interior, afford the clearest evidence of this; but in the west also, on the so-called horst of the Yenisei, Meister has since observed overfolding towards the interior, and the horseshoe-shaped folds of the Angara beds, to the north-east of Nishni Udinsk, show that at a time even later than the Jurassic a constriction of the amphitheatre occurred in this otherwise Archaean tract (III, p. 23). Here the backfolding is also accompanied by late granitic intrusions, as at Kruglaja, near Nishni Udinsk, and the rapids of Strielka above the mouth of the Angara [1].

The *arc of Verkhoiansk*, the innermost branch of the Anadyrides, is folded, according to Toll, towards the interior; he expressed this view many years ago, when it was little likely to be accepted; and it is not generally recognized even now (IV, p. 341).

There is no doubt that the *Romanzov range*, in contrast to the other Alaskides, is folded towards the interior. The overfolds near cape Lisburne directed towards the north, and the arrangement of the beds shown in the section of the Endicott range, bear witness to this (IV, p. 352).

[1] Geologische Beobachtungen in den goldführenden Gebieten Sibiriens, Gebiet des Jenissei, Meister, sheet K-8, 8vo, St. Petersb., 1903, 89 pp , maps. Earlier data led to the conjecture that the Kropotkin mountains (III, p. 44) were also backfolded; doubts have recently arisen with regard to this region; op. cit., Region of the Lena, A. Guérassimow, Sheet III-6, 1907, 229 pp., map (in Russian).

Since the *Rocky mountains* form a syntaxis with the Romanzov mountains (not with the Alaska range) and are moved in the same direction (that is, are turned away from the forefolding, which is directed towards the Pacific Ocean), they must be regarded as backfolded with reference to the Asiatic system. The backfolding is expressed in the movement towards the east, while the Elias range is moved towards the west. In the southern part of the Rocky mountains, however, unilateral movement is, as a rule, scarcely perceptible.

Between the several branches of the great system blocks stand out which have resisted the foldings of more recent date. The largest of these lies in *North China,* and in the elbow of the Hoangho its western and northern border stands in the position of a foreland in face of the folds of the desert of Gobi. In the east of this block B. Willis and Blackwelder have shown that the coal-formation of Shansi is folded, and that in the Ki-tshou-shan folding and overthrusting towards the south-east prevail in the Cambrian and pre-Cambrian rocks. Ki-tshou-shan strikes to the north-east and forms the junction with Wutai-shan, which is likewise folded[1]. (These facts relate to the mountains marked red on pl. VII, vol. III.) Thus the bend of the Wutai-shan into the direction of the Great Khingan is determined; the latter strikes to the east-north-east even as far as the Dolon-nor[2], and must now, in accordance with earlier conjectures, and the observations made in the north (III, pp. 116, 208), be included among the folded structures.

The insertion of the folds which approach from Kuku-choto marks the north-eastern end of the block of North China. All these branches then are forefolded.

The behaviour of the block of *South China* differs fundamentally from that of North China. It does not act as a foreland, damming back the folds towards the west, but the chains of the great ranges are continued into it and gradually flatten out.

The chains of Yünnan, running almost north-and-south in lat. 27° 30′ N., and very closely crowded together, begin to diverge from one another to the south of this locality, extending in the Patkoi range towards the south-west, and on the south-east of Talifu in the direction of the Red river. In the north-west other meridional chains advance east of Batang to the Ta-pa-shan and the Red basin. A particularly long coulisse (anticline of Tung-tshwang) is cut through by the Yan-tse-kiang at its most southerly point. All these folds, according to Leclère's observations, flatten out in broad anticlines towards the south. Devonian, Carboniferous, marine Permian,

[1] B. Willis, E. Blackwelder, and R. H. Sargent, Research in China, 2 vols., in 3 parts, 4to, Washington, 1907, atlas.

[2] Communication by letter from Mr. Ogawa, on a journey from Peking to Dolon-Nor performed in 1903.

marine Trias, and Rhaetic and Liassic plant-bearing beds broaden out over the land, and it is not till we approach long. 108° E. that an older foundation becomes visible beneath them. Flexures, striking to the north-north-east, and a general subsidence are the predominant features in east Yünnan and Kwang-si [1].

Thus we may indeed say that this part of China bears the drooping remains of the sedimentary mantle which formerly covered the high mountain ranges (III, p. 231).

Further to the east the block of South China is but little known. Proceeding from Fu-chu towards the interior, gneiss, amphibolite, granite, and ancient schists have been met with, overlain unconformably by beds of Mesozoic appearance [2].

Let us return to the chains of Yünnan. The chains which follow the Red river towards the south-east send off in the west the cordillera of Annam, which becomes convex towards the east and conforms to the direction of the line of the Philippines. The eastern coulisses reach the delta of the Red river in low spurs, but towards the interior they are followed, according to Zeil, by further folds, the strike of which makes a bend in the regions situated to the north and north-east of Ha-Noi, out of the south-east into the east-north-east, with the convexity turned towards the south and south-south-east; we await further information concerning these coulisses [3].

Then come still additional intercalated segments in *Cambodia* and *South Borneo.*

These details are given to show that in these great branches of the eastern periphery backfolding has almost completely disappeared. A local exception occurs in the Burman arc, in South Sumatra, where Tobler, while surveying the petroleum-bearing anticlines of Tertiary age, found that they had been produced by a movement directed towards the north and north-east, i. e. by backfolding [4].

In the Mustág-Ata, on the east side of the Pámir, there is a tremendous overfold or overthrust towards the east, that is towards the concave side of the Yarkand arc (III, p. 273); something similar may also be seen in the folds which surround the Helmund.

[1] A. Leclère, Étude géologique et minière des provinces chinoises voisines du Tonkin, Ann. Mines, 1901, 9e sér., XX, pp. 287–506, maps.

[2] Kinosuki Inouye, A Journey along the Min Kiang, Province of Fukien, China, Journ. Geogr. published by the Tokyo Geographical Society, 1898, X, pp. 583–592 and 637-641, map (in the Japanese language, kindly translated by Mr. Yamasaki).

[3] G. Zeil, Contribution à la géographie tectonique du Haut Tonkin, Ann. Géogr., 1907, XVI, pp. 430-450, map.

[4] A. Tobler, Topographische und geologische Beschreibung der Petroleum-Gebiete bei Mocara Enim (S. Sumatra), Tijdschr. Nederl. Aardrijkskund. Genootsch., 1906, pp. 199–315, maps, in particular pp. 261 and 273.

We will now return to the inner vertices.

In the *vertex of Minuzinsk* backfolding also occurs. Near the Yenisei the West Sayan is overfolded towards the north, that is, towards the interior, and the horseshoe-shaped folds of Devonian below the town of Minuzinsk probably play a part similar to that of the horseshoe-shaped folds of Jurassic near Nishni Udinsk (III, p. 79).

In the vertex of the Altai, the question as to the presence of backfolding must remain undecided. Some observations seem to show that the border of the Kusnetskii Alatau is folded towards the west over the coal-bearing beds of Kusnetzk, but they scarcely enable us to arrive at a decision[1] (III, p. 152).

After these numerous examples of the repeated occurrence of backfolding we will now extend our inquiry to *Europe*. The Timan-Kanin chain in the north and the Dinarides in the south retain the normal forefolding towards the south, even on this continent. The line of the Altai, which reaches a point to the north of the horst of Azov, behaves in a manner characteristic of Asia, and this is also true of the problematical lines of Karpinsky. On the other hand the trend-lines coming from the Caucasus, which reach the south of the horst, turn from this point onwards towards the north, in contrast both to the mountains situated in the north and those in the south. At first, it is true, we only see posthumous chains (Balkans and others). In this respect, however, they resemble the typical western Altaides; these first become visible in the Sudetes (IV, p. 3).

From the horst of Azov onwards the whole of the western Altaides (along with their posthumous structures) exhibit backfolding as far as Texas and Oklahoma.

From this fact a number of conclusions may be drawn.

The Rocky mountains proceed from the island-festoons, the Appalachians from the Altaides, but it is only the fact that both ranges are backfolded with regard to the great Asiatic system which renders it possible to regard *Laurentia as the common foreland of both*, and at the same time of the United States chain, which exhibits fore-folding.

At the same time it appears that both in the east and west it is precisely the backfolded free branches which extend farthest beyond the periphery, namely the Rocky mountains in the east and the western Altaides in the west. But we also see *that they die away more rapidly.*

In the Rocky mountains folding commenced as early as the upper Cretaceous, thus offering a contrast to the Elias range which is still in course of formation. The branches of the Altaides which lie outside the horst of Azov became rigid even before the Permian period, but later, it is

[1] J. P. Tolmatschew, Geological Observations on the Kusnetzkii Alatau, Izviestija Imp. ross. Geogr. Obsch., 1903, XXXIX, pp. 390–436 (in Russian); Bogdanow's statements (Verh. russ. min. Ges., 1883, XVIII, pp. 149–211) have already been mentioned.

true, they gave rise to posthumous structures, such as the Alps, in the European subsidences. The northern part of the Urals is old, but in its southernmost part it presents very recent offshoots. All the rest of the periphery, from the Mediterranean to the Elias range, may be regarded as characterized by true forefolding, possibly not yet completed. Without anticipating some observations to follow later, we may refer to the mode of arrangement of the active volcanos, which is in complete harmony with all the preceding conclusions.

A restriction of the area over which the orographic force operates occurs simultaneously with a falling off in the intensity of this force.

The backland is not the starting-point of an active fold-forming force. The Cambrian beds lie just as undisturbed in the backland of Angara as in the foreland of Laurentia. The backfolding is a secondary phenomenon, the result of a redundancy in the planetary envelope.

This is naturally not true of those forced backfoldings which have been produced by a violent bend in the strike, such as occurs at the Iron Gates and the bend of the Alps to the Apennines.

Analysis of the Arcs. The structure of the northern Antilles may first engage our attention. A considerable foredeep lies in front of its northern half. Following one another with great regularity in concentric arcs are: a series of Tertiary islands, a short series of extinct volcanos, the arc of active volcanos, and finally the cordillera. A concentric structure is also possessed by the Asiatic arcs. A tendency to the same plan may be recognized even where the lines separate in virgation.

We may select for comparison with the Antilles four types of arcs, represented by the Philippines, the Liu-Kiu islands, the Alaskides, and the Bonin islands.

1. *The Philippines* (II, p. 171; III, p. 246, pl. II.) present in the east a long foredeep which sinks below 7,000 meters. They open out towards the south in a virgation of cordilleras, and between their branches several series of volcanos make their appearance. The virgation extends across Mindanao, and dies away in Celebes and Halmahera, following directions which run transverse to that of the Burman arc [1].

[1] For Celebes (III, p. 257) the most important source of information, in addition to Wichmann's works, is P. and F. Sarasin's Entwurf einer geographisch-geologischen Beschreibung der Insel Celebes, 1901, 4to, 344 pp.; petrological supplement by C. Schmidt and atlas. The succession of rocks is granite, gneiss, mica-schist, and other schists; further, crystalline limestones, radiolarian rock, some brown coal, lower Tertiary, and more recent limestone and Miocene clays. In addition, glaucophane rocks, peridotite, dunite, and diabase, then trachytic and leucitic rocks, and, finally, recent volcanos are present. The theory that a separation into two virgations occurs is supported in particular by the strike to north and north-north-east in the extreme north-west (III, p. 258). On the other hand the interruption of the cordillera near the Equator may be cited as an objection, and also Wichmann's statement that a strike to north 45° east occurs to the

The inner branch, formed by the Sarawak or upper Kapoewas range of north Borneo (folded Trias and Cretaceous), marks the limit of a large alien segment which occupies the south of Borneo between the branches of the virgation. On the west is Pontianak, lying in the broad alluvial stretches of the river Laudak. To the north of this locality Wing-Easton observed granite with transgressive Cenomanian, which must belong to the alien segment [1]. In the east, according to Molengraaff, it is bounded by a trough in the direction of the cordillera. On the south border of the trough, in the direction of the alien segment, rise the extinct volcanos of the Müller range.

2. *Liu-Kiu islands.* The strike of south Honshiu, which also prevails in the south of Kiushiu, is cut through here by the volcanic line of the Liu-Kiu arc as it enters this region. This is, as we have seen, the meaning of the bay of Kago-shima, the caldron fracture in which it ends, the volcano of Sakura on the margin of the caldron, and the volcano of Kiri-shima which rises further inland. But still further to the north, near the town of Kumamoto, and in the western part of the Amakusa islands, which lie off the coast towards the south-west, deflexions of the ancient rocks towards the north and north-west occur, and in north Kiushiu the Tertiary beds rest upon long tectonic lines of post-Tertiary age, which run across the main strike in a north-and-south direction. Japanese geologists think it possible that these may be ascribed to the influence of Liu-Kiu [2].

The middle and southern part of Korea is of great age. Some folds occur striking to the east-north-east or north-east, but it is the younger fractures which determine the character of the country.

A great fault-trough extends from Gensan on the east coast, in about lat. 39° N., and becomes so broad towards the south-south-west that the north border reaches the west coast in lat. 37° 50′ N., the south border in lat. 36° N. Recent basalts occur in the fault-trough. That part of Korea which lies towards the north-west (Kôtô's Palaeo-Chyo-sôn) is cut up into

south of this interruption in about lat. 0° 45′ S. (Tijdschr. Aardr. Genootsch., 1890, 2. Ser., VII, p. 987). This seems to point to a single virgation starting to the north-east of Minahassa. Kruijt's map of the kingdom of Mori (op. cit., 1900, 2nd ser., XVII, pl. II) does not show any bend of the chains at the head of the gulf of Tomori (Mori) from the south-east to the north-east peninsula, while a bend of this kind from the south-east to the north (to lake Posso) is certainly marked. For the north, Molengraaff, Zeitschr. prakt. Geol., 1902, pp. 249–257. The volcanic mountains of Bowonlangi and the volcanic group of the Pic von Bontaing lie in the furrow or fault-trough of the valley of Tempe.

[1] N. Wing-Easton, Geologie eines Theiles von West-Borneo, 8vo, Batavia, 1904, 542 pp., atlas. For the transgressive Cenomanian, Krause, Samml. geol. R. Mus. Leiden, 1902, VII, 1, 28 pp. The trend-lines of the folded mountains in the oil-bearing beds of the bay of Brunei in Labuan have been described by K. Schmidt; Gerland, Beiträge zur Geophysik, 1904, VII, 121–136, map.

[2] Outlines of the Geology of Japan, descriptive text to geological map, 1 : 1,000.000, Tokyo, 1900, pp. 26, 76, 102.

numerous segments. In the south-east, lines of fracture occur which represent a virgation starting from Gensan or a point lying further to the north. One of these fractures forms the greater part of the arcuate east coast; it is followed by three long parallel fractures; others diverge towards the south-west, and the south coast of Korea becomes a rias coast. These long fractures are disjunctive lines in a virgation which may possibly be included among the inner zones of Liu-Kiu [1].

We have shown previously (II, p. 176) that the arc of Liu-Kiu consists of an outer rocky cordillera and an inner volcanic zone. But the resemblance to the Northern Antilles does not stop here, an arc of Tertiary beds being present outside the cordilleras.

The innermost zone extends from the volcanos in the south-west of Kiushiu through Iwo-shima to Tori-shima and other islands, and finally to the volcano of Taiton in the northern extremity of Formosa [2]. The second zone is a mountainous cordillera; Yaku-shima, O-shima, Tokuno-shima, Okinawa-shima, and Migako-shima are its most important members. Palaeozoic beds dip here towards the west, and are thus probably overfolded towards the Ocean, as in south Honshiu. The third zone consists partly of Lepidocyclina-limestone; it includes Tanega-shima, Kikaiga-shima, the southernmost part of Okinawa-shima, and other islands.

In the southern group of Yaeyama, Ishigaki belongs to the cordillera, but andesite also occurs, and the (volcanic) mountain of Nasoko which, precisely like the extinct volcanos of the Antilles, rises more towards the exterior. Iriomote is formed of folded Tertiary. The influence of the Philippines probably expresses itself here in the strike, which is directed in places towards the north-north-east [3].

3. *The Alaskides* (IV, p. 346). Within the foredeep rises a cordillera formed apparently of very ancient rock, and accompanied on its south side by Flysch-like sediments as well as by folded Tertiary beds, in part oil-bearing (Kenai and Chugatsk range). Within the cordillera lies the trough of Shelikof strait and Cook inlet, with beds ranging from the Jurassic to the Tertiary, with disjunctive lines and the arc of the volcanos. Within

[1] Kôtô, Orographical Sketch of Korea, Journ. Coll. Sci. Tokyo, 1903, XIX, 1, 61 pp., map; also K. Inouye, Geology and Mineral Resources of Korea, Mem. Geol. Surv. Japan, 1907, I, 1, 91 pp., map. An isolated andesitic cone within the rias coast is also remarkable; E. Sagawa, Kôjô Island, Corea, Bull. Geol. Surv. Japan, 1901, XIV, pp. 31–50, map (in Japanese language; long. 128° 32′ E.).

[2] F. von Richthofen, Geomorphologische Studien, III, Die morphologische Stellung von Formosa und der Riukiu-Inseln, Sitzb. k. Akad. Wiss. Berlin, 1902, pp. 944–975, map.

[3] S. Yoshiwara, Raised Coral Reefs in the Islands of the Riukiu Curve, Journ. Coll. Sci. Tokyo, 1901, XVI, Art. I, 14 pp., map; Geological Study of the Riukiu (Loochoo) Curve and its relation to the north part of Formosa, op. cit., Art. II, 67 pp., maps; R. B. Newton and R. Holland, Fossils from the Islands of Formosa and Riu-Kiu, op. cit., 1902, XVII, Art. VI, 23 pp.

the volcanic arc again rises the main cordillera (Alaska range), accompanied by secondary branches.—An alien fragment is inserted between the branches of the virgation (Seward and Chuchki peninsula).—The last cordillera presents backfolding towards its concave side (Romanzov range).

4. *The Bonin islands* (III, p. 146; IV, p. 296). From the profound disturbance which cuts through Honshiu rises the series of the Shichito volcanos [1]. It continues the western, volcanic series of the Bonin islands, in front of which there lies in the east a second chain of islands, the Ogasawara chain, formed of Tertiary sediments. This, it is true, is only known from lat. 27° 40′ N. to lat. 26° 38′ N.

These four types present a definite structure and a definite serial order of elements, which may sometimes be incomplete, but is never inverted. The first element, on the convex side, is the foredeep; the second is a Tertiary belt which is often folded, and often characterized in a striking manner by the presence of Lepidocyclina (outer series in Liu-Kiu, Ogasawara chain in Bonin). Then follow the folded cordilleras, the innermost of which are sometimes backfolded (Romanzov range), and sometimes separate from each other in virgation (Philippines, Alaskides). Finally there is the volcanic arc. This *always lies in the cordillera, and more precisely in the zone of forefolding,* never in that of backfolding, and never in the foredeep. In the Philippines several volcanic lines follow the virgation. In the Liu-Kiu disjunctive lines may possibly be recognized as far as Korea. Alien fragments sometimes occur between the branches of the virgation (South Borneo, Seward, and Chuchki peninsulas).

The same structure is also present in the northern Antilles, but in these islands no cordilleras occur within the volcanic zone. In general, the cordilleras are the first to show a tendency to disappear, as may be seen in the Bonin islands, while the volcanos hold their ground with great tenacity, as in the Aleutian islands.

Arc of the Oceanides. In the light of the preceding facts the structure of the Oceanides becomes evident. It has long been known that the older rocks become rare out towards the Ocean. This corresponds with the disappearance of the cordillera. Sometimes only the Tertiary belt with the volcanos remains, as in the new Hebrides; sometimes little more than the Tertiary belt alone, as in the Paumotu group; or it may be that only a chain of volcanos marks the course of the trend-line, as in Hawaii, out in the middle of the Ocean.

The virgation which proceeds from New Zealand, and follows the lines of New Caledonia to New Guinea, the New Hebrides to New Ireland,

[1] Mr. Ogawa informs me that on the upper Tenrim, on the west side of the Akaishi mountains, he has observed overthrusts of gneiss over younger rocks in a south-easterly direction, that is towards this disturbance (the Fossa magna), and that Dr. Suzuki has observed similar overthrusts near Aoki, further to the south.

and the Gilbert islands to the Carolines, shows clearly the gradual disappearance of the cordilleras; and the possibility that Viti Levu may be an older segment lying between the branches of the virgation and not forming part of the cordillera becomes more readily intelligible. In front of the east side of the structure lies the foredeep of Kermadec and Tonga.

The Marianne islands encounter the Carolines in linking; this is also true of the traces of the Raroia group with respect to the Paumotu islands.

There is no essential difference between the structure of the arc of the northern Antilles, the island festoons, and the Oceanides. At the same time it must be remembered that this structure cannot be recognized further than Hawaii and the Marquesas, and that beyond these islands in the direction of South America a region intervenes in which islands are rare, and are arranged rather in groups than in lines.

Analysis of the Andine structure. Here comparison is much more difficult, owing to the presence of an eastern and a western foredeep.

The foreland which lies between the two groups of Antilles is not let down in an arc; nor does it resist the great movement coming from the west, but in Bolivia and Argentina it is itself thrown into folds and flakes over a considerable area. The Cordillera de la Costa, which forms the starting-point of the movement, and must, according to older views, be regarded as the central chain, presents, in complete contrast to the general rule, plant-remains belonging to the Keuper and Lias, and in the extreme south to the middle Jurassic, as though during these periods there had been dry land over large areas, or as though a coast had existed in the vicinity. At the same time we have the still unexplained fact that to the north, in South Oregon, plant-bearing beds of the middle Jurassic set in, as well as abyssal radiolarian rocks, probably of upper Jurassic age. The latter contribute to the structure of the Californian coast ranges, which are regarded in this work as part of the Andes.

The further we carry our comparisons towards the north, the more striking becomes the correspondence between certain characters of the Andes and the Intermediate range. In the first place there is the frequent association of marine Mesozoic deposits and recent volcanos, then the repeated recurrence of long ranges of granodiorite; and at the same time there is the fact, not to be overlooked, that in South America the volcanic activity dates from the middle Jurassic or Lias, and in the Aleutian islands from the Volga stage or Kelloway.

In the fault-trough of the Aleutian volcanos the same Mesozoic series occurs as in California, with the same unconformity at the base of the Neocomian. These formations are continued into the interior plateau and the Basin ranges as a folded region, divided into numerous submeridional horsts and fault-troughs, among which we will only mention Death valley (190 kilometers long, and sinking to as much as 123 meters below the sea level). In its broadest part this region is bounded on the east by the slope of the Wahsatch, and on the west by the eastern scarp of the Sierra Nevada, as though the whole range, 600 to 700 kilometers in breadth, had been let down in strips between these two 'lines of weakness' (I, p. 578).

Further south, from Arizona onwards, this structure becomes constricted, or terminates. In Mexico it reappears; again we observe the Mesozoic series, the long folds, striking here to the south-east, the faults and volcanic phenomena, and the bolsons devoid of outflow. Thus we reach the Atlantic Ocean, while to the south the giant volcanos of Mexico mark the bend of the strike in the Sierra Madre.

Still further south we reach the Depresión central of Chiapas with the volcano of Zontehuitz, which is compared by Böse with lake Nicaragua, and further away follow the volcanos of Guatemala. The cordillera, which must be regarded as the continuation of the Sierra Madre, strikes away towards Cuba and Jamaica. In Guatemala the volcanos do not follow this swerve, but are continued towards the south-east, extending, according to Sapper, in repeated, alternating series, as far as Costa Rica. Of these series that included between the volcanos of Coseguina and Madera (lakes of Managua and Nicaragua) stands in a fault-trough.

Nothing similar is known in the Antilles. On the mainland, a fault-trough probably occurs between Cumaná and the gulf of Paria; the valley of the Rio Magdalena has also been described as a fault-trough. We have already called attention to the not infrequent arrangement of the volcanos in straight lines within the volcanic zone, and the occurrence of fault-troughs, as for example near Antofagasta and as far as Lonquimay, and also outside this zone in the Argentine Andes. Several of these fault-troughs, as in the Basin ranges for example, are over 100 kilometers long and only 8–9 kilometers broad.

On the north, to the west of the syntaxis, in Cook inlet, the presence of true freshwater beds of the Kenai stage shows that in the Tertiary aera the trough must have been occupied by a long, narrow lake, cut off from the sea. On the south, at a distance from the Kenai stage, the gypsum which is intercalated in the Jurassic formation of the volcanic zone leads to a similar conclusion. In this region also, waters cut off from the Pacific Ocean, or only imperfectly united with it, must once have occupied the site of the great Cordillera de los Andes. Schiller has collected all the facts known concerning these gypsums. They already make their appearance in lat. 23° S., near Caracoles, where they overlie the Kelloway; they are possibly repeated in the Cretaceous, and are known in greater detail in the region of the Aconcagua; in these more southerly districts they lie upon the Kelloway and beneath the upper Jurassic, and extend upwards in the territory of the Neuquen as far as the Kimeridge.[1]

The distance from Caracoles to Neuquen amounts to almost 16 degrees of latitude. An account of the region between lats. 32° and 39° S. is given in two important works by Burckhardt. A porphyry conglomerate is widely distributed over this long tract in the western part of the Andes, and attains a considerable thickness; in the east it is replaced by sandstone. Both conglomerate and sandstone are inserted immediately above the gypsum, and are therefore upper Jurassic. Burckhardt concludes that a long narrow arm of the sea must have existed in the form of a fault-trough, like the Red sea, and that it was bounded on the west by continental land, which was the source of the porphyry pebbles and now lies submerged beneath the Ocean.[2]

In addition to all these longitudinal disturbances there are the two longitudinal valleys of the Sacramento and of Chile. The considerable depth which borders the west coast, and descends, between Antofagasta and Copiapó, below −7,600 meters, is independent of the volcanos, but apparently does not lie in the usual series.

This whole zone is folded; up to the outcrop of older rocks in Arizona the movement in the Basin ranges is directed towards the west, at least in so far as a movement in one direction can be recognized. Then, in North Mexico, it is directed towards the east and north-east. This direction also prevails in the Argentine Andes. If these were folded towards the west, or if we might regard them as produced by backfolding, then the east would be a normal backland, the bay of Arica a normal syntaxis, and the deeps off the west coast normal foredeeps. But this explanation is contradicted by the signs of a Mesozoic mainland visible along the Cordillera de la Costa, as well as by the observations of Steinmann and his colleagues, and those of the Argentine geologists who state that the movement is directed almost exclusively towards the east.

Southern and western parts of the Asiatic system. The periphery of this system has been divided into: 1. The United States chain; 2. The whole of eastern Asia as far as lake Banda; 3. Corresponding to this in the west, the Uralides; then, the long, free branches of the Altaides, extending beyond the periphery, which include, 4, the eastern (the Burman arc), 5, western Altaides; and finally, 6, the three inner marginal arcs (the Himálaya to the Dinarides). We will return to our original order.

[1] Schiller, Geologische Untersuchung bei Puerto del Inca, p. 722, note 2.

[2] C. Burckhardt, Traces géologiques d'un ancien continent pacifique, Rev. del Museo de La Plata, 1900, X, pp. 177–193, map; Beiträge zur Kenntniss der Jura und Kreideformation der Cordillera, Palaeontographica, 1903, L, 144 pp., in particular p. 124 et seq. Steinmann thinks that the volcanos alone would have sufficed to form the conglomerate, N. J. f. Min., 1902, II, p. 429.

In the *Uralides* (3) Nova Zembla is connected by linking with the Urals (III, p. 374; fig. 18). The whole of the northern part of this system is of considerable age; on the other hand, the Yergeni mountains in the south are of comparatively recent date, and recall the free offshoots of the east Asiatic branches. Disjunction is unknown [1].

The *Burman arc* (4) is clearly related to the eastern arcs. In the south it is accompanied by a foredeep of about 7,000 meters. Several Tertiary islands lie in front of it (Mentawei and others), and the largest and most regular volcanic disjunctive zone of the earth accompanies it deep into the mainland. It is distinguished however from the arcs of eastern Asia by the convexity of its main branch, which is directed towards the west and south-west, while some of its inner branches, diverging from this main branch, adapt themselves in Annam to the direction of the Philippines. The place of separation is marked by the insertion of the mass of Cambodia. The free end is directed, not to the south or south-west, but to the east, and in respect to this direction it presents a similar contrast to the Philippines and the Celebes, as the Caucasus does to the Yergeni mountains.

The western Altaides (5) extend beyond the periphery in free branches which are even longer than those of the eastern Altaides. They became rigid, outside the horst of Azov, as early as the Permian period, gave rise subsequently to posthumous ranges in sunken areas, and are wholly backfolded; they thus present peculiar features which are not repeated elsewhere.

The inner marginal arcs (6) present a remarkable contrast to the Altaides, which strike across and beyond them. This contrast is already apparent between long. 100° and 96° E. (III, pl. VII.), in the manner in which Khrebet Pustyinji strikes across the directions of the Lun-shan (north-west) and San-sjan-tsy and Shi-boa-shan (north-east), in the region where these enter into syntaxis. The Thian-shan as it proceeds forms the chord of the arc which encloses the plain of the Yarkand, and then strikes across the western end of this arc in the Pámir. Maintaining the same invariable direction to the west-north-west, the coulisses of the Hindu-Kush strike from the Balchan to the Caucasus, forming the chord of the arc of the south Caspian, and in like manner the Caucasus itself crosses the syntaxis of the second and third of these marginal arcs.

All these marginal arcs are folded towards the exterior, as is the entire periphery of this great system. Recumbent sheets are formed on the

[1] On this question also Duparc, Mrazec, et Pearce, Sur l'existence de plusieurs mouvements orogénétiques successifs dans l'Oural du Nord, C. R. Acad. Sci., 9 mars 1903, pp. 629–631. The description of the Kwarkush and Bassegi chain given in III, pl. V, must be modified in some respects; Duparc et Pearce, Recherches géologiques et pétrographiques sur l'Oural du Nord, etc., II, Mém. Soc. phys. hist. nat. Genève, 1905, XXXIV, p. 557 et seq.

boundary of Tibet at Hundes and probably at other localities. The back-folding which sometimes occurs has already been mentioned [1].

In Baluchistán the regular folded ranges are separated, according to Vredenburg's accounts, by broad desert plains, and in numerous examples the movement is always towards the low-lying area, whether that lies to the north or the south; the prevailing direction is to the south. The intervening valleys are in many cases true subsidences.

In spite of the contrast presented by the directions of the Thian-shan and the Yarkand (Himálaya) arc, unconformity occurs in both at the base of the upper Carboniferous or Permian, and in both the movement is continued into the Tertiary aera, as is the case on the outer border of all the marginal arcs.

The Iranian arc displays a remarkable tendency to the formation of secondary intervening spaces. One such space is produced by the Suláimán range which, on the other side of the Salt chain, advances far beyond the outer border of the Iranian arc towards the south, and then breaks up into chains of less elevation; these swerve round to south-west, west, and finally north-west, and thus enclose the 'parasitic' space of *Sewestán* (III, p. 284). The inner principal ranges of Iran, running normally to the south-south-west or south-west, that is towards Kandahár, bound this interval along the chord of the arc in a manner precisely recalling the Altaides. Near Quetta these border ranges turn back to the main chain.

[1] The structure of Tibet is gradually becoming clearer. To the east of Darjeeling first the Tertiary belt and then a belt of lower Gondwána dip to the north-north-west beneath the gneiss of the great range, which is over 100 kilometers broad and extends to about lat. 28° N. (I, p. 449). On the Guicha-La (5,007 meters), in the midst of the gneiss and only 11·7 kilometers to the south of the peak of the Kanchinjunga (8,579 meters), the walls of the Pandim (6,711 meters) exhibit in the zone of contact altered sediments with garnet, scapolite, and other minerals, traversed by dykes of pegmatite. A crinoidal limestone altered in a similar manner, and probably of Palaeozoic age, was encountered to the north of this locality on the north boundary of the gneiss, on the other side of the Jonsong-La. So far Garwood.—Further to the east, on lake Cholarno, also on the northern boundary, Hooker mentions crinoidal limestone, and still further east Hayden observed a mass of Trias (?) let down in gneiss (long. 89° 15′ E.). On the other side of lat. 28° N. lies a vast region of sediments which are in part strongly compressed, with the exception of a narrow strip of Cretaceous and Eocene; this has so far furnished fossils of Jurassic age only. It extends beyond Lhassa, and in all likelihood as far as the Cretaceous of the Tenri-Nor. This broad Mesozoic zone is interrupted by granite on the Brahmaputra south of Lhassa, near Lhassa itself, and at some other points. Garwood conjectures that Kanchinjunga and the great gneiss zone is a granite intrusion of Palaeozoic or even later age. E. J. Garwood, Notes on a map of the Glaciers of Kanchenjunga, Geogr. Journ., 1902, XX, pp. 13–24, map; Geological structure and physical features of Sikhim, in D. Freshfield, Round Kanchenjunga, 8vo, London, 1903, pp. 275–299 and 307, map; H. H. Hayden, Preliminary Note on the Geology of the Provinces of Tsang and Ü in Tibet, Rec. Geol. Surv. in India, 1905, XXXII, pp. 160–174, map; and Geology of the Provinces of Tsang and Ü in Central Tibet, Mem., op. cit., 1907, XXXVI, pp. 122–301, map.

Within the main chain this arrangement is repeated on a larger scale. North of Quetta the ranges run to the south-south-west, separate from one another, bend in an arc towards the west, and then north-north-west, at the same time losing in height, and finally disappear in the north of the desert. Thus, a second space is marked out; the bend of its border is reflected in the bend of the Helmund. At the same time long ranges extend from Bampur towards the north-west, bounding the desert of Dasht-i-Lut. On the outer border a secondary syntaxis possibly occurs in the strait of Hormuzd, and then at last this border strikes along the Persian gulf and the Tigris to its syntaxis near Diarbekr.

The formation of the basin of Sewestán, the basin of the Helmund, and the desert of Dasht-i-Lut, narrowing away in a wedge towards the south-east, does not conclude the process of inner sub-division. Around the south border of the Caspian the *Alburs range* makes its appearance as an independent secondary arc; in the province of Ghilan its west side merges into the normal chains of Iran (III, p. 289).

The Tauro-Dinaric arc (I, p. 498, III, p. 316) consists of two arcs, each of which has opposed the development of the other. Their encounter takes place, according to the later investigations of Philippson, west of the peninsula of Kyzikos, and west of lake Manias, along the river Simau. To the south of this river their course becomes somewhat erratic, since a great tract of crystalline rocks, the Lydian-Karian mass, occupies the region from this point southwards across the Meander and as far as Denizlu and Milas[1]. Dinaric ranges striking to the north-east extend through Rhodes to Asia Minor; in west Lycia the Tauric direction makes its appearance. Within the Taurides a smaller, East Pontic arc may be distinguished, which includes the coast almost as far as Sinope. The principal Tauric arc is of much greater size; it comprises the Taurus and Antitaurus, Amanus, Cyprus, and in western Asia Minor a considerable number of chains running to the north-west. It encloses the depression of Lycaonia. The West Pontic arc is less clearly marked; to its western part, striking to the west-north-west and west, we may assign the Olympus of Brussa and the broad serpentine region to the south of it, as far as Taushanli and Kiutahia. The chains situated further to the south which advance from the south-east, near Afiun-Karahissar and Ishikli across the lakes of Pisidia, belong to the principal Tauric arc.

Within the Dinarides the tendency to form secondary arcs is not so

[1] Thus the north-and-south strike to the north of Smyrna does not possess the significance assigned to it (III, p. 325); Philippson, Sitzb. k. Akad. Wiss. Berlin, 1903, VI, p. 114, and Zeitschr. Ges. Erdk. Berlin, 1905, p. 421. Cayeux proposed to draw a trend-line from Crete westwards; I think we must retain the older view, which is also represented by Philippson.

great. There is a difference of opinion as to whether a secondary arc exists in Albania[1].

The encounter of the Burman and the Yarkand arcs might, as we have seen, be described as a normal linking with an eastern dominant, but the insertion of a foreign fragment (Assam) alters the case.

The arcs of Yarkand and Iran meet in the syntaxis on the Jhelam, which is still traceable on the north as far as the Pámir.

On the boundary between the Iranides and Taurides a syntaxis occurs between the secondary arc of the Alburs and extends through east and west Karabagh and the east side of the East Pontic arc, while in the south the Persian chains of Zagros enter into syntaxis with the Taurus somewhat to the east of the meridian of Diarbekr[2].

The Dinarides surround the Adriatic as far as Monte Gargano and Monte Conero, near Ancona, and, maintaining an uninterrupted strike, which turns, however, gradually towards the west, reach the southern side of the Alps. They not only retain this southwardly-directed folding of the marginal arcs, but are traversed by overthrusts as they make their concave bend towards the south-west[3].

The *volcanos* do not always stand in such obvious relationship with the mountain-structure as in the eastern periphery of Asia; and they lie further towards the interior. The Yarkand arc includes the basalt zone of the Stok, which, accompanied by Eocene, occurs to the south of the gneiss chain of Ladakh, and will be considered later.

A fragment of an arc formed of great volcanos surrounds the south side of the plain of the Helmund (Koh-i-Sultán and others). Somewhat further towards the south-west and towards the exterior rises Koh-i-Tafdán (4,111 meters), and from this point onwards the volcanos appear to be arranged between the coulisses in a common zone which strikes towards the north-west. In this zone we must include Koh Hazar (south of

[1] Cvijic describes a secondary syntaxis near Skutari, Sitzb. k. Akad. Wiss. Wien, 1901, CX, pp. 437–478, map. A divergent opinion is represented by F. Baron Nopsca, Zur Geologie von Nord-Albanien, Jahrb. k. k. geol. Reichsanst., 1905, LV, pp. 85–152, map, in particular p. 139. The observations of Vetters (Anzeig. k. Akad. Wiss. Wien, 21 Dec. 1905) show the complicated structure of this region.

[2] A tectonic sketch of Armenia published by F. Oswald marks a 'Tauric horst' to the south of lake Wan, running to the south-east. This represents the bend of a part of the Zagros chains, still unfortunately but little known; F. Oswald, Treatise on the Geology of Armenia, 8vo, Beeston (Notts), 1906, 516 pp., maps, in particular pp. 109 and 270. In addition for the west, the trend-lines in F. X. Schaffer, Cilicien, Peterm. Mitth., 1903, Erg.-Heft no. 141, pl. I. G. W. v. Zahn (Stellung Armeniens im Gebirgsbau von Vorderasien, publ. by the Inst. f. Meereskunde, 1906, Heft 10, 89 pp., maps) and Schaffer (Grundzüge des geologischen Baues vom Türkischen Armenien, Peterm. Mitth., 1907, pp. 145–153, map) have since published divergent views. Pending further observations I may refer to I, pp. 632–636, and III, pp. 402–405.

[3] Kossmat, Palaeozoische Schichten der Umgebung von Eisnern und Pölland, Verh. k. k. geol. Reichsanst., 1904, pp. 87–97 et passim.

Kirmán). The volcanos have been observed as far as the other side of lat. 35° N. In the vicinity of the syntaxis the same direction towards the north-west sets in, e.g. on lake Goktshai, but the number of the volcanos increases considerably; they extend into the south-westerly chains of the Taurides, and there seems to be no law as to their distribution. In the syntaxis itself rise the two parallel chains of Ararat (5,159 meters) and Tandurek-Aladagh.

On the secondary arc of the Alburs rises mount Demavend, affording the rare example of a crest volcano, and this is repeated in a striking manner in the adjacent branch of the Altaides, namely, the Caucasus (Kasbek and Elbruz).

It is only within the Taurides, on the border of the Lycaonian plain, that a fragment of an arcuate series is again seen (Erdshias-Dagh and others) [1].

Within the Dinarides a volcanic arc extends from Nisyros through Santorin.

Throughout the region of the marginal arcs, with the exception of the Dinarides, such continuous circumvallation occurs that closed drainage systems are produced. In the first arc there is the basin of the Yarkand, in the second that of the Helmund and the South Caspian, in the third the Lycaonian depression. The Dinaric enclosure is open to the sea.

As the result of these comparisons we see that the North Antilles (probably also the South Antilles), the Alaskides and all the island festoons as far as the Philippines, the Oceanides also, and in Asia the oppositely-curved Burman arc, present a similar structure, and that this structure, although less sharply defined, is also perceptible in the southern marginal arcs situated in great part on the mainland.

The constant occurrence of the arc of active volcanos within the zone of forefolding is a remarkable fact.

Analysis of certain transverse sections. The filling up of depressions, the universal action of denudation, and the advance of the mountains, all work together upon the continents to conceal the foredeeps, yet we perceive how commonly these features are indicated, either by a long outer zone of thick younger sediments, such as the Flysch, or a broad valley, such as that of the Ganges or the Guadalquivir, seated directly over the boundary between the foreland and the mountains. Frequently, however, the foredeep has left no signs of its existence, and we are unable to discover whether it has ever been present, or whether the mountains have stepped completely across its whole extent.

Although the Alpides occupy an exceptional position as representing

[1] A. Penther, Reise in das Gebiet des Erdschias-Dagh, Abh. geogr. Ges. Wien, 1905, VI, pp. 1–48, map.

posthumous folding within the frame, yet they are known in such detail that we may select them as our first example.

In front of the Alps lie two sedimentary zones of varying breadth which sometimes becomes considerable; these are the Flysch and the Mediterranean Molasse, beneath which, in the east, lie the thick upper Oligocene beds of Dobrotov.

Near *Boryslav* (IV, p. 207), where numerous borings for ozokerite, sometimes 1,000 meters deep, reveal the structure of the land, the outer border of the Flysch is thrust in repeated flakes over the Mediterranean salt formation and the Dobrotov beds. The two latter slope gently beneath

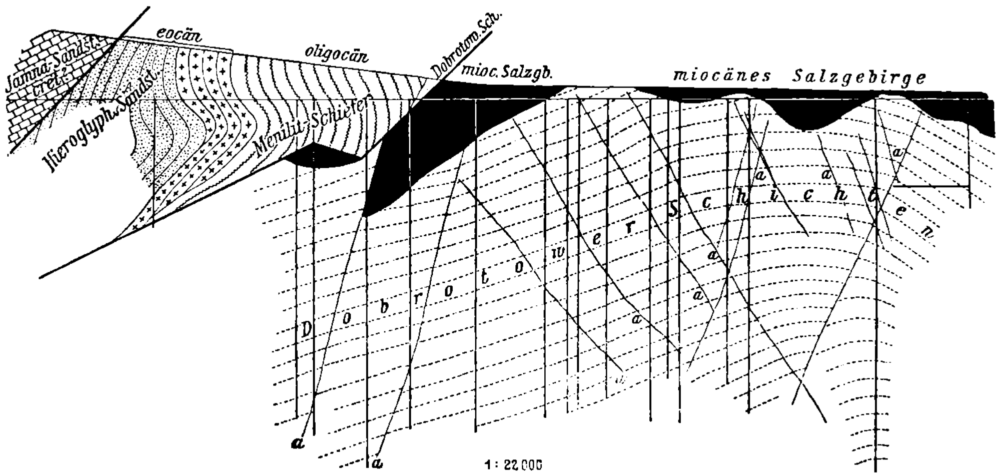


Fig. 37. *Deep borings at Boryslav* (after Grzybowski and Miacynski). *a, a*, fissures with ozokerite.

the Carpathians. At the same time the Dobrotov beds are arched up in an anticline, as a result of the general pressure which acted from the south.

This is perhaps the origin of the crushed anticlines further west in the salt formation of Bochnia and Wieliczka. Still further west, towards Ostrau and Weisskirchen, the Flysch (sub-Beskidian and Beskidian zone) rests on the Carboniferous of the Variscan foreland. Even still further south, where the Jurassic of Nikolsburg, superposed on the foreland, is exposed beneath the outermost border of the Flysch (autochthonous Klippen of Uhlig), the case may be similar. In Lower Austria the contrast between the Bohemian mass and the Alps becomes sharper; they are separated by a narrow but well-defined Mediterranean zone. Still further west lies that locality in Upper Austria, 17 kilometers from the visible border of the Bohemian mass, and 26 kilometers from the border of the Alps, where, as we have seen, the Bohemian gneiss has been revealed by boring beneath middle Tertiary sediments, 1,037 meters in thickness, without encountering any trace of Alpine formations. In Bavaria the border of the foreland, marked from Regensburg onwards by the Danube fault (flexure), departs from the Alps, and there the lower limit of the Bavarian molasse was not reached by boring at a depth of 600–700 meters.

From the Black Forest onwards other conditions set in. The Jura mountains, although stowed against the foreland, are attached to it. The Rhine trough forms a gap, and several arcs press into it, like waves into a bay.

This feature is represented in the accompanying illustrations: fig. 38, a preliminary diagrammatic sketch by Steinmann, and fig. 39, by von Huene.

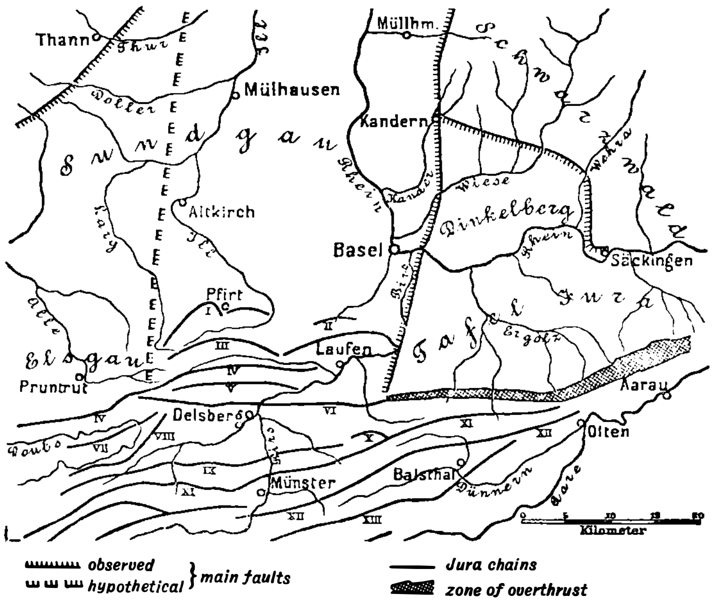


FIG. 38. *The Rhine valley near Bâle* (after Steinmann).
The chains are as follows:—I. Bürgerwald; II. Flühen; III. Blauenberg; IV. Blauberg; V. Movelier; VI. Mt. Terrible; VII. Clos du Doubs; VIII. Claquerelle; IX. Mout; X. Rothmatte; XI. Raimeux; XII. Hauenstein; XIII. Weissenstein; XIV. Chasseral; XV. St. Verena.

Near Kandern the Dinkelberg, which is continuous with the table-Jura, is thrown down by a fault. The Dinkelberg and the table-Jura represent the foreland. It disappears towards the south beneath the mount Terrible chain and the mighty overthrust which succeeds further towards the east. In the south-western part of the table-Jura a fractured area is formed by subsidence, in which we see the remains of one Jurassic arc to the south of Liesthal (*L*, fig. 39), and another to the north of it; as to the continuation of the latter into the Rhine trough nothing is known. The Bürgerwald and Flühen chains are the foremost of the arcs which enter the trough; they are followed by others. Near Liesthal it seems as though the subsidence had been renewed during the advance of the arc[1].

This close connexion with the foreland is maintained, and in the east of the Central Plateau, according to Michel Lévy, the mountains exert an effect upon the foreland.

The sharply-marked northern boundary of the Alps does not disappear. It follows the south border of the Molasse as far as the lake of Geneva, and if, at the time of the Molasse, a foredeep, or the commencement of a foredeep, were present here, it must have lain in the midst of the Helvetian region, between the Alps and the Jura, thus affording a remote resemblance to the Caiman deep of the West Indies.

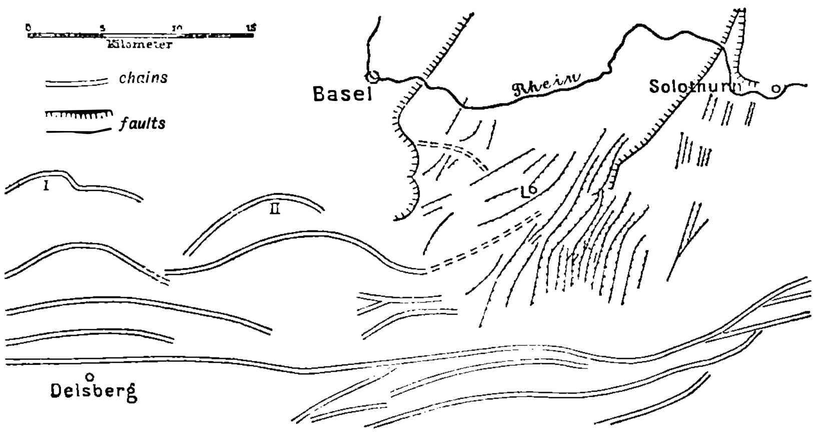


FIG. 39. *Fractured area in the Tafel-Jura* (after von Huene).
I. Bürgerwald chain; II. Flühen chain.

Further examples will be found in the preceding chapters. Cases are also known in which the foreland, having been overpowered, was carried up again to the surface within the folded mountains.

In the Caledonian zone of disturbance Nicol recognized, as early as 1844, that a series which rests on the western (foreland) gneiss dips again beneath the gneiss in the east; in 1860 he was able to state definitely that this eastern gneiss was carried up over this series by a dislocation, and Nicol thus became one of the first representatives of the more recent

[1] G. Steinmann, Beziehungen der oberrheinischen Tiefebene zu dem nordschweizer. Kettenjura, Ber. naturf. Ges. Freiburg i. B., 1892, VI, pp. 150–159; F. v. Huene, Geologische Beschreibung der Gegend von Liestal im Schweizer Jura, Verh. naturf. Ges. Basel, 1900, XII, pp. 293–372, map; also A. Tobler, Jura im Südosten der oberrheinischen Tiefebene, op. cit., 1898, XI, pp. 283–369, map; and A. Buxtorf, Vor- oder altmiocäne Verwerfungen im Basler Tafel-Jura, Eclogae Geol. Helv., 1900, VI, pp. 176, 177; E. Greppin, Hörnli bei Grenzach, Verh. naturf. Ges. Basel, 1905, XVIII.

tectonic views. Since then the continued labours of the Geological Survey of Great Britain, in particular the work of Peach and Horne, and the investigation of the ancient crystalline rocks by Teall, have given us a deeper insight into the structure of this region. The gneiss has in fact been carried from the east, in masses more than 1,500 feet thick, over the Cambrian and pre-Cambrian series, which rest in autochthonous superposition upon the gneiss of the foreland[1].

Similar processes may have led to the exposure of the Variscan basement in the gneiss masses of the mont Blanc zone.

For several decades past the notion that the Carpathians had advanced for great distances over an heterogeneous foreland was regarded with profound scepticism. But it soon appeared that the views prevailing with regard to the unilateral movement of the Alpine structure towards the north represented only a small fraction of the truth. What was manifest to the eye was declared to be physically impossible. Now throughout the long chain of the Alpides, from the window of the Paring to cape de la Nao at the end of the Betic cordillera, we are acquainted with overthrusts of entire mountain masses on the grandest scale, and the window of the Hohe Tatra is repeated, for example, in the Trois Seigneurs of the Pyrenees.

The question may be raised, whether the cause of these unexpected phenomena does not lie in the exceptional position of the mountains within the frame of the Altaides, and the restriction of all orogenetic activity to a limited interval in a meridional direction. This question can only be answered by the comparative method. To this end we will choose three types of different age, namely, the zone of Eriboll from the Caledonides, the coalfield of Belgium from the Variscan system (the comparison of which with younger mountains led M. Bertrand, many years ago, to most instructive conclusions), and, finally, parts of the Alps.

We have already seen what peculiar and powerful movements are produced by the constriction of currents of water (II, p. 343) or tongues of ice (II, p. 344, fig. 36, and p. 358, fig. 37). The stream dives downwards, with extraordinary power hollows out its bed into colks, carries heavy boulders upwards, and spreads them out, in an arc. The inland ice, as it

[1] B. N. Peach, J. Horne, Gunn, Clough, and Hinxman, Geological Structure of the North-west Highlands, with petrological chapters and notes by J. J. H. Teall, ed. by Sir A. Geikie, Mem. Geol. Surv. Gr. Britain, 8vo, 1907, 668 pp., map. Here again we find the interpretation of the facts gradually becoming clearer. The structure of the Caledonides in Scandinavia, overthrust on both sides, and the attempts made to explain it (III, p. 395), will not again be discussed here; the supposition that the covering segments, which in part resemble gneiss, belong to a Devonian transgression can scarcely be the solution. This view presupposes a mighty dynamic alteration, and consequently great tectonic processes after the time of the Devonian, an assumption which is supported by no other evidence. Cf. K. O. Björlykke, Centr. Norges Fjeldbygning, Norg. geol. Unders., 1905, no. 39, 610 pp., map.

comes down between the nunataks, flows with accelerated velocity, carries the ground moraine up from the bottom and spreads it out in an arc over the ice in front. The latter occupies the position of a foreland, and fig. 36 shows indeed, to the south of Nasausak, two arcs lying one behind the other.

Different as these cases may seem from those of mountain building, yet they illustrate the occurrence of important upward movements, and show their tendency to find expression at the surface in regular arcs.

In the Alps we can distinguish with the greatest clearness three horizons of movement. The first movements are the uppermost, and the most effective in bringing material within reach of denudation. The sheets rise from the depths on a *gently ascending sole-plane*, then frequently, but not invariably, climb over a rolling ridge or 'yoke' (Joch)[1], above which they form a dome (Lugeon's 'carapace'), and beyond the yoke they reach a *descending sole-plane*. As they move over this the force of gravity may lead to acceleration and tension, and thus give rise to the phenomenon which Reyer many years ago described as glide-folding. Beyond the descending sole-plane the sheet breaks up into simple or steeply-upreared flakes (Deckschollen), or it may happen that the movement of the sheet is retarded or arrested next the sole-plane while it continues its advance unchecked above, so that the upper layers of the sheet move on something like the scoriæ of a lava stream, which travel fastest on the surface, are carried down by rotation at the front, and form a pavement beneath the stream on its bed. Such a movement gives rise to the *rotated fold* (Drehfalte). Sometimes these ends of the sheets lie in *basins*, some of which may have been scooped out, while others are due to the weight resting on them.

The yoke may be a foreign body or an accumulation of earlier sheets. It must be distinguished from later arching up.

Still deeper lie the very extensive sole-planes upon which the most important movements take place, such as that of the Dinarides towards the Alps; of these we will only observe for the present that they do not seem in any way to owe their origin to folds.

(*a*) *The zone of Eriboll* (II, p. 82; III, p. 397). In this zone, as we have already seen, observations have been made on the great overthrusts by Nicol, Lapworth, Hicks, and Callaway, and the Geological Survey has issued such a masterly report by Peach and Horne and their colleagues that it may almost be said to make the mountains transparent[2]. The strike is to the north-north-east; the movement proceeds from the

[1] In the original 'ein sattelförmiges Joch'. 'Saddle-like' would be a misleading translation, as only one curve of the saddle is intended, that namely given by a section from side to side. 'Joch' is also used in a rather special sense: the English word 'yoke', once used to denote a chain of hills or a single hill (Troutbeck yoke), may serve as an equivalent. [Note by Editor.]

[2] Peach, Horne, and collaborators, in Geological Structure of the North-west Highlands, &c., Mem. Geol. Surv. Gr. Britain, in particular p. 463 et seq.

east-south-east; and from the same direction come the ascending sole-planes. Some of the planes of movement have been originated in overturned folds; other planes which form an imbricate structure have not been produced by folding, and their angle of inclination differs from that of the greater planes of transport (major thrusts). The latter vary a little in their strike and dip, the inclination as a rule being gentle. Each major thrust may be overridden by one following it. The rocks of the east may be carried along them, over all other disturbances, away to the foreland in the west. The gneiss of the east may even come to rest on the flat-lying Cambrian beds of the west. On the brow of advancing sheets friction at the base may produce a tendency to overfold the brow from above forwards, so that the upper part inserts itself in reversed order beneath the sheet itself, that is beneath the gneiss. Thus we have something resembling a recumbent fold, as on Ben More (fig. 40).

On the extreme western border overlapping folds occur, or imbricate structure, and also detached segments, bounded by a circular dislocation.

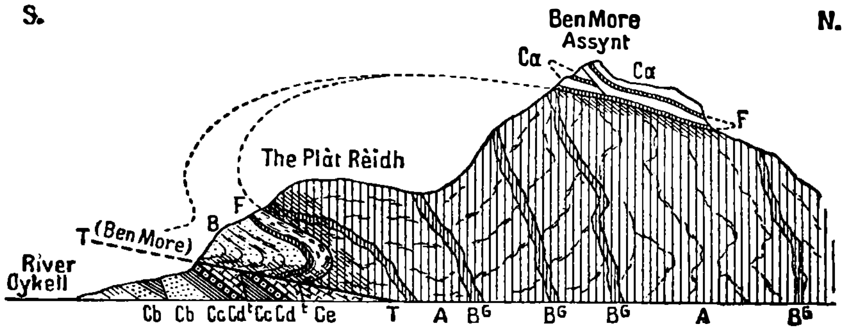


FIG. 40. *Rotated Fold of Ben More, Assynt* (after Peach and Horne).
A, Ancient Gneiss; B^G, Basalt dykes in the Gneiss; B, Torridon sandstone (Pre-Cambrian); C, Cambrian (Ca, basal Quartzite; Cb, Pipe rock; Cc, Fucoid beds; Cd, Serpulite grit; Ce, Limestone); F, Intrusive rock; T, Ben More thrust plane; t, t, minor thrusts.

These are the basins or pans; several pans may even occur (e. g. Loch Lamarscaig, op. cit., p. 593, fig. 66) one behind the other.

Finally, among many other interesting facts it may be noticed that in the north, west of Loch Eriboll, fragments of the foreland, along with fragments of the overthrust border, which rests upon them, are let down along great faults. Some of these are strike faults, others transverse (flaws, perhaps), and the horizontal displacement along one of the latter amounts to 8 kilometers. The trough-like subsidence is Durness Basin [1].

Thus in the zone of Eriboll there are several ascending sole-planes; they are the 'major thrusts' and are distinguished by special names such as, Moine thrust, Glencoul thrust, and others. The yoke is often indicated

[1] Op. cit., pp. 479, 487, figs. 21, 23.

in sections by a curved dotted line. Not much mention is made of descending sole-planes; typical basins, however, with recumbent flakes (Deckschollen) occur in the west.

(*b*) *The Belgian coalfield* (I, p. 141; II, p. 92). Here the Faille du Midi plays a part somewhat similar to that of the Moine thrust in Scotland; in fact the movements seem to be restricted even more closely to this surface. The Faille du Midi carries Silurian and Devonian from the south up an ascending sole on to the Coal-measures, and it is present on both sides of the syntaxis of Valenciennes.

In the west, near Lens (Pas de Calais) it ascends, according to Barrois, at an angle of less than 25°: the Coal-measures which lie beneath it are compressed into a basin inclined towards the south. A pinched-in fragment with reversed bedding is visible on the border of the Faille du Midi; Gosselet terms such fragments 'Lambeaux de poussée[1]'.

In the cusp of the syntaxis, according to Chapuy's description, the same Coal-measures pass, in spite of all disturbances, from the Variscan into the

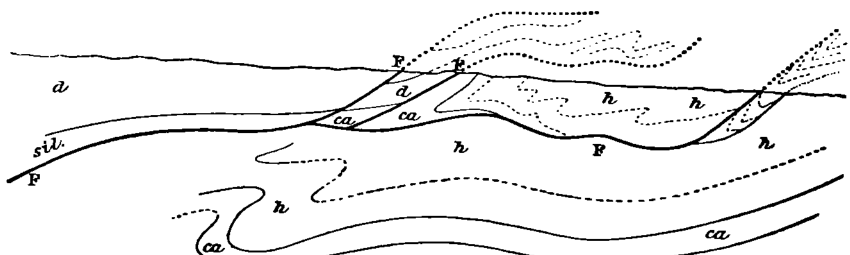


FIG. 41. *Structure of the coalfield near Denain and Anzin* (after Marcel Bertrand).
sil, Silurian; *d*, Devonian; *ca*, Carboniferous limestone; *h*, Coal measures; F, surface of dislocation.

Armorican region[2]. Here Marcel Bertrand drew the section upon which is based that comparison between the Provençal folds and the Alps which was destined to exercise so great an influence upon our conception of the Alpine structure. We will adopt for the present the terminology of his time.

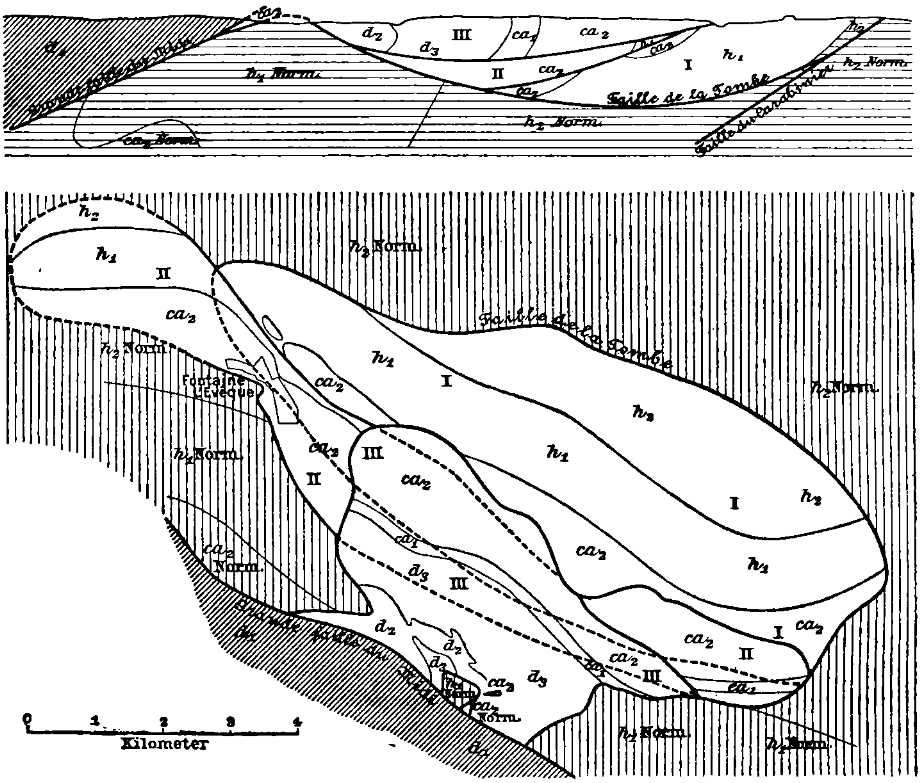
FF (fig. 41) is the Faille du Midi; *sil* and *d* resting upon it is the 'massif charrié'; all that lies in front of it is cut through here by a disturbance *F*, so that two parts are formed (lambeau de poussée and lame de charriage), and in front of them, outside the principal disturbance, there lies a narrow boundary zone (retroussé). All these parts rest upon the principal coal basin (*ca* and *h*); M. Bertrand conjectured that they had sunk down owing to their own weight[3]. Cornet and Briart had already

[1] C. Barrois, L'extension du Silurien supérieur dans le Pas-de-Calais, Ann. Soc. géol. du Nord, 1898, XVII, pp. 212–225; Gosselet, L'Ardenne, 4to, 1888, p. 735.

[2] Chapuy, Note sur la constitution du midi du bassin houiller de Valenciennes, Ann. des Mines, 1895, 9e sér., VIII, pp. 192–217, map.

[3] M. Bertrand, Sur le raccordement des bassins houillers du Nord de la France et du

attempted, in the year 1877, to explain these strange phenomena. They thought that great overfolding had occurred, then subsidence on the north side, and not till later the overthrust on the Faille du Midi (I, p. 142, fig. 17). Particular stress was laid on the reversed position of the beds in that fragment which Gosselet termed the lambeau de poussée. Gosselet himself declared that subsidence in the north was the cause of the great forefolding. Later, in the year 1894, Briart brought forward a new theory



FIGS. 42 and 43. *Recumbent flakes of Fontaine-l'Évêque* (after Briart).
d_1, d_2, d_3, Devonian ; ca_1, ca_2, Carboniferous limestone ; h_1, h_2, Coal-measures ; h_1 Norm., and h_2 Norm., Coal-measures below the recumbent flakes. The broken lines are hypothetical.

more closely approaching the ideas of Bertrand. The lambeau de poussée of Fontaine-l'Évêque, which is 11 kilometers in length and 3 kilometers in breadth, was believed to owe its origin to recumbent flakes lying one over the other [1]. In this section we are able to perceive with greater clearness

Sud de l'Angleterre, Ann. des Mines, 1893, 9e sér., III, pp. 5–83, maps; Études sur le bassin houiller du Nord et sur le Boulonnais, op. cit., 1894, 9e sér., V, pp. 569-640, maps ; le Bassin crétacé de Fuveau et le Bassin houiller du Nord, op. cit., 1898, 9e sér., XIV, pp. 5–85, maps.

[1] A. Briart, Géologie des environs de Fontaine-l'Évêque et de Landelies, Ann. Soc. géol. de Belge, 1894, XXI, pp. 35-69, map.

that the Faille de la Tombe, which lies immediately in front of the ascending sole (Faille du Midi), must be regarded as the pan.

According to this description the filling of the pan consists of the three wedge-shaped pieces I, II, and III. If these are regarded as forming a whole, they present a reversed bedding, extending from d_2 to h_2. It was this reversed order which attracted the attention of Cornet and Briart in 1877, and led them to assume the presence of a subsidence.

After a series of systematic studies, among which we must mention those of Dorlodot, Brien came to the conclusion that the series I + II + III, included in the Faille de la Tombe, does in fact form a single whole, and must be regarded as an overturned fold [1].

Thus we arrive at the conception held by Scotch investigators with regard to Ben More, namely, that of the rotated fold. The movement along an ascending sole has been arrested. The upper beds h_1 and h_2 of this thick sheet have continued the movement, and are folded over the northern margin of the sheet. The h in the basin is not a part of the subjacent h_1, marked normal, but has been transported a long way from the south and carried high up over the Faille du Midi.

The extensive investigations of Fourmarier to the east, between Liège and Verviers, have furnished the following rather unexpected result [2]:—

Coming from the south-east we encounter first the syncline of the Eifel, and then the broad anticline of the Ardennes, from the northern part of which projects the pre-Devonian mountain core of Stavelot (Hohe Venn). This is followed by the syncline of Dinant and its north-eastern continuation on the Vesdre, then by the coal basin of Herve, and the north-easterly continuation of the coal basin of Namur. The whole formation follows the general Variscan movement, which is here directed towards the north-west. The Faille du Midi is splintered up.

Near Theux, to the north-west of Spa, the singular *Massif de Theux* makes its appearance, pushing its way beneath the Cambrian and lower Devonian rocks of the overthrust northern border of Stavelot. It presents a series of beds ranging up into the Coal-measures h_2. It has been regarded as downthrown; according to Fourmarier, it is a window, not indeed of the adjacent basin of Dinant, but of the basin of Namur situated to the north. The southern basin (Dinant) has been carried forward for a distance of

[1] V. Brien, Description et interprétation de la coupe de calcaire carbonifère de la Sambre à Landelies, Ann. Soc. géol. Belge, 1904-1905, XXXII, Mém., pp. 239-259; Lohest (Observations au travail de M. V. Brien, etc., tom. cit., pp. 257-260) believes that the phenomenon is a great faulted fold; according to this view the Faille de la Tombe becomes the continuation of the Faille du Midi. This does not alter the fact that the contents of the pan were derived from above.

[2] P. Fourmarier, La structure du Massif de Theux, Ann. Soc. géol. Belge, 1906, XXXIII, Mém., pp. 111-138, maps; and La tectonique de l'Ardenne, op. cit., 1907, XXXIV, Mém., pp. 15-124, maps.

about 15 to 20 kilometers. The coal basin of Herve belongs to it, and rests as a recumbent flake on the northern basin (Namur). This northern basin (Namur) appears near Theux as a window beneath the southern basin (Dinant).

Proceeding from south to north, let us attempt to apply the expressions employed here to Fourmarier's conception.

The outrunners of the Faille du Midi which make their appearance in the mass of Stavelot represent the ascending sole. The dome over the yoke, now denuded away, lay high above the window of Theux, and once united, across Theux, the basin of Namur with the Coal-measures of Herve. In this way we have arrived at a new tectonic conception, *the window on the yoke*.

Let us now turn to the deeper-lying movements.

In 1894 it was shown by L. Cremer that the coalfield of Westphalia is cut through by oblique thrust-planes, dipping at a variable angle with an

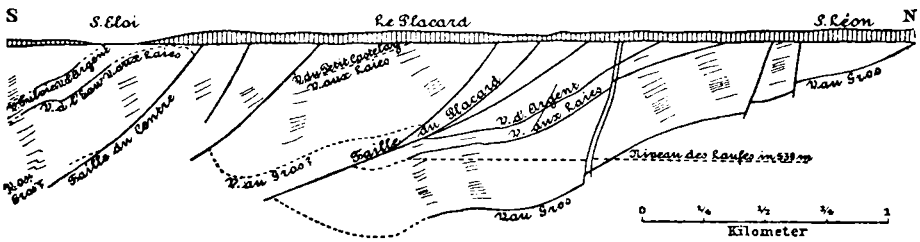


Fig. 44. *Section of the coalfield from Saint Éloi to Saint Léon* (after Briart, with the omission of numerous details).

average of 15°, along which parts of the same coal-seam may lie 700 meters, or in one case probably much more than 1,000 meters, distant from one another. Such thrust-planes may be followed along the strike for a distance of 28 kilometers. They *are folded with the Coal-measures*, and consequently older than the folding and not the result of it[1].

The breadth of the principal coal basin of Belgium (h_2 normal in figs. 42 and 43), measured at the outcrop in the Hennegau, varies from 8 to 15 kilometers. Fig. 44 presents a generalized section of part of this basin. Oblique planes, all inclined towards the south, and all slightly concave upwards, cut through the Coal-measures. Towards the south they lie flatter, towards the north steeper, and each one becomes steeper as it approaches the surface. This is the rule as far as the Pas de Calais. The Faille du Placard splits up, and each branch follows the same law[2],

[1] L. Cremer, Ueberschiebungen des westfälischen Steinkohlengebietes, Glückauf, Essen, 1894, nos. 62–65.

[2] A. Briart, Les Couches du Placard (Mariemont), Ann. Soc. géol. Belge, 1898, XXIV, pp. 237–255; cf. Harzé and Habets, Notes, op. cit., 1899, XXVI, Mém., p. 129.

Smeysters has published a varied series of these sections[1]. On these planes, almost without exception, the southern part is thrust up over the northern. Thus in the district of Boubier (Charleroi), for example, an anticline overfolded towards the north is cut through obliquely by the Faille du Carabinier, which ascends towards the north at an angle of 10°, and one of its moieties is carried upwards for at least 1,000 meters. On the Faille d'Ormont the ascent amounts to over 2,000 meters[2]. In the examples selected from Westphalia the folding was younger than the thrust-planes, but here it is older.

There is no doubt that the principal coal basin of Belgium, regarded as a whole, is a syncline overfolded towards the north, since it is bounded both on the north and south by the Carboniferous limestone, and on both sides it begins with the lower Coal-measures. In the south, however, it extends beneath the Faille du Midi; and if we imagine these concave planes of movement to be prolonged in the same direction, then the whole coal basin would be divided into a number of concave wedges, lying obliquely one upon another, which have been thrust upwards and northwards more or less against one another by independent movements. This movement of the wedges is due to their efforts to escape the tremendous pressure exerted from the direction of the Faille du Midi. This pressure still manifests itself in earthquakes. The earthquakes of February 23, 1828; of November, 1881; and of September 2, 1896, proceeded from the Faille du Midi, and Smeysters therefore describes them as 'séismes de chevauchement'; they recall the Kangra earthquake which proceeded from the planes of overthrusts in the Sewalik mountains.

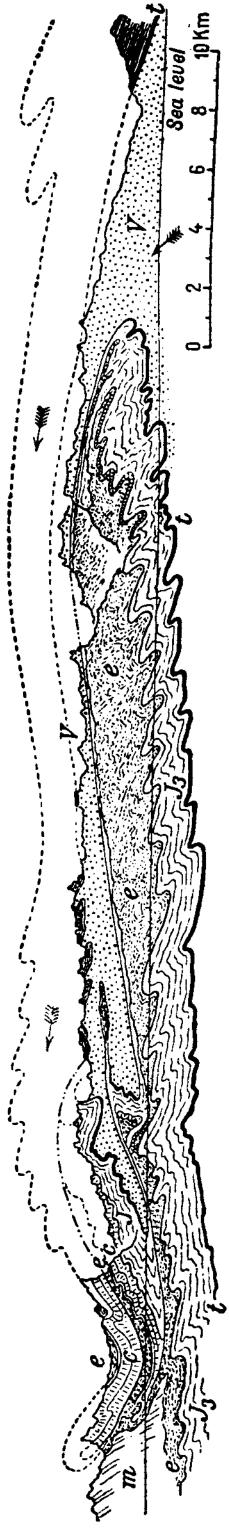


Fig. 45. *Recumbent Fold of Glarus* (after Albrecht Heim). *m*, Tertiary Nagelflue; *e*, Lower Tertiary Flysch; *c*, Cretaceous; *J*, Jurassic; *t*, Helvetian Trias (Röthi Dolomite); *V*, Verrucano.

[1] J. Smeysters, Étude sur la constitution de la partie orientale du Bassin houiller du Hainaud, Ann. Mines Belge, 1900, V, 127 pp., maps.

[2] J. Smeysters, Ann. Mines Belge, 1900, V, pp. 68 and 123, fig. 24.

Planes of movement, such as the Failles du Carabinier, du Placard, and the others shown on fig. 44, cannot therefore be described as faults; neither are they produced by folding; they are planes of a special character. We will term them *listric planes* (λίστρον, a shovel).

The Alps. The section of the Simplon (IV, p. 124; fig. 17) shows broad dotted arcs, convex above. Similar lines may be seen above the section of the fold of Glarus (fig. 45)[1] and above each of the general sections of the Swiss Alps, which have been published during recent years to illustrate the views of Schardt and Lugeon on the Alpine sheets. These lines are intended to show that there are ascending and descending soles; that broad yokes were once present high above the existing Alps, which have been destroyed, and that the whole of the Helvetian Alps

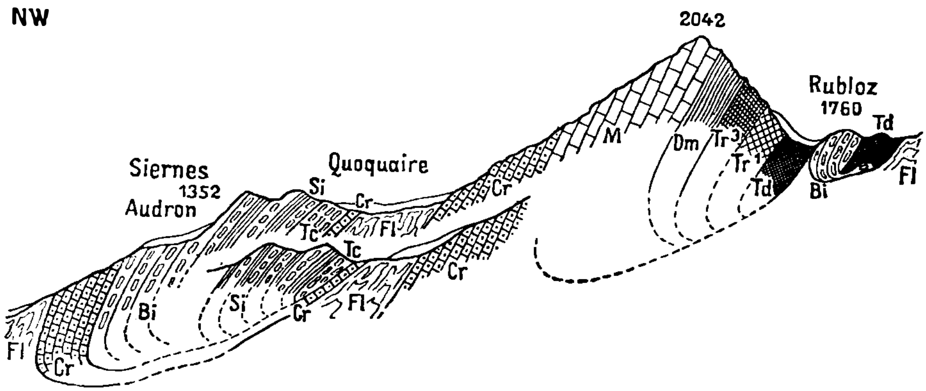


FIG. 46. *Section through a part of the pre-Alps of*
T, Trias (Tc, Rauchwacke; Td, limestone); Si, Lower shales and limestone; Bi, Lower
Cr, Cretaceous; Fln,

from the lake of Geneva to the Rhaeticon is surrounded by the remains of Lepontine domes. Thus this part of the Helvetian Alps becomes as it were a window with a Lepontine frame (IV, p. 154) or it may be described as a great window in the yoke.

The Dent Blanche is a fragment on an ascending sole: it is probably derived from the Dinaric border, and it presents Lepontine rock resting on Lepontine rock. The Lepontine recumbent flakes near the northern border of the Flysch reached their present position on a descending sole, crossing regions in which the great chains (Wildstrubel and others) were produced at a later period of folding.

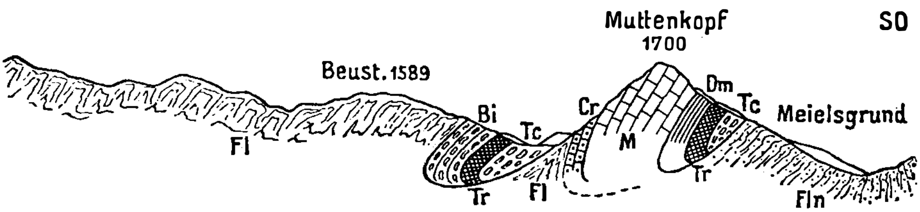
It is precisely in these cases, however, that the sole has least the appearance of a single sharp plane of dislocation; it seems much rather to be the

[1] Albrecht Heim, Bau der Schweizeralpen, Neujahrsblatt der naturf. Ges. für 1908, no. 110, 4to, Zürich, 26 pp.

sum of such planes lying between the extremely elongated middle limbs of dragged-out folds. This elongation must have taken place rather slowly in those cases where it has produced marmorization of the limestone beds, since solution and crystallization are improbable accompaniments of a catastrophe [1].

These facts, however, greatly modify the conclusions drawn from the transportation of recumbent flakes over long distances. It is thus difficult to resist the suggestion that a certain amount of persistent gliding has occurred over the northern descending sole, so that here the older conception of Reyer again comes to the front [2].

The zig-zag folds of mont Joly (IV, p. 117, fig. 16) show how horizontal anticlines and synclines are produced by constriction from above downwards.



Freiburg (Préalpes médianes), after Jaccard.
Breccia; Dm, Dogger or Lower Oolite, with Mytilus; M, Malm, or Middle and Upper Oolite; Niesen Flysch; Fl, Flysch.

It almost seems as though a mountain segment of much greater size had passed over these folds and had, so to speak, taken them with it. The ends of the plunging sheet or rotated folds are, however, more difficult to explain.

Jaccard's description of the Hornfluh may serve as an example [3].

[1] Arnold Heim states with regard to the upper Cretaceous limestone of the Säntis that when it is drawn out to twice its original length only the arragonite shells of the Foraminifera are calcitized. When the extension is fivefold, half of the whole mass is converted into calcite with a fibrous structure. Whether the extension ever rises to twentyfold cannot be tested in this manner because the process of calcitization would already have advanced too far (Arnold Heim in Albrecht Heim, Säntis-Gebirge, p. 471 et seq.).

[2] E. Reyer, Theoretische Geologie, 8vo, Stuttgart, 1888, p. 475 et seq.; Ueber Deformationen und die Gebirgsbildung, 8vo, Leipzig, 1892, p. 16 et seq.

[3] F. Jaccard, La région de la brèche de la Hornfluh, Bull. Lab. Géol. Lausanne, 1904, no. 5, 205 pp., map; and La région Rubli-Gummfluh, Bull. Soc. Vaud. Sci. Nat., 1907, XLIII, pp. 407–548, map; also de Girard et Schardt, Programme de l'excursion dans les

Here we stand between lake Thun and the lake of Geneva, to the south-west of Saanen. The basement is formed of Flysch and upper Cretaceous. The alien superposed series does not form true flakes but is represented chiefly by two lenticular masses, 8½ and 7 kilometers in length, the Gummfluh (2,461 meters), and the Rubli (2,288 meters) which form part of Lugeon's series of breccia sheets (IV, p. 152). Judged by their strike these masses are divided into 3, 4, or 5 strips, more or less separated by Flysch, *which represent so many rotated folds overtaking one another*. These rotated folds or ends of plunging sheets are sunk into the Flysch from south-east to north-west [3].

The complete rotated fold begins on the south side with the lower Trias, and this is followed by the whole of the Mesozoic series as far as the upper Jurassic, which rises high in steep rocks. This series surrounds in an arc the oldest core of lower Trias. The structure is the same as that of Ben More and Fontaine-l'Évêque, but here, as we have seen, it is repeated five times in succession. In each case, the whole series must have bent downwards as far as it could go, the sheet must then have moved forwards, and another rotated fold must have separated off as the upper part acquired a higher velocity. This process is only conceivable if we consider the nature of the Flysch. It would seem that the Flysch was not capable, by itself, of supporting the sheet and this in its forward movement always found a basis of attachment in the preceding rotated fold which had already sunk itself to the lowest limit. This is the reason why the descending lobes follow each other in such close succession; indeed it may even happen that one is almost embedded in that preceding it.

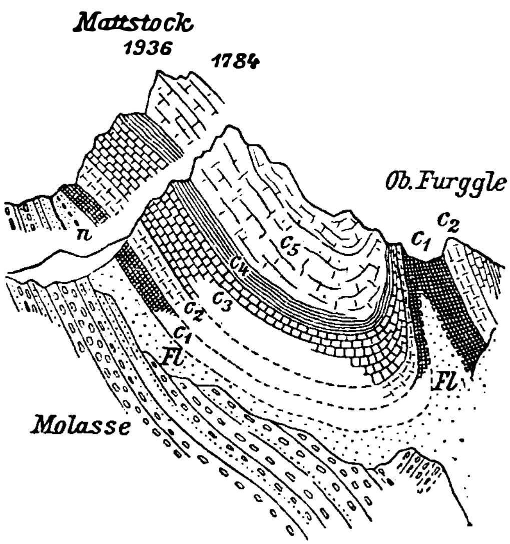


FIG. 47. *The Mattstock between Thun and the Walensee* (after Arnold Heim).
$c_1 + c_2$, Valengian; c_3, Siliceous limestone; c_4, Drusberg bed; c_5, Schrattenkalk; Fl, Flysch; *n*, Nummulitic beds.

Alpes de la Gruyère et du Pays d'En-haut vaudois, Eclogae Geol. Helv., 1908, X, pp. 165–195 et passim.

[1] 'Têtes de pli-faille, plantées dans le flysch' . . . Jaccard, Rubli-Gummfluh, p. 455 et passim. A beautiful example is given by Lugeon south of the lake of Geneva on the Drance near St. Jean d'Aulph (Grandes Nappes de Recouvrement, Bull. Soc. géol. France, 1902, 4e sér., I, pl. XII, fig. 2).

In addition, lobes of Cretaceous occur which, according to Jaccard's statement, do not belong to the series of rotated folds, but more or less envelop them and plunge down with them into the Flysch.

In the east, north of the Walensee, a thick conglomerate, the Nagelfluh of the Molasse, lies opposite the advancing border of the Alps. It dips towards the south. Arnold Heim and E. Blumer have made us familiar with the mode of contact[1]. The rigid Nagelfluh is interrupted along the zone of contact by hollows possibly due to erosion. Into these the Flysch has been driven like a plastic mass, and the great advancing sheet of Cretaceous limestone rears itself up, creeps upwards over the Flysch, assumes a vertical position, and finally turns over backwards. Arnold Heim has termed this a turnover klippe. It is the reverse of a rotated fold; in the Mattstock the movement takes place from below upwards, and the oldest member of the series lies towards the exterior (syncline, fig. 47); in the rotated fold the movement is directed from above downwards, and the youngest member, outstripping the others, lies on the exterior (fig. 46, anticline).

It is precisely these ends of the sheets which have directed attention anew to the diminution of the earth's circumference, which they indicate. In the case of the individual sheet, the end of which may lie 80 kilometers or more away from the root, two circumstances must be taken into account: first, the supposed gliding on the descending sole; this is, strictly speaking, a secondary phenomenon, but may have had some effect in determining the distance traversed; secondly, the stretching of the rocks, which may be left out of account in estimating the length of the path, but is of some importance when considered in connexion with the correlated reduction in the length of the earth's circumference. It may diminish this reduction to the extent of a fifth, or tenth, or even some smaller fraction.

It is the number of sheets lying one upon another, as seen in the Swiss alps, which most impresses us with the magnitude of the phenomenon; it is impossible, however, to arrive at a numerical estimate.

But even in these outer envelopes of the Alps the influence of the load due to overlying rocks is already unmistakable. The greater this is, the more the contrast in the nature of the rocks disappears, and the conception of a general flow comes to the front. For this reason, Sollas, when he employed in his experiments a 'glacier of pitch', instead of alternating layers of rigid and plastic material, came a step nearer to nature and was even able to produce genuine 'recumbent folds', that is, rotated folds[2].

[1] Arnold Heim, Brandung der Alpen am Nagelfluh-Gebirge, Vierteljahrschr. naturf. Ges. Zürich, 1906, LI, pp. 441–472, map; E. Blumer, tom. cit., pp. 473–480.

[2] W. J. Sollas, Recumbent folds produced as a Result of Flow, Quart. Journ. Geol. Soc., 1906, LXII, pp. 716–721. Here we may refer to B. Willis's beautiful figure in Ann. Rep. U. S. Geol. Surv., XIII, 2 pl., XCVI, B.

In spite of all this we are left with the impression that the advance of the Lepontine sheets far over the Helvetian formations was only an episode, and the subsequent up-folding which produced the great Helvetian chains was a process quite independent of it. This later process altered the Lepontine sole, and the great lower-lying planes of movement are easier to trace in the east.

In the *East Alps*, notwithstanding the numerous questions which still remain open, we see clearly the advance of the Dinarides towards the north over the East Alpine sheet, then of the East Alpine over the Lepontine sheet, and of the Lepontine over the Helvetian sheet. Nowhere are recumbent folds or other details of this kind so far known. In general, however, the following comparison may be permitted.

As soon as the older Helvetian formations (although subsequently up-folded again) gave the first impulse, in a part of Switzerland, to the formation of the yoke which the Lepontine sheets were forced to ascend, an extensive Lepontine range, the Tauern, became the yoke which the east Alpine sheet has ascended. The window, from which the Lepontine sheets look out, has been formed, not only by erosion, but possibly also by rending of the sheet. It is a window on a yoke, like the little Massif de Theux in Belgium, and like a part of the Helvetian Alps within the girdle of Lepontine remnants.

The anticline folded on the core of the Tauern, which was so long regarded as a proof of the symmetrical structure of the Alps, now forms with its southern limb the ascending sole, and with its northern limb the descending sole of the east Alpine sheet. It is not impossible that the Eastern Alps, like the Bernese Alps, were subsequently up-folded. The limestone zone, with its concave sole, holds the position of a recumbent flake in a basin.

Concerning the sole-planes of these great movements we can as yet say little, except that there is nothing to show they originated in folding; that, like the major thrusts of Caledonia and the listric surfaces of Belgium, they probably ascend obliquely at a gentle angle, and indeed that they were already in existence as gently ascending planes before the folding. This supposition seems at least to correspond with the fact that the East Alpine sole, below the Selvretta and the Oetz, bears upon its surface great crystalline masses, and that these disappear towards the north from above the sole, so that on the boundary of Flysch the sheet does not extend downwards beneath the Trias.

An instructive study is afforded by the *Carpathians*.

Marcel Bertrand has repeatedly drawn attention to the fact—and especially in a lecture delivered in 1894 at Zürich—that certain sedimentary facies are repeated in the great ranges. As examples, he mentions: the sediments which have been transformed into gneiss, the Carboniferous, the

Cretaceous and Eocene Flysch, and finally the molasse. These are said to have collected in depressions, and then to have been involved in the formation of the mountains. The Carboniferous of the West Alps is termed 'un Flysch houiller'[1].

At the time when these views were expressed they were merely conjectures, but the conjectures of a master mind. They were understood by few. It is now known that a girdle of Coal-measures accompanies the whole outer border of the western Altaides, wherever this border is visible from Silesia to the other side of the Mississippi, and that near Paruschowitz in Silesia its lower limit was not reached by boring at a depth of 2,003 meters. In like manner the Flysch is known on the outer border of a number of mountain chains.

The structure of the Belgian Carboniferous would be unknown were it not for mining operations; that of the Flysch may be recognized wherever rocks of some resistance are intercalated with it.

The extremely regular arc of klippen which surrounds the Hohe Tatra indicates an extensive movement towards the north, which can only have been directed obliquely from below upwards. When Lugeon wrote his famous treatise on the Carpathians he had no doubt that the klippen had emerged in an arc from below, out of the Flysch. Uhlig, while supporting Lugeon, has taken an even

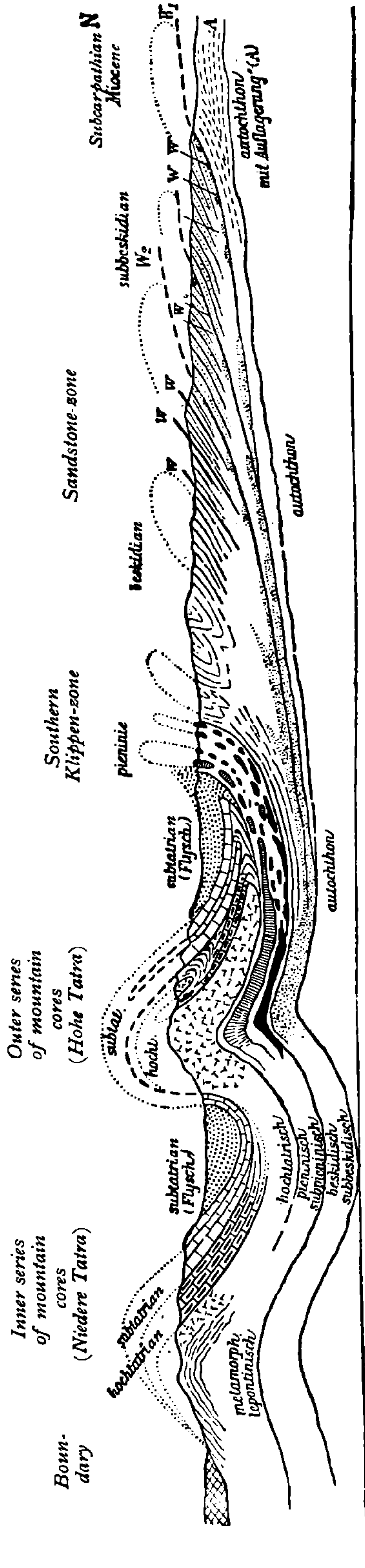


FIG. 48. *Diagrammatic section of the Hohe Tatra* (after V. Uhlig). W_1, Overthrust of the Sub-Beskidian sheet on to the autochthonous Salt-clay; W_2, Overthrust of the Beskidian sheet; *W*, *W*, Minor Overthrusts. The dotted lines over W_1, and at the ends of *W*, *W*, indicate dragged-on Mesozoic masses.

[1] M. Bertrand, Structure des Alpes françaises et récurrence de certaines facies sédimentaires, C. R. VI. Congr. géol. intern. Zürich, 1894, pp. 163–177.

broader view of the facts. He believes that the 'surging frontal region' of the Pienine klippen emerges along oblique planes from beneath the Hohe Tatra (fig. 48, *W*, *W*).

These planes of movement W, W are listric surfaces. They correspond to the Faille du Carabinier and other faults in Belgium. They first ascend gently, and then become steeper; they bound a number of wedge-shaped bodies which may be thrust northwards one against the other, and it is very probable that the arc of klippen was brought to the surface upon these listric planes.

With this our series of comparisons comes to an end. The structure of the Alps may be recognized not only in its main features, but also in many of its details, in the zone of Eriboll and in the Belgian coal-field. The Flysch and the Coal-measures were laid down under very different circumstances, but in tectonic processes they play similar parts.

This analysis leads for the present only to the conclusion that the tangential force acting in one direction expresses itself mainly in two independent forms, namely as folding and as the movement of isolated fragments, or even of great masses over surfaces ascending obliquely from below. The listric planes lie in compressed synclines and are a part of them. Their concave form is possibly only a consequence of the fact that their forepart has been less heavily weighted. The sole planes of the major thrusts—the Faille du Midi, the Alpine sheets, and the Dinarides—belong to another order of things. All these planes are distinct, both in their origin and nature from the *disjunctive* planes.

CHAPTER XV

THE DEPTHS

Classification of the depths. Emission of gas, batholites, ores. Intrusion by melting through. Passive lateral injection. Green stones.

Classification of the depths. In the following discussion of the depths of the earth we will take for our starting-point the parallel drawn by Daubrée between the total mass of the meteorites preserved in collections, and the total mass of the earth. According to this parallel the assumption that all meteorites were once arranged according to their density as parts of a common mass lead us to the conception of a body constituted like the earth. A core of nickel-iron (e. g. the meteorite of Agram or Elbogen) would be followed by an envelope of nickel-iron with peridote (e. g. Rittersgrün), and this would probably form the transition to a less ferruginous envelope of magnesium silicates (Chassigny). Then the felspar-bearing rocks would begin (eucrite; Juvinas, Stannern). But the resemblance does not end here. The acid felspar rocks of the earth are represented among the meteorites, so far as their chemical composition is concerned, by the once completely molten tektites (Moldavite, Australite, Billitonite). The lightest carbon-bearing meteorites might be regarded as tuffs.

Thus Daubrée's parallel leads us so far, that we may now venture to take a step further. When we consider the recurrence of definite petrographical types in the several cases, the discovery of small celestial bodies outside the orbit of Jupiter, and inside the orbit of Mars, and the probability that certain planetoids are angular fragments, we are led to regard the meteorites as planetary fragments, possibly parts of an anonymous body once occupying the gap between Mars and Jupiter [1].

[1] Einzelheiten in der Beschaffenheit einiger Himmelskörper, Sitzb. k. Akad. Wiss. Wien, 1907, CXVI, sect. 1, pp. 1555–1561. As is well known, the theory of the cosmic origin of meteorites is based on the great rapidity with which they enter the atmosphere, but the observation of this fact is attended by so many difficulties that the most distinguished astronomers have obtained for some cases a hyperbolic and for others an elliptical path. The fact that the hundreds of known meteorites may be divided into a small number of groups (three to five or six), indeed that a petrographical classification is possible at all, is a decisive argument against cosmic origin. Soon after the appearance of this work G. Tschermak published an extremely comprehensive study, according to which meteorites of a similar nature reach the earth at intervals of a year, or with a regular

Further, we assume the existence of three zones or envelopes as determining the structure of the earth, namely, the barysphere or the Nife (Ni-Fe), Sima (Si-Mg), and Sal (Si-Al). This division differs from the classification which has been proposed by distinguished American petrographers, in the separation of the metallic barysphere (Nife).

Wiechert arrives, on mathematical grounds, at the existence of a rocky mantle, 1,400 kilometers in thickness, with a density of 3·0 to 3·4, and within this of a nucleus of iron 5,000 kilometers in radius, with a density of 7·8; he finds confirmation of this in seismic observations, from which he infers the existence of a comparatively sharp boundary at a depth of about 1,500 kilometers. Oldham also conjectures from seismic observations that a boundary exists at a depth equal to about one-fourth of the radius (1,594 kilometers), and this corresponds in a striking manner with Wiechert's calculations; but this limit only holds as regards the propagation of earthquakes beneath the Pacific Ocean and not beneath the Eurasiatic Continent [1].

Let us return for the present to the other method of comparison.

In meteoric irons the heavy metals are also met with. Davison, for instance, has found platinum and iridium, and Liversidge gold [2]. On the earth these metals occur where we should be most inclined to suspect an autochthonous origin, in the Sima, and particularly, as among the meteoric irons, in association with nickel, chromium, and iron. In the nickel ores of Sudbury (Canada), which we shall discuss directly in greater detail, it pays to separate the platinum from the nickel. It makes its appearance in this locality as sperrylite (Pt As_2). Vogt records gold and platinum from Scandinavian nickel ores. The platinum grains of Nishni-Tagilsk occur in chromite (or limonite), according to Inostranzeff. The richest finds of platinum in North America occur on the river Similkameen (British Columbia), in a Sima chromite-bearing region. Kemp states that sometimes chromite and sometimes platinum was excreted first. Beck mentions cases in which platinum and osmiridium did not separate out till after the consolidation of chromite and pyroxene [3].

displacement of the annual date of falling (e. g. six falls of eucrites with a regular advance of the node). This does not close the question of the cosmic origin, but opens up a new and important path of inquiry; Tschermak, Ueber das Eintreffen gleichartiger Meteore, tom. cit., Abth. II a, pp. 1407–1441.

[1] E. Wiechert, Massenvertheilung im Innern der Erde, Nachr. Ges. Wiss. Göttingen, 1897, pp. 221–243; Was wissen wir von der Erde unter uns? Deutsche Rundschau, 1907, pp. 376–394; R. D. Oldham, Origin of Oceans, II, Quart. Journ. Geol. Soc., 1907, pp. 344–350, in particular p. 347.

[2] Liversidge, Proc. Roy. Soc. N.S.W., 1902, p. xxix; such occurrences have long been conjectured *a priori*, E. Suess, Die Zukunft des Goldes, 8vo, Wien, 1877, p. 354.

[3] A. Inostranzeff, Gestalt des Platins in seinem Muttergestein am Ural, Trudi d. naturhist. Ges. St. Petersburg, geol. und min. Abth., 1906, XXIII, pp. 1–7; and C. R. Acad. Sci. Paris, 1894, CXVIII, p. 264; Vogt, Platingehalt in norwegischem Nickelerz, Zeitschr.

In addition, we have the occurrence of the metallic nickel-iron (awaruite) under similar conditions; this has been mentioned above when describing the Klamath mountains. Awaruite was discovered by Skey to the north of Big Bay (Awarui) in South New Zealand, and is known in gold placers at Lilloet on the Fraser river (British Columbia), at several localities in the gold and osmiridium-bearing serpentine of Oregon, on the Smith river, Del Norte City, California, and finally, in upper Italy on the river Elvo, near Biella, where it occurs in gold-bearing sand, which appears to be derived from the moraine of the Aosta valley [1].

Rocks of abyssal origin, or at least presenting the characters which we should imagine abyssal rocks would possess, are thus not infrequently seen on the earth's surface. This explains the peculiar interest attached to tectonic studies of the so-called green rocks. The most frequent form in which they occur is serpentine with chromite, more or less nickeliferous, and more seldom with nickel ore. Since chromium is the element which possesses the widest distribution we term this typical form Crofesima; Nicrofesima would be more correct, and, in some cases, Nifesima.

There are certain circumstances which seem to indicate that the Sal envelope is of no very great thickness.

From the studies of J. H. L. Vogt it appears that the series of nickeliferous magnetic pyrites (Nifesima) of Norway is different in the zone of norite contact from the metallic series in the zone of Sal contact. Further, the observations of Sir Norman Lockyer lead us to conclude that the Nifesima series is formed of the same materials as those which appear in the spectrum of α Cygni and the sun (with the exception of platinum). The typical metals of the Sal series, on the other hand, do not appear (with the exception possibly of yttrium and lithium) in α Cygni; several of them are certainly represented in the Fraunhofer spectrum of the sun, but they do not occupy a prominent position [2]. From this we may infer that if the earth is of a similar nature to the sun and the star α Cygni, and if these were all dissolved in one great ball of fire, then on this ball also the Sal metals would occupy a less prominent position than those of the Sima series.

prakt. Geol., 1902, pp. 258–260; D. Day, Ann. Rep. U.S. Geol. Surv., 1898, XIX, 6, p. 268; J. F. Kemp, Geological Relations and Distribution of Platinum and associated Metals, Bull. U.S. Geol. Surv., 1902, no. 193, 95 pp.; R. Beck, Nickelerzlagerstätte von Sohland, Zeitschr. deutsch. geol. Ges., 1903, pp. 296–331; and Struktur des uralischen Platins, Ber. Ges. Wiss. Leipzig, 1907, LIX, pp. 387–396.

[1] G. H. F. Ulrich, Discovery, Mode of Occurrence and Distribution of the Nickel-Iron Alloy Awaruite, Quart. Journ. Geol. Soc., 1890, XLVI, pp. 619–632, map; Jamieson (IV, p. 421, note 1), Am. Journ. Sci., 1905, 4th ser., XIX, pp. 319 and 413–415; Q. Sella, C. R. Acad. Sci. Paris, 1891, CXII, p. 171.

[2] J. H. L. Vogt, Zeitschr. prakt. Geol., 1894, p. 887; 1900, p. 233; 1901, pp. 10, 180, 289; N. Lockyer, Publication of the Solar Physics Committee, 1907, Spectroscopic Comparison of Metals present in certain Terrestrial and Celestial Light Sources, p. ix; also Sitzb. k. Akad. Wiss. Wien, 1907, CXVI, pp. 1555–1561.

That the Sal envelope, the most accessible to observation, does not form a very important part of the mass of the planet is also evident from its trifling density (about 2·7) when compared with the density of the earth as a whole (5·5 or 5·6).

We therefore infer that even if the existence of a comparatively sharp boundary at a depth of 1,500 kilometers should be confirmed, yet it cannot represent the limit between Sal and Sima, but only between Sima and Nife, that is, it is the upper limit of the barysphere. If we compare a series of those meteorites which consist both of Sima (peridote) and Nife, we may justly be astonished, not only at the sharp delimitation between these constituents, but at the contrast in their densities. In the mass of Tula the density of Nife is 7·33, that of the accompanying Sima (possibly not quite free from iron?) 4·15; in the mass of Krasnoiarsk the respective densities of the two zones are 7·16–7·86 and 3·43, in that of Rittersgrün 7·5 and 3.23, and so on [1].

Such great differences might well favour the formation of a comparatively sharp differentiation limit. Wiechert's calculations led him to place the limit of the rocky crust of the earth at a depth of 1,500 kilometers, with a density of 3·0 to 3·4 as against the iron nucleus with a density of 7·8. The correspondence in the densities is obvious.

The Sal envelope is chiefly formed of gneiss, or rather of that series of various altered sediments and batholites which are included under this term, and range from the hornblende gneiss of the Sima in the Baikal vertex to the so-called normal gneiss of Freiberg with a percentage of 65 to 66 SiO_2, and the red gneiss of the Erzgebirge with 76 SiO_2. Here an analogy with the other heavenly bodies is only presented by the tektites.

The stratosphere, or younger sedimentary envelope has been formed almost entirely at the expense of the Sal envelope, and to use Bischof's and Walther's happy expression, by the method, or more correctly by the methods, of selection [2]. These indeed are of many kinds, from the weathering of orthoclase, to the sweep of the storm across the sandy desert, and the quiet work of living organisms. The greater part, as much as 99·06 per cent., of the outer part of the earth is formed, according to F. W. Clarke, of only eight elements. These are: O, Si, Al, Fe, Ca, Mg, Na, and K [3]. In the

[1] Such inclusions of olivine scarcely contain any nickel, whereas nickel is very widely distributed in terrestrial olivines. Daubrée points out that Ni has less affinity for O than Fe, and ascribes the fact to this circumstance; on this point see also Farrington, Am. Journ. Geol., 1901, X, p. 397.

[2] J. Walther, Ueber die Auslese in der Erdgeschichte, 8vo, Jena, 1895, 36 pp.

[3] F. W. Clarke, The relative Abundance of the chemical Elements, Bull. U.S. Geol. Surv., 1891, no. 78, pp. 34–42, and op. cit., 1897, no. 148, pp. 9–14; J. H. L. Vogt, Ueber die relative Verbreitung der Elemente, Zeitschr. prakt. Geol., 1898, p. 225 et seq.; also L. de Launay, La distribution des éléments chimiques dans l'écorce terrestre, Rev. gén. des Sciences, Paris, 30 avril 1904, pp. 386–404.

work of living creatures two of the chief of these elements, Al and Mg are neglected, Ca is preferred, and in addition the scarcely soluble Si. Bacteria perform their work of selection to a certain extent outside the range of these eight elements, since they cover the bottom of the Black Sea with iron pyrites; nodules of manganese are secreted by algae, and so on.

We thus arrive at the following hypothetical conception of the interior of the planet. A nucleus of Nife and heavy metals extends from the centre outwards for three quarters of the radius; then follow, at a depth of about 1,500 kilometers below the surface, separated by a fairly sharp boundary, Crofesima and Nifesima, and all the other rocks of Sima up to Sal. Further observations may lead us later to infer the existence of a more detailed subdivision. The stratosphere, although in places interrupted and covered by Sima masses, may be assigned as a whole to Sal.

Some idea of the nature of the upper parts of the planet may be obtained from Coleman's description of the richest known deposit of nickel at Sudbury in Canada [1].

Here a series of rocks about 2,000 meters in thickness rests upon gneiss, granite, quartzite, and other rocks, and is covered by thick Cambrian or pre-Cambrian sediments. It forms a basin 58 kilometers in length and 26·5 kilometers in breadth. Its upper part consists of granitic rock with an average of 66·87 SiO_2; as the proportion of Si, Na, and K decreases, and of Ca and Mg increases, this gradually passes into rocks which are described by the several observers as granodiorite, quartz-diorite, or micropegmatitic syenite. The terminal member is a grey norite with 54·61 SiO_2.

At its base, and without a sharp upper limit, the nickel ores rest upon and within the inequalities of the foundation; they are followed by a girdle of mines surrounding the base of the great basin. Beside iron, nickel, and copper, cobalt occurs, then, in order of richness, silver and platinum, a small quantity of native gold, iridium, and osmium, and traces of rhodium and palladium.

Thus within the trifling depth of 2,000 meters we have passed from Sal granite to a Nife zone with heavy metals. These observations coincide with those made by Vogt in the Norwegian nickel mines. The differentiation has occurred in these cases chiefly under the influence of gravity, as is shown by the relation of the ores to the foundation, and for the present we may bear in mind that Na and K decrease before Ca and Mg.

The nickel-bearing rocks at Sudbury must have formed a molten

[1] A. P. Coleman, The Sudbury Nickel Field, Rep. Bureau Mines, Toronto, 1905, XIV, 3, 188 pp., map; The Sudbury Laccolitic Sheet, Am. Journ. Geol., 1907, XV, pp. 759–782, map; also A. E. Barlow, Origin, geological Relation and Composition of the Nickel and Copper Deposits of the Sudbury Mining District, Rep. Geol. Surv. Canada, 1904, XIV, 236 pp., maps, and op. cit., XV, A, pp. 254–269.

mixture when they were carried upwards into their present position, otherwise it would have been impossible for them to suffer the same kind of differentiation for a second or possibly even a third time.

The product, however, coincides very nearly with that which we have pictured, from other considerations, as the result of the primary differentiation accompanying the original formation of the earth's body. The re-melt, indeed, seems to provide us with an experiment.

Emission of gas. That steam is the driving force of volcanic eruptions has long been known, but it was not known from what source the steam was derived. Appeal was made to the proximity of the sea. Daubrée believed that he was able to show by an experiment that infiltrating water might succeed in reaching even the heated abysses of the earth. Poulett Scrope objected, that apart from all other difficulties, this experiment only shows that water may find its way to the surface of subterranean lava, but does not explain the intimate admixture which is known to exist. Bischof inquired how the escape of carbonic acid gas could be explained by such infiltration. Thus very serious doubts were entertained on this question [1].

The explanation lies in another direction.

Just as molten iron absorbs extremely large quantities of gas, and gives them out again as it cools, so the globe of the earth once absorbed extremely large quantities of gas, which it is now still continuing to emit.

The recognition of this fact led to the distinction of two kinds of waters. The *vadose* waters—a name originally chosen by Pošepny for the waters which infiltrate from the surface and escape from mineral lodes—include all the waters of the earth's surface, such as oceans, rivers, clouds, atmospheric precipitations, and artesian springs. *Juvenile* waters, on the other hand, are those which arise when the hydrogen issuing from the earth's interior, under very high pressure and at a very high temperature, combines with the oxygen of the atmosphere. The white balls of steam emitted by the volcano become clouds, and a juvenile rain pours down its slopes. The juvenile hot springs bring up unexpected mineral matters from the depths [2].

[1] Complete list of the older literature in E. Reyer, Beiträge zur Physik der Eruptionen, 8vo, Wien, 1877; this subject is discussed in detail by G. Tschermak, Ueber den Vulcanismus als kosmische Erscheinung, Sitzb. k. Akad. Wiss. Wien, 1877, LXXV, pp. 151–176; A. C. Lane, Geological activity of the Earth's originally absorbed Gases, Bull. Am. Geol. Soc., 1894, V, pp. 259–280. Van Hise says: 'In regional extrusions it . . . appears highly probable that the occluded water has been held by the magma from the first'; Trans. Wisconsin Acad. Sci., 1898, XI, p. 498, note; further, C. Doelter, Physik des Vulcanismus, Sitzb. k. Akad. Wiss. Wien, 1903, CXII, pp. 681–705, in particular p. 703. N. S. Shaler thought that the explanation lay in the water contained in deep-lying sediments; Conditions and effects of the expulsion of gases from the earth, Proc. Boston Soc. Nat. Hist., 1897, XXVII, pp. 89–106.

[2] E. Suess, Ueber heisse Quellen, Verh. Ges. deutsch. Naturf. und Aerzte, Karlsbad, 1902, Allg. Theil, 20 pp., Leipzig, 1902.

Just as there is juvenile hydrogen, so there is juvenile chlorine, fluorine, sulphur, arsenic, carbon, and a series of other elements, all emitted by volcanos. In fumaroles we may even observe that the elements emitted towards the close of an eruption succeed one another in a definite order, so that when in certain eruptions a great variety of gases is poured forth, the chlorine and fluorine (Cl and F) come to an end first, then the sulphur and arsenic (S and As), while the carbon (C) continues its escape longest. In this way a certain scale of temperatures is given, namely ClF, SAs, and C, but in spite of this the fact remains that exhalations of Cl may continue for a very long period, as in Java, for example; that solfataras are fairly widely distributed, and that the solfatara of Puzzuoli gives out S and As; finally, that carbonic acid gas issues in quantity from the ground in places which have experienced no volcanic eruption since the Tertiary epoch.

Hot springs, so far as they are juvenile, are simply a milder form of the volcano. The chlorine contained in hot springs now becomes intelligible, and we can understand how those of Carlsbad, for example, bring yearly to the surface a million kilogrammes of juvenile salt *through* the granite but not *out* of it.

Laspeyres has pointed to the great quantities of carbonic acid gas which the granite contains; he states that one cubic kilometer of this granite is sufficient to feed the springs of Nauheim for 2,730 centuries. But the carbonic acid gas is sealed up in a liquid state in cavities of the quartz, and as Delkeskamp justly observes, it is hard to understand under what circumstances a continuous escape could take place [1].

Thus with every volcanic eruption the quantity of vadose water present on the earth's surface is increased. The atmosphere also is continuously enriched. While formerly the Ocean was supposed to be the source from which by infiltration the volcanos are supplied, now it is regarded as the receptacle for juvenile waters; the quantities of chlorine which it contains are consistent with this view; and thus *the waters of the Ocean bear witness to the escape of gas from the planet* [2].

The rhythmic pulsations which are sometimes visible in craters have the same origin as the pulsations of hot springs. In September, 1902,

[1] R. Delkeskamp, Vadose und juvenile Kohlensäure, Zeitschr. prakt. Geol., 1906, XIV, pp. 33–47. This fact is also overlooked by Gautier, La genèse des eaux thermales et ses rapports avec le volcanisme, Ann. des Mines, (1906) 1907, 9e sér., XI, pp. 316–375. The gases of the fumaroles which serve Gautier for comparison do not contain Cl, possibly because they were not extremely hot; the Cl contents of the springs could hardly be derived from granite.

[2] This is dealt with in detail by F. Freiherr von Richthofen, Das Meer und die Kunde vom Meer, Rectorats-Rede gehalten zu Berlin am 3. August 1904, 4to, 45 pp., in particular p. 12 et seq.

Sapper observed pulsations of this kind in a secondary crater of Izalco [1]. In March, 1871, two sets of rhythmic pulsations were observed at Vesuvius, one of slower period in the principal crater, and the other more rapid in a secondary crater on the outer slope of the cone. The lava of the secondary crater contained crystals of leucite bearing signs of superficial fusion, but not completely molten. As soon as the matrix was molten, the gases welled up, probably in clusters of bubbles, through the lava, united together, and raised the level of the boiling mass in the funnel for about one meter; then after 6–8, or sometimes 15 seconds, the explosion followed.

Doelter places the melting-point of the Vesuvian lava at 1,090° C., of the leucite at 1,310° C. Johnston-Lavis describes the leucites in detail; they may be broken, and partly healed together again, fused at the edges, or traversed by concentric zones of microliths or gas cavities. They bear witness sometimes to violent movements, sometimes to the variation of temperature in the funnel [2].

In the Cheviot hills, on the Scottish border, andesite lavas are cut through by dykes of quartz-felsite. But Teall found that the phenocrysts of the andesite correspond to the basic part of the original magma, while the quartz-felsite of the dykes corresponds to the glassy ground-mass, i. e. to the mother-liquor remaining after the removal of the phenocrysts [3].

In the tuffs of the Albanian mountains groups of leucite crystals may be found fritted together, along with loose, sharp-edged crystals of augite.

The incandescent cloud which destroyed Saint-Pierre in Martinique on May 8, 1902, contained crystals of plagioclase and hypersthene. Lacroix and other observers came to the conclusion that it issued from the earth with a temperature below 1,280° C.; it did not melt the copper wires of the telephone circuits, and must therefore have been below 1,058° C. when it reached the unfortunate town, but it must have exceeded 650° to 700° C., as is shown by Sapper's observations on half-melted bottles [4].

In the first two cases the presence of the phenocrysts shows that the last flows were re-melts. The processes active in Vesuvius, which caused

[1] K. Sapper, Centralbl. f. Min., 1903, p. 111. A good comparison between the pulsations in hot-springs and volcanos was given as early as 1842 by C. F. von Graefe, Die Gasquellen Süd-Italiens und Deutschlands, 8vo, Berlin, 1842, pp. 35 and 42.

[2] G. vom Rath, Zeitschr. deutsch. geol. Ges., 1871, p. 710; also hot springs, p. 6; H. J. Johnston-Lavis, Geology of M. Somma and M. Vesuvius, Quart. Journ. Geol. Soc., 1884, XL, pp. 35–119, in particular pp. 90 and 94.

[3] J. J. H. Teall, Anniversary Address, Quart. Journ. Geol. Soc., 1901, LVII, p. lxxxii; a very instructive example is given by Lacroix, C. R. Acad. Sci. Paris, 8 déc. 1902, pp. 1068–1071. Many examples of such fractional crystallization are given by Daly, Am. Journ. Geol., 1908, XVI, pp. 401-420.

[4] K. Sapper, N. J. f. Min., 1904, II, p. 17.

the temperature to rise to the melting-point of the lavas but not of the leucite, cannot fail to awaken a suspicion that the *rhythmically ascending gases themselves were the heat carriers in the volcanic funnel, just as they are in hot springs.* The two other cases illustrate the more violent intrusion of the gases which leads to the dissipation of the lava into dust. From this point of view the difference in the height of the two volcanic lakes of Hawaii becomes more intelligible. A difference of two or three thousand meters in the relative level becomes as nothing in comparison with the depths from which the gases are derived; it only reveals a certain degree of independence in the two funnels.

This conception of heat-carrying gases must greatly modify many other of our views. The juvenile water will possess the power to which Arrhenius and McMahon call special attention, that of dissolving quartz[1]. The geothermic stage loses its significance in connexion with the origin of juvenile springs. With the lavas which come from subterranean depths the re-melts associate themselves; and in this we find an explanation of the not infrequent tendency to a separation of the phenocrysts from the groundmass in these re-melts. The sun is in a state of almost free gas-emission. In the moon this state appears to have ended. The body of the earth has given forth its seas, and is now in an intermediate phase.

Batholites. This term was proposed (I, p. 168) for the great cake-like masses, composed chiefly of granite, which appear to be inserted in the stratified formations. In describing these bodies, I started from the theory —based on Hopkin's 'residual lakes' and Dutton's 'maculae'—that the intrusion of the granite mass must have been preceded or accompanied (owing to damming back and unloading of pressure) by the formation of a corresponding cavity. But a renewed examination of the granites of the Erzgebirge made in 1893, with the assistance of notes provided by Herr Credner and under the friendly guidance of Prof. R. Beck, convinced me of the fact that the contours of these intrusive masses cut through both the strike and the folds of the mountains in the most uncompromising fashion, much as a white-hot soldering-iron thrust through a plank cuts across the grain. Then came the observations made on the escape of molten matter in the moon, and now batholites may be described as intrusive masses, which are continued down into the 'eternal depths', in opposition to laccolites, which are lateral intrusions upon an alien foundation[2].

Indeed, a consideration of the facts as they occur in nature leads to the

[1] S. Arrhenius, Zur Physik des Vulcanismus, Geol. Fören. Stockh. Förh., 1900, XXII, pp. 395–420, in particular p. 415; McMahon, Presidential Address, Geol. Sect. Brit. Assoc. Belfast, 1902, pp. 589–696.

[2] Some observations on the moon, Sitzb. k. Akad. Wiss. Wien, 1895, CIV, pp. 21–54, in particular p. 53.

certain conclusion that batholites have reached their present position (mise en place) by *melting and absorbing the adjacent rock.*

This theory has been rejected by many distinguished petrologists, on the ground that cases in which absorption of the adjacent rock has affected the chemical composition of the intrusive magma, are rarely discoverable. It is, however, by no means new. Many of the earlier geologists adopted it; its truth may be recognized in definite instances, the granite of Wünsiedel, for example, as shown on Gümbel's map of Bavaria. More recently, Michel Lévy's work on the granite of Flamanville has had considerable influence in affecting opinion in its favour [1].

Long ago De la Bêche had recognized the subterranean continuity of the granites which extend from Dartmoor to the Scilly isles, and he even drew attention to the connecting elvan-dykes [2].

The granite masses of the western Erzgebirge are, as Dalmer pertinently observes, bosses intruded into the schist formations, and they form part of a ridge-like elevation of a still greater mass which extends for a considerable distance under this range [3]. Barrois makes a similar statement with regard to the granites of Brittany, and refers to a tourmalinized patch of sandstone as one of the indications of subterranean connexion [4]. One more stroke of the plane, says Lacroix, and the granites of the Pyrenees are united.

In Cornwall the granites follow the Armorican strike as far as the Scilly isles. The case is similar in Brittany. In the eastern, Variscan part of the Central plateau, Michel Lévy entertains no doubt as to the connexion of the granite of the Morvan with that of the Lyonnais. It sometimes seems, however, as though the granite preferred certain zones of rock, especially clay slates of various ages. In Brittany cases are even known in which the granite has consumed the slate and spared the intermediate beds of quartzite, so that these, highly altered, project into the granite [5].

Daly explains the intrusion as similar to the process which the miner terms 'overhand-stoping'. The weight of the walls and roof is greater than that of the liquid or viscous magma. Fragments are set free by the action of heat and gravity, and sink into the magma. These either form highly altered inclusions, or they are consumed on their way to the depths [6].

[1] M. Lévy, Contribution à l'étude du Granite de Flamanville et des Granites français en général, Bull. serv. Carte géol., 1893, V, pp. 317-357.

[2] H. de la Bèche, On the Formation of Rocks of South Wales and South-west England, Mem. Geol. Surv. England and Wales, 1846, I, pp. 1-296; for example, pp. 233 and 236.

[3] K. Dalmer, Die westerzgebirgische Granitmassivzone, Zeitschr. prakt. Geol., 1900, pp. 297-313, map.

[4] C. Barrois, Bull. serv. Carte géol., 1903, XIII, pp. 538 et seq.

[5] C. Barrois, Le Bassin de Ménez-Bélair, Ann. Soc. géol. Nord, 1894, XXII, pp. 181 to 350 et passim.

[6] R. A. Daly, The Mechanics of Igneous Intrusion, Am. Journ. Sci., 1903, XV, pp. 269-

We are now able to understand the nature of the pegmatite veins which proceed from the margin of the batholite. They often begin as fissures, which prepare the way for the detachment of a considerable mass of the roof. Hence their course is irregular, and hence they thin out as they proceed farther from the batholite. They become filled with hot solutions and tin ore, and deposits representing the whole series of the ClF fumaroles are formed. This is described in the most instructive manner by R. Beck, who at the same time calls attention to the part played by the juvenile gases[1]. Fluor spar represents the fluorine, tourmaline the boron, and so on; the native gold which occurs might well be regarded as an indication of chlorine. It is well known that great losses occur when gold ores are placed in the reverberatory furnace along with common salt[2].

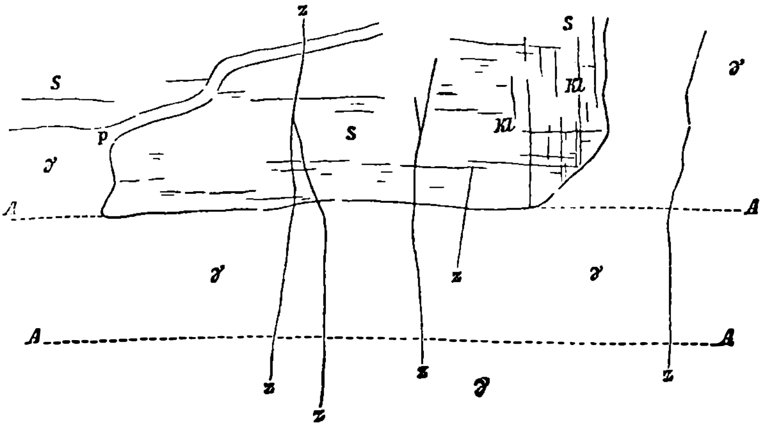


FIG. 49. *Roof of the granite of Markersdorf.*

γ, γ, Granite; *A*, *A*, horizontal joints in the granite; *S*, andalusite hornfels; *p*, pegmatite vein; *z*, *z*, 'Zwitter' clefts; *Kl*, *Kl*, joints.

Fig. 49 represents a part of the roof, about four meters in width, of the tin granite at Markersdorf (south-east of Dresden) on the way to Gottleuba. *S* is clay slate, transformed into andalusite hornfels. The pegmatite vein *p* shows that part of the roof is already becoming detached. Delicate vertical fissures (*z*, *z*) ascend from the granite into the roof; these are the so-called Zwitter, accompanied on both sides by a belt formed by tin

298, and XVI, pp. 107-126; also Geology of Ascutney Mountain, Vermont, Bull. U.S. Geol. Surv., 1903, no. 209, 122 pp., map. Detailed information on the literature in J. J. Sederholm, Om Granit och Gneis, etc., Bull. Com. géol. Finlande, no. 23, 1907, 110 pp., map.

[1] R. Beck, On the Relation between Ore Veins and Pegmatites, Trans. Geol. S. Africa, 1905, pp. 147-150.

[2] E. g. Engineering and Mining Journal, New York, Aug. 29, 1903.

exhalations. These hot exhalations were the latest phenomenon; they were even later than the overhand-stoping[1].

This is a short episode in the course of the manifold processes revealed by observation as soon as we proceed to trace the stages of cooling and to examine the primary distribution of the ores in the accompanying lodes[2]. At the same time it may be observed that nothing is known as to the temperature of the hottest existing fumaroles (ClF), except that it exceeds 500°C. The Zwitter (*z*) in fig. 49 may thus have been formed at a temperature far below that of the pegmatite *p*, and the fissure *z*, which cuts through *p*, may even be a contraction crack due to cooling.

On an earlier page we distinguished between chlorine, fluorine (Cl, F); sulphur, arsenic (S, As); and carbon (C) fumaroles. A great number of lodes are known in which only phase I (Cl, F) or phase II (S, As) is represented in metallic combinations; if both occur, I is uppermost; phase III (C) is seldom visible, and generally lies lowest. In such lodes the ores follow the series of the fumaroles, and cooling takes place in a downward direction. Phase I is that of the tin, which we have just referred to above; phase II is that of the sulphur and arsenic combinations of copper, silver, and other metals. In Cornwall, phase I alternates with II represented by copper pyrites. In Freiberg it is said that some lodes of copper pyrites have a tin hat[3]. The third phase (III) of decreasing temperature represented by the carbonates includes the uranium ores of Joachimsthal.

On the summits of the Erzgebirge lies an ancient, tin-bearing, alluvial land, partly protected by a basalt covering, which was formerly washed for tin (phase I). On the slopes silver was obtained at several localities (Abertham, Gottesgab, and other places). Still lower lies Joachimsthal. In the sixteenth century it furnished abundant supplies of silver, and from this valley the coinage of the (Joachims) thaler spread over the whole world; in the seventeenth, and still more in the eighteenth century the output diminished, and there came a time when this once famous district maintained itself by preparing blue pigment from cobalt pyrites (end of phase II). Still lower down the carbonates were reached. The filling of the lodes is here symmetrical. A thin crust of quartz, which turns the points of its pyramids towards the interior, is followed on both sides by pitchblende, with a botryoidal surface, doubtless deposited from solution;

[1] Similar examples in R. Beck, Die Contacthöfe des Granits und Syenits im Schiefergebiete des Elbethalgebirges, Tschermak und Becke, Min. Petr. Mitth., 1893, XIII, pp. 290–342.

[2] Details in J. H. L. Vogt, Zeitschr. prakt. Geol., 1895, pp. 145 et seq. Many more recent examples may be found in the text-books of Beck, de Launay, and Bergeat; also de Launay, Sur les types régionaux de gîtes métallifères, C. R. Acad. Sci. Paris, 12 mars 1900, and Sur la notion de profondeur, appliquée aux gisements africains, op. cit., 23 juin 1902.

[3] H. Müller, Freiberger Erzgänge, Erläut. geol. Spec.-Karte v. Sachsen, 1901, p. 140.

the middle part of the lode is completely filled by crystalline dolomite (phase III)[1].

The history of this mining town, the transition from tin washing to the prosperous mining of silver, and then to the production of cobalt-blue and last of uranium pigments, illustrates the primary differences of depth at which the ores occur, and at the same time the succession from the sublimated ores to the thermal hot-spring deposit and the last abyssal expressions.

This is a field in which further investigations will bring to light much that is new. This is shown by Brögger's studies of the Norwegian granite pegmatites, which establish, for example, the occurrence of uranium and thorium compounds, in association with topaz, beryl, tourmaline, and other minerals of phase I, and with pyrites of phase II, under such circumstances as might give them a place in our classification even above phase I[2]. In Colorado, pitchblende occurs along with pyrites (phase II). This recalls the fact that in volcanos all the phases appear at first together, and only become separated when cooling begins. In the case of tin, as was shown long ago by Daubrée, the stability of the compounds at a high temperature is especially manifest.

Apart from these phases of cooling, the system of pegmatite veins which so often surrounds undisturbed the summit and parts of the sides of a batholite shows that no important tectonic changes have occurred since the intrusion. The tin-granites of the Erzgebirge are thus later than the Variscan folding, or at least their intrusion did not come to an end until after the close of the folding.

Connexion with volcanos. In an earlier place (I, p. 172) we endeavoured, by following the stages of a denudation series, to find the path which leads from the ash-heaps of the present day to the granite masses of the Erzgebirge.

We will now return to the same path, following other indications. It was a great step in advance when Rosenbusch distinguished, more definitely than had ever been done before, abyssal, dyke, and flow rocks. The abyssal rocks include all those which ascend from the depths of the earth 'but do not reach the earth's surface', and thus do not attain the explosive phase.

[1] J. Step and F. Becke, Das Vorkommen des Uranpecherzes im St. Joachimsthal, Sitzb. k. Akad. Wiss. Wien, 1904, CXIII, pp. 585–618, in particular p. 614. The height of the tin-beds above sea-level is about 1,050 meters; from the Werner-Schacht (height above sea-level 917·7 meters), 302·5 meters below Tagkranz (height above sea-level 615·2 meters, Danielli-Stollen), down to the greatest depth accessible to us at present (height above sea-level 502 meters), Uranium ores prevail almost exclusively. Dalmer (Zeitschr. prakt. Geol., 1900) conjectures, in opposition to the fluor-fumaroles of tin, that sub-granitic hot springs may occur.

[2] W. C. Brögger, Die Mineralien der süd-norwegischen Granit-Pegmatit-Gänge, I, Niobate, Tantalate, Titanate und Titaniobate, Kristiania Vidensk. Selsk. Skrift, 1906, no. 6, 159 pp.

The tourmalinized spots marked on the detailed map of Saxony represent localities which have been reached by boron vapours, i. e. by pneumatolitic influences, but not yet by the uprising batholite. If the denudation were to proceed further, a system of pegmatite veins and lodes would probably be exposed, and then, beneath the highly altered roof the granite of the batholite. It may, however, be asked what would have happened if the melting process or the overhead-stoping itself had approached nearer the surface.

We now come upon a gap in our existing terminology, and it occurs indeed in all European languages. *Veins* (Adern) is the name given in this work to the outrunners of a considerable mass, which are thicker at their origin and thin out towards their distant extremity, without straight selvages or a definite strike and dip. Typical examples are the pegmatite veins in the neighbourhood of a batholite; these are often fissures, as in fig. 49, which may lead later to the detachment of part of the roof. These must be carefully distinguished from *dykes* (Gänge), although under this term the most diverse forms of fissure may be included. Daubrée termed those fissures which are accompanied by a dislocation, paraclases, and those which do not exhibit a dislocation, diaclases. The former correspond to Stelzner's exokinetic fissures, which are opposed to the endokinetic (contraction and dilatation) fissures.

Instead of following further these attempts at classification, let us consult one of the most instructive works on this subject which has been produced in recent times, Barrell's Description of the Mining District of *Marysville*, Montana [1]. The batholite of Marysville consists of quartz-diorite, and is associated with the much larger batholite of Boulder. The mine follows contraction fissures, which lie a little outside its surface, and parallel to it. This surface is exposed to a depth of about 1,000 feet, and descends on the whole gently, but sometimes in gigantic steps. Injected dykes also occur. *These must have originated suddenly and at various times* (intermittent). If they had not been sudden the injection would have grown cold on account of its considerable length. In this respect, says Barrell, these dykes recall volcanic action.

We can easily imagine how a dyke of this kind may reach the surface; a volcano then arises, the hot juvenile gases stream towards the funnel as it becomes broader, and with their discharge the upward course of the batholite ceases its progress. In another case it may happen that the roof collapses over the crown of the batholite, a network of fissures is produced, numerous eruptions and flows take place, and then this batholite likewise remains below the surface.

[1] J. Barrell, Geology of the Marysville Mining District, Montana, U.S. Geol. Surv., Prof. Papers, no. 57, 1907, 174 pp., maps, in particular p. 158.

The second case seems to be of frequent occurrence, but there are well-known examples in which the process was different, and the denudation of an ash-cone would reveal, even before reaching its base, the abyssal rock of a batholite. Close to the slopes of the broad basalt mass of *Duppau* in Bohemia, theralite traversed by dykes of elaelolite syenite comes to the surface [1]. At the base of the ashes and lavas of the *Euganaean* hills augite-syenite is visible [2]. In these and a great number of similar cases the formation of such rocks extended up to a considerable height within the ancient funnel. The dismantled giant volcano of *Kenia* also exposes kenyte, a rock resembling nephelin-syenite, on its summit (about 5,790 meters). Here we can scarcely escape one of two conclusions, either that a magma was carried up high above the surrounding country, and by the expulsion of a comparatively thin sheet of loose and scoriaceous rock was able to solidify in holocrystalline form, or that the persistent influx of heat has transformed the ashes and lavas themselves into kenyte (IV, p. 275).

Widely as this conception differs from traditional views, it was yet suggested many years ago by Hague in connexion with the *Absaroka* mountain of the Yellowstone. He doubted the necessity of a great superincumbent mass for the production of granular crystalline rocks, and believed that intrusive bodies of great size might be brought to a standstill without the occurrence of important phenomena at the surface.

Weed and Barrell arrived at precisely the same result in the case of the batholite of *Boulder*, which extends over 5,000 square kilometers. It consists of quartz-monzonite, covered, so far as it is known, by andesites only. On the boundary of the andesite a zone of acid granite sets in. Fine processes run from the batholite into the andesite, which is therefore regarded as the older. Near Elkhorn it rises, even at the present day, to a height of 9,000 feet (2,700 meters) (5,000 feet above Boulder valley).

The question naturally suggests itself whether it would not be sufficient to regard the *andesite as the volcanic facies of the quartz-diorite*, and the result of the same melting process as produced the batholite, and still maintained its activity, in a modified form, even after reaching the surface [3].

[1] F. Becke, Verh. k. k. geol. Reichsanst., 1900, pp. 351–353; J. B. Wiesbauer, Theralith im Duppauer Gebirge, Sitzb. Ver. Lotos, Prag, 1901, new ser., XXI, pp. 62–69; J. E. Hibsch, Das körnige Gestein von Rongstock, Tscherm. Min. Mitth., 1895, XV, pp. 487–489; Sodalith-Augit-Syenit im böhmischen Mittelgebirge und die Beziehungen zum Essexit, op. cit., 1902, XXI, pp. 157–170 et passim. The Essexite of Rongstock and the Sodalith-Augite-Syenite of Gross-Priessen are visible at the surface.

[2] F. Graeff and R. Brauns, Zur Kenntniss des Vorkommens körniger Eruptiv-Gesteine bei Cingolina in den Euganeen bei Padua, N. J. f. Min., 1893, I, pp. 123–133.

[3] W. H. Weed, Geology and Ore Deposits of the Elkhorn Mining District, Jefferson City, Montana, with a petrographical Appendix by J. Barrell, Ann. Rep. U.S. Geol. Surv., 1901, XXII, 2, pp. 399–549, maps, in particular p. 451; and Barrell, op. cit., Prof. Papers, no. 57.

Barrell draws attention to the penetration of granite into the andesite of the Cascade range (IV, p. 416).

As a further example we may quote Molengraaff's description of the *Buschfeld* granite of the Transvaal, which north of Pretoria covers 60,000 square kilometers, and is thus larger than Bohemia. So far as the facts are known, the surrounding sediments, which are possibly pre-Cambrian, dip *beneath the granite*, normally to the north of Pretoria and then in step-faults. A broad aureole of contact surrounds the granite. We reach first an outer border of Sima compounds, that is, a zone of pyroxenite and norite with chromite and magnetic iron, and also dykes of cobalt, then a zone of nepheline-syenite, and finally the vast region of the red granite.

From this description we conclude that the Sudbury type is repeated here, and that the Crofesima belt underlies the Sal rocks, the transition being marked by nepheline syenite.

In the granite, tin ores occur together with the usual pneumatolytic series. Upon the granite rest isolated patches of Waterberg sandstone, the highest member of the Karoo series; these become over 1,000 meters thick towards the north. At another locality, in the Springbok Vlagte, an amygdaloid basalt, which Molengraaff is inclined to regard as representing the final phase of the molten rocks, spreads out above the granite over an area of about 3,400 square kilometers[1].

The intrusive masses of Sudbury, Boulder, and Buschfeld are generally regarded as laccolites: a view hard to reconcile with the extension of the two latter masses.

With regard to Sudbury, Coleman finally arrived at the hypothesis that the place of emission lay beneath the great basin. This will also hold good for Boulder if the quartz-diorite and andesite are genetically connected. The presence of tin supports the same conclusion with regard to Buschfeld.

Important in this connexion is the statement of Lacroix that in mount Pelée rocks with free quartz consolidated in a crystallized state under a very slight covering of ash, almost indeed in the open air, and that consequently the thickness of superincumbent rock necessary for the formation of holocrystalline rocks has been greatly over-estimated[2].

Among the cases we have adduced, there is none which has been affected by the formation of a considerable fissure. Since Nifesima and Crofesima are so frequently represented, we must assume that the juvenile

[1] G. A. F. Molengraaff, Géologie de la République Sud-Africaine, Bull. Soc. géol. France, 1901, 4e sér., I, pp. 13–105, map; F. H. Hatch, Geology of the Marico District, Trans. Geol. Soc. S. A., 1904, VII, 6 pp., map; also Kynaston, op. cit., 1905, VIII, pp. 56–62 et passim; H. Merensky, Neue Zinnerzwerke in Transvaal, Zeitschr. prakt. Geol., 1904, XII, p. 409; A. L. Hall, Geological Notes on the Bushveld Tin Area, Trans. Geol. Soc. S. A., 1905, VIII, pp. 47–55 et passim.

[2] A. Lacroix, Le Mont Pelée après ses éruptions, 4to, Paris, 1908, p. 69 et passim.

gases are originally liberated beneath the Sal mantle. Owing to their high temperature they melt and stope their way through the overlying rocks, and thus force their way upwards. In this process an increasingly great quantity of fragments of Sal rocks and also of sediments become molten and are received into the gas-filled magma, sinking by their weight. The magma approaches the surface as a mixture. Then follows explosion, pulverization, the piling up of a cone, and the outflow of lava. The emission of juvenile gases continues. Eruptions are repeated from time to time. A continually increasing area of the earth's surface becomes covered with ash and lava. The afflux of gases still persists; they heat and melt part of their surroundings, but they no longer cause eruptions. Their own ejectamenta, spread out at the base of the cone and round about it, are melted and converted into holocrystalline rocks, and concurrently the Nifesima they contain separates out at the base while the lighter Sal rocks remain above. The effects of this process may be restricted to the region below the cone, leaving beneath it a fragment of the original roof only traversed by dykes (and this appears to be the rule), or they may extend higher up the funnel (Euganaean hills), or through the whole cone (Kenia), or over a wide area (Boulder). Finally the emission of hot gases recedes into the funnel. Here, too, differentiation may take place next the walls, but the original course along the axis of the funnel is destroyed by the melting, and can only be recognized in exceptional cases by a belated intrusion, as e.g. in Magnet Cone, Arkansas, where a differentiated product, derived from deep-lying Sima, ascends towards the middle of the funnel [1].

Thus assimilation and differentiation succeed each other. But the cessation of eruption by no means marks the close of the process. Fissures are formed by cooling, and are lined and filled with ores deposited in a definite order which recalls the fumaroles. Tin may thus find its way into the andesites of the Bolivian Andes and the rhyolites of Mexico. At the same time all the subterranean parts are finally transformed into a broad batholite.

For many years the belief has prevailed that Sal batholites are much more numerous than Sima. A knowledge of the Charnockite masses of Southern India and the Anorthosites of Canada is likely to modify this impression. The Sal masses are usually surrounded by Sima, these together represent the separated products of a mixed magma [2]. The last after-efforts appear, as a rule, to give rise to Sal, often very siliceous.

[1] Washington, Bull. Am. Geol. Soc., 1900, XI, pp. 389 et seq.

[2] 'True batholiths of gabbro are uncommon, perhaps because batholithic intrusion is always dependent on assimilation'; R. A. Daly, Differentiation of a Secondary Magma through Gravitational Adjustment, Festschrift für Herrn von Rosenbusch, 8vo, Stuttgart, 1906, p. 233; also his Geology of Ascutney Mountain, Bull. U.S. Geol. Surv., no. 209, 1903, p. 110 et seq. We do not wish to deny that in this zone later layers have been

Passive injection. There are certain dykes which are filled from below, not with molten rock, but with sandstone; these show that hydrostatic pressure must not be overlooked in considering subterranean processes.

An instance has been described by Rogers and Du Toit from Elands Vley, not far outside the region of the South African dolerite dykes. The dyke is intruded into the Witteberg beds; it ascends steeply between parallel walls, with a breadth of only 2·4 to 2·5 meters, but a length, according to one estimate, of 11 kilometers, and according to another of more than 57 kilometers. The beds on each side are slightly upturned, and the infilling material is not dolerite, but sandstone [1].

Many examples of a similar kind have been observed in the United States. In these cases also, the acting force was often sufficient to cause an upward bend in the adjacent rocks and to carry up torn-off fragments towards the surface [2].

In the case of bituminous dykes gas pressure may play some part, but the results are much the same. In *Utah*, according to Eldridge, a bituminous dyke, known as the Culmer vein, may be traced through the desert for a distance of 11 kilometers; its breadth varies from 30 inches to a fraction of a line. It is straight, with smooth lateral walls, and runs completely independent of the strike of the rocks it traverses. Similar dykes occur in association with it [3].

The gas pressure which sometimes assists in the formation of these dykes leads us on to those injections which have been brought into their present position, at least in the opinion of the observers, by hydrostatic pressure, though they are also accompanied by contact minerals. Such are, according to Pošepny's view, the dykes of Réxbanya in south-east Hungary (I, p. 160); Salomon ascribes the ascent of the tonalite mass of the Adamello to the subsidence of the plain of Lombardy, and Brögger is inclined to explain the ascent of the Drammen granite on the Christiania fjord in a similar manner [4].

The passive movement is seen more clearly, owing to the great rarity or entire absence of contact minerals, in the local swelling up of sills, which Gilbert terms *laccolites* (I, p. 148). We shall return to these later, because not infrequently much too wide a scope is given to this expression, and bodies

formed by solution; the garnierite of New Caledonia is an example of this, and others are given by Foullon (Jahrb. k. k. geol. Reichsanst., 1892, XLII, pp. 223-310). According to T. Beck they even seem to occur in the case of platinum.

[1] Rogers and Du Toit, Geological Survey of parts of Ceres, &c., Geol. Comm. Cape of Good Hope, Ann. Rep. (1903) 1904, IX, p. 17.

[2] For examples of such dykes, J. F. Newsome, Clastic Dikes, Bull. Am. Geol. Soc., 1903, XIV, pp. 227-268.

[3] G. H. Eldridge, The Asphalt and Bituminous Rock Deposits of the United States, Ann. Rep. U.S. Geol. Surv., 1901, XX, 1, pp. 209-452, maps, in particular p. 343.

[4] Salomon, Sitzb. k. Akad. Wiss. Berlin, 1901, pp. 743–747, Brögger, Eruptivgesteine des Kristianiagebietes, 1895, II, pp. 116 et seq.

of this kind are even sometimes regarded as active elements in the formation of mountain chains.

Daly has collected definitions of the word, and there can be no doubt as to what is meant by a laccolite. 'The first step in its formation', says Gilbert, 'is the penetration of a thin layer of lava along a bedding plane, which spreads out on the principle of the hydraulic press, until its area corresponds to the deformation of the covering beds. . . . As soon as the lava is able to arch up the beds it does so, and this position gives rise to a laccolite . . .[1]'.

A characteristic feature lies in the fact that although the roof is arched, the basement remains unaltered. The latter may, at most, become slightly concave, probably owing to its load, and then a cross-section is lenticular in form. Thus it appears that a laccolite may well produce a local intumescence, but not a mountain-chain.

Whitman Cross has made a number of instructive observations in Colorado, Utah, and Arizona; he points out, for example, that the bedding-planes are sometimes cut through at an acute angle, and that the lifting of the load may be facilitated by tectonic processes, as in cases where the beds are about to become folded, he also calls attention to the similarity of the rocks in all American laccolites, the absence of vesicles and contact minerals.

On the northern periphery of the Little Belt mountains Weed describes no less than fifteen of these bodies, each of which terminates steeply in the direction of the plain[2].

This lateral extrusion of less hot magma affords one of the clearest examples of the behaviour of molten masses during tectonic processes.

The force which produced the arching up of American laccolites has frequently been overestimated, judging from idealized sections, because, as we have seen above, the overlying load necessary for the formation of holocrystalline rocks has also been overestimated[3].

The green rocks. Under this name, which corresponds to the 'pietre verdi' of Italian geologists, we include the Nicrofesima and Crofesima sills, which are very widely distributed as intercalations in many folded ranges. They never form the axis of a range, and there is scarcely a case in which a Sima batholite can be fairly regarded as their probable point of origin. They occur as intercalations in the Caledonides, in the pre-Permian Altaides, and in the youngest ranges, and in some places their injections are certainly

[1] R. A. Daly, Classification of Igneous Intrusive Bodies; Am. Journ. Geol., 1905, XIII, pp. 485-508, in particular p. 493.

[2] W. Cross, The Laccolitic Mountain Group of Colorado, Utah, and Arizona, Ann. Rep. U.S. Geol. Surv., 1895, XIV, 2, pp. 157-241; Weed, op. cit., XX, 3, p. 394. For the mode of contact in laccolites, M. Lévy, Porphyre bleu de l'Esterel, Bull. Soc. géol. France, 1896, 3e sér., XXIV, pp. 123-138.

[3] Lacroix, La Montagne Pelée après ses éruptions, 4to, Paris, 1908.

as recent as the middle Tertiary times. They are frequently associated with nickel and chromium, in many places also with platinum, gold, awaruite, and the whole abyssal series.

In the Pyrenees Lacroix distinguishes the lherzolites (peridotite with diopside, bronzite and spinell) from the ophites (labrador-diabase or andesitic diabase). In some cases, not very frequent, they are associated with Sal sills. Stoliczka marks Sal and Sima injections in the limestone cliffs of Afghanistan. J. H. L. Vogt states with regard to northern Norway, that the extremely great length of the sills points to contemporaneity with the folding. Here they consist of gabbro, or sometimes of a white granite, and of intermediate rocks such as adamellite and others. The granites have as a rule suffered from pressure, while the isolated occurrences of gabbro have not [1].

Throughout they exhibit occasionally, but not invariably, volcanic contact; the Mesozoic serpentines in the Carpathians of Roumania, for example, are associated with hornfels and contain inclusions of garnet and idocrase (IV, p. 18) [2].

There is a sharp line of division between the mode of occurrence of these rocks and that characteristic of basalts. On the outer border of the Tauric range, in the Kurden range, and as far as Antioch, post-Cretaceous green rocks occur, especially olivine-gabbro and serpentine. They are repeated, correspondingly with the outer border of the range, in Cyprus. At the same time the African fractures are continued towards the north into the foreland of the Dead sea; these are accompanied by basalt, and it is stated that they extend into the neighbourhood of Marash, far into the interior of the folded range (IV, p. 279).

In the outer chains of younger folded mountains the green rocks make their appearance as long bands, as is especially well seen in the Burman arc; here we must refer the serpentine bands of Arakan. The serpentines of Guatemala and Cuba, and many others, might be cited as examples.

They occur with particular frequency in association with radiolarian rock, as, for example, in a part of the Lepontine sheets of the Alps, and in the Pienines, but more especially in the Californian coast ranges; Ransome thinks that glaucophane owes its origin to this association [3].

[1] J. H. L. Vogt, Söndre Helgeland, Norg. geol. Unders., 1900, no. 29, 175 pp., maps, in particular p. 3 (note) and 159; C. F. Kolderup, Die Labradorfelsen des westlichen Norwegens, Bergens Mus. Aarb., 1903, no. 12, 129 pp., map, in particular pp. 92, 126 et passim. A very instructive discussion of these questions also in Sjögren's work on Sulitelma and in Holmquist, Profil nach Kvikkjok (Sver. Geol. Undersökn. Afh., 1896, XVIII, and 1900, XXII).

[2] L. Mrazec, Sur les schistes cristallins des Carpathes méridionales, Congr. géol. intern., C. R. IX^e Congr. géol. Vienne, 1903, pp. 631-648, map, in particular pp. 638, 639.

[3] F. L. Ransome, The Geology of Angel Island, with a note on Radiolarian Chert, &c., by J. G. Hinde, Bull. Geol. Univ. Cal., 1894, I, pp. 193-240, map. The bedding of the

The green rocks never proceed into the foreland. In the eastern part of the Appalachians (Piedmont) a thick zone of gabbro and serpentine strikes from New York State to Virginia. Far to the west, outside the Appalachians, some remarkable, but isolated Sima dykes make their appearance, certainly at a great distance from one another, but so far as their age is known, they are more recent than the Appalachians, and in some cases resemble far more closely the diamond pipes of South Africa [1].

G. Steinmann, in a compendious work brings these green rocks into connexion with deep-sea deposits, and supposes that 'magmatic masses of extreme basicity accumulate in the great abyssal depths', while more acid magmas ascend beneath the sockles of the continents [2].

This view is based on numerous cases in which radiolarian chert is associated with these green rocks.

All these cases are well attested. In fact, heavy Sima rocks also emerge not infrequently from the sea. Basalts probably lie beneath a part of the North Atlantic Ocean, and gabbro occurs in the east of Iceland [3]. The island of St. Paul, in the middle of the Atlantic (lat. 0° 58′ N., long. 29° 15′ W.), is formed of peridotite (sp. gr. 3·287), with dark bands composed of olivine granules and chromite [4]. Hawaii consists of heavy Sima rocks, and nowhere is the development of the green rocks so considerable as in New Caledonia and New Zealand.

In the majority of the cases cited, we may doubtless assume that the radiolaria really point to the deep sea. This is in complete accord with what has already been said as regards the foredepth of the Northern Antilles and the radiolarian rocks of Barbados. In the Alps, e. g. in Wähner's sections of the Sonnwend range, this view is also supported by their

radiolarian rocks is so regular that Lawson and Palache assume a rhythm; op. cit., 1902, II, no. 12 (The Berkeley Hills), p. 354 et seq. A survey of the outcrops on the periphery of the Asiatic system is given by F. Sacco, Les formations ophitifères du Crétacé, Bull. Soc. géol. Belge, 1905, XIX, pp. 247–266.

[1] Diller, Peridotite of Elliot county, Kent, Bull. U.S. Geol. Surv., no. 38, 1887, 31 pp., recognizes the resemblance to South Africa (p. 23). Kemp and Ross mention the following occurrences: 1. three dykes of mellilite basalt and serpentine, one of them near Syracuse, another to the east of it, and a third 400 kilometers to the south-west of the town. 2. South-west Pennsylvania, 320 kilometers from the latter locality, two dykes of peridotite, side by side with pyrope and ilmenite, recalling diamond pipes; 3·440 kilometers to the west of No. 2 a thick dyke of mica peridotite; and 4·480 kilometers south-west of No. 3, near Pike City, Arkansas, another dyke of this kind said to be younger than the Cretaceous. No. 2 converts the coal into coke for 50 feet and is younger than the Permian, Ann. N.Y. Acad. Sci., 1907, XVII, pp. 509–518.

[2] G. Steinmann, Die geologische Bedeutung der Tiefseebildungen und der ophiolitischen Eruptiva, Geologische Beobachtungen in den Alpen, II, Ber. naturf. Ges. Freiburg, 1905, XVI, pp. 44–65.

[3] Thoroddsen, Island; Peterm. Mitth., Erg.-Heft no. 153, 1906, pp. 264–265.

[4] A. Renard, Report on the Petrology of the Rocks of St. Paul, *Challenger* Narrative, II, 29 pp. The rock bears the closest resemblance to the peridotite of the Ultenthal (Tyrol).

association with Aptychus limestone, and the fact that the calcareous base of the sharks' teeth has been dissolved and removed. From this it follows, however, that the Tethys, where it extended over many places now occupied by the Alps, or over the region in which the roots of the Lepontine sheets are to be found, can hardly have been less than 4,000 meters in depth.

Yet where the folded mountains have not been formed in the deep sea, the green rocks still make their appearance. This is particularly well shown in the Pyrenees, where, in the west, north of the plain of Mauléon, the external form of the mountains is completely lost, the Trias is only represented by gypsum, and the whole stratified series is of trifling thickness and repeatedly interrupted, but at the same time it is dislocated, and as far as Dax, accompanied by ophite (IV, p. 239). The green rocks are here associated with dislocations, but not with the deep sea.

The green rocks are sills in dislocated mountains, which sometimes follow the bedding planes and at others the planes of movement[1]. They follow the planes of movement, for example, in the window of the Paring and in the window of the Inn, but in the latter there is a possibility that they were transported as an already consolidated injection. This doubt does not attach to the great plane of movement upon which the Tibetan segments have been carried over parts of the Himálaya; for this reason it deserves a closer consideration.

We have repeatedly made mention of the chain of Eocene and possibly Miocene beds, which accompanies the upper Indus; it attains a length of over 300 kilometers; a breadth, in places, of 30 kilometers, and a height, in the Stok (south of Leh) of 6,400 meters.

On its north-east side, according to Lydekker, the Tertiary beds, often lying remarkably flat, rest normally superposed upon the gneiss and syenite of Ladákh. Its south-west side is accompanied at both ends by two long ranges of Sima rock, with a maximum breadth of 16 kilometers. Both the Tertiary sediments and Sima rocks terminate towards the south-west along a fracture which separates them from the Carboniferous and gneiss of the chain of Zanskár.

Basalts and ashes occur, which point to eruption, and from the Puga valley (north of lake Tsomoriri) McMahon describes holocrystalline peridotite, gabbro, and serpentine. These form part of the eruptive zone, and occur in it, both in the south-east near Hanli (Rupshu) and in the Markha valley (south of Leh)[2].

Let us now turn our attention to a point 300 kilometers further to the

[1] E. Suess, Sur la nature des charriages, C. R. Acad. Sci., 7 nov. 1904.

[2] R. Lydekker, Geology of the Káshmír and Chamba Territory, Mem. Geol. Surv. India, 1883, XXII, pp. 99-121; C. A. McMahon, Petrological notes on some Peridotites, &c., op. cit., 1901, XXXI, pp. 303-329.

south-east, following the strike of the mountains, and consider Griesbach's map of the watershed between the Indus and Sutlej, in conjunction with Krafft's map of the heights of Balchdura and Kiogarh, situated near this watershed; the last-named map also embodies the results of Griesbach and Diener [1] (III, p. 278, fig. 15).

The traveller approaching this watershed from the south-west sees before him the great scarp of the Silakank, facing to the south (I, p. 437, fig. 46), which includes the whole series of Spiti, from the Silurian to the Cretaceous Flysch (sandstone of Gieumal). This series, some thousand meters thick, forms the basement of the plateau of Hundés.

Griesbach, approaching Hundés across the Niti pass (very nearly north of the Silakank) observed, besides Flysch with Inoceramus, an altered rock with Nummulites, which he correlated with the above-mentioned Eocene zone of the upper Indus. Hundés is covered by Tertiary deposits, in which the Sutlej has excavated its bed [2]. Further to the south-east, on the Balchdura pass, he met with basic eruptive rocks, which he assigned forthwith to the great mass of similar rocks observed by Strachey on lake Manasarowar, and regarded as the continuation of those on the upper Indus [3].

Balchdura pass is one of those points at which the alien recumbent sheets of Tibet rest upon the Flysch and the Himâlayan series. The great similarity of its facies with certain East Alpine stages of the Trias and Lias has been established by Diener [4].

Krafft has shown that the Flysch, into which no dykes extend, is here followed by eruptive rocks, filled in places with hundreds of exotic Tibetan blocks. Some of the blocks have been injected with narrow dykes which have marmorized the limestone. On some of the Kiogarh hills the proportion of eruptive rock is so small that these hills may be regarded as limestone. The blocks are chiefly very much altered andesites or diabases; on Balchdura serpentine with chromite has also been found.

Krafft justly observes that the source of these rocks must lie towards the north or north-east, for there no dykes occur in the basement. In the same direction also lies the probable source of the exotic blocks.

These observations show *that the overthrusting of the Tibetan segments and the emergence of the Sima rocks occurred simultaneously.*

[1] Griesbach, Geology of the Central Himalaya, Mem. Geol. Surv. India, 1891, XXIII, 232 pp., maps; A. v. Krafft, Notes on the 'Exotic Blocks' of Malla Johar in the Bhot Mountains of Kumaon, op. cit., 1902, XXXII, pp. 127–183, pl. 14.

[2] Griesbach, op. cit., Mem. Geol. Surv. India, 1891, XXIII, pp. 83, 130, 155.

[3] Cf. Oldham, Manual of the Geology of India, 2nd ed., 1893, p. 348. The pass of Balchdura slopes north-east to the Sutlej, the distance is only about 23 kilometers; the distance of the lake from the conjectured continuation of the strike would not be much greater (according to Griesbach's map).

[4] K. Diener, Die Faunen der tibetanischen Klippen von Malla Johar (Central Himalaya), Sitzb. k. Akad. Wiss. Wien, 1907, CXVI, pp. 693–714.

If the Sima rocks of Balchdura and Kiogarh may be regarded as actually forming the continuation of those of the lake of Manasarowar, then we arrive, by conjecture, at the following result:—

From Kargil, on the Indus, onwards, a Tertiary intercalation extends, parallel to the strike of the mountains, for about 600 kilometers; it is accompanied for long distances by Crofesima, andesitic, and basaltic rocks, and in places by ashes. The latter indicate that a zone of volcanos formerly existed here, lying in the strike of the mountains. —

Hochstetter recognized long ago that the Nifesima rocks of New Zealand form a mighty sill. Most probably, according to Mackintosh Bell, and Fraser, they have forced their way into the great range east of Hokitika, along lines of weakness at the base of monoclinal folds [1]. But that these sills were primary, independent paths of discharge from magmatic depths hardly admits here of direct proof, unless we are content to recognize the abyssal, Nifesima series, such as awaruite, nickel ores, &c., as in itself sufficient evidence.

Balchdura represents the margin of a plane of movement of the first order, along which sedimentary series of divergent facies rest one upon the other.

The sole of the Dinarides on the south border of the Alps is a plane of the same kind. In association with this, also, intrusions occur. Sometimes they coincide with the boundary, and at others lie to the north or south of it. We have already referred to the relations of the several parts of this structure to one another, and especially to the green rocks of Ivrea, the tonalite zone, and the Styrian andesites (IV, p. 135). Lacroix concludes that the green rocks of the Pyrenees are derived from the marginal facies of granitic batholites. They would thus be separations from a mixed magma, recalling the base of Sudbury, and it is possible that the question may one day be raised, whether the principal range of Ivrea with its nickel ores and peridotite is not the natural base of the diorites. It sends its green sills only into the Alps, not into the Dinarides.

As soon as we attempt, however, to discover a path of discharge we must not forget that an actual superposition of the Dinarides upon the Alps, such as might be expected, is preserved, as a matter of fact, only at one restricted locality, and we must bear in mind that along considerable intervals only violent compression, or fracture is shown, and that in Carinthia the tonalite range is accompanied for more than 40 kilometers by a narrow, younger range of granitite, which is separated from the tonalite by a narrow band of highly altered schist; further, that the tonalite is occasionally converted into gneiss by later metamorphism—in short, that this line of thrusting of the first order must also have been the scene of further

[1] J. Mackintosh Bell and C. Fraser, Geology of the Hokitika Sheet, &c., Bull. Geol. Surv. N.Z., no. 1, 1906, 101 pp., maps, in particular p. 68.

tectonic processes of a different kind. Along the Drau and the Gail a long downthrown area actually makes its appearance in the Alps.

Both the ashes and lavas of Tsomoriri, and the andesites of South Styria point to the presence of volcanos. These facts will come under consideration in discussing the occurrence of active volcanos [1].

[1] Here, as in the two following chapters, we meet in all cases with a peculiar difficulty in giving specific gravities. Sal is given as 2·7 (p. 546), while many works mention 2·8 as the mean result of numerous determinations. But since most collections contain only a few specimens of uniform and widely distributed gneiss, but a great many of various kinds of dyke rocks, inclusions, and so on, I think that 2·8 is too high. For the same reason 3·287 may be correct for the peridotite of St. Paul (p. 563), but for the general questions considered here the associated chromite must also be taken into account.

CHAPTER XVI

ORIGIN AND ARRANGEMENT OF VOLCANOS

Phreatic explosions. Association with dykes. South African funnels. Distribution of the volcanos. Volcanic lines. Atlantic and Pacific lavas.

Phreatic explosions. When juvenile hydrogen encounters an unlimited quantity of vadose water, we witness a spectacle such as was presented by Krakatoa in 1883. In discussing the great pulverization which preceded the formation of Monte Nuovo, Johnston-Lavis suggests the possibility that the first outbreak may occur with increased violence if the ascending lava meets with a water-bearing stratum [1]. In this case the effect may have been due to phreatic water in the neighbourhood of the sea, but when phreatic water is confined in the fissures of a limestone formation, the explosion shatters the limestone, and finds relief in eruption channels (Diatrèmes, Daubrée). This may have been the origin of the millions of small angular fragments of Apennine limestone in the tuff of the Albanian mountains, and to the same cause may be attributed the fluorspar-bearing volcanetti, discovered by Scacchi round the margin of the central Italian inbreak, from Mondragone, north of the lower Volturno, through Caserta to the north border of the peninsula of Sorrento. Scacchi thinks that they were all of late origin and short-lived [2].

The almost circular *Ries*, near Nördlingen, has been regarded as an inbreak (I, p. 197). Branco has since described over a hundred tuff-filled eruption channels (necks, embryonic volcanos) which occur in its immediate neighbourhood. A number of parallel instances have convinced me that the Ries was produced by a phreatic explosion at the base of the Jurassic limestone [3]. Sedimentary and in part granitic blocks have been driven out beyond its borders, but the preservation of the granitic mass in the

[1] Johnston-Lavis, Geology of Mt. Somma and Mt. Vesuvius, Quart. Journ. Geol. Soc., 1884, XL, pp. 35–119, in particular p. 40.

[2] A. A. Scacchi, Le regioni vulcaniche fluorifere della Campania, Mem. Com. geol. ital., 1890, IV, 47 pp., map (a first edition appeared in 1885).

[3] E. Suess, Einige Bemerkungen über den Mond, Sitzb. k. Akad. Wiss. Wien, 1895, CIV, pp. 21–54, in particular p. 34. Daubrée's experiments show the force of an explosion, but presuppose the presence of a fissure; Expériences sur les actions mécaniques exercées sur les roches par des gaz, etc., C. R. Acad. Sci. Paris, 24 nov. 1890 et seq.

centre is significant. The complete fragmentation (Vergriesung) of the Jurassic limestone is the same phenomenon as the shattering of the Apennine limestone. The limestone blocks also, which lie within the volcanetti are said to fall to pieces beneath a blow of the hammer [1].

The same explanation also holds good for the eruption canals of *eastern Fife*, described in a masterly manner by Sir Archibald Geikie [2].

The peninsula between the Firth of Tay and the Firth of Forth consists on the north, south of Dundee, of Old Red Sandstone, and on the south, of Carboniferous, probably 7,000–8,000 feet thick, with repeated dykes and intercalations of dolerite. In the Carboniferous area a zone about 13–16 kilometers broad, extending from St. Andrew's bay south-south-west to Largo bay, presents about eighty volcanic necks or eruptive chimnies. Only one of them lies outside the Carboniferous, and to the west of it. Almost all are filled with a tuff produced by the pulverization of a basic lava; the rare exceptions have apparently remained empty, and now contain nothing but ordinary débris. Sections observed along the coast show that they are independent of the faults, and the lie of the Carboniferous beds, and that each of them must have been bored out as a more or less cylindrical cavity. They vary in diameter from 9 to about 800 meters. Loose crystals of orthoclase, sometimes more or less rounded and corroded, and in one case as much as two pounds in weight, as well as hornblende, augite, pyrope, and a great deal of quartz sand lie in the tuff. All the more striking is the fact pointed out by Geikie, that although they contain innumerable splinters of Carboniferous rocks, yet no trace of the subjacent Old Red Sandstone or of still deeper-lying sediments has been observed. 'It must be admitted,' says Geikie, 'that from the nature of the contents of the necks no argument can be drawn in favour of a deep-seated origin for the eruptions.'

We should be inclined to look for this origin in a phreatic layer at the boundary of the Old Red Sandstone and the Carboniferous.

Connexion with dykes. Where it is possible to approach the deeper-seated afferent paths we generally arrive at fissures. A simple illustration is afforded by Dutton's description of the region situated between the

[1] W. Branco, Schwaben's hundert fünf-und-zwanzig Vulcan-Embryonen und deren tufferfüllten Ausbruchsröhren, Jahresh. Ver. Naturk. Württ., 1894 and 1895, 816 pp., maps; also a number of works by Branco, Koken, E. Fraas, Knebel, Gaiser, and Oberdorfer. I only mention Branco, Das vulcanische Vorries, etc., Abh. k. Akad. Wiss. Berlin, (1902) 1903, 132 pp., map. The twisted trachyte drops of the adjacent Haarhof are of no value (without inclusions of an older lava) as indications of a former eruption; on this point see Mercalli, Notiz. Vesuv., 1895, pp. 7, 10. Branco describes the process in the Ries as a contact explosion; by contact he means the lower limit of the subterranean water.

[2] A. Geikie, The Volcanic Necks of Eastern Fife, Mem. Geol. Surv. (from the Geology of East Fife), 1902, pp. 200–283, map.

Rio San José and the Puerco, close to the south-east border of the Colorado plateau[1].

Mount Taylor (3,471 meters), an andesitic cone, dominates the volcanic mesa (2,500 meters) which surrounds it. The mesa descends steeply to a plain formed of horizontal Cretaceous beds. In the north it terminates

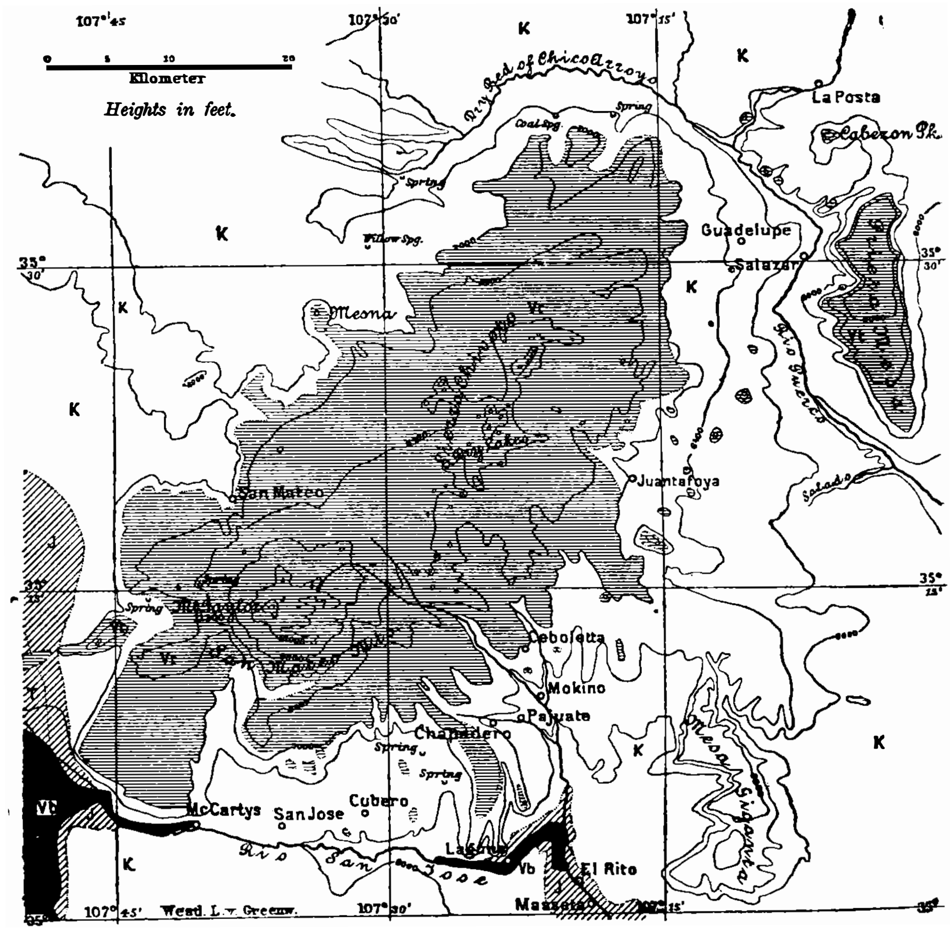


Fig. 50. *Mesa of mount Taylor and Prieta Mesa* (after Dutton).
T, Trias ; J, Jurassic ; K, Cretaceous ; Vt, Tertiary eruptive rock ; Vb (black), recent Basalt.

along a depression, 19 kilometers broad, which lies 250 to 450 meters lower, and is traversed by the Puerco; on the other side of the river lies the mesa Prieta, which once formed the continuation of the mesa of mount Taylor (fig. 50).

[1] C. E. Dutton, Mt. Taylor and the Zuñi Plateau, Ann. Rep. U.S. Geol. Surv., 1885, VI, pp. 111-202, map.

Above these two volcanic plateaux rise between 100 and 200 scattered necks, representing so many centres of eruption. Between the plateaux the Puerco has removed by denudation not only the volcanic sheets, but in places also, a thickness of 300 meters of friable Cretaceous sediments, so that the upward course of the funnels is visible. At first glance the cross-section appears to be circular; but this is only true of the upper parts. Further down a lateral extension occurs. 'The longer axis,' says Dutton, 'is often continued right and left into dykes which extend far from the centre of eruption.'

A number of similar examples, in which a network of dykes is exposed beneath effusive masses might be cited. Here we will only mention those in which active agency of the gases, and the secondary results of this agency are visible.

In the course of about twenty years, subsequent to 1874 a long fissure opened up, during repeated eruptions, across the crater and all the upper part of mount *Aetna* (I, pp. 84, 177), and as early as 1883 Silvestri observed that as the fissure became wider, a greater quantity of gas escaped, and the activity of the mountain in other places was diminished by this discharge [1].

In the coal-mines of *Ostrau* the lower horizons present a large number of steeply-ascending fairly parallel basalt dykes; at higher horizons the miner can drive his levels without encountering them. Only at one locality, near Polnisch-Ostrau, does such a dyke, ascending through marine Tertiary sand, reach the existing surface. The basaltic injection, after rising upwards in the dykes for many thousands of meters, and on the way converting the coal for a short distance inwards into coke, then came to a full stop one or two hundred meters below the existing surface [2].

Geikie has described the manner in which the *Cleveland dyke* of Scotland remains, for a considerable distance, just under the surface; in places it seems as though its subterranean head followed the irregularities of the ground, although it has ascended from depths in which the thickness of the sediments alone amounts to 5,000 meters. As the dyke approaches the surface it sometimes thins out, so that while at some distance below the

[1] 'Perchè avendo esse (le materie vaporose) potuto trovare un immediato sfogo da estesa fenditura rimasta aperta, fecero rapidamente diminuire quella tensione necessaria a spingere al di fuori la lava di centri di dove avea incominciato a scaturire,' O. Silvestri, Sulla esplosione eccentrica dell' Etna arr. il 22 Marzo 1883, Acc. Gioen. Catania, 1884, XVII, 195 pp., maps, in particular p. 125; A. Riccò e S. Arcidiacono, L'eruzione dell'Etna nel 1892, R. Osserv. di Catania ed Etneo, 1904, I (in three parts, maps) et passim.

[2] The older known examples are recorded by J. Niedzwiezki, Jahrb. k. k. geol. Reichsanst., 1873, XXIII, pp. 283-288, map. A sketch of the details was presented to the members of the Ninth Geological Congress of 1903 by Director of Mines Dr. Fillunger in Mähringen-Ostrau. On the low temperature, Jičinksky in Monographie des Ostrau-Karwiner Steinkohlen-Revieres, 4to, Teschen, 1885, p. 11, figs. 3-7.

surface it may measure 24 meters; at about 100 meters higher it becomes only 6 meters, and then wedges out; sometimes it ends bluntly and suddenly[1] (fig. 51).

In the sapphire mines of *Yogo cañon*, Montana, a dyke of basic lamprophyre 3 to 6 feet thick ascends through limestone. Weed and Pirsson describe a spot at which this dyke fails to reach the surface and terminates abruptly. Its head, however, is converted, by the inclusion of more or less altered fragments of limestone and shale, into a breccia; it is in this that the sapphires are found[2].

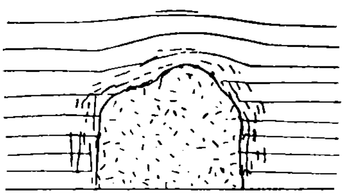


FIG. 51. *End of a basalt dyke* (after Teall).

In Ostrau, as in the Yogo cañon, indications of a high temperature are visible even in the upper parts of the dykes. Fig. 51 can only be explained on the assumption that a fissure existed, and that the parallel walls were forced asunder.

In Ostrau I was left with the impression that the injection of the dykes took place simultaneously and fairly equably. When it arrived at a point 100 or 200 meters below the existing surface an eruption may have occurred somewhere, which caused a general relief of pressure and a consequent cessation of movement. Possibly we may connect with this Geikie's statement that in the basalt dykes of Scotland a lateral movement of vesicles is indicated.

It is obvious that a whole network of dykes may be present in the neighbourhood of a volcano, and yet, owing to the relief of pressure brought about by the volcano, may fail to reach the surface. But the recognition of this fact does not advance us much, for the dykes which reach the surface may either represent fissures formed in the roof of an ascending batholite, or they may be fissures formed by faults; as regards the latter, however, especially when they are arranged in steps, the question still remains whether they may not have arisen by an after-subsidence of the magma. Such step-faults have been described in detail by Hibsch in the region comprised in sheet Priesen of the Bohemian basalt mountains[3]. The question is much more difficult of solution where undoubted tectonic disturbances occur beneath a volcanic region, as well as step-faults of

[1] A. Geikie, Ancient Volcanos of Great Britain, 8vo, 1897, II, p. 147 et seq.; J. J. H. Teall, Petrological Notes on some North of England Dykes, Quart. Journ. Geol. Soc., 1884, XL, pp. 209-246.

[2] W. H. Weed, Geology of the Little Belt Mountains, Montana, accompanied by a Report on the Petrography of the igneous Rocks by L. V. Pirsson, Ann. Rep. U.S. Geol. Surv., 1900, XX, 3, pp. 257 to 581, maps, in particular pp. 454-459 and 552.

[3] J. E. Hibsch, Geologische Karte des böhmischen Mittelgebirges, Blatt V; (Tschermak), Becke, Min.-petr. Mitth., 1902, new ser., XXI, pp. 465-590, in particular p. 469, map.

various ages. Such a case has been described in central France by Michel Lévy, Giraud, Boule, Glangeaud, and other observers [1]. In other cases two formations of a different nature are brought into close apposition, and the occurrence of volcanic rock on a tectonic boundary is undoubted, as in the Banat (I, p. 162, fig. 21); sometimes we have an inbreak as in the Lipari isles, sometimes great afferent paths of the first order, which become visible in long volcanic lines.

In addition to the various kinds of dykes just enumerated, there is yet another group of different origin. This includes dykes which are very long, parallel, and rectilinear, with smooth selvages, often of trifling thickness, and cutting across the strike of the formations. Examples of this kind were quoted in discussing passive injections; the bituminous dykes of Utah are typical. Diller found, in 1890, that certain dykes of sandstone in California follow the cleavage [2]. This, indeed, is the only adequate explanation. Neither explosion, folding, nor contraction, but only general pressure, possibly accompanied in places by a slight secondary torsion, is capable of producing parallel lines of this kind. No small part of Daubrée's diaclases must be referred here. Parallel volcanic injections of this kind are also known, and their connexion with the cleavage has long been recognized. In not a few cases parallel lodes must be included under this head.

A peculiar feature of these fissures consists in the fact that when they reach the boundary of another rock less suited for the formation of cleavage planes, they suddenly splinter out or come to an end. The German miner says 'the dyke smashes itself up'. Bituminous dykes behave in a similar manner [3].

South African funnels. South Africa affords examples of injection and explosion in most manifold variety.

The dolerite sills of the Karoo belong to an older phase of that widely extended process, the more recent phase of which is represented by the *diamond-bearing funnels.* On the north side of the Cedar mountains the sills reach the Atlantic Ocean; in the Great Kei they reach the Indian Ocean.

[1] Here we will only refer to M. Lévy, Bull. Soc. géol. Belge, 1890, 3e sér., XVIII, p. 700, fig. 3, and M. Boule, op. cit., 1893, 3e sér., XXI, p. 552, fig. 11; further to Giraud, Bull. serv. Carte géol., 1903, XIII, p. 397, fig. 97, and Glangeaud, Limogne, Sept périodes d'activité volcanique du Miocène inférieur au Pleistocène, C. R. Acad. Sci. Paris, 9 mars 1908.

[2] J. S. Diller, Sandstone Dykes, Bull. Am. Geol. Soc., 1890, I, pp. 411–442. We will not here enter into the question whether and to what extent torsion is responsible for the cleavage.

[3] As, for example, in West Virginia, Eldridge, The Asphalt and Bituminous Rock Deposits of the United States, Ann. Rep. U.S. Geol. Surv., 1901, XX, 1, pp. 209–452, maps, note 4, p. 236.

Still wider is the distribution of the funnels. One only is known in the folded mountains, not far from Heidelberg; it is younger than the Uitenhage series [1]. Even to the east of Rietfontein, more than 7 degrees of latitude to the north of Heidelberg, Cohen has observed the same mellilite-basalt [2], and diamonds are found even on German territory up to the neighbourhood of Lüderitz bay. Harger mentions funnels in the north-west as far as Damara land, and in the north-east even into the neighbourhood of the Zambesi [3]. The whole land, extending over about 16 degrees of latitude, must be regarded as a region of great gaseous eruptions. No other example is known which can even approach it in magnificence.

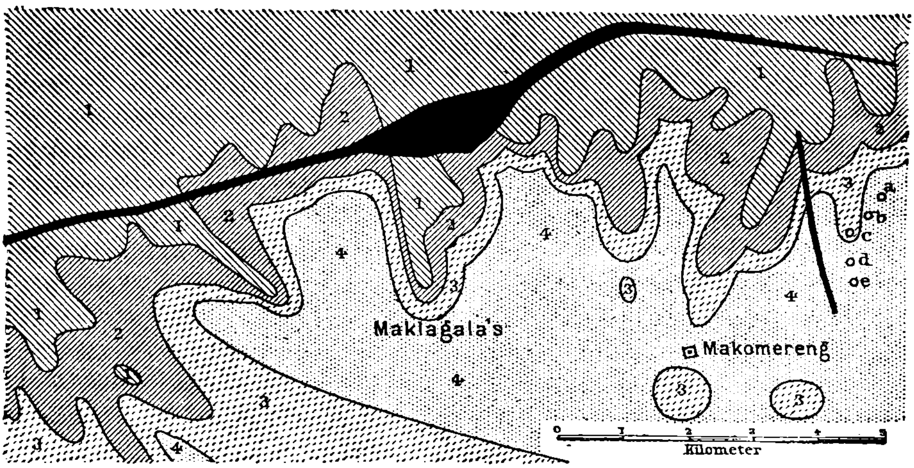


FIG. 52. *Dyke near Makomereng* (after Schwarz).
Black, Dolerite ; 1 to 4, Stages of the Karoo series ; a to e, small pipes.

Rogers and Schwarz conclude, as the result of their valuable investigations, that the dolerite sills are inclined on all sides towards the basin-shaped centre of the Karoo, or more precisely, *that they lie, towards the centre, in the deeper beds of the Karoo series.* This result is brought about

[1] A. Rogers and E. Schwarz, Ann. Rep. Geol. Comm. Cape of Good Hope, (1898) 1900, p. 62. On the Zuurberg a fault occurs accompanied by a dyke of mellilite basalt, also more recent than the Uitenhage stage ; Trans. S. African Phil. Soc., 1905, XVI, pp. 189–199. At a great distance from this point towards the north-west two other dykes occur in the folded mountains. Since ashes and flows are mentioned on the Drakenberg in cavernous sandstone (Rhaetic or Lias), the eruptions seem to have been of long duration ; cf. Du Toit, Trans. S. African Phil. Soc., 1905, XVI, a., pp. 53–70, map.

[2] E. Cohen, Mellilith-Augit-Gesteine und calcitführender Aplit aus Süd-Afrika, Tschermak, Min. Mitth., 1895, new ser., XIV, pp. 188–190. Cohen was one of the first to give a detailed description of the occurrence of diamonds.

[3] H. S. Harger, The Diamond Pipes and Fissures of South Africa, Trans. S. African Phil. Geol. Soc., 1905, VIII, pp. 113–115.

in one of two ways; either the sills cut through the beds at an acute angle, or a sill suddenly and abruptly enters a lower bedding plane. It is inferred that *the centre of the Karoo has subsided.* Rogers remarks that a true batholite has never been observed in the Karoo [1]. The various ascending dyke-fissures and eruptive centres are also affected by these general conditions.

In Matatiele, under the slopes of the southern Quathlamba, E. Schwarz has described 19 doleritic outbreaks, and in part also their connexion with the dykes. Fig. 52 represents one of these dykes, over 160 kilometers in length, and for the most part only 18 to 20 meters in breadth, but at one place it rapidly widens out. This is the lemon-shaped cross-section of an

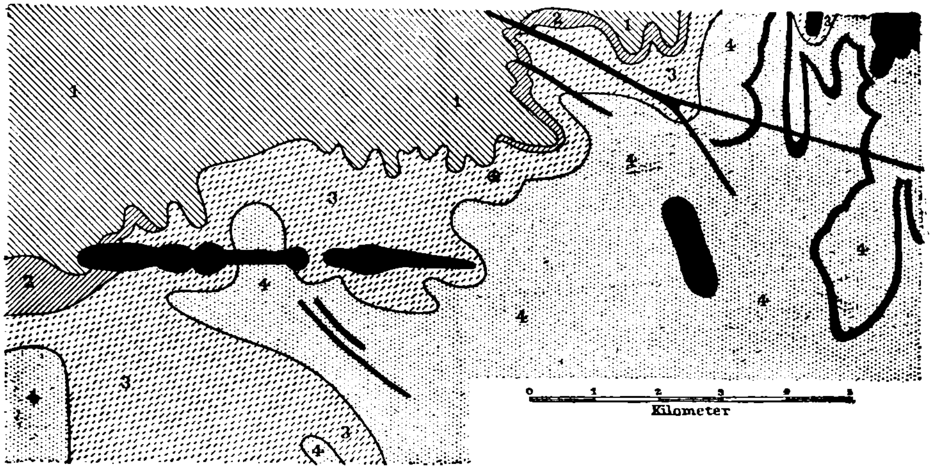


FIG. 53. *Interrupted dyke in Matatiele* (after Schwarz).

eruptive centre, which continued drilling has brought constantly nearer a circular form. A second dyke (fig. 53) is only visible for 6·5 kilometers; its thickness is very variable, but reaches 360 meters. It forms a high wall between two of the uppermost tributaries of the Umzimburu (St. John's river), and is broken up into conical peaks by weathering. Near its centre the dyke is suddenly interrupted, and the sandstone beds extend horizontally over it [2].

A little west of Sutherland (S.W. Roggeveld), Rogers and Du Toit

[1] Rogers and Schwarz, Geological Survey in the South Parts of the Transkei and Pondoland, Ann. Rep. Geol. Comm., (1901) 1902, pp. 25–46, map, in particular p. 30; Rogers, An Introduction to the Geology of Cape Colony, 8vo, London, 1905, p. 247; and Gouritz River, Trans. S. African Phil. Soc., 1903, XIV, p. 377 et passim.

[2] E. Schwarz, Geological Survey of Part of the Matatiele Division, Griqua Land East, Geol. Comm. Cape of Good Hope, (1902) 1903, VIII, pp. 11-96, map, in particular p. 48 et seq., 'Fissures of Eruption.'

observed a semi-circular dyke of mellilite-basalt 2 kilometers in length, split at one end, and at the other narrowing away along a line of disturbance (fig. 54, II). On the south the sandstone dips away from the dyke on both sides, but on the north only in places, and then only on the south side. In the angle of I a shaft was sunk in bluish grey tuff; towards the southwest we see a breccia of sandstone and schist; between the fragments the microscope reveals mica, augite, perofskite, and other minerals. At other localities a grey rock occurs, with numerous crystals of olivine, and bits of

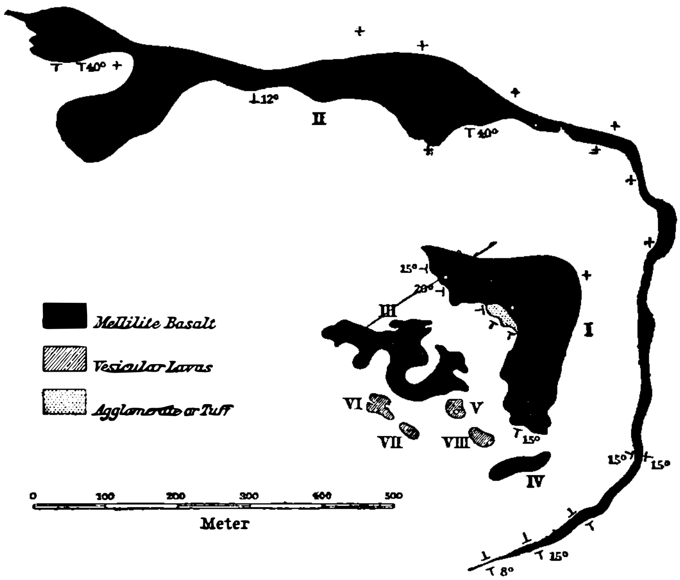


FIG. 54. *Intrusion of Mellilite Basalt near Sutherland* (after Rogers and Du Toit).

ilmenite, as in the diamond-bearing funnels; III and IV are mellilite-basalts: V to VII are imperfectly exposed, but certainly different from the others; they contain, in addition to many shards of sandstone and shale, only an extremely vesicular glass [1].

This case may possibly represent an attempt to form a crater. II may have been discharged through V–VIII.

We now approach the diamond-bearing funnels. They often traverse thick doleritic sills. Broadening towards their upper part, they attain diameters up to 300 and exceptionally even 685 meters. Many of the smaller funnels are lemon-shaped in cross-section [2]. Harger shows that

[1] A. Rogers and A. L. Du Toit, Ann. Rep. Geol. Comm. Cape of Good Hope, (1903) 1904, p. 43 et seq. The Sutherland Volcanic Pipes and their Relationship to other Vents in South Africa, Trans. S. African Phil. Soc., 1904, XV, pp. 61–83.

[2] See, for example, Hatch and Corstorphine, Geology of South Africa, 8vo, 1905, p. 290,

several hundreds of these funnels are scattered through South Africa. They appear to occur in groups, and many dykes are known besides, from 30 meters down to a few inches in width, which often contain diamonds but are not worth the trouble of working. They are frequently filled with harder rock, and sometimes broadening out suddenly, assume all the characters of the funnels. Thus we must conclude *that the diamond-bearing funnels are also connected with a network of dykes.*

Du Toit's description of the St. Augustin mine at Kimberley gives some idea of this connexion (fig. 55).

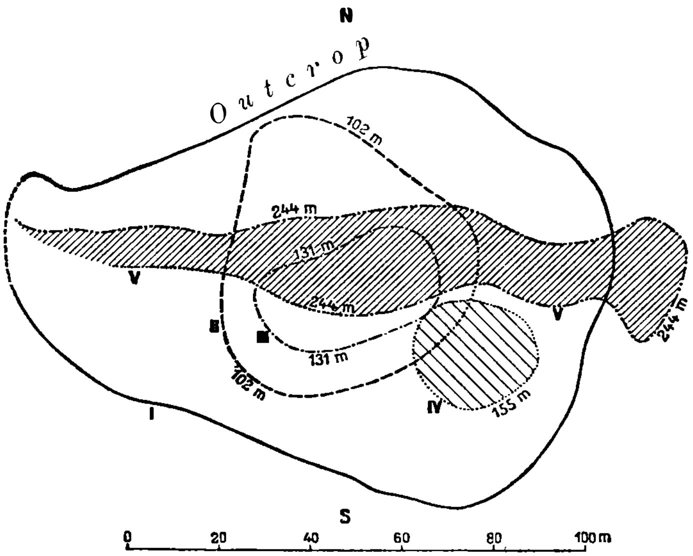


FIG. 55. *Saint Augustine mine, near Kimberley* (after Du Toit). Explosion along a crooked path proceeding from a fissure.

At a depth of 244 meters we see the fissure; between this depth and 155 meters the mixture of gases and diamond-bearing tuff, forcing its way upwards, found a spot, situated more than 20 meters to the south of the fissure, where it was able to bore its way through and explode. Where the perforation begins the fissure disappears (evidently owing to discharge), and at a depth of 155 meters (IV) it is seen no more. At a depth of 131 meters the axis of the perforation is displaced to the extent of over 30 meters; from this point onwards it ascends and becomes rapidly broader [1].

in particular Harger, Trans. S. African Geol. Soc., 1905, VIII, pp. 113-115, and numerous accounts by Graichen, Macco, Voit, and R. Beck, in Zeitschr. prakt. Geol., especially 1906 and 1907.

[1] Du Toit, Geological Survey of the East Portion of Griqua-Land West, Geol. Comm. Cape of Good Hope, Ann. Rep. (1906), 1907, XI, pp. 87-176, in particular p. 140.

We will not in this place enter into a detailed description of the composition of the kimberlite, the rock which fills the pipes. In spite of many points of resemblance with rocks which must be regarded as representing the great depths, a difference may yet be observed. Chromium plays only a subordinate part, and nickel is not mentioned. It is possible that the ilmenite which sometimes occurs here in great quantity may indicate an opposition between nickel and titanium similar to that which is observed in many iron ores, in some of the fixed stars, and in sun-spots. Titanium accompanies the great gaseous eruptions of the sun, just as it has accompanied here the greatest gaseous eruptions of the earth [1]. Among the many problems with which we are confronted in passing, this is one of the most fascinating.

The presence of diamonds is known at not a few places; they always occur in sporadically distributed deep-seated Sima rocks, and always in regions which have long been consolidated. One such locality is Ruby Hill, Dinoga, Murchison county, New South Wales [2]. In Borneo diamonds are found in peridotite. Widely scattered occurrences of similar rocks have already been mentioned in the United States, but they have so far yielded no diamonds.

In their typical form, as they occur in South Africa, the diamond pipes are indications of mighty gaseous eruptions which proceed from very great depths. They form an independent group among explosive phenomena.

Distribution of volcanos. The emission of gases does not take place so freely on the earth as in the sun, and has not advanced so far as in the moon. It is restrained by the lithosphere. Thereby it is brought under the control of definite circumstances, which admit of classification, with a remainder, it is true, of outstanding exceptions.

The distribution of volcanos does not follow the same plan in the Atlantic and the Pacific hemispheres.

In the *Atlantic region* we meet with (*a*) diffuse volcanic areas; (*b*) volcanos standing on disjunctive lines produced by tension; (*c*) volcanos collected in groups.

(*a*) An example of a *diffuse* volcanic area is afforded on the largest scale by the basaltic lavas, which extend from Greenland to the north of Ireland and cover a considerable part of North Siberia (IV, p. 261). It cannot be shown that this boreal region was ever simultaneously active

[1] E. Suess, Eigenthümlichkeiten einiger Himmelskörper, Sitzb. k. Akad. Wiss. Wien, 1908, CXVI, pp. 1555–1561.

[2] E. F. Pittman, Ann. Rep. Depart. Mines, N.S.W. (1900), 1901, pp. 180, 181, map. In Brazil different conditions prevail; cf. O. Derby, Am. Journ. Geol., 1898, VI, pp. 121–146.

over its whole extent. On the lower Tunguska the flows appear as early as the Permian flora, and further south they are younger than the existing valleys; in Franz-Josef Land they belong to the middle Jurassic; in the island of Disko, West Greenland, they range through the period of the lower and middle Cretaceous; in Ireland they are Tertiary; the active volcanos in Iceland and Jan Mayen are probably their last remains. Where they have been studied in detail, as in Scotland, these lavas are found to have issued from an extensive network of dykes. In Greenland they rest upon parts of Laurentia; in Scotland, Ireland, and the Faeröes upon the Caledonides; in Siberia upon Angara land and also upon parts of the Baikal vertex.

A second example is presented by the effusive sheets of the Deccan trap (I, p. 411). The date of these is supposed to lie nearly on the boundary between the Cretaceous and the Eocene. Their outliers extend from the Indian peninsula to the outer folded ranges of the Iranian chains of Sind, which form part of the periphery of the Asiatic system.

The sheets and deposits of the Karoo are of Permian and lower Mesozoic age; they are distinguished by the gaseous eruptions which followed them.

(*b*) The volcanos standing on *disjunctive lines* are represented in the African troughs. The troughs of the Rudolf-See—Syria, Tanganyika, and Kameroon are the most important. The fissures from which they proceed have been produced by tension, and the after-subsidence of the borders has given rise to the long horsts in the fault-troughs.

One of these lines, the Rhine trough, lies outside Gondwána land, in the midst of the western Altaides; but the direction is the same, and we must assume the existence of similar tensions.

It is worthy of note that in the panzer-horst of Iceland, also, the simple fissures show a tendency to pass into troughs.

(*c*) Examples of *groups* of volcanos are afforded by the Azores, the Canary isles, and the greater part of the Cape Verd islands. Isolated lines afford evidence that fissures exist in these islands also.

In the *Pacific* region we are acquainted with:

(*a*) *Diffuse* areas; these are only present where the boreal region encroaches from the north into Mongolia and the northern part of the ancient vertex. It is possible, however, that the Mongolian basalts belong to the next division.

(*b*) Volcanos on *disjunctive* lines. These play the principal part in the whole of the Pacific region, throughout the periphery of Asia, and in the Andine structure. The volcanic arcs of both groups of Antilles are also to be included under this head.

The observations made within the Oceanides are unfortunately very disconnected, and throw little light on the question of distribution.

So far as the relations of the lines of volcanos to the fore-troughs and the folding can be determined, they correspond to those recognized in Asia.

(*c*) *Grouped volcanos.* Between the Oceanides, Hawaii, and the west coast of America, we were able to distinguish a region in which, instead of Pacific arcs, only groups occur, such as the Galapagos and Easter island.

(*d*) The volcanos of the *Alpides* form a distinct group, even if judged only by their mode of origin. They present us with a combination of different characters; while the little range of andesite in the south of Styria, along with the great tonalite range of the East Alps, exhibits Andine characters, the Lipari islands, on the other hand, may be regarded as a typical example of grouped volcanos.

Although the above-mentioned subdivisions include by far the greater number of the Pacific volcanos, and especially the so-called 'girdle of fire', yet there are some isolated occurrences, both large and small, which are not embraced by this classification. Above all there is the volcanic range which extends across the general strike of the mountains from the Yellowstone park through the fluvial regions of the Snake and Columbia rivers. Then there are the volcanos which surround the border of the Colorado plateau; of these it is impossible to say (especially in the south-east, near the extremities of the Rocky mountains) whether or not they can be correlated, in a tectonic sense, with the volcanos of the Basin ranges. Further, we have the two peak-volcanos of the Caucasus, and Demavend on the south Caspian arc; the volcanos of Auvergne, which M. Lévy has brought into connexion with the syntaxis of the Armorican and Variscan folds; and within the latter the Eifel, and the basalts extending from the Vogelsberg to Bavaria and Bohemia. The youngest eruptions of these basalts lie close beneath the fracture of the Erzgebirge, and yet reappear in the east on the summits of the Riesengebirge, and may be followed further as far as Ostrau, where the dykes have been exposed by mining. To this group we must also refer the Euganaean mountains in the Dinarides; mount Vulture, situated, as an exception, on the outer border of the Apennines; and in the far east, the but little-known volcanos of Mergen (III, p. 118), not to mention others.

Neither the information nor the space at my disposal permits of a detailed discussion of all these exceptions. It will suffice to examine this remarkable phenomenon in its main features, and wherever possible to elucidate further the relations of the Atlantic to the Pacific hemisphere.

Volcanic lines. A consideration of the moon shows that direct melting down, i. e. complete absorption of the roof is the lunar form of volcanic action. With regard to the existing state of the terrestrial lithosphere three processes are in question: *subsidence, inbreak, folding,* and *rending.*

Inbreak, associated with shattering, must be distinguished from extensive subsidence more strictly than it has been hitherto.

We may recognize in the Lipari islands, if we share Hoffmann's view, three volcanic lines which converge towards the centre as so many radial fissures; or, if we agree with Bergeat, we may continue the two northern lines to form a curve—Ustica, Salina, Stromboli—parallel to the Calabro-Sicilian shore (Salina, Vulcano, Aetna remaining as the only radial line); but in either case this group of islands will still represent a fractured area in process of subsidence[1]. We say in process of subsidence, for since its seismic peripheral line has been described it has repeatedly been the scene of devastating catastrophes.

In the case of other volcanic groups observations on the periphery are lacking; they are for the most part islands. Shorter lines of volcanos are visible, for example in the Canary islands, and most of these groups are doubtless similar local areas of fracture, and sinking roofs of batholites.

The exceptional position of the Alpides, which often exhibit inner borders beset with volcanos, also leads us to suspect that the western Mediterranean consists of inbreaks. Here we have an instructive contrast. With the exception of the line from Hohentwiel to the Ries, and the whole divergent boundary between the Carnic range and the Alps, the borders of the subsidences in which the Alps took their birth nowhere exhibit younger volcanic formations, neither in those parts which belong to the Russian plain, nor in those which belong to the Bohemian mass or the Altaides or the Sahara. Yet more than this may be seen. The Variscan subsidences show marginal fractures which they have not themselves produced, but have availed themselves of, and rendered visible (IV, p. 30). This is true, for example, in the case of those Karpinsky lines which in eastern Bavaria become the marginal fractures of Variscan horsts.

The same relations, on a far grander scale, are manifest in the Indian Ocean (IV, p. 285). The Sahyádri fracture on the west side of the Indian peninsula extends through 12 degrees of latitude, and cuts partly through gneiss, and partly through the lavas of the Deccan, which are independent of it. All the east side of Madagascar represents an almost rectilinear fracture, extending through 10 degrees of latitude. Both these lines are devoid of volcanos. Still more striking is the coast of Syria, which lies so near the trough of the Jordan, and differs so greatly, in its rectilinear course, from the other Mediterranean coasts. It is unaccompanied by volcanos, as is likewise the south-eastern Mediterranean as far as Cyprus, Crete, and Malta.

Throughout this vast region there seems to be a latent tendency to

[1] I, p. 83, fig. 4; A. Bergeat, Die äolischen Inseln, Abh. k. bayer. Akad. Wiss. München, 1899, XX, 274 pp., maps, passim.

submeridional disjunction, which is both aroused and made use of, in some places by subsidences, and in others by rending, but not by both together.

The Red sea and the Arabian sea are fault-troughs and contain volcanos. The conditions on the Terror line are doubtless similar. In the west the Kameroon line runs transverse to the course of the coast and is clearly continued far into the sea.

The existence of such a latent disjunction in Africa has already been conjectured by French investigators, who have brought it into connexion with the submeridional strike of the Saharides. Isolated accounts certainly indicate that these mountains diverge in the south towards the south-west (almost in the direction of the Kameroon line), but our knowledge of South Africa does not at present support the supposed connexion with folding.

These observations acquire increased significance from the fact, that in the Pacific region, also, the volcanic lines are everywhere absent from the outer borders of the foredeeps. Even a subsidence to depths of 8 and 9 kilometers does not succeed in exciting a volcanic eruption in this region. It may be objected, that the foredeeps were sunk in ancient and long-consolidated forelands, which were little favourable to volcanic activity, but the African fractures have awakened numerous volcanos in ancient land of precisely this nature.

Local inbreak, Oceanic subsidence, and linear disjunction are thus different and independent phenomena. We have several times remarked that the contraction of the earth resolves itself into a radial (sinking) and a tangential (folding) element. The Oceanic abysses and likewise the foredeeps are the expressions of the radial element, i. e. of the subsidence; not brought about by internal cavities, but by a diminution of the planetary volume.

The Oceanic subsidence resolves itself, more or less after the plan of the stresses in an asphalt pavement, into isolated, elongated arcuate fragments. Contraction has left the outer and in part sedimentary covering of the earth in excess. The tangential force carries this excess, in arcuate folds, into and over the subsided foredeep. The arcs encounter one another in linking or syntaxis. The movement increases; under the stupendous pressure the folds are urged on; they overturn; possibly also listric planes are produced. Finally backfolding sets in.

In all these processes the upper parts of the lithosphere play a passive rôle. Through the contraction of the deeper parts they are carried forwards, folded and overthrust. The stratosphere, and a considerable part of the Sal envelope do not fold themselves, but *they are folded*. But this outer part of the planet also exhibits a process peculiar to itself, it *rends asunder*.

That this rending takes place from above downwards has already been stated in describing the African fractures. This is very clearly shown by the relation of the rents to the folding. In East Africa and in Syria the direction of the fault-troughs is most probably independent of the folding. In the Rhine trough it is certainly so. Equally certain, on the other hand, is its partial dependence on the strike of the folds in the greater part of Asia.

The innermost parts of this vast continent are traversed by disjunctive lines which for long distances run with the strike of the folds, and in others diverge from it, yet taken together they give rise to a configuration which corresponds on the whole with the disposition of the folds. Frequently they produce disjunctive troughs along which porphyrites with tuffs and breccias, basalt and various other eruptive rocks occur. Two recent cones of loose scoriae and lava rise on the Vitim. The Cis-Baikal range owes most of its existing form to these disjunctions. Three disjunctive troughs cross the Selenga. Lake Baikal itself seems to consist of two of these troughs united, and all the elongated subsidences and horsts of the Dsapchyn which issues forth from the valley of the Lakes, and those of the horst of Altain-Nuru up to the trough of Ljuk-tshun have originated between lines of this kind. In the west the case is similar. The autonomy which such lines present in isolated cases may be seen most clearly in the trough of the Ebi-nor, which cuts across the Dsungarian Ala-tau.

Such influence exerted by folding upon disjunction, even if only partial, can be comprehended only on the supposition that the folding movement occurs at the same time. That the island festoons were originally accompanied by rectilinear volcanic fissures, and that they were converted into arcs by the folding is an impossible assumption. Since the volcanic lines always occur within the forefolding, they find themselves at the same time in the place to which the folded series asserts the chief claim. But they are not produced by the folding; they recall rather the resolution of superficial stresses in the asphalt, and their autonomous continuations betray their independence.

They are simple lines, and sometimes no doubt there may be two parallel lines (e. g. Ecuador), or these may be joined by other lines (e. g. western Java). Between these lines troughs arise, in which, or on the border of which, stand volcanos, as, for example, the Wrangell group, the Aleutian volcanos in Cook inlet, those in the Fossa magna of Honshiu, possibly also in Mindanao. The arcs of volcanos stand without exception in the zone of forefolding from Wrangell to Santorin, and they always remain independent of the foredeep. The autonomy of the disjunction finds expression in the prolongation of the line of the Kuriles across the strike of Hokkaido, and in the entrance of the volcanos of Liu-kiu, into southern Kiu-shiu.

The same situation recurs in the Intermediate range of America and in the Andine structure. Volcanos and troughs united extend through the Basin ranges, Mexico, and the Andes. The northern Antilles show the same arrangement as the peripheral arcs of Asia. But where the influence of the folding diminishes, the resemblance to Africa increases. The volcanos of Omotepec and Madera in the trough of the lake of Nicaragua may be compared with the volcanos of Höhnel island in the trough of the Rudolf-See, and also to the Kaiserstuhl in the Rhine trough.

The volcanic lines of the island festoons and the disjunctive lines of Central Asia are identical phenomena.

This fact, however, could not be recognized before the Central Asiatic lines were known. It was not understood how two opposed processes such as folding and rending could arise side by side. Originally we regarded the arcs of volcanos as the fractured borders of vast subsidences (I, p. 457). Subsequently Ferdinand von Richthofen was so impressed by the contrast between folding and rending that he attributed a divergent structure to island festoons in general. In the last of his comprehensive works on this subject he maintains that the island festoons have indeed the resultant form in common with the Alpine type, but differ from the geogenetic standpoint.

On the one hand, we see in the Alps an overwhelming of a foreland—usually a subsided foreland—as the result of a force directed outwards; in the island festoons, on the other hand, we see a tendency to a retreat of the foreland, and a rending on the other side of the outer border [1].

Rothpletz, a year earlier, regarded the troughs as evidence of dilatation, and supposed that volcanic action proceeds continuously over the whole earth, while folding only occurs periodically, and he thought that in this way the conflicting views on the dilatation and contraction of the earth's body could be explained [2].

The preceding analysis of the arcs has shown, however, that the main features of the structure of the island festoons are repeated not only in the Aleutian islands and the Antilles, but also in the Burman arc, and in the marginal arcs as far as the Adriatic. They are separated in time just as little as they are in space, and it is generally admitted that the young mountain ranges display the most active vulcanism. Yet it is hard to understand how the ascending course of the lava can maintain its existence in a folding range.

There are two solutions to this problem. The first applies when the disjunction is turned aside into the direction of a thrust-plane, or at least

[1] F. von Richthofen, Geomorphologische Studien aus Ost-Asien, IV and V, Sitzb. k. preuss. Akad. Wiss. Berlin, 1903, p. 872.

[2] Rothpletz, Ueber die Möglichkeit, den Gegensatz zwischen der Contractions- und der Expansionstheorie aufzuheben, Sitzb. k. bayer. Akad. Wiss. München, 1902, XXXII, pp. 311-325.

follows this direction on the whole, apart from possible divergence at its autonomous ends. This case is not improbable in itself, for the strike of the disjunction alone shows the great influence of the tangential movement. The disjunction may, it is true, become broken up, as it approaches magmatic depths, into a girdle of fine cracks. Some of these may offer a path to the juvenile gases, and be bored out, not along their whole length, but in favourable places, to form volcanic pipes, as along the Laki fissure in Iceland. Thus, a long, linear series of eruptive centres may arise, the connexion of which, at some depth, is beyond doubt, but which can only be recognized at the surface by the serial arrangement.

A second tentative solution is suggested by the transverse crevasses of glaciers. These, with steep, straight walls, cut through the viscous, moving mass of the ice. They are carried along for some distance with the ice, bend more or less into its arcuate strike, and finally close up, while fresh crevasses arise in the old place. They hold their ground by repeated renewals.

There are some volcanos which are not stationary but wandering. In so far as this wandering points to a decrease of activity, as in the case of the gradual restriction of the Phlegraean fields, or to an elongation of the volcanic line, as in Hawaii, it may be left out of account. But in the arcs themselves indications occur of a lateral displacement both on a large and small scale. The tract of rhyolite and dacite, characterized by silver-tin lodes, which extends through six degrees of latitude, from lake Titicaca to Argentina, lies to the east of the line of the Andine volcanos, and, judging from the direction of the folds, in front of them. In the West Indies, the zone from Anguilla to Desiderade lies, with its older lavas, outside of and in front of the active volcanos. In Sumatra the case is probably the same (I, p. 457)[1]. In the Aleutian islands, on the other hand, the volcanos Bogosslowsk and Grewingk have arisen within the arc, as though a new parallel line were about to be formed.

Among the volcanos of Central America, transverse lines are recorded by Dollfuss and Montserrat, along which the volcanic activity appears to approach the main line in the direction of the adjacent sea. The most northerly line, that of Chiquimula, offers an exception. In later times, owing to the eruption of the volcano of Santa Maria this most northerly line also appears to have conformed to the rule (IV, p. 454), but the existence of other transverse lines has been rendered doubtful, since Sapper mentions new eruptive centres between them. Sabatini conjectures that a similar displacement in the direction of the sea may be perceived in several of the Roman volcanos[2]. The transverse line of Ixtaccihuatl-Popocatepetl in Mexico shows clearly a movement of approach to the principal line

[1] Volz, Sitzb. k. preuss. Akad. Wiss. Berlin, 1907, p. 139.

[2] V. Sabatini, Vulcano Laziale, Mem. Carta geol. ital., 1900, XI, 392 pp., map; cf. note to p. 32.

(IV, p. 440). Jensen describes an example of displacement along transverse lines, on a smaller scale, in the trachyte mountains of Queensland [1].

In this connexion we may also refer to a fact already mentioned in discussing Kamchatka and the Aleutian islands, namely, that within the principal zone (with the exception of some closely adjacent points such as mount Bogosslovsk) a large number of extinct, but no active volcanos occur. None of these circumstances, however, afford any evidence as to the renewal of the volcanic fissures, such as occurs in the case of the crevasses of a glacier. The recurrence of the crevasses is produced by a constant cause, as a rule by a sudden increase in slope of the rocky floor; as to whether anything corresponding to this might be operative beneath the folding, whether it might be produced by a displacement fissure of the kind illustrated by the lines in pl. IV, whether, indeed, it is physically possible at all, we are not in a position to judge.

The numerous blocks of diorite which have been ejected by Bogosslovsk of late years, and the large number of amphibolite blocks ejected by Santa Maria de Chiquimulo in 1902, certainly point to actual displacement of the funnels, but if we turn from isolated examples and take a broader survey the manifold variety of the phenomena becomes apparent. On one line only isolated eruptive centres have been formed, recalling the row of borings made by the Eskimo in a reindeer's antler preparatory to splitting it; on another line an elongated batholite is exposed; on a third the crust is cut through by long parallel fissures and let down in troughs, which may or may not be occupied by volcanos. In those places where such troughs lie outside the younger folding, as in Africa and Central Asia, there is no clear evidence of volcanic displacement, although in Central Asia the lines are bent in the direction of the folding. In both regions there are also troughs without volcanos, such as the district of lake Tanganyika, lake Baikal, and the subsidence of Ljuktshun. That in the younger folded regions injection may proceed from the sole is shown, for example, by the occurrences on the upper Indus and the band of Ivrea. It is highly probable that the bands of amphibolite which occur in the north along the Caledonian overthrust are similar injections, and that the olivine gabbro of Sulitelma, for example, finds its continuation in the amphibolite of the Tarrekaisse and the Sarjek, that is to say, in the zone of overthrusting [2].

[1] H. I. Jensen, Geology of the Volcanic Area of the East Moreton and Wide Bay District, Queensland, Proc. Linn. Soc. N.S.W., 1906, pp. 73–173, maps, in particular p. 97 (the place lies between lats. 27° and 28° S.).

[2] H. Sjögren, Om Sulitelma-området Bergarter och Tektonik, Geol. Fören. Stockh. Forh., 1896, XVIII, pp. 346-376, in particular p. 361; P. I. Holmquist, En geologisk Profil öfver Fjellomradena emellan Qvikkjokk och Norska Kusten, op. cit., 1900, XXII, pp. 72–104, 151–177, and 232-272, in particular p. 255, map; Hamberg, Om fasta bergets geol. inom Sarjektrakten, op. cit., 1901, XXIII, pp. 18-23, further p. 26; for similar occurrences see, in addition to the works of Vogt already mentioned, in particular

Where, however, the sole lies as flat as in the latter case, it cannot at the same time have been the path followed by eruptions. Here again nature is not cast in one mould.

While in the range of Ivrea the voluminous injection which followed the direction of the folding (opposed to the direction of the Dinarides), and the occurrence of nickel ores, points to the proximity of the funnels; in the east, on the other hand, the tonalite band shows that a zone of disjunction was present close to the boundary, separating the Alps from the Carnic mountains and the Dinarides, and that this zone was subsequently affected by an overthrust from the south. The long parallel range of granitite, which accompanies the tonalite, and further west the fractured area of Lienz, are doubtless indications of this disjunction. The whole tonalite zone has been overturned subsequently towards the north and converted into tonalite gneiss. This movement, however, does not mark the termination of the volcanic processes, for the andesites of South Styria, which we regard as the continuation of the tonalites, are more recent than the movement. We are still, however, far from completely understanding this process, since far to the north, on the Wolfgang-see, blocks of tonalite (and gabbro) occur which, to all appearance, have been transported in the Werfen shales, and consequently on the East Alpine sole, which lies tectonically lower than the Dinaric sole.

Let us examine another example.

At the time of the deposition of the Kenai stage, Cook inlet formed a trough, and enclosed a freshwater lake; later on subsidence occurred; Tertiary folds on the eastern sea-border may be taken to show that the zone of the mountains lying outside the trough was moved independently. On the other side of the syntaxis the St. Elias mountains and the Rocky mountains diverge far apart, and the greatest cicatrice of the earth, the granodiorite of Columbia makes its appearance between them. By carrying von Richthofen's theory a little further we might assume an extensive movement in the Pacific direction (approximately the line *fae*, IV, p. 503), in accordance with the conjecture that a movement of segments occurred along the African fissures to the east of Ankober. There are so many problems and difficulties connected with these questions that it would scarcely be profitable to pursue them further at present.

Atlantic and Pacific lavas. The fact that, with the exception of the riven continent of Africa, none of the ancient forelands, neither Laurentia nor Brasilia, nor Angara land nor Australia possesses active volcanos remote from the sea has long since attracted attention. In North America in particular, geologists have occupied themselves with the contrast between East and West. The classification of the dislocations upon which volcanos are seated, given by M. Lévy in 1898, also distinguishes in the first place

C. F. Kolderup, Labradorfelsen des westlichen Norwegen, Bergen's Mus. Aarbog, 1903, no. 12, 129 pp., map.

between those in folded and those in unfolded land[1]. That there is a regional difference in the lavas, however, was not known.

In 1902 Becke published the surprising observation that two types are to be distinguished in recent volcanic rocks, and that regions which in the main are folded tangentially belong to the one (Andes type), while regions with dominant radial dislocations (segmental fractures) belong to the other (type of the Bohemian Mittelgebirge)[2].

A few months later, in 1903, Prior arrived independently at the same conclusion, as the result of his investigations of east African rocks[3], and in the same year, 1903, Becke's more detailed work on this subject appeared, in which these two types are distinguished as Pacific and Atlantic.

Thus there is a tephritic or Atlantic, and an andesitic or Pacific series. The Atlantic series is characterized by the greater quantity of alkalies, especially sodium, while in the Pacific series the alkalies diminish and calcium and magnesium occur in greater quantity. The ultra-basic magnesian rocks (i. e. Crofesima) appear to be common to both series. Both also possess acid members.

According to existing observations, the tephritic series is found in the Atlantic Ocean, Africa, Antarctis, and parts of Europe. It predominates within an arc drawn from Tristan d'Acunha through Trinidad, Fernando Noronha, Ascension, the Cape Verd islands, Teneriffe to Pantelleria, Aden, and Madagascar. All the African fractures, the isolated outcrops on lake Tchad and Schari[4], and the Transvaal belong to it. In the south it includes Kerguelen, the Gaussberg (according to Philippi), Cape Adare, and South Victoria Land. Prior thinks that Dunedin in South New Zealand must be referred here, but not the northern island.

To the north of the Mediterranean this group includes the Bohemian Mittelgebirge, Rhone, Vogelsberg, Eifel, Höhgau, the Kaiserstuhl in the Rhine trough, and further north the Inner Hebrides, Faeröes, and Iceland.

The Siebengebirge on the Rhine, the Gleichenberg in Styria, Predazzo, and Auvergne are doubtful; either rocks transitional between the series occur, or there are differences of opinion as to their interpretation.

The Pacific, andesitic series occurs in Santorin (Dinarides), the Carpathians, and in the andesites at the eastern end of the tonalite zone

[1] M. Lévy, Sur la coordination et la répartition des fractures et des effondrements de l'écorce terrestre en relation avec les épanchements volcaniques, Bull. Soc. géol. France, 1898, 3e sér., XXVI, pp. 105–121.

[2] F. Becke, Verh. Ges. deutsch. Naturf. und Aerzte zu Karlsbad, 1903, 2. Theil, Protok. d. naturw. Abtheil. vom 22. Sept., pp. 125–126. [This was first pointed out by Harker, Science Progress, 1896, vol. vi, pp. 12–23.]

[3] G. T. Prior, Contribution to the Petrology of British East Africa; Comparison of volcanic rocks from the Great Rift Valley with rocks from Pantelleria, the Canary Islands, Ascension, St. Helena, Aden, and Abyssinia, Min. Mag., 1903, XIII, pp. 228–263, and Nat. Antarct. Exped., I. Geol., 1907, p. 122 et seq.

[4] Gentil et Freydenberg, C. R. Acad. Sci. Paris, 17 févr. 1908.

of the Alps. Vesuvius and the Phlegraean fields are assigned by Becke to the tephritic series.

All the coasts of the Pacific Ocean—from New Zealand to Java, Alaska, and all the western coast of America belong to the andesitic series. Where the northern Antilles advance into the Atlantic region the andesitic rocks advance with them. Lacroix points out the affinity between the volcanic rocks of the Lesser Antilles and the rocks of Ecuador and South Columbia studied by Küch. On the other hand, tephritic rocks are known in the tableland of Texas.

Tephritic rocks also prevail in the eastern part of the United States, whereas in the west, as we have seen, andesites occur. The rocks of the laccolites and sheets to the east of the Rocky mountains in Montana are regarded by Becke as a peculiar development of the tephritic series.

Although many important points still await investigation, yet the results already obtained are so comprehensive that we do not hesitate to accept the proposed designations, and to recognize the tephritic as the Atlantic and the andesitic as the Pacific series. Becke even goes a step further, since he regards these designations not merely as geographical but as indicative of two regional types, the one connected with inbreaks due to radial contraction (tephritic, Atlantic) and the other with folding by tangential thrusting (andesitic, Pacific)[1]. Many facts may be cited in favour of this view, as for example the advance of the andesites into the Antilles, and in contrast, the occurrence of tephritic rocks in Texas, or again, the entrance of the andesites into the Aegaean sea, the Carpathians, and parts of the Alps. Even the tephritic nature of the rocks in the surrounding neighbourhood of Naples is in accordance with the supposed existence of an inbreak at this locality.

The island of Java, as described by Verbeek and Fennema, affords an instructive instance. The volcanic zone is formed by 116 volcanos, all of considerable size. In addition to this zone there exists a region of limited extent characterized by tephritic leucite lavas (III, p. 261). It is formed by five volcanos situated along the north-east coast and on the adjacent island of Bawéan, and extends, according to the latest accounts, through Saleyer into south Celebes. At the same time an important abyss (— 5,121 meters) occurs in the sea of Flores to the south of Saleyer and the small adjacent islands (also leucitic), and separates them from the leucitic volcanos in Bawéan and Java. Thus it seems possible to distinguish the boundaries of an Atlantic region, the existence of which is also suggested by the older rocks of the Karimoen islands; yet within this region stands the volcano of Lourous, one of the leucitic cones of the north-

[1] F. Becke, Die Eruptivgebiete des böhmischen Mittelgebirges und der americanischen Anden. Atlantische und pazifische Sippe der Eruptiv-Gesteine, Becke, Min.-petr. Mitth., 1903, XXII, pp. 209–265.

east coast, which in a comparatively late eruption poured out hornblende andesite, the Pacific rock of the principal zone [1].

This may be a boundary phenomenon; nevertheless it points to a comparatively sharp separation of the two rocks below the surface.

We have already alluded to the tephritic nature of the Terror volcanos as a reason for assigning South Victoria Land to the Atlantic hemisphere, and Gourdon has called attention to a block of alkali-rich granite on the island of Wandel which he regards as an erratic in an Andine region [2]. Future research will show whether it is an indication of the Atlantic foreland. The confirmation of the tectonic and petrographical results is mutual. We may regard the tephritic nature of the Atlantic islands as testifying to the organic unity of the Atlantic coasts, and in like manner the andesite rocks in the Carpathians and Alps as an indication of their connexion with the Asiatic system.

Becke's hypothesis rests on the assumption that in the funnels of the Pacific volcanos a very considerable consumption of sedimentary rocks occurs; this would explain the large amount of calcium and magnesium contained in them. The following observations may also be considered in this connexion:—

In the Atlantic hemisphere rigefaction must have made particularly rapid progress during the later periods. Towards the close of the Carboniferous the western Altaides were folded across the Ocean, and the folding of the Cape mountains must have continued into the epoch of the lower Trias. After this time, however, no important folding occurred from the Ganges to cape Horn. In the middle of the Tertiary aera rigefaction was already so far advanced that the Rhine trough opened up obliquely across the Variscan strike. In Laurentia rigefaction is much older still, and in the Sahara it dates at least from the upper Silurian.

Thus the question arises whether the diminution of calcium and magnesium in the Atlantic hemisphere may not stand in some connexion with the progress of consolidation (IV, p. 547). We may also inquire whether it was the subsidence of the Altaides (an event anterior to the posthumous building up of the Alpides) which gave rise to the Pacific rocks, while at the same time Atlantic rock made its appearance in the foreland. But as Becke justly observes, we have first to determine whether this distinction between Atlantic and Pacific rocks can also be recognized in the earlier eruptive epochs.

[1] R. D. M. Verbeek et R. Fennema, Description géologique de Java et Madoura, 2 vols., 8vo, Amsterdam, 1896, atlas, p. 986 et seq., p. 1015; and Verbeek, Rapport sur les Moluques, 8vo, Batavia, 1908, 844 pp. and atlas, in particular pp. 772, 773. The latter very comprehensive work came to hand too late to be made use of in the preceding chapters.

[2] Gourdon, Expédition Charcot, Géogr. phys. etc., p. 208.

CHAPTER XVII

THE MOON. HYPOTHESES. RETROSPECT

The moon. Lunar and terrestrial sea basins. Separation of the moon and its consequences. Isostatic compensation of mountains. Compensation of continents. Compensation, in general. Contraction of the earth's body. Retrospect.

The moon (see pl. V). The satellite which accompanies our planet is a fragment of our planet itself. The elevations on the moon probably reach a height of 7,000 meters. This measurement is obtained from the steep interior slopes of Casatus and Newton, situated on the southern limb of the moon. The shadow which descends into the crater of Theophilus reveals a precipice of 5,500 meters; the peak of Huyghens in the lunar Apennines rises to as great a height. Colours may also be recognized, dark spreads of lava in the Mare Crisium, Mare Tranquillitatis, and elsewhere; spots also of dazzling whiteness, such as Aristarchus; long white rays, such as proceed from Tycho, Copernicus, and others.

If we would attempt to compare the earth with the moon we must first remove from it not only the atmosphere which breaks the brilliance of the sunlight, but also the masses of Polar ice, the snow fields of the high mountains, the prairies and forests, the soil, and finally all the waters of the Ocean and all the features consequent on erosion and abrasion. Its bare face shows at once how accustomed we are to compare the relative heights of the earth with the absolute heights of the moon. The heights of the moon may descend more steeply than those of the earth; but they are not more considerable.

Let us now imagine ourselves ascending from the deepest abysses of the Oceans to the highest mountain summits, and let us follow at the same time the figures published by H. Wagner[1]. When in our ascent we have reached a level of – 4,000 meters, 39 per cent. of the surface of the lithosphere already lies below us. At a level of – 3,000 meters, 52 per cent.; that is, more than half the planetary surface lies lower than – 3,000 meters. When we reach the sea-shore we have left behind 71·8 per cent. of the surface. Only 28·2 per cent. forms dry land, and of the entire surface of the planet only 6 per cent. lies above a level of + 1,000 meters So trifling is the total surface of the mountains as a whole, while that of the high mountains alone is more trifling still.

[1] H. Wagner, Lehrbuch der Geographie, 7th ed., 8vo, 1903, I, p. 254.

The morning sun shines far below us over the coast of North Chile, where the watershed of Atacama rises almost 13 kilometers above the exposed abysses. From the summit of Llullaico the height is more than 14 kilometers, but the abysses are too remote to show the whole length of the shadows cast by the mountains, nor in the early light can we discern the boundary between the abyss bordering the coast and the sea floor which overlooks the abyss. Above the sea floor rise hundreds of islands arranged in curves, some of them considerable masses, others like slender turrets, and yet others more slender still, almost resembling minarets. These are 4 to 5, in one case (Guam) more than 9 kilometers high, and as the day advances their shadows move beneath our eyes as if cast by the gnomons of so many gigantic sun dials. In the north a dark spot is visible, the basalt field of the Snake and Colorado, and while, filled with astonishment, we contemplate this spectacle, twilight sets in, and further north a white spot stands out in southern Alaska. This extends from lat. 60° 44′ N., long. 138° 30′ W. (O'Connor glacier, north side of mount St. Elias) into the valleys of the lower Pelly, lower Lewes, and White river, and finally almost to lat. 64° 30′ N. and long. 141° W. (Forty Mile district in the region of the Yukon). This spot represents the white ash probably derived from the volcano of Na-taz-hat (about lat. 61° 30′ N., long. 141° 30′ W.)[1]. Before night descends the shadow of Fusiyama shows a height of 11 kilometers.

All the laborious and conscientious efforts made by Mädler, Julius Schmidt, and other distinguished investigators to represent the surface of the moon by drawings have been surpassed by the achievements of photography. In particular the Atlas of the Moon, containing photographs by Loewy and Puiseux, and published by the Paris Observatory, affords a rich store of information[2]. In addition we have the series of photographs by the Lick and Yerkes observatory, published by the Smithsonian institution, with descriptions furnished by Shaler[3]. In this place reference will

[1] IV, p. 400; also Brooks, Ann. Rep. U.S. Geol. Surv., 1900, XXI, 2, p. 365. Schwatka first observed the ash as a white streak in the forest soil. At many places it is only an inch to a foot thick; towards the Skolai range it reaches a thickness of 100 feet.

[2] M. Loewy et P. Puiseux, Atlas photographique de la Lune, publié par l'Observatoire de Paris, 1896; so far 59 maps, folio, and 9 parts of text. Unfortunately M. Loewy did not live to see the completion of this beautiful work. The views expressed above on melting up and lunar volcanic activity were first published by me in 1895 (Einige Bemerkungen über den Mond, Sitzb. k. Akad. Wiss. Wien, CIV, pp. 21–54). They were adopted as regards essential points by M. Puiseux (La Terre et la Lune, 8vo, Paris, 1908, 176 pp., maps, in particular p. 139). On the other hand, subsequent observations have convinced me that as regards the rays of Tycho, &c., the theory of Loewy and Puiseux is more correct. Several figures from this atlas are given by F. Sacco, Essai schématique de Sélénologie, 8vo, Turin, 1907, 47 pp. It is impossible to give a list of all the recent literature.

[3] N. S. Shaler, A Comparison of the Features of the Earth and the Moon; Smithson. Contrib., 1903, XXXIV, 79 pp., 25 maps.

be made to some special points only, and first of all the volcanic phenomena.

Great smelting furnaces. The so-called seas of the moon are for the most part insunken plains of consolidated lava, with a regular round or oval outline and fairly sharp boundaries; sometimes, however, they overflow into neighbouring depressions, as is particularly well seen on the margin of the Mare Humorum, where the lava of this 'sea' flows away into several older craters and almost submerges others. The crowding together and confluence of the circles may, it is true, give rise to comparatively irregular outlines, but a number of typical cases, such as the ellipse of the Mare Crisium (570 and 450 kilometers) or the Sinus Iridum (215 kilometers) as it opens into the Mare Imbrium clearly show the normal form. In the Mare Nectaris, Loewy and Puiseux distinguish five subsidences in succession, with a total fall of several thousand meters. Where two contours intersect, wedge-shaped horsts are formed. Such are cape Heraclides and cape Laplace on the boundary between the Sinus Iridum and the Mare Imbrium, and on a larger scale the Apennines and Carpathians between the Mare Imbrium and the almost circular Mare Serenitatis.

The terrestrial batholites show us how a heated mass in the interior of the earth may, if the heat is continually renewed, approach the surface by melting its way up. If it reaches the surface, then, as we see in the moon, a lava plain is formed, the outline of which, owing to the comparatively small diameter of our satellite, must approximate to a conic section. The regular peripheral subsidence-fractures which surround the Mare Humorum at some distance from its margin, and other similar examples show, however, that in some cases the circular subsidence extends beyond the surface of the lava.

Such very considerable melting-up of the moon's substance shows us also how widely nature departs from any regular course of cooling. The renewed occurrence of high temperatures in regions which have already solidified is frequent in the history both of the earth and the moon, and we do not know whether the consolidated outer envelope of the earth may not be exposed, even at the present day, to similar attacks from within.

Circular ramparts. These are smaller smelting furnaces, and are seen most clearly in the face of the moon. In the midst of a gently rising, or even perfectly level surface, a vast abyss opens up, with steep, often terraced, walls, descending in many cases to a depth of several thousand meters. At the bottom lies a consolidated lava lake; frequently the first subsidence has been followed by a second, third, sometimes a fourth, and exceptionally even by a fifth. The lake sinks deeper and deeper, almost always becoming smaller at each descending stage, and at the last, when it has become smallest, it may lie more than 5,000 meters beneath the surrounding surface.

Loewy and Puiseux justly regard the Sinus Iridum as a connecting link between the seas and these smaller and more sharply defined smelting furnaces, some of which, such as Clavius, for example, still attain a diameter of 228 kilometers. With equal justice Dana compared them as early as 1846 to the volcanos of Hawaii, and Pickering has published a series of instructive photographs of these terrestrial volcanos which were taken for the special purpose of comparison with the moon[1]. In Hawaii the lava lake of Mauna Loa lies on the summit of a gigantic mass of lava which rises 4,175 meters above the sea-level, or 9 kilometers above the sea-floor, and slopes gently down on all sides. A few lunar volcanos, and in particular Wargentin, have had force enough to drive their lavas upwards till they overflowed the margin of the pipe. It is clear that, if the number of these lunar volcanos had been less and the force more considerable, their repeated overflow would have produced mountains of a similar kind to those of Hawaii.

At the same time it must not be forgotten that beside the lofty Mauna Loa there stands the much lower Kilauea (1,280 meters), which also bears a lava lake, and that with a distance between them of little more than 30 kilometers the difference in height between the two lakes of glowing lava amounted, at the time of Dutton's visit in 1882, to not less than 2,834 meters[2].

In the case of terrestrial volcanos, the margin of a comparatively large crater is not seldom surmounted by a younger crater which is almost always smaller; this *rides* upon the edge. Thus in the Phlegraean fields the crater of Agnano rides upon Astroni. In the Albanian mountains the crater lakes of Nemi and Albano are seated upon the border of the crater of Tusculum. The lake of Bolsena is surrounded, according to Moderni's investigations, by four craters, each of which has an independent history; they surround traces of eighty-nine pipes (including doubtful cases). Within the immediate surroundings of the lake of Bracciano, Moderni has counted fifty-two of these pipes[3].

[1] Loewy et Puiseux, Atlas photographique de la Lune, II, p. 54; J. D. Dana, On the Volcanos of the Moon, Am. Journ. Sci., 1846, 2nd ser., II, pp. 335–355; J. W. Pickering, Lunar and Hawaian physical Features compared, Mem. Am. Acad. Arts and Sci., 1906, XIII, pp. 151–179.

[2] C. E. Dutton, Hawaian Volcanos, Ann. Rep. U.S. Geol. Surv., (1882–1883) 1884, IV, pp. 75–219, maps, in particular p. 120 (also IV, p. 322).

[3] P. Moderni, Contribuzione allo studio geologico dei vulcani Vulsini; Boll. R. Com. geol. ital., 1903, XXXV, p. 121 et seq., map; Le bocche eruttive dei vulcani Sabatini, op. cit., 1896, XXVII, p. 57 et seq., map. It is true that Pareto and Ponzi already conjectured that these two lakes are not craters but 'avallamenti,' i.e. valleys, formed by the coalescence of several ejectamental cones. But it is very difficult to believe that these great circular water basins, situated on the broad cones of tuff, and the straight line of the

This riding of the younger circle upon the edge of the older long since attracted the attention of selenologists. It may be observed in Stoefler, Baronius, Albategnius *A*, Thebit *A*, Davy, Clavius *a* and *b*, and even several successive generations may be distinguished, as a rule with a continually decreasing diameter, and the lava lake always at a lower level. If we could wander around Clavius or Stoefler it might be possible to count as many remains of pipes as Moderni counted around the lake of Bracciano (pl. V, fig. 2).

The 'riding' on the ancient rampart may perhaps be explained by the fact that in the ancient crater, on the margin of the obstruction next the inner side of the rampart, peripheral fissuring frequently occurs; out of the fissures gases ascend. This is beautifully exemplified in the Phlegraean solfatara[1]. The outrushing gas bores a way for itself and a new crater is formed. From these smaller peripheral apertures, according to Loewy and Puiseux, proceed the long rays of white ash which surround many of the craters. This is why some of these rays are not radial, but tangential, with regard to the crater. From Meissier two slightly divergent tangential lines proceed, which were probably produced by the same ash-cyclone. It has been shown, in particular, that the rays proceeding from Tycho exhibit a denser whiteness where they encounter an obstacle, and that in general lines of this kind flatten out upon plains. Consistently with this Sapper observed in the eruption of Santa Maria in Guatemala, October, 1902, that the slopes facing towards the volcano were more thickly covered with ash than those facing away from it[2].

The smaller bright white flecks, such as occur in Humboldt and Werner, are possibly formed of alum, which also occurs at the bottom of the Phlegraean solfatara.

The occurrence of ash and pulverization in the lunar eruptions produces a further important approach to terrestrial conditions, but ejectamental cones are rare. Loewy and Puiseux describe Cichus as such a cone; another is described by Pickering; it occurs between Ries and Mercator. Hyginus is rather a pit on a fissure, and is itself cut through by the fissure; it reminds us of Tarawera in New Zealand, which in a short space of time—a few hours—was cut straight across by a fissure in 1886. The fissure of Tarawera presents numerous smaller pits and craters along its course; they may be as much as 800 feet deep and have emitted ash but no lava. Such fissures accompanied by numerous smaller

Roman eruptive centres should have arisen by the accidental grouping together of smaller volcanos.

[1] G. Mercalli, Stato att. d. Solfatara di Pozzuoli, Atti Accad. Ponton., 1907, XXXVII, no. 6, 16 pp.

[2] Loewy et Puiseux, III, p. 37 et seq., VII, 17; VIII, 14 (cyclones) et passim; Sapper, Centralbl. f. Min., 1903, p. 43; cyclones are described by this author in N. J. f. Min., 1904, I, p. 63; also Lacroix, Mont Pelée, II, pp. 20, 21.

pits and craters, and here and there by a small accumulation of débris, occur at a number of places in the moon and sometimes even cut through the surface of a smelting furnace. They may be clearly seen, for example, between Copernicus and Eratosthenes. They are related to the smelting furnaces somewhat in the same way as the long straight fissures of Iceland, with their rows of pits and craters, are related to the caldron of Askia (IV, p. 265).

On the slopes both of Kilauea and Mauna Loa isolated ejectamental cones occur, distinct from the lava lakes. Mauna Kea (4,230 meters) to the north of Mauna Loa does not possess a lava lake, but bears a number of these cones. From its general structure we see that it has been formed in the same way as its neighbours; the ash cones are here of later formation, following on the extinction of the open lava lake.

In this way the transition is made from the open pipes to the accumulations issuing from fissures, and the normal terrestrial ash cones.

The moon presents yet another distinct group of circular apertures distinguished by a sharply-defined margin and great depth; these may attain a diameter of 15 and even 18 kilometers. Sometimes the lip seems to be produced into an almost conical form. Of this group Ptolemaeus *A* may be regarded as a type. These apertures have probably been formed by isolated explosions of gas. They may, perhaps, be compared to the diamond-bearing pipes of South Africa [1].

Whatever other physical differences distinguish the earth and the moon they agree in the fact that the volcanic activity on both has passed through a very similar course of development. Light and dark coloured ash may be distinguished, showing the separation of Sal rocks. This also presupposes a certain amount of oxygen for the formation of oxides. If the occurrence of alum should be confirmed, we should have another important point of resemblance to terrestrial conditions. Everything points to the original presence of juvenile gases.

Considering how close a correspondence exists, the question arises whether the terrestrial sediments do not conceal some sort of substructure which may have been formed in the course of time in the same manner as the lunar surface, and may have influenced, or even controlled, all the tectonic features of the earth.

A comparatively simple case is presented by the *valley of the Alps*, a rectilinear furrow, 130 kilometers in length; its breadth at its commencement is 9 to 10 kilometers, thence onwards it decreases at first and for a distance of 90 kilometers very slowly, and then very suddenly, as it undergoes, to all appearance, a slight bayonet-shaped displacement; but it is still recognizable for another 40 kilometers. The very steep walls on its

[1] On this group and the not infrequent occurrence of twins, see also Einige Bemerkungen über den Mond, Sitzb. k. Akad. Wiss. Wien, CIV, p. 46.

two sides are 3,000 meters in height. We should take the valley for a fault-trough were it not that its bottom is perfectly level. It is supposed that a slight displacement of the walls may have occurred [1].

Supposing that before the formation of this split, the lava, more than 3,000 meters in thickness, as shown by the walls, had been overlain by several thousand meters of gneiss and ancient schist, as in East Africa, then the rending would have started from the surface, where the cleft would have been broader, and owing to fragments detaching themselves from the sides and slipping down it would have preserved the characters of a disjunctive trough, let down along step-faults. The conjectured displacement of the faulted-down strips would, at most, have found expression in its breadth. In addition, we may call to mind the theories formed in connexion with the right angle in the descents near Ankober, and with the low-lying Afar.

The valley of the Alps terminates near the Mare Imbrium; its outline there is not clear; the end of the fissure occurs, however, at its broadest part, and in this it resembles the southern end of the Rhine valley.

The *Wall* in the moon is a simple fault.

There are a number of straight parallel lines on the moon, which seem to indicate a tendency in its surface to form fissures; several of these lines occur, for example, between Arzachel, Albategnius, and Ptolemaeus. We mention them here because it cannot be denied that the earth exhibits a similar tendency in the contour of the Indian Ocean, and as far as the region of the East African faults (where, however, they run in a more north and south direction), possibly also in the northernmost part of the Atlantic Ocean as far as Greenland. The fissures which run from Hyginus to the Mare Tranquillitatis are arranged in an alternating series. In the East African trough, as is well known, a repeated, abrupt, oblique backward movement takes place from the neighbourhood of meridian 36°, and an equally abrupt return.

Ocean basins of the moon and earth. At the conclusion of the first volume of this work it was stated that the Oceanic basins of the earth arise and increase in extent by subsidence and inbreak (I, p. 604). Evidence for this was found in the outlines of the Atlantic horsts, which cut through the structure, the breaking off of whole folded ranges, and the not infrequent advance of plant-bearing beds to the coast. At the conclusion of the second volume the excess of the eustatic, negative displacements of the strand led to the conclusion that the subsidences must take place in abrupt gradations. The wedge-shaped outlines of some of the continents were shown to have arisen through the intersection of two areas of subsidence of different age (II, p. 537). The lunar seas are likewise areas of subsidence,

[1] Einige Bemerkungen über den Mond, p. 39; Loewy et Puiseux, III, p. 23 et seq., IX, p. 45.

are likewise separated by wedge-shaped horsts, and also of unequal age. Thus the lunar Apennines and Caucasus, for example, are wedge-shaped horsts separating the Mare Serenitatis and Mare Imbrium (pl. V, fig. 1); the marginal fractures on the west side of the Mare Nectaris, for example, at the foot of the lunar Pyrenees bear witness to the inbreak; the repeated lines on the border of the Mare Humorum show the after-subsidence; the Mare Nectaris and Mare Crisium are more recent than others, and so on.

Iceland, a volcanic panzer-horst, the subsidences of which probably belong to a higher horizon of the earth's interior, may furnish us with the truest conception of the caldron fractures of the moon. They occur in the north-west peninsula (IV, p. 265, fig. 23), and still more clearly in Faxafjord. Here the two promontories of Snefells Jökul and Reykjanes represent the lunar capes of Heraclides and Laplace at the entrance to the Sinus Iridum. They are followed by the considerable fracture which extends in an arc from the north-east to Reykjavik and cuts through the whole of Iceland.

The Calabrian earthquakes show how the growth of a caldron fracture may continue under our very eyes. In this region the Lipari volcanos rise in the centre, Aetna on the periphery. If the lavas of the Lipari volcanos were to spread out over the whole depression and become visible to the eye, then the correspondence with lunar forms would be still greater. The Rousillon cuts into the Pyrenees as a caldron fracture and has no relation to their structure. Many similar examples have been given previously (I, p. 134).

On the east border of the Alps two caldron fractures appear to come into contact. In the Paris basin, and in certain parts of the Mediterranean the circular form is more or less preserved; when the extent of the subsidence becomes still greater the circular form disappears.

The explanation of the fact that lava floods do not occur to anything like the same extent on the earth as on the moon is probably to be found in the thickness of the outer, and in part sedimentary, envelope. The longer duration of the processes has also caused the outlines to encroach on one another. In the Pacific Ocean we have in addition the confusion caused by later tectonic processes, and in the Indian Ocean the use made of isolated fissures by the subsidence. The wedge-shaped masses of Greenland, Africa (including the Cape mountains) and the Indian peninsula are not opposed by a second wedge, as the lunar Apennines are by the Caucasus.

Loewy and Puiseux find that three constant stages may be distinguished in the moon, each of which indicates a long period of rest and consolidation. The first of these corresponds to the higher-lying, but little interrupted and older regions in the southern part of the moon; the second, at least 3,000 meters lower, to the general level of the seas, and the third, again 3,000 meters lower, to the bottom of the circular walls, which were formed at the expense of the seas after their consolidation. Each of the two latter stages is regarded as indicating the retreat of the lavas to an equal extent; fresh seas and circular walls have been formed later, at the expense of the most recent stage, and we have no reason to assume that this formation took place in a different manner from the seas themselves [1].

We have already observed, in comparing Mauna Loa and Kilauea, to how great an extent the upward impulse may vary in adjacent vents; a general sinking of the lava in the vents, however, may indicate a general increase in the gas emission and contraction.

On the earth not an inch of the surface is known the height of which has remained unaffected by denudation or other processes, and thus a point of comparison with the first phase, the ancient land in the south of the moon, is lacking. We must have recourse to mean values, but these also fail to give the original level. In the case of Africa we have five estimates of the mean height, all lying between 602 and 662 meters. Eight figures for Asia vary between 920 and 1,010 meters. Two divergent figures lie below these numbers [2]. The mean depth of the three great Oceans amounts, according to Krümmel's later calculations to 3,997 meters, 3,858 for the Atlantic, 3,929 for the Indian and 4,097 for the Pacific Ocean [3]. Thus the depths of the Oceans approach so closely to a round 4,000 meters, that an observer on the moon might regard them as the result of one and the same phase of consolidation (in the lunar sense). We might object that they are of different age; he would reply that the sum of the aeons which is embraced by the stratigraphical chronology of the geologist, lies wholly within the epoch of such a phase.

Here we are in the danger zone of mean figures. The way in which the foredeeps in front of the Burman arc advance into the Indian Ocean, and those in front of the North Antilles into the Atlantic region shows that they are independent of the general Pacific subsidence, and more recent than it. The bottom of the Ocean behaves like a submerged foreland. The observer in the moon would distinguish three stages, that of the Indian peninsula, that of the Pacific Ocean, and that of the foredeeps, each of them about 4,000 meters in height. The continent of Asia would correspond to the folded sediments which are absent on the moon. We must seek a broader basis for our discussion.

The terrestrial sea basins are such mighty interruptions of the general surface, that distinguished naturalists, such as Wallace, have believed them to be immutable forms of the body of the earth imprinted on it from the beginning; no new Oceanic basin could be formed, and no existing basin could be destroyed. Observation does not confirm these views. We must

[1] Loewy et Puiseux, Atlas photographique de la Lune, IX, p. 12.

[2] Table in Supan, Grundzüge der physischen Erdkunde, 4th ed., 1908, p. 48. The divergent figures in the height of Asia are, Humboldt (1844) 351 meters, and Lapparent, 879 meters; for mean heights and depths, see also Penck, Morphologie, 8vo, 1894, I, p. 151.

[3] O. Krümmel, Handbuch der Ozeanographie, 8vo, Stuttgart, 1907, I, p. 144.

certainly distinguish between the outlines of the seas and of the sea basins. The outlines change, and not without reason are transgressive or supracontinental seas distinguished from the deep basins. The former are produced by changes in the shape of the hydrosphere, the latter by deformations of the lithosphere. The outlines of the transgressions change; the deep basins change also.

The subsidences of the Altaides which occurred in Europe were accompanied by displacement of the folding processes, and it even seems as though it were just these subsidences which led to the interruption of any further folding of the Altaides in Europe and North Africa.

In later times the Tethys was subjected to pressure, which came from the north in Asia, and from the south in Europe; in the great mountain ranges overthrusts and foldings occurred, the deeps were closed up and the sea displaced. Then new inbreaks took place; in the Mediterranean they are still in progress. All examples of caldron fractures, with the exception of those of Iceland, lie inside the Altaides or their posthumous structures, Not one crosses to Africa, and this explains the divergent structure which characterizes the south-eastern part of the Mediterranean as far as the rectilinear Syrian coast.

A deep sea, extending from Sunda to southern Europe was incorporated with the continent, and that this process really involved the advance of the Pacific and very profound movement is proved not only by the entrance of Tibetan faunas into the East Alps, but also by the occurrence of Pacific lavas in the same region. In this, too, lies the affinity of Gibraltar with the North Antilles.

The changes which the earth's surface has experienced in later times are incomparably greater than was formerly admitted, and we hesitate therefore, to press further, on the basis of mean figures, this comparison with the phases of consolidation of the moon. —

Previous to the recognition of the process by which terrestrial batholites melt a way for themselves, the filling of the lunar seas with lavas appeared so inexplicable, that even experienced investigators believed that these forms were produced by the impact of foreign bodies[1]. A batholite on its upward course does not produce a fissure extending through several degrees of latitude. If it does not actually reach the surface by melting its way, then—and this, as far as the facts can be discovered, is generally the case—its roof opens in a network of fissures, and the lavas issue forth. This is the explanation of the group volcanos.

Outside the Atlantic region, group volcanos occur only in an eastern part of the Pacific Ocean (Galapagos, Easter island), and in the western Mediterranean. In the Atlantic region itself we have the Azores, the Canary islands, and the Cape Verd islands. We should mention also

[1] Shaler, Smithson Contrib., 1903, XXXIV, p. 15.

the repeated submarine eruptions, the numerous earthquakes, which Rudolph records particularly in the neighbourhood of St. Paul, and the fact that while there are no active volcanos in Brazil, yet in the west of the Ocean the only islands are those formed of volcanic rock (Trinidad, Fernando Noronha, Abrolhos). It is well known that the majority of Oceanic islands are of volcanic origin[1]. In any case the distribution of recent volcanos over the bottom of the Oceans contrasts with their absence in India, Cambodia, the North China mole, Angara land, Laurentia, and Brazil, and also with their rare occurrence in all ancient lands, excepting Africa, where they arise in a different manner. At the same time it is a striking fact that the Sandwich islands, with possibly the greatest accumulation of heavy lavas in existence, and with their glowing lava lakes recalling those of the moon, should rise from the midst of the Pacific Ocean.

Separation of the moon and its consequences. It is with extreme distrust that the geologist regards all attempts to apply the exact methods of mathematics to the subject of his studies. For him the present is a rapidly passing moment, and while he measures, according to his own standard of time, the age of the foundations upon which the superstructure, admirable enough in itself, of modern geodesy is erected, yet these foundations themselves appear to him mutable and temporary. We have no precise knowledge as to what extent the strand-line, upon which so many investigations have been based, may be influenced by continental attraction; but that its level changes is well known. A considerable part of the European and North American coasts is surrounded in the Atlantic Ocean by a shallow shelf with a well-defined boundary next the great depths. This enters the Arctic seas, and Nansen sounded its edge to the north of the New Siberian islands at −100 meters. Further to the north, i.e. beyond lat. 80° N., the sea is 3,000 to 4,000 meters deep[2]. This shelf records the existence of a lower level of the strand at a time when all the coasts mentioned above already possessed the principal features of the existing relief.

At another, and probably still later period, the water over the North Pole rose to a much higher level than at present. Great parts of Siberia were submerged. In Scotland the strand reached a level of +161 meters. In Arctic North America, as for example in Discovery Harbour (lat. 81° 45′ N.), *Mya truncata* has been recorded at a level of about +591 meters; in Montreal the sea reached a level of 143 meters, in Nantucket of 26 meters; its traces disappear towards lat. 40° N. At that time, as is

[1] II, p. 133; E. Rudolph, Ueber submarine Erdbeben und Eruption; Gerland, Beiträge zur Geophysik, I, 1887, p. 133 et seq., in particular p. 289, maps (also following volumes).

[2] F. Nansen, The Norwegian North Polar Expedition, 1893–1896; Scientific Results V, 1904; Bat hymetric Features of the North Polar Seas, 4to, 232 pp., maps.

shown by the shells, both the Gulf stream and a cold counter current were already in existence.

Each of these epochs would have afforded a different value for the ellipticity of the earth, and we must console ourselves with the reflection that in those stretches of coast of which we possess the most precise knowledge such general alterations of the hydrosphere are not established with certainty [1].

Making the reservations which attach to these and similar observations, we will now attempt to discover whether a number of events, which are all for the most part older than the formations accessible to the hammer of the geologist, have or have not left their last and most external traces on the existing face of the earth.

Kant was aware, as early as 1754, that the rotation of the earth is retarded by the tides, and that this retardation will continue until the earth at last will always turn the same side to the moon [2]. At the present day we are able to measure the bodily tides of the planet [3]. Jacobi has shown that an ellipsoid with three axes may represent the equilibrium figure of

[1] In forming an opinion of the Bothnian movements we must be careful to disregard the prehistoric indications, which were determined by other factors. The traces in question here can hardly have originated very long before the close of the seventeenth century (II, p. 413). We still regard them as phenomena produced by discharge. If we are unwilling to attribute such an effect to a change in the atmospheric precipitations alone, we may assume that at that time a particularly large quantity of heavy water produced by storms travelled from the Cattegat across the threshold of the northern basin, and maintained the freshwater supplies at a higher level, until it gradually disappeared by diffusion (II, p. 397). Rosén's works show the difficulties connected with exact measurements in these waters which fluctuate with the season (Ymer, 1896, XVI, pp. 65–77, map).— At Swinemünde the mean level has remained unchanged since 1811 (Seibt in Veröff. k. preuss. geodät. Inst., 1881, 1890). A divergent statement for Memel was based on a displacement of the gauge (II, p. 400). In the Y in front of Amsterdam the mean level did not alter from 1700 to 1860 (H. G. van der Sande-Bakhuyzen, Akad. Amsterdam, 1908, pp. 703–710). — Spratt's statements with regard to a tilting movement in Crete (II, p. 437) are based, as Cayeux has since shown, on an error (Ann. Géogr., 1907, XVI, pp. 97–116). — A. Grund finds that the strand-line at Ephesus has maintained the same level since the time of the oldest harbour structures (Sitzb. k. Akad. Wiss. Wien, 1906, CXV, 1, pp. 241–262, map). The discovery of pholas holes, which are older than *Elephas antiquus*, in the caves of Monaco (M. Boule on Les Grottes de Grimaldi, 4to, Monaco, 1906, II, p. 152 et seq.) shows that mistakes arise if we confuse such borings with historic characters. From the works of MM. Lamothe, Depéret, Choffat, Négris, and others, which relate to tracts of considerable extent, it may be seen which of the earlier movements of the Mediterranean must be regarded as eustatic, and which as local.

[2] Immanuel Kant, Untersuchung der Frage, ob die Erde in ihrer Umdrehung um die Achse . . . einige Veränderungen seit den ersten Zeiten ihres Ursprunges erlitten habe, Königsberg, Frage- und Anzeigungsnachrichten, 1754, nos. 23 and 24 ; also his Sämmtliche Werke, Ausgabe Hartenstein, 1867, I, pp. 179–186.

[3] O. Hecker, Beobachtungen an Horizontalpendeln über die Deformation des Erdkörpers unter dem Einflusse von Sonne und Mond, Veröff. preuss. geodät. Inst., 1907, new ser. no. 32, 95 pp.

a rotating fluid. Poincaré has determined the conditions with greater exactitude. Considerations of this kind have formed the starting-point of a series of brilliant studies in which Sir George H. Darwin has devised new methods of investigating the remote history of our planetary system.

The most important results obtained by Darwin are the following. The body of the earth was in fact at one time an ellipsoid with three axes, rotating with a considerable velocity. A constriction began to form (Jacobi's pear), *finally, a smaller body, the moon, detached itself from the equator.* Its mass amounts approximately to $\frac{1}{80}$ of the mass of the remaining body of the earth. Each of the two bodies gave rise to tides in the other; and these, owing to the proximity of the two bodies and their viscous state at that time, were of great magnitude, and had a retarding action owing to the internal friction of the bodies. The action of the earth on the moon was much more powerful than that of the moon on the earth. The moon began to move away. Its velocity of rotation diminished; as in like manner did that of the earth, which at that time took only a few hours to complete a single rotation, and now requires 24 hours. This change proceeded in the different bodies to a different degree. Thus it has come to pass that the moon has almost entirely lost its movement of rotation, and that the time taken by the moon to make one revolution round the earth (month) was once 29 (at that time somewhat shorter) days, whereas at present it is only 27 days. A time will arrive, as the rotation of the earth becomes slowed down, in which the day will reach a length of 55 hours; the day and the month will be of equal length, as during the period of Jacobi's pear, and from that time onwards the earth will always turn the same side to the moon, supposing that no disturbances are caused by other bodies[1].

The mathematician was confronted with a new problem in the resolution of the common centre of gravity; the geologist is concerned with the discovery of some traces of these past events, and seeks in particular for indications of the place of disruption, of greater bodily tides, and finally of a more rapid rotation.

[1] We cannot attempt in this work to give any idea of the merits of investigators such as Thomson and Schwarzschild, who besides those already named have contributed to a clearer conception. A history of the process has been given by A. Prey in the Astronomischer Kalender der Wiener Sternwarte für 1905, pp. 114–125. G. H. Darwin's results were first published in some detail in the Phil. Trans., vol. 170 A (1879), 1880 (On the Bodily Tides of Viscous and Semi-elastic Spheroids, and on the Ocean Tides upon a Yielding Nucleus, pp. 1–35; On the Precession of a Viscous Spheroid and on the remote History of the Earth, pp. 447–538; Problems connected with the Tides of a Viscous Spheroid), which were followed by others (in particular op. cit., 1880, vol. 178 A, pp. 379–428, and 1902, vol. 198 A, pp. 301–331; also in particular Poincaré, op. cit., pp. 333–373). A short summary was given by Darwin before the British Association in Capetown, 1905 (Nature, 1905, vol. 72, p. 441 et seq.); his works on this subject are collected in Scientific Papers, Cambridge, 8vo, so far I and II, 1906 and 1907.

There is no lack of attempts. As early as 1881 Robert Ball believed that the scar left on the earth, at that time by no means consolidated, would soon have closed, but since the magnitude of the tides decreases with the cube of the distance, we must assume the existence of extremely high tidal mountains in the earliest times.

When the distance of the moon from the earth was $\frac{1}{6}$ of what it is at present, these waves must have been 600 feet high on the earth. Excessively large waves of lava must have swept over the moon. Robert Hull concluded that great planes of denudation must have been produced. Darwin attempted to moderate these views. The high tides assumed by Ball must have belonged to a period at which the ellipticity of the earth was about twelve times as great as at present; such a state is probably anterior to any of those which are recorded in the stratified rocks. The movements of the atmosphere, storms, and atmospheric precipitations, must have been very violent; Osmond Fisher proceeded from the assumption that heavy basic lavas form the bottom of the Ocean. The separation of the moon involved the peeling off of a layer of unequal thickness; the thicker places would be our existing seas; it was the lighter (Sal) parts that were removed; basic lavas would have welled up and filled up the basins [1].

Somewhat later Jeans expressed the opinion that in Darwin's investigations the influence of gravitation had not been sufficiently considered. Sollas attempted to approach the problem by means of morphological comparisons, and both observers arrived by different roads at the conclusion that the existing form of the earth still presents traces of the pear: the land hemisphere corresponds to the broad end, and a place somewhere in the Pacific Ocean would correspond to the stalk of the pear. Lapworth thought that the land of the Arctic regions must be regarded as the broad end [2].

For us one fact alone is certain, that the distribution of the great Ocean subsidences is not accidental, but must be the result of a process of development, inherent in the nature of the planet, which is not yet at an end. Any serious attempt to obtain further knowledge of this process of development, and, if possible, to bring the results of the mathematician into connexion with those of the geologist is to be welcomed.

Of the further studies by mathematicians only those of Love need concern us here. They take into account an eccentric position of the centre of gravity, an inherited tendency to an ellipsoidal form, the earlier and the existing influence of the moon, and the rotation of the planet. An

[1] R. Ball, Nature, 1882, XXV, pp. 103 et sqq.; E. Hull, tom. cit., p. 177; G. H. Darwin, ibid., p. 213; O. Fisher, ibid., p. 243.

[2] J. H. Jeans, Vibrations and Stability of a Gravitating Planet, Proc. Roy. Soc., 1903, LXXI, pp. 136–138; W. J. Sollas, Figure of the Earth, Quart. Journ. Geol. Soc., 1903, LIX, pp. 180–188; Lapworth, tom. cit., p. 188.

attempt is made to show by analytical methods that the earth, in order to reach its existing state, must have passed through three phases (spherical harmonics), each of which has been impressed on the one preceding it. The first harmonic is the simplest; it corresponds approximately to the figure described by Dante as impossible (II, 6, fig. 2). The centre of gravity is eccentric; it is the centre of the hydrosphere which hangs from the planet 'like a drop of water on a greasy shot'. The centre of the dry land would lie approximately near Wady Halfa. The second harmonic leads to two antipodal depressions at the places where the ellipsoid of the lithosphere passes beneath the spheroid of the water; one of these depressions would be the Pacific Ocean, the other the Mediterranean with its surroundings, Africa, and parts of the Atlantic and the Indian Oceans; this phase appears to be less clearly marked (Africa would have been submerged). The third harmonic gives an oval central piece of land, formed by parts of Europe, Asia, and Africa, surrounded by a depression corresponding to the Arctic, Atlantic, and Indian Oceans, together with West Africa, North and West Europe, and fragments of Asia. This is followed by a protuberant ring extending through both the Americas, Antarctis, Australia, and New Guinea. Finally, we should have the Pacific Ocean, which Love regards as the broad end or crown of the pear. Love adds that the changes in the earth's form must be ascribed to two causes, gravitation and tectonic processes. Gravitation influences the mass, and displaces the Oceans. Tectonic processes must be held responsible for the formation of mountains, and possibly of the Oceanic abysses. Except where they incidentally accompany the action of gravity, tectonic changes must be ascribed to the cooling and contraction of the earth [1].

Love's results are described by the author himself as tentative essays, and as regards their correspondence with the facts of nature, they must not be subjected to a severe scrutiny. Our object is merely to show how the mathematician obtains deformations of the earth, which far exceed, both in extent and significance, the dislocations studied by the geologist; beside these, indeed, tectonic processes may be regarded as mere incidents. These

[1] A. E. H. Love, Gravitational Stability of the Earth, Phil. Trans., 1907, vol. 207 A, pp. 171–241; Address Brit. Assoc. Leicester, 1907, 12 pp.; and Figure and Constitution of the Earth, Roy. Inst., March 6, 1908, 15 pp. Of the most recent works the following may be mentioned: L. Waagen, Wie entstehen Meeresbecken und Gebirge? (Verh. k. k. geol. Reichsanst., 1907, pp. 99–121), takes the point of view of the contraction theory and deals with its connexion with folds; R. D. Oldham, Origin of the Oceans (Quart. Journ. Geol. Soc., 1907, LXIII, pp. 344–350), deals with the difference in the propagation of seismic waves beneath the Pacific Ocean and the Eurasiatic continent; W. H. Pickering, The Place of Origin of the Moon; the volcanic Problem (Am. Journ. Geol., 1907, XV, pp. 23–38, map); the place of separation lies in the middle of the water hemisphere, about 1,000 miles (1,600 kilometers) north-east of New Zealand in lat. 25° S. The land hemisphere was torn apart; hence the symmetry of the Atlantic contours.

two branches of study have not yet, however, been brought into connexion, and we can only offer now a few isolated suggestions.

1. Twin bodies, which are later constricted off, are known among the Tektites. These glassy meteorites seem to occur, so far as observations exist, over a long strip of the earth's surface extending from Australia, through Billiton island, to Moravia, the south of Bohemia, and possibly even as far as Kristianstad in Scania. Such twin bodies have so far only been met with among the Australites. As early as 1898 R. H. Walcott ascribed their origin to a violent rotation, and thought they pointed to the tearing apart of a dumb-bell form.

F. E. Suess compared them with the constricted ellipsoid of Jacobi, and the double stars. It is as though Nature had provided us with an illustration [1].

2. The moon, with a density of 3·4 is lighter than all the inner and heavier than all the outer planets. We are once more reminded of the light crystals of peridote in the heavy bath of Nife, exhibited by certain meteorites, and the sharp boundary, drawn by Wiechert at a depth of about 1,500 kilometers, between the heavy metallic core of the earth, and the stony crust with a density of 3·4. From the latter the greater part of the moon was probably derived. In the main body the metallic material must for the most part have already been concentrated in the core. At the time of the separation of the moon almost all the Sima rocks of the earth's surface certainly possessed a density below 3·4, and the white ashes show that the moon, at the time of separation carried Sal materials with it. Since it cannot contain much Nife, while it possessed a sufficient quantity of juvenile gases, we may suppose that on the earth also these gases and with them our volcanic eruptions do not proceed from the depth of the Nife but from Sima, i. e. from that zone of the earth's body which extends for almost 1,500 kilometers beneath the Sal envelope.

3. As examples of ancient abrasion, caused by powerful tides, we might point to the Pre-Cambrian surfaces of North Canada, and North Russia, but even these were preceded by foldings and unconformities. Profound abrasion is also exhibited by the gold-bearing beds of the Transvaal.

[1] R. H. Walcott, Occurrence of So-called Obsidian-Bombs in Australia, Proc. Roy. Soc. Victoria, 1898, new ser. XI, 1, pp. 23–53, in particular p. 35; F. E. Suess, Herkunft der Moldavite, Jahrb. k. k. geol. Reichsanst., 1900, L, pp. 193–382, in particular note to p. 339; also F. Eichstädt, En egendoml. af rent glas beståend. meteorit, funnen in Skåne, Geol. För. Stockh. Forh., 1908, XXX, pp. 323-330. The 'buttons' generally become surrounded with a broad and flat equatorial girdle, which may possibly be due to the resistance of the air. Walcott also figures a twin with an equatorial girdle; in this case the rotation was probably lost before the separation. In another button the elongated remains of the attached part (the stalk of the pear) is still present; in this case the equatorial girdle became detached like one of Saturn's rings, and is open where the stalk occurs.

4. Darwin states that if bodily tides have influenced the arrangement of the mountain chains, then we should expect to find at the equator a north and south strike, towards the north a north-easterly strike, and towards the south a south-easterly strike. This supposition holds for almost the whole of the Pacific region. The advance of the Antilles towards the east, the arrangement of all the arcs of Eastern Asia and the Oceanides, and in particular the fact that almost all the Asiatic virgations open towards the west and south-west are consistent with the theory. But there is no lack of exceptions; the St. Elias range is folded towards the west or south-west, likewise the great Burman arc and the Urals. The whole of that part of the Western Altaides lying outside the horst of Azov is opposed to the rule.

An attempt has been made to explain the arrangement from the rotation of the earth. Douvillé has adduced the earlier, more rapid rate of rotation and obtains a prevalent east and west direction. Prinz, on the other hand, finds a prevalent north and south direction [1]. We may also point to the folding, directed to the south, of the United States chain, situated on the other side of the Pole; also of the Aleutian islands and the southern marginal arcs, and in particular to the Cape mountains directed towards the north; the exceptions are the same.

5. In the pre-Cambrian regions and in horsts parts of older plans are visible, and the subsidences, which follow upon them and bound them, are independent of these older plans. In Europe the situation is particularly striking, owing to the manner in which the Caledonides in the north and the Saharides to the south are cut through by the Altaides. The contrast between the directions which dominate the Bohemian mass and that of the East Alps affords another example, and similarly, in North America, the contrast between Laurentia and the Appalachians.

The fact must therefore be recognized that the face of the earth presents several plans, imposed one upon the other.

6. The dislocation which preceded the upper Carboniferous is of such extraordinary extent that it might be described as a deformation of the earth's face. As this disturbance is characterized by its extent, so the Tertiary movements in the Alpides are characterized by their intensity; they must also have been succeeded by widely distributed rending apart. The disturbance preceding the Neocomian in the west of North America and other examples of importance might also be mentioned. These, we may suppose, are all of later date than the changes of form produced by the spherical harmonics. Whether they are causally connected, I am not in a position to judge.

[1] Douvillé, C. R. Acad. Sci. Paris, 7 mars 1904; Prinz, Sur les similitudes que présentent les cartes terrestres et planétaires (torsion apparente des planètes), Ann. Observ. Brux., 1891, 34 pp.

Isostatic compensation of the mountains. Pratt found that the Himálaya in Kaliána, about 64 kilometers to the south of its foot, only gives a deflexion of 6″ or 7″ instead of 27″ which is the theoretically determined amount. This led him to conclude, in 1852, that gravity does not attain its normal value in the Himálaya. He went even further, and believed that the distribution of mass around the earth is uniform; on the continents there should be a deficiency of mass below the surface, beneath the sea; on the other hand there should be a compensatory excess. He named this the *compensation theory*. The pendulum measurements quoted by Basevi and Heaviside between the years 1865 to 1873 do, in fact, show a deficiency of mass in the foothills of the Himálaya; Moré, the highest station, and the only one situated within the high mountains (4,696 meters) gave a particularly large deficiency. Opinions differed, until Sterneck invented a more convenient and exact pendulum apparatus and made numerous measurements in Austria, while Helmert applied to the subject ingenious mathematical methods.

A calculation made by Helmert, which appeared in 1892, created a deep impression; this was based on measurements made by Sterneck at thirty-seven stations situated on a line 356 kilometers in length, extending through the heart of the Tyrolese Alps and surrounding Oetz and Stubai in a ring. The result in this case also showed that a deficiency of mass occurs, even if it does not completely compensate for the mass of the mountains. This deficiency must occur in the upper layers of the earth's crust, since it is scarcely perceptible at Munich and Padua. The density appears to be greater in the layers beneath the sea, which are inaccessible to direct observation, than beneath the continents. The deficiency beneath the Tyrolese Alps was estimated at a thickness of 1,200 meters, with a density of 2·4 [1].

There is a similar basis for Dutton's view, according to which the foreland is sinking and the mountains are rising. This is designated by Dutton as *isostasy*, and he believed at first that a part of the effect must be ascribed to the sediments carried down from the mountains, but that in any case a special elevating force is required to account for the tablelands [2].

This theory found much support, especially in America. The position of the Appalachians seemed to accord with it particularly well. At the same time some doubts were expressed. As the measurements increased in number, the compensation was found, as a rule, to be only partial. To geologists, cavities of a height of 1,000 meters or more seemed out of the question, and no mountain rock is known of so low a density that it could

[1] F. R. Helmert, Die Schwerkraft im Hochgebirge, Veröff. k. preuss. geodät. Inst. u. d. Centralbur. d. internat. Erdmessung, Berlin, 1890, 52 pp., map.

[2] C. E. Dutton, Some of the greater Problems of Physical Geology, Bull. Phil. Soc. Washington, 1892, XI, pp. 51–64.

represent the deficiency. The continuation of Sterneck's work revealed much that was unexpected. In contrast to the Tyrol, the Carpathians showed a deficiency beneath the foreland; this deficiency extends from the north into the mountains near Slavsko (594 meters), becomes more considerable, and ends 'quite suddenly' about 20 kilometers to the north of the crest (Beskid, 799 meters) against an area of excess, which extends from this point onwards (still north of the crest) over the whole of the Hungarian plain. This region of excess also advances fairly deep into the most easterly part of the Alps. In South Tyrol, also, a marked excess within the mountains already occurs at Ala; it persists through Verona into the plain; Mantua shows a deficiency in the foreland. In the Caucasus Stebnitzki found no correspondence between the deficiency and the mountain boundaries. Costanzi thinks that the negative values, in general, do not coincide with the axes of the mountains, but are displaced in the direction of a neighbouring depression; in the case of the Alps and Carpathians he conjectures that the displacement follows the tectonic movement [1].

In the case of isolated mountains the results become incomprehensible. At the foot of Mauna Kea in Hawaii (3,980 meters), Preston obtained from observations with the pendulum the extraordinary density of 3·7, while the upper half of the mountain gives 2·1; the mean of the two, however, 2·9, is probably near the truth [2]. A similar result, according to Ricco's statement, is afforded by Aetna. In the centre of Sicily the data show a deficiency of gravity, towards the mountain this diminishes and an excess sets in, which increases as we proceed, but on the summit (2,993 meters) a deficiency occurs. As shown in a section, the curve of the density corresponds in a striking manner to the negative of the curve of the surface [3].

From these facts we learn the following. On the isolated summit of a cone, such as Aetna, the lesser mass of the summit should be taken into account (but not cavities in the mountain). Since the action of gravity decreases with the square of the distance, the cause of such a rapid change as that occurring in the Carpathians and in South Tyrol cannot possibly lie at any considerable depth. At the surface, however, four factors only come under consideration: the relief, tectonic structure, density of the rock, and mode of reduction of the observations. The first three are known;

[1] R. v. Sterneck, Schwerkraft in den Alpen, Mitth. k. k. milit. geogr. Inst. Wien, 1892, XI, 108 pp., map; Relative Schwerebestimmungen ausgeführt im Jahre 1893, op. cit., 1894, 102 pp., map, in particular p. 87; G. Costanzi, C. R. Acad. Sci. Paris, 21 oct. 1907.

[2] E. D. Preston, Gravity Determinations at the Sandwich Islands, Am. Journ. Sci., 1893, CXLV, pp. 256, 257. The specific gravities in Kilauea lie according to Silvestri between 2·72 and 3·03; Silvestri in Tacchini, Relazione sugl' eclissi totali di sole 1882–1887, 52 pp., in particular p. 50.

[3] A. Riccò, Anomalia della gravità e magnetismo terreno in Calabria e Sicilia, Boll. Soc. Sism. Ital., 1908, XII, et passim.

the mode of reduction is indicated by the case of Mauna Kea, where the extracted mean gives a probable value for the density.

The law of Bouguer (or Young), which is generally employed in these calculations, includes two factors; the first of which relates to the height above the sea of the observing station, the second to the vertical attraction of the mass which lies between this station and the sea level; in the case of an irregular surface, a local correction for the relief must also be made. In the second factor, the entire mass situated between the station and the sea level is regarded as a slab of the equated mean height of the continent, and of infinite extent. Modifications of these laws have been introduced by Helmert. As early as 1880 and 1883, Faye proposed to omit the second factor of Bouguer's law, but to make use of the first and of all local corrections. In making this proposal, Faye was able to point out—as Clarke had done previously—that, with the omission of this factor, the great deficiency below Moré, the highest point in the Himálaya measured with the pendulum, completely disappeared. At the same time he observed that it would be impossible to determine, even approximately, the density of the planet from isolated mountains, if these mountains were themselves lighter, and were compensated by masses beneath the sea [1].

This is not the place to discuss in detail points of this kind. An example on a large scale may be mentioned, the measurements of which have been calculated according to the methods both of Bouguer and Faye: this is Putnam's cross-section of the United States [2]. Bouguer's law gives negative results throughout, from Boston to San Francisco (with the exception of Washington, to be discussed later). The deficiency increases gradually from the east, especially from 1,000 meters upwards, and above 2,000 meters becomes very considerable. The maximum of these negative values lies in Gunnison, Colorado (2,340 meters), close to the main body of the Rocky mountains; in California the values decrease. Thus this law gives a deficiency along the whole line, becoming very considerable beneath the high mountains, and it stands in complete opposition to the relief. If, on the other hand, the calculation is made for the first factor only of Bouguer's law, then though it also gives a deficit in the east and beneath the plains, yet this is much more trifling than that obtained by the first calculation; in the Appalachians indeed, a small positive value occurs, and the deficiency does not increase in the direction of the mountains. Further

[1] Faye, C. R. Acad. Sci. Paris, 24 mai 1880, 21 juin 1880, 30 avr. 1883 et passim. The fact that the density of the earth is measured by the attraction of mountains is also mentioned by Hann as incompatible with compensation; Schwerecorrection bei barometrischen Höhenmessungen, Peterm. Mitth., 1903, pp. 163-166.

[2] G. R. Putnam, Results of a transcontinental Series of Gravitational Measurements, Bull. Phil. Soc. Washington, 1895, XIII, pp. 31-60; and G. K. Gilbert, Notes on the Gravity Determinations reported by Mr. Putnam, op. cit., pp. 61-75.

in the mountains themselves, all the stations which lie above 1,800 to 2,000 meters (with the single exception of Gunnison) give, instead of a deficiency, an excess with a considerable maximum beneath Pikes Peak (4,293 meters, Rocky mountains), the highest point on the line. Finally the introduction of local correction levels out the inequalities, shifts to some extent the positive values from the high mountains towards the eastern foothills, reduces the excessive maximum beneath Pikes Peak, makes Gunnison also positive and so on.

Thus while Bouguer's calculation leads to a great deficiency beneath the high mountains, that of Faye accords on the whole with the general form of the surface; at the same time the differences between the theoretical gravity and that determined by the pendulum are so far reduced that Putnam no longer ascribes any importance to what remains. For this reason Gilbert concludes that the lithosphere possesses a greater load-bearing capacity than is assigned to it by the champions of isostasy. *The Appalachians, Rocky mountains, and Wahsatch plateau are extra loads which are supported by the rigidity of the earth.* Here, therefore, the results of the geodesist and those of the geologist are in complete accord.

The question now arises as to how this result can be reconciled with that obtained in Central Tyrol after so much exact observation and ingenious calculation. From Helmert's table we see that $g—\gamma$ (difference between the measured and the theoretical value of gravity) is negative in all the 37 stations of the ring, but that towards both the heights of the Brenner and the sources of the Etsch (Reschen-Mals) this difference becomes less considerable. The greatest height in the ring is 1,483 meters, its mean height 790 meters. It is surrounded by much higher mountains, and the mean height of the enclosed mass (Oetz and Stubai) is over 2,000 meters. Many peaks exceed 3,000 meters, not a few even 3,500 meters. If we leave the ring in the south and enter these high mountains, we still find a negative value at a height of 1,636 meters (Pfelders), but this is considerably smaller than in the ring, and at a level of 2,967 meters (Sandbüchel) the value is positive, which is not the case anywhere inside the ring. We obtain the same result if we ascend from the ring towards the south-west to Franzenshöhe (2,188 meters), and the Stilfser Joch (2,760 meters); both localities are positive. We must, therefore, suppose that conditions prevail similar to those in the Rocky mountains, and that the imaginary deficiency beneath the Alps is caused by the low-lying position of the ring. This admirable work should, therefore, be completed by pendulum measurements on the summits.

We will next pass to the more recent work in *India.*

Burrard divides India into four regions. These are: I, the Himálaya; II, the vast plain traversed by the Ganges, the southern border of which maintains a remarkable parallelism with the foot of the mountains; III, the peninsula; and, IV, north-western India, situated on the other side of the syntaxis. In IV the investigation has not made much progress, so that for the present it may be left out of account[1].

The peninsula, III, exhibits heavy rocks widely distributed. The most ancient are the batholites of charnockite; next worthy of mention are the basic rocks, which near Rájmahál, for example, on the boundary between II and III are 2,000 feet thick; they belong probably to the period of the upper Gondwána; finally, in the west there is the extensive Deccan trap. Near Bombay it reaches a thickness of 6,000 feet, if we include some intercalated sedimentary beds. It forms broad table-mountains, which in the Sahyádri reach a height of over 4,000 feet.

To the north of Delhi the ranges of the Aravali mountains striking towards the north-east, disappear beneath the plains of II. Here we must refer a range of quartzite and itacolumite; situated upon it is Kaliána (lat. 27° 4′ N., not far from Muzaffarnagar), Everest's observing station, and the starting-point of Pratt's compensation theory. Much further towards the north-west, the remains of the Aravali quartzites of II crop out in the Koràna mountains on the Chenab, about 60–70 kilometers away from the Salt range[2].

The high mountains of I are separated from II by the belt of the Tertiary Sewalik hills, which consist of sandstone and conglomerates, the latter completely resembling the existing alluvium of II. The gneisses which occur in Sikkim and still further towards the east, to the north of this zone and on the border of the Himálaya, are overthrown towards the south; Gondwána beds dip beneath them. They doubtless correspond to the gneisses of III (peninsula) precisely as the zone of mont Blanc corresponds to the Variscan foreland.

The first, and, as Burrard justly observes, the most remarkable fact is that in general a distribution of the weight in well-marked zones is manifested. *Zone II obviously corresponds to the foredeep of the Himálaya*, and according to observations made elsewhere, no serious objection could be raised to the assumption that here, in front of the Himálaya, there lies a subsidence 6 to 7 kilometers in depth, or even more, which is filled with a sediment of a much lower specific gravity than 2·8. The pendulum observations are calculated according to Bouguer, on the assumption that the general density of the rocks is 2·8, which is certainly too high; a comparison of these with other results is thus rendered very difficult.

[1] S. G. Burrard, Intensity and Direction of Force of Gravity in India, Phil. Trans., vol. 205, A, pp. 289-318, map; Burrard and H. H. Hayden, Sketch of the Geography and Geology of the Himálaya Mountains and Tibet, 4to, Calcutta, 1907, Part II, pp. 51-56, maps.

[2] I, p. 447; Medlicott and Blandford, Manual of the Geology of India, I, p. 52; for Kaliána, R. D. Oldham, Rec. Geol. Surv. India, 1889, XXII, pp. 51-56.

The results obtained by Burrard and Lenox Conyngham may be summed up as follows.

Across the peninsula the deflexions of the plummet are variable but not considerable; of greater extent are the variations of gravity as determined by the pendulum. Towards the north border, that is 120 to 200 kilometers to the south of the foot of the Himálaya, an excess of mass gradually sets in, so that at Kisnapur, for example, the height above the sea-level would have to be increased from 35 meters to 339 meters in order to accord with the requirements of the pendulum; in other words, the pendulum shows an excess of 304 meters in height with the density of 2·8. This has led Burrard to suppose that to the visible Himálaya is opposed a second, parallel and *invisible range.* Starting from this border or invisible range, with its hypothetical great weight, the value of gravity gradually decreases in II (foredeep); the plummet, however, remains turned to the south, i. e. the attraction of the peninsula is still greater than that of the Himálaya. Then the southern attractions of the peninsula encounter the northern attractions of the Himálaya, and they partially compensate each other. This explains the exceptionally small deflexion of the plummet in Kaliána, on which Pratt's compensation theory is based. It amounts, in place of the theoretical attraction of the Himálaya, to only 5 or 6″ N., while 88 kilometers further north, in Dehra Dun (Sewalik zone) it is as much as 37″ N. Nevertheless the pendulum shows a considerable decrease of gravity at this place. In general, a large deficiency may be observed in the northern part of the trough; Pathankol in the foothills would be converted, according to the pendulum, from a height of 331 meters into a depression of – 1,208 meters. The turning of the plummet towards the north takes place with remarkable sharpness (Kurseong 50″, Tonglu 42″, and other places all belonging to the outer Himálaya). Here lies the maximum of the northern deflexions; it is true that they are known as far as 80 kilometers to the north of the foothills, but they diminish in comparison to the mountain border (most remote point Kidarkanta, 3,813 meters, deflexion 27″ N.). The fact that the deflexions of the plumb-line are greatest on the mountain border is explained by Burrard on the hypothesis that, as we proceed into the mountains the region passed over exerts a compensating action on the plummet.

The measurements which have been made in the high mountains with Sterneck's apparatus are still few in number; they have, in general, considerably reduced but not destroyed Basevi's negative values. Moré was not reached; according to the earlier determinations and Bouguer's formula, its height (4,696 meters) should give a deficiency of 4,484 meters. We have already observed that Clarke by simplifying Bouguer's formula has caused this deficiency to disappear. The fact that on the other side of Moré the plummet is deflected also towards the north led Burrard also to doubt the accuracy of the figures obtained by the pendulum for this station and the next higher station of Mussooree (2,109 meters, deficiency 1,333 meters). No other pendulum measurements have as yet been made in these high mountains.

Burrard also thinks that the general deflexion of the plummet towards the south in II (foredeep) is caused by a decrease in mass beneath the plain rather than beneath the mountains. In fact, all the figures determined by the plummet may be explained on the assumption that the foredeep is filled with sediment of a less density, beneath which the ancient rocks of the foreland dip from the south, until they arrive in front of the steep brow of the Himálaya. The boring of the Bohemian granite at Wels, in front of the brow of the Alps, led to precisely the same conjecture. It is not impossible that calculations of the subterranean form of the foredeep may one day be made, similar to those which Eötvös has attempted to make from the data obtained with his torsion balance near Arad [1].

A boring at Lucknow, sunk for about 300 meters below the sea-level, did not reach the base of the recent sediments. It is even possible that the question may one day be raised whether the problematic 'Swatch of no ground', a pit 400 to 600 meters deep, in the delta of the Ganges, may not be one of the last traces of this foredeep, bent round in the direction of Burmah.

In the Himálaya, therefore, while the deflexions of the plumb-line may be brought into tolerable accord with the structure, doubts exist as to the interpretation of the pendulum measurements. The geologist, who finds it hard to understand a deficiency in the high mountains, finds it no less hard to understand an excess, and an invisible range in the plain [2]. It is to be expected that the method indicated by Clarke in explanation of Moré will also lead to the explanation of other difficulties.

The existing state of observation does not justify us, in the face of so many contradictory facts, in regarding the existence of deficiencies of mass beneath the mountains as proved. It would be inconsistent with all geological observations.

Compensation of the continents. In addition to the question of the compensation of mountains we are confronted with the far more important question whether, as Pratt maintained, the continents are held in a position of equilibrium by heavier masses beneath the sea; and we are called upon to solve a second question, whether, as Dutton believed, the sinking of the sea-basins caused the elevation of the continents.

[1] Baron R. Eötvös, Bestimmung der Gradienten der Schwerkraft und ihrer Niveaufläche mit Hülfe der Drehwage, Verh. XV. Conf. d. allgem. Erdmessung (1906), 4to, 1908, I, pp. 337–395, in particular p. 388, and fig. 8, p. 366.

[2] Doubts of another kind are expressed as to its existence by O. Fisher, Phil. Mag., 1904, 6th ser., VII, pp. 14–25; on the other hand Burrard, ibid., pp. 292–294.

Here we may cite three examples; one of them is based on the hypothesis of a distinguished geologist, a second depends on deflexions of the plummet, and a third is founded on observations made with the pendulum.

Bailey Willis, who possesses a detailed knowledge of the Appalachians, has travelled through the eastern part of Asia, and has attempted to apply the isostatic theory to that continent. It is true that in doing so he has given this theory a new form. He takes it for granted that heavier rocks lie beneath the Ocean than beneath the continent. The two kinds of rocks meet in contact. The continued pressure of the heavier part overcomes the rigidity. A zone in which a slight flow takes place from the heavier towards the less heavy, that is from the sea towards the continent is established. We might, for example, assume that the action at the surface is zero, that it increases in a downward direction, and at a depth of 100 miles (160 kilometers) is again zero, since the basement is rigid. Asia would thus have been formed by pressure proceeding from the Indian and Pacific Oceans and directed towards the Baikal vextex. It was a submarine extension (oceanic spread), constantly in progress, but manifested spasmodically, which compressed the lighter rocks, and Asia was therefore formed, not by overthrusting, but by *underthrusting*.

This hypothesis—for so it is termed by its ingenious author himself—has this advantage, that it does not presuppose the existence of cavities beneath the mountains. If we attempt to apply it to the overturned, outer marginal folds, we find that the convex form of the arcs is opposed to it, and it is difficult to see how the other main features of the structure, such as the overthrusting of the Tibetan segments, directed towards the south, the linking, the virgation of Thian-shan, and the advance of the Bonin islands towards the middle of the Ocean can be reconciled with an underthrusting which would extend to lake Baikal [1].

The *plummet* forms the basis of the extensive surveys which have been made by Tittman and Hayford across the whole breadth of the United States, and through more than 31 degrees of latitude. An attempt to represent the geoid in equipotential curves by means of these observations shows a parallel slope along the Atlantic coast from lat. 45° to 47° N.; the Adirondacks and Alleghanies are fairly well marked: the deepest place lies in the eastern part of the Oberen lake, which descends here 100 meters beneath the sea-level. Thus with one problematic exception in the south—where, throughout Alabama, an ascent of the geoid surface occurs in the direction of Mobile—we see that the geoid surface is dependent on the form

[1] B. Willis, Research in China, 4to, 1907, pp. 115–133; similar views are expressed in his Theory of Continental Structure applied to North America, Bull. Am. Geol. Soc., 1907, XVIII, pp. 389–412.

of the earth's surface, or is, as it were, a generalized or modified image of the relief of the land [1].

This result is instructive and admirable in itself, but it is hard to follow the report beyond the limits of these data. The foregoing data led to the conclusion that it was necessary to use as large a radius as possible for comparison at each station. Radii were finally employed of as much as 4,126 kilometers, so that a station in the extreme east included in its radius the Pacific coast, and *vice versa*. As a natural result, an increasingly large number of mean estimates was found necessary, in particular as regards the sea [2].

In spite of the difficulties involved in this method, its authors believed that they were in a position to assert positively that the United States do not maintain their height above the sea owing to the rigidity of the earth, but that they are 'buoyed up' or 'floated' owing to their lesser density. If the isostatic compensation is uniform, it must be effected within 114 kilometers, or certainly between 80 and 160 kilometers.

These statements have led Chamberlin to observe that compensation may also occur in a body with the rigidity of granite or steel. A viscous foundation is not necessary. Such a foundation would bring about something like perpetual movement, and its state would render it incapable of accumulating the lateral stresses, and then of resolving them, a process which the tectonic movements lead us to assume. Rigidity and isostatic compensation are not, therefore, to be regarded as completely opposed [3].

We now proceed to observations made with the *pendulum*.

In the neighbourhood of the coasts positive results are obtained almost everywhere. An isolated positive result, observed in Washington, has been mentioned above. The numerous pendulum observations which have been carried out by the Austro-Hungarian navy on remote coasts and islands, the large number of observations made by the German navy from Cameroon to Cape Town, and many other investigations have confirmed this fact. Helmert estimates the excess of the coast stations over the interior at + 0·036 cm. [4]

[1] O. H. Tittman, Report on Geodetic operations in the United States, Verh. XIV. Conf. d. allgem. Erdmessung (1903), 1904, I, pp. 182-212, map; Tittman and J. F. Hayford, op. cit., XV, Conf. (1906) 1908, I, pp. 192-235, map.

[2] The mean depth in fathoms was multiplied by 3·69 (1·03 for water + 2·66 for the mean density of the rocks), and the result given as a negative height in feet. This process was continued down to depths of almost 3,000 fathoms.

[3] Chamberlin, Journ. Geol., 1907, XV, pp. 73-78; Hayford, tom. cit., pp. 79-81, conforms in all essential points with Chamberlin's views.

[4] Relative Schwerebestimmungen durch Pendelbeobachtungen, ausgeführt durch die k. und k. Kriegsmarine, 1892-1894, herausgegeben vom Reichskriegsministerium, Marine-section, 8vo, Wien, 1895, 630 pp., maps; M. Loesch, Bestimmung der Intensität der Schwerkraft auf 20 Stationen der westafricanischen Küste von Rio del Rey (Kamerun-Gebiet) bis Kapstadt, 4to, Reichsmarineamt, Berlin, 50 pp., map. For the theoretical

The diversity of the coasts which have been taken into consideration is alone sufficient to remove any suspicion that this excess can be based on the nature of the rock, and it became a matter of importance to discover some method of making gravity measurements in the open sea. This difficult problem was solved in a brilliant manner by O. Hecker, who devised a method based on the comparison of the readings of the boiling-point thermometer and the mercury barometer. As a result we are told that it may be regarded as proved that the lesser density of the waters of the Oceans is compensated by the greater density of the sea bottom. On the other hand the continental protuberances rising above the sea-level are not really accumulations of mass in the earth's crust, but the apparent excess of mass is counterbalanced by a defect beneath the continents[1].

For a closer consideration of the results we must first omit the measurements made in the coast regions; we will disregard all measurements above − 200 meters. Then, so far as a conclusion can be drawn from observations along isolated lines, the following results present themselves to the geologist.

With a trifling exception in the south-east of Australia, positive values are obtained for the whole region of the Red sea and of the Indian Ocean, as well as across the northern part of New Zealand as far as the Tonga plateau; on the latter, at a level of −2,700 meters, a very high positive value was obtained, while the Tonga foredeep, down to a depth of 8,500 meters, gave considerable negative figures. This region from Suez to Tonga separates two areas, distinguished by a much greater diversity, namely, the Mediterranean and the Atlantic Ocean on one side, and the large remaining part of the Pacific Ocean on the other.

As opposed to the Indian region, the Mediterranean, according to eight measurements made down to −3,500 meters, furnished only negative values.

In so far as we may make preliminary generalizations at all from these determinations, the lines measured in the Atlantic and Pacific Oceans show concordantly, first a broad positive belt surrounding the continents, then a neutral or negative zone, and within this a closed, positive region. The latter is connected with two of the heaviest places known anywhere on the

side of the question, O. E. Schiötz, Ueber die Schwerkraft auf dem Meere längs dem Abfall der Kontinente gegen die Tiefe, Skrift. Vedensk. Selsk. Christiania (1907), 1908, no. 6, 28 pp.

[1] O. Hecker, Bestimmung der Schwerkraft auf dem Atlantischen Ocean, Veröff. k. preuss. geodät. Inst. Berlin, 1903, new ser., no. 11, 137 pp., map; and Bestimmung der Schwerkraft auf dem Indischen und Grossen Ocean, op. cit., 1908, new ser., no. 12, 233 pp., maps, in particular p. 213. In the case of the data given in this work, it is a pity that the extremely exact observations on gravity are not accompanied by soundings; the depths have been taken from the English Admiralty map and the Monaco map.

earth. In the Atlantic Ocean it is marked by the island of *St. Paul* (lat. 0° 58′ N., long. 29° 15′ W.), formed of peridotite, the density of which, apart from the still heavier intercalations of Crofe and olivine, is 3·287 (IV, p. 563). The positive Pacific region coincides with the mighty basaltic accumulation of the *Sandwich islands* (Honolulu, lat. 21° 17′ N., long. 157° 30′ W.), the mean density of which must be at least 3.[1]

Let us consider the position in greater detail. In the Atlantic Ocean, on the lines from Hamburg to Rio, and Rio to Lisbon, Hecker made 67 measurements at and below −200 meters; of these one gave a zero value, 29 are positive and 37 negative. The excess of values is negative. Both routes lie to the north-west of St. Paul, and the excellence of the observations is shown by the fact that in both cases (from lat. 1° 58′ S., long. 31° 23′ W. to lat. 6° 39′ N., long. 27° 25′ W., and from lat. 3° 37′ N., long. 29° 47′ W. to lat. 10° 54′ N., long. 27° 21′ W.) the instruments revealed the extension of the heavy rocks. The depths descend to −5,000 meters, and the positive maximum was encountered at the highest point crossed on the equatorial ridge, at −2,000 meters, about 140 kilometers from St. Paul. This interval includes 10 of the 29 positive Atlantic measurements, so that a considerable negative value remains over for all the rest of the Ocean. But even in this remaining part we observe two high positive measurements, adjacent to one another, near lat. 35° N., long. 12° W. (−3,500 and −3,600 meters), between the submarine heights which run from Madeira towards Gettysburg and which may be regarded with great probability as volcanic.

The conclusion is *that heavy rocks are certainly present beneath the Atlantic Ocean, but that they probably form a locally restricted feature in a region chiefly negative.*

The Sandwich islands have been previously described (IV, p. 322) as a series of islands extending almost from long. 180° to 155° W.; in the west-north-west they are small, low, and extremely steep, and covered with limestone; towards the east-south-east they reveal in increasing extent the volcanic foundation. The volcanic activity becomes displaced towards the east-south-east; the gigantic Mauna Loa lies near the extremity of the series in lat. 19° 30′ N., long. 155° 28′ W. Since Hecker travelled not very far to the north of this island chain and records positive values in lat. 29° 30′ N. and long. 177° 14′ W. we conclude that the heavy rocks of Hawaii actually extend through 10 degrees of latitude and 22 degrees of longitude from west-north-west to east-south-east. Hecker also reached the closed positive region as early as lat. 12° 19′ N., long. 161° 38′ W., so that we may conjecture that the extension is very great in this direction also. On the other hand, towards the north-east, in the direction of San Francisco, no such indications are mentioned. The high positive values in the neigh-

[1] Dana says 3·4; cf. p. 609, n. 2.

bourhood of Honolulu and Oahu are soon followed by a zone, beginning between lats. 24° and 25° N. and extending to lats. 36° or 37° N., which shows 16 negative as against only 3 positive measurements; then we reach the positive girdle of California.

The negative zone also is clearly marked towards the south-west in the direction of Tonga, but less clearly towards the west-north-west in the direction of Yokohama, where, in contrast to the foredeep of Tonga, which gives high negative values, the Japanese foredeep lies within the positive girdle, and on its eastern slope, at levels of −6,100 and −6,400 meters, has given positive values[1].

The results obtained in the Pacific Ocean correspond in all essential points with those obtained in the Atlantic.

Hecker's investigations do not furnish a complete picture of the oceanic basement, but they have supplied the first outlines; in their bearing on the constitution of our planet they are of the greatest importance, and open up a completely new method of exploring that part of it which is concealed by the Oceans.

The following remarks may help us to appreciate the value of his conclusions in respect to the question of isostatic compensation.

Disregarding loose sand and pebbles, the densities of the various rocks of the earth's crust vary from 1·2 or 1·5 (coal) to 3·3, a figure very rarely exceeded except in the case of metallic ores. The mean density of the gneiss of Pikes Peak, as obtained from twelve specimens by Whitman Cross and Gilbert, is 2·615, and the density of the massive rocks which come into question in considering the high mountains seldom lies below 2·3 or above 2·85. These narrow limits show how difficult it is to admit that deficiency or excess can compensate each other within the series of rocks known to us.

Only the heaviest Sima eruptive rocks exceed these limits, and here the highly fluid basaltic rocks with a density of about 3 have a particular significance. In those parts of the sea bottom where few sediments are formed, lava may rest upon lava. Since no erosion occurs, the tablelands are not interrupted by valleys, and the action upon the pendulum or barometer is direct.

On the mainland, bare tablelands of basalt may easily be undermined; their remains are carried into the sea. The tableland of the Deccan trap (basalt), which once extended through almost 10 degrees of latitude and 16 degrees of longitude, covering the Indian peninsula over scarcely less than 300,000 square kilometers, would still be preserved in its entire extent if it had overflowed the sea bottom. On dry land it has been broken up

[1] 34° 57′, 149° 55′, and 34° 56′, 148° 27′; according to the Japanese isobaths of 1899 it should be −6,600 and −7,100 meters.

into isolated patches. The western part, which is still continuous, was spread out over a continent, levelling up mountain and valley, and it contains intercalations of freshwater beds, but near Rájámahendri, on the lower Godáveri, an isolated patch occurs 336 kilometers from the margin of the main mass as it now exists, and contains intercalated brackish water beds, which show that at this place the lava flows reached the coast. Thus the fall of the land was directed towards the east, as at present, and the fragments worn away from the tablelands were carried into the bay of Bengal. This is a case in which the mean density of the submarine rocks is increased by transported material, since trap is heavier than gneiss.

The great basalt plateaux of the substructure of Iceland have not been raised out of the sea, as is shown by the intercalated plant-bearing beds; the downthrown continuations of the horst occupy, however, a large submarine area. In addition, there are not only the Sandwich islands and St. Paul, but also the basalt plateaux of Kerguelen and numerous other islands. We are reminded of the dark lavas of the lunar seas, which likewise do not invariably reach the border of the sea.

Thus it would not be surprising if Hecker's measurements had given a still greater and more uniform submarine density. But it is a long way from this to the proof of a deficiency beneath the continents or of an active compensation, i.e. to a deforming tectonic influence exerted on the continents and the mountains by the sea, such as is presupposed by the isostatic theory of Dutton and his successors: whether the influence is exerted through a viscous medium, or acts upon a rigid body in Chamberlin's sense, is of little importance in this connexion. It is true that some examples of passive injection produced by subsidence have been recorded; thus Salomon thought that the igneous magma of the Adamello had been extruded by the subsidence of the plain of Lombardy. In these cases, however, we are always dealing with molten magmas and secondary phenomena of the great mountain-forming process. When this process is contemplated as a whole, all suppositions of this kind prove inadequate.

Hecker's largest positive region, the centre of which is the Indian Ocean, belongs chiefly to the Atlantic hemisphere. The correspondence of great parts of the coast in the east and west of the Atlantic, as well as the continuation of the Cameroon line into the sea, show that considerable parts of the sea bottom resemble on the whole the neighbouring continents, possibly with the addition of volcanic flows.

In regard to the Indian Ocean in particular, we can speak with greater certainty.

Towards the end of his active life, I had the pleasure of a conversation with Ludwig Griesbach, the distinguished Director of the Indian Survey, on the subject of the Indian peninsula. There is no doubt, he said, that it is simply a fragment. It might at most be compared with the north-western segment of a much greater circle, namely, with the most recent rocks situated towards the north-west, but even these are probably pre-Cambrian. We have described South Africa and India as a broken-up continent (I, p. 387). One of the chief arguments we then adduced in support of this view rested on the horizontal superposition, in both countries, of the Gondwána beds containing Glossopteris upon much older rocks. Since then the same relations have been discovered in Madagascar [1]. At the time of the Glossopteris flora, Gondwána land was a continuous continent. Then it broke down, sometimes along extensive rectilinear fractures, into fragments. The concordant results of the work of English investigators in Cutch and Kattyawár, of Bornhardt in German East Africa, and Lemoine in Madagascar, show that the marine Lias in Madagascar is the first indication of the presence of the sea. Then the great transgression of the lower Oolites coming from the extreme north reaches Franz-Josef Land, extends across parts of European Russia, Bokhara, and Baluchistán to lat. 22° N. on the west coast of the peninsula, also along the west coast of Madagascar to about lat. 23° S., and along the east coast of Africa, according to observations hitherto made, as far as lat. 10° S. The upper Cretaceous transgression everywhere extends further towards the south, and penetrates between Madagascar and India [2]. The west coast of the peninsula is formed, through 4 degrees of latitude, by the Deccan trap. It is not, as we have seen, raised out of the sea, but its western continuation is downthrown.

The east coast of Madagascar is also a fracture. Depths of 5,349 meters have been sounded in its neighbourhood. Towards the north the sea bottom shows traces of chloritic schist with sericite; Réunion and Mauritius contain volcanic rocks, chiefly basaltic [3].

There is every reason to suppose that the nature of the basement of the Indian Ocean resembles that of the surrounding continents. A greater value for gravity would point to a wider submarine distribution of the Deccan trap, further to the south, for example, in continuation with the basalts of Crozet, Kerguelen, Heard island, and elsewhere, but there is nothing to indicate an influence exerted laterally on the continent or the high mountains of Asia by lava-flows of this kind.

Similar data concerning the sea bottom are difficult to obtain in the Pacific hemisphere owing to folding, but the mere fact that folding is present in the New Hebrides and overthrusting in New Caledonia, and that arcuate cordilleras advance far into the Ocean, is opposed to the hypothesis

[1] M. Boule, C. R. Acad. Sci. Paris, 2 mars 1908.

[2] A little map of the transgressions is given by Lemoine, Madagascar, p. 466. Kitchin has given an excellent account of the difficulties which still exist in the case of the lower Cretaceous; Invertebrate Fauna and Palaeontological Relation of the Uitenhage Series, Ann. S. African Mus., 1908, VII, p. 21, p. 250, in particular pp. 51–60.

[3] J. Thoulet, C. R. Acad. Sci. Paris, 18 févr. 1907.

of an isostatic compensation acting from the sea outwards. Such a compensation should first of all close up the foredeeps, but it is just the deepest measurements in one of the foredeeps (Tonga) that have furnished Hecker with negative values.

The investigations inspired by the compensation theory have thus furnished much fresh information, particularly as regards the supposed nature of the sea bottom, but so far no new light has been thrown on the development of the face of the earth. Many conceptions might perhaps have received less support if it had been possible in practice to avoid making sections on a distorted scale, if comparison of the continents with vertically descending blocks had not been so generally made as to exceed all moderation, and if the fact had constantly been borne in mind that more than one half of the planetary surface lies about 3,000 meters deep beneath the sea, while altogether only 0·06 parts rise more than 1,000 meters above it.

Contraction of the earth's body[1]. In this work we have taken as our starting-point the conception that dislocations are the result of movements produced by a diminution in the volume of the planet (I, p. 107). These movements we have divided into radial (sinking) and tangential (thrusting and folding) movements, according to the manner in which the stresses are resolved. The theories of Élie de Beaumont were also based on the contraction of the planet, and he believed that folded ranges were produced as it were in a vice, two powerful masses moving one against the other. In opposition to this view it is assumed in this work that a general, unilateral, but not equable movement occurs. This gives rise to the contrast between the foreland and backland, which led to the idea *that the foreland is overtaken by the folding*. This earliest conception owed its origin to the approximate correspondence in strike of the Alpine and the Variscan trend-lines[2].

A consideration of the forelands revealed with increasing clearness the unilateral structure of the folded ranges. Instances became known in which the foreland exhibited a strike so completely divergent that a common movement was out of the question. In the Caledonides it seemed possible that the older conception of Élie de Beaumont's might hold good, but on their southern border their direction is cut through by that of the

[1] We may mention as one of the most decided champions of this theory in Germany Bergrath von Dücker, who, basing his position on the works of Favre and É. de Beaumont, contended against the theory of elevation in favour at his time, in a number of essays which appeared in the 'Berggeist' of Cologne from 1861 to 1866, also in addresses delivered before the Naturalists' Association at Giessen in 1864, at Hanover in 1865, and at Baden-Baden in 1879. 'The cause,' he said in 1864, 'lies in the wrinkling of the earth's crust due to the shrinkage of the whole earth.' A similar opinion is expressed by Runge in Roemer, Geologie von Ober-Schlesien, 8vo, 1870, p. 460.

[2] Anzeig. k. Akad. Wiss. Wien, 17. Juli 1873, pp. 130–131.

Armorican folds. On the upper Hoangho the mole of North China is an obstructing foreland, as is shown by the overfolding of the Alashan range. At the same time it forms in the east a backland for the folded ranges of Shan-si. Here existing accounts point to a universal, common movement over a considerable part of Asia. The tortuous trend-lines of the Alpides bear witness to the resistance of the horsts. In the Argentine the foreland, which may be recognized by its stratified succession, is involved over a considerable breadth in the folding of the Andes.

Thus the degree of stowing differs in the different cases, but with the exception of the first they all point to unilateral movement.

In the Asiatic system *backfolding* has been shown to result from an excess in the volume of the upper zones of the earth. In the periphery of Asia, it is restricted, so far as is known, to a narrower area than the forefolding, but where the areas become free ends, backfolding predominates, as is seen on the one hand in the Rocky mountains, and on the other in that part of the Altaides lying outside the horst of Azov. It is true that in the Rocky mountains the peculiar oblique division into coulisses occurs in addition, and outside the horst of Azov the normal forefolding is not visible at all; only the continuity of the system as a whole justifies a description of its structure as backfolding.

The objection has been raised *that the amount of the subsidences does not correspond with that of the tangential movements.* Estimating the mean depth of the existing seas at 4,000 meters, and their extension at three-quarters of the planetary surface, the sum total of the subsidence, that is, of the diminution of the radius, would amount to 3,000 meters. This would correspond to a diminution in the circumference of about 19 kilometers only, which is not nearly as great as the amount ascertained by observations. This objection neglects the fact that it is not alone the localized sea basins which bear witness to the contraction of the planet. The forefolding, in particular, attains its greatest importance under the direct influence of a subsiding foreland. At first only one great example, that of the Belgian Faille du Midi, was taken into consideration (I, p. 142). When the Caledonides in the West of Scotland and the Alps also were compared with the Belgian coalfield, it appeared that in these three cases, which represent the greatest mountain structures of Europe, the movement took place over obliquely-ascending soles, and the folding thus becomes a secondary phenomenon. At the same time there is no complete separation between the radial and the tangential stresses.

The resolution of the stresses proceeded uniformly, and occurred on one or more surfaces (soles of the first order), which correspond more or less to the resultants of the two forms of stress. Great wedge-shaped fragments of the earth were transported over the foreland, *and the subsidence was consummated in the range itself and possibly in the foredeep also.* The forces must have found expression, however, at such a depth that they led to the ascent of Pacific rocks in the Alps, and enabled the green rocks in the foothills of the north-western part of the Pyrenees and in the Mediterranean Atlas to force their way into lagoon sediments, and into the Trias of Germanic type.

Among recent high mountain ranges the Alps are at present known in the greatest detail. For this reason we may call to mind that it is not only their outer border which was overfolded subsequently to a part of the Tertiary formation. It is true that there are older unconformities and ingressions, such as that of the Gosau beds and that of the Eocene of North Tyrol, which place beyond doubt the existence of older structures, but at the same time a variety of circumstances, such as the pinching-in of the long Tertiary Flysch zone of the Aiguilles d'Arves to the east of mont Pelvoux and mont Blanc, the long syncline of the advancing Dinarides in the western Tyrol, or the pinching-in of the sediments of the second Mediterranean stage near Borgo in the val Sugana, as well as many other features—all enable us to perceive with certainty that in the Alps, and also in the above-mentioned part of the Dinarides, the essential features of the existing structure were not produced before the middle of the Tertiary aera. On this point all recent observers are in accord.

It is certain that the contraction which has taken place here is of extraordinary extent. In the northern Variscan foreland the movement is directed towards the north. To the south of this foreland lay a foredeep, and south of this again followed the great sheet-like overthrustings likewise directed towards the north. The Carnic Alps, of equal age with the foreland, were also driven towards the north, and likewise, in spite of their southwards-directed folding, the Dinaric series superposed on the Carnic foundation. The Dinarides are now wedged in between the Alps and the Apennines, and the latter are driven towards the north-east, so that the Dinarides become the foreland of the Apennines. It is impossible to say to what distances this great rending of the planetary surface extended towards the south and south-west.

Beneath the high mountains, however, even down to great depths, no deficit occurs, such as is required by the theory of isostatic compensation; in reality they surmount the previously overthrust zone.

It was these very investigations on isostatic compensation that led to views on the *rigidity of the earth* which we have now to take into account. Lord Kelvin, and after him Sir George H. Darwin, believed that the rigidity should be about that of steel.

So far as our studies are concerned it would appear as though it were simply a function of the contraction of the planet, and of the pressure, which first manifests itself at the moment of resolution of pressure. The material is probably that which is brought up by intrusions, namely Sima or Sal rock. The melting is produced by juvenile gases. It is these also which give rise to such batholites as may occur.

The question now arises as to what we are to understand by the term *rigefaction*, a word frequently employed in this work. We have encountered its effects in a particular form, as disjunctive lines and fault-troughs, that is as rents, which open from the surface downwards. In East Africa their rectilinear course shows that uni-directional, mountain-forming stresses are absent. The arcuate rents in eastern Asia, on the other hand, indicate the presence of the uni-directional stresses. The rectilinear course of the Rhine valley shows that there the ancient Variscan thrusts were absent in the Tertiary epoch, as were the Alpine. This is the more remarkable since the Variscan trend-lines do not differ so very much from those of the Swiss Alps, so that the Alps may be described as posthumous Altaides, and in the formation of the Alps we may conjecture a renewal of activity after a long summation of stresses. The fact that on the Rhine uni-directional mountain-forming stresses are absent led us to conclude that this region is rigefied. It has not been proved that this mode of rigefaction is dependent on a local cooling of the earth. The Alps occupy an exceptional position as a folding within the frame. If a larger number of such cases were known, and it were possible to take a general survey of the earth, we should see how the lateral stresses are distributed in space. That they were once universal is inferred from the widely extended folding of pre-Cambrian rocks; that they are not so at present is evident from the distribution of the folded ranges. In Asia this distribution has long been very uniform, as is shown by the correspondence of vertex and periphery. Here, however, the fact must be taken into account that the two free branches of the Asiatic structure, the Rocky Mountains and the Altaides which lie outside the horst of Azov, were rigefied, the former towards the close of the Cretaceous period, the latter after the dislocation of upper Carboniferous. The question has also been raised whether the European subsidence may in this case have led to the rigefaction, i. e. the conclusion of the stresses. In contrast to the rigefaction of these ends, mountain-forming movement occurred not only on the outer border, but also in the interior of Asia up to a late period; examples are afforded by the folded Jurassic beds on the Bureja, the recent folds beneath the plain of north-west Manchuria and on the Amur, the pinched-in syncline of the recent Gobi beds between the Richthofen range and the Tolai-shan in the Nan-shan, the overfolded Artush beds at the south foot of the Thianshan, the backfolded Jurassic Angara beds on the Angara, with other examples extending up to the vertical plant-bearing Tertiary beds of New Siberia.

A contrast is presented by *Africa*, and the absence of folding might lead us to seek the place of separation of the moon in the Atlantic region. The rigefaction, however, did not occur in the Sahara until after the upper Silurian, nor on the Armorican line until after the middle Carboniferous, nor in the Cape mountains until after the Permian. Here it may be asked whether the interruption caused by the Atlantic subsidence brought about the rigefaction of the Appalachians. On these questions the existing state of observations throws no light; we only know that in the Pacific hemisphere the case is different.

Round about the Pacific Ocean, and along the southern marginal arcs of Asia to the Adriatic sea, on the other side of the Pole in the United States chain, and again far away in the Cape mountains, there makes its appearance, notwithstanding the exceptions already mentioned (Elias mountains, Burman arc, Urals), such an arrangement of the folded ranges that we are led to consider whether, in respect to this great part of the earth, we must not admit the action of *bodily tides* or of the *rotation*, in addition to the contraction of the planet, as a possible factor in determining the plan of the folded ranges. The possibility of such an influence would also modify certain elementary conceptions in tectonics, for whereas it has been supposed hitherto that the deeper lying zones of the earth contract and carry the upper zones forward, it would now be necessary to take into account an action working from above downwards. In the Alps a distinctly marked peak-folding is well known. This action would also simplify our conception of overthrust sheets, but it is precisely in the Alps that the direction does not follow the lines of the tides and the rotation.

The distinction between the Atlantic subsidences and the *foredeeps* stands out very clearly. *While the Atlantic and especially the European subsidences lie transversally across the folds, which are interrupted and of earlier date, the foredeeps on the other hand are intimately associated with the folds and follow the same direction.*

Many years ago Middlemiss recognized the foredeep of the Himálaya as a zone of subsidence, and believed that forefolding and subsidence went as it were hand in hand [1].

Similar relations may be seen, on a very small scale, on the border of the Jura mountains towards the table-Jura; there, however, the subsidence of the Rhine valley afforded an opportunity for the folding to advance (IV, p. 527). We might almost suppose that the foreland had been forced down by the advancing range. Other facts, as for instance the position of the northern Antilles, support the conclusion that the subsidence was the primary phenomenon.

The coal-bearing zone on the north border of the western Altaides, extending from Silesia to Ireland, and on the other side of the Ocean to

[1] C. S. Middlemiss, Physical Geology of the Sub-Himálaya of Garwhál and Kumaun; Mem. Geol. Surv. India, 1890, XXIV, pt. 2, 143 pp., maps, in particular p. 138 et seq. Similar observations by this distinguished geologist are already to be found in his work, On the Structure and Relationship of the South Portion of the Himálaya Ranges between the Rivers Ganges and Ravee, op. cit., 1864, III, pt. 2, 209 pp., maps; and in The Alps and the Himálaya, a Geological Comparison, Quart. Journ. Geol. Soc., 1867, pp. 34–52.

beyond the Mississippi; the Flysch and Molasse zone in the north of the Alps, and the Sewâlik zone in the south of the Himâlaya are, in the main, deposits in foredeeps. In the subsequent history of the foredeep the part lying next the mountains was overstepped by them and folded in, so that the Belgian coalfield, for example, comes to lie beneath the older rocks in the south as a compressed syncline divided by listric planes. That part of the zone, however, which was more remote from the mountains remained, as well in the Belgian as in the American coalfields, in the Molasse of Switzerland and in the Sewâlik zone, flat, and undisturbed. *The foredeeps are not synclines in the tectonic sense of the word,* for one side belongs to the foreland, the other to the folded mountains. Speaking generally, with the exception of bays belonging to rias coasts, no tract of the sea is known which has been transformed by lateral pressure into a syncline. The manner in which sea basins arise by the coalescence of subsidences is illustrated by the history of the Mediterranean [1].

Not all folded ranges possess foredeeps; many flatten out, or form parmas, as for instance the Urals and the Appalachians. Nor is it by any means an established fact that all folded ranges have ascended from below on obliquely inclined soles. It is highly probable that very many of them have developed by repeated folding, or, like the Appalachians in Alabama, have allowed the folds to pass in places into thrust planes. The Faille du Midi itself belongs rather to the periphery of the Altaides. But all folded ranges, impelled by the general struggle for space, have a tendency to enter into the subsidences, as for instance the above-mentioned Jurassic folds in the Rhine valley, or to overthrust the subsidences, or to throw the subsidences themselves into folds. This is the reason we so frequently encounter a richer marine series in the folds than in the foreland, and why compressed sea basins have been so frequently mentioned. At the same time it is remotely suggested that secondary subsidences interrupt the progress of the folding, but the connexion between cause and effect is not established in this case, and the folding of the Rocky Mountains comes to an end without any known inbreak or subsidence. On the other hand it is not impossible that the overridden and subsided foreland sinks beneath the high mountains and assists in producing zonal differences, or such flakes as are too large to be produced by folding. This is possibly true for parts of the Alps; a good example seems to be afforded by Hazára [2].

[1] The lie of the sediments which fill it is possibly synclinal, somewhat as described by Haug, Traité de Géologie, I, 1907, p. 159, fig. 36. This, however, is not the tectonic conception of the *geosyncline*, and the *geanticline* cannot be regarded as its opposite; the geanticline was originally conceived by Dana in a different sense, but to many authors both words seemed to presuppose equilibrium and the germ of the isostatic theory. For this reason I regret that I at first employed the term geosyncline in this work; subsequently I avoided it.

[2] Middlemiss, Hazara, Mem. Geol. Surv. India, 1896, XXVI, p. 261.

The great significance of the subsidences also becomes apparent in the *negative movements* of the strand. The so-called 'epeirogenetic' movements, which, in addition to tectonic movements, are said to be produced by some unknown force, are in my opinion either local phenomena, connected with the general structure of the land, as for example in the case of the marine upper Tertiary deposits which Diener observed resting upon the broken-up fault-plexus of the desert of Palmyra, or they are based upon changes in the form of the hydrosphere. From the extensive tablelands of lower Palaeozoic between the Jenisei and the Lena to the flat-lying patches of lower Silurian which are scattered over the Canadian shield, and again to the flat-lying Cretaceous platforms of the Sahara and Texas, the upper Tertiary belts of the Mediterranean, the recent strand-lines, and the terraced islands of the existing Oceans—in all these features we see negative processes of such extent that they can only be ascribed to subsidences of the sea bottom and the consequent sinking of the strand-line, a process recognized long ago by Strabo. No form of tectonic movement could produce the uniform elevation above the sea of a tract of land so extensive as the African desert.

Of greater diversity and more difficult of explanation are the *transgressions*. Apart from the uninterrupted positive activity of transported sediment, they appear sometimes to stand under a scarcely explicable influence, produced by rotation; at others we are tempted to ask whether some great tectonic change, the gradual folding up of a range or a new subsidence, may not have influenced the centre of gravity of the earth, in consequence of which compensation has occurred through a change in the form of the hydrosphere in accordance with Clairaut's principle.

This is by no means the only phenomenon the solution of which must be left to the future. The deeper reason for the difference between the Pacific and Atlantic hemispheres is not known; for the present we can only record the facts. The intercalation of the apparently loosened zone of the American Intermediate mountains with the Basin ranges, and also with the South American Andes, is not explained in a perfectly satisfactory manner, and the position of the depression along the west coast of South America is not in accord with the general arrangement of the deeps. Our knowledge of Timor and the islands lying off it is not sufficiently far advanced to permit us to form an opinion on the relations of Australia to Gondwána land. The two-sided structure of the Caledonides, as it is represented in existing accounts, is difficult to bring into accord with other observations on mountain structure. The nature of Karpinsky's lines is unknown. A number of doubts and questions remain unanswered in this incomplete attempt to obtain a general conception of the face of the earth; they hang from it like the loose threads of an unfinished texture.

Summary. From the summits of the Tauern we look towards the south, where the white peaks of the Dolomites rise from the haze of early dawn. The eye feasts on the alternating splendour of snowfield, rock, and forest, and follows the play of the white mists which rise from the Pusterthal and the valley of the Rienz. It is not without reluctance that the traveller turns from the charms of the landscape.

The outer walls of an ancient temple are covered over with sculpture, and in the midst of the skilful carving gape the joints of the masonry, widened by the hand of time; so we, through the midst of this noble scene, draw the dividing planes. The Tauern themselves become a window, and the dark heights, which separate them from the Dolomites, become the border of a sheet, the continuation of which lies far to the north, on the other side of the Tauern; we separate the Dolomites completely from the Alps, and assign them to the Dinarides, which approach from Dalmatia. We separate the eastern from the western Pámir, the east Sayan from the west Sayan, and the horst of the Gobi-Altai from the folded range of the Russian Altai; and we unite the Sudetes with the Harz, Brittany with Cornwall, with Newfoundland and the Appalachians, and the Antilles with the Andes.

Thus unexpected unities have taken form, and now, once more, as at the beginning of this work, we will suppose the earth to rotate beneath our eyes.—

Let us place in the middle of the picture the meridian of 105° E., and bound it by the meridians of 130° E. and 80° E.

A great part of the Asiatic system is visible. In the north-east lie the New Siberian islands with beds folded towards the north-east. Tertiary leaf-bearing beds emerge steeply upturned. The delta of the Lena lies in the folded Mesozoic offshoots of the arc of Verkhoiansk. Then we perceive the northern part of the broad and ancient Angara land. Cambrian beds lie horizontal; they are exposed for a great distance along the Lena. On the Chatanga gneiss makes its appearance from beneath them. This ancient land extends on the south to the amphitheatre of Irkutsk, where it is bounded by the horseshoe-shaped, backfolded border of the ancient Baikal vertex. In this interval posthumous horseshoe-shaped folds are seen, formed of plant-bearing beds of Jurassic age. Its south-eastern boundary lies a little to the west of the western margin of lake Baikal; the south-western boundary is formed by the Sayan.

This horseshoe-shaped or arcuate vertex is the innermost and oldest part of a structure formed of many similar arcs, which are convex towards the exterior, and frequently cut through by more or less continuous disjunctive lines. A second vertex, probably of Devonian age, is to be seen near Minuzinsk, a still more recent vertex, constructed later as part of the Carboniferous, on the Altai. Towards the east arcuate trend-lines succeed one another as far as the Pacific Ocean, from the Anadyrides to the Philippines, and in the south they form the marginal arcs as far as the Dinarides. On the disjunctive lines stand the volcanos, and in those places where the cordilleras are submerged, volcanos reveal the trend-lines of their arcs as far as the Bonin islands and the Marianne group.

As we look towards the periphery we see the gradual completion of the marine series, and from the Okhotides to the Dinarides the folding seems to extend throughout the whole region into the middle Tertiary or even later times.

This uniform structure is interrupted by two long, free branches, which stretch far beyond the periphery. They proceed from the south of the Altai and are therefore termed the Altaides. The eastern Altaides form the Burman arc. The western Altaides strike in a straight line to the west-north-west across the northern border of the Pámir and the Iranian-Tauric syntaxis, and finally reach the Caucasus, where they enter Europe.

Turning our glance towards the south-east we see in Australia a land which seems to occupy, within the arc of the Oceanides, a position similar to that of Angara land within the arcs of Asia. Australia is continued to the south through Auckland and other countries towards the Antarctis.

The Asiatic system, if we disregard the advance of the Altaides, has added arc to arc with the greatest regularity since pre-Cambrian times, and has been completing itself on the old plan up to a recent period; and Australia with the Oceanides is possibly a repetition of this plan; now, however, as we look towards the south-west, we perceive a different and divergent structure—the Indian peninsula.

Here there is no approach to an arcuate arrangement, and recent folding and the Mesozoic and Tertiary series are only represented in a fragmentary manner. It is true that ancient sediments of various kinds are folded, but they have never yet furnished any organic remains. We only perceive that the direction of these folds is foreign to the Asiatic structure, and that the peninsula is a fragment bounded by fractures on all sides.

This is the alien foreland, against which the Burman arc, the Himálaya, and the Iranides are stowed.—

The planet has now continued on its journey for six hours, so that we are facing the interval between 40° E. and 10° W., and the meridian of 15° E. runs through the middle.

This interval comprises Europe and almost the whole of Africa.

In Spitzbergen a trace of the pre-Devonian Caledonides protrudes from the flat-lying Mesozoic sediments which, as a part of the circumpolar transgressions, form both Franz Josef land and the surrounding islands, together with Bear island.

Jan Mayen and Iceland are of recent volcanic origin. In the most northerly part of Scandinavia an outrunner of the Uralides makes its appearance crossing over from Swatoi Noss. Then we come to the sub-meridional Caledonides, which include the whole of the west of the Scandinavian peninsula, the Orkneys and Shetlands, Ireland down to the lower course of the Shannon, Wales with the exception of its outermost southern border, Scotland with the exception of its outermost western border, and England nearly as far as the Mendips.

The Caledonides divide the Bothnian shield (which we assign, together with the Uralides, to the Asiatic structure) from a gneiss region of no very great extent, and chiefly represented by the western Hebrides, which is assigned, although with some reserve, to Laurentia.

Here, on the line from the Shannon to the Mendips, which finds its continuation in the north border of the Belgian coalfield, we observe another order of things.

From the extreme north down to this line there is no folding which is later than parts of the Devonian. From this line onwards younger folds occur; in place of the submeridional Caledonides a more east and west direction makes its appearance. This is the region of the western Altaides which crowd in from Asia. With a direction to west-north-west they strike across the Caspian sea as branches of the Thian-shan. A rather weak, northern branch dies away in the coalfield on the Donetz; a much stronger branch extends from the Caucasus to the southern side of the horst of Azov.

From this point onwards the folding turns to the north, abandoning the southerly folding of the Asiatic arcs which has prevailed hitherto, and at the same time the Dinarides, one of the marginal arcs of Asia, makes its entrance. It is very broad, occupies the interval as far as Cyprus, Crete, and the Adriatic sea, forces its way between the Alps and the Apennines, and retains, in contrast to the Altaides, the Asiatic folding directed to the south.

The Altaides broaden out, push forth new branches, and thus at last occupy all the south of Europe, and surround as well the western Mediterranean. Their southern boundary forms the south of the Great Atlas, then of the Mediterranean Atlas and the zone of encounter with the Dinarides.

In this area assigned to the Altaides, ranges, however, arise, which are of different ages.

The western Altaides, in the narrower sense, comprise the Variscan and the Armorican arc, the Montagne Noire, Corsardinia, the greater part of the Iberian peninsula, as far as the Guadalquivir and the Great Atlas, and finally the Carnic Alps, which emerge between the Alps and the Dinarides. Their folding had terminated before the close of the Carboniferous, and at the time of the Permian they may be regarded, except for some quite insignificant undulations, as having already passed into a state of rigidity.

Then the chains become broken up into horsts by a number of subsidences, which recall to some extent the limited subsidences of the Mediterranean; and out of these subsidences, that is, out of the very heart of the rigid Altaides, and to a large extent bounded by their horsts, rises a new structure, that of the posthumous Altaides.

These fall, according to the subsidences, into separate groups. Of these by far the largest is that formed by the Alpides, extending from the

Balkans, through the Carpathians, the Alps, the Apennines, the Mediterranean Atlas, and the Betic Cordillera to Majorca. This group is folded, like the Altaides, to the north; frequently diverted by the horsts; forced, in the Mediterranean Atlas, to assume folding to the south, and in no small part built up as late as the Tertiary aera.

A rather more independent position is occupied by the Provençal folds, which are continued into the outer border of the Pyrenees and through these into the Cantabrian range.

Independent but gentler posthumous folding is presented by the London and Paris basins and a subsidence of western Portugal.

A characteristic rias-coast marks, in the south-west of Ireland and in Brittany, the foundering of the Armorican arc. From this point nearly to the Wady Draa the Atlantic coast belongs to the Altaides.

In addition the following elements must be taken into account: the Cimmerian mountains, that is, the remains of a folded range of Mesozoic age, which forms the Crimea and Dobrudsha, embraces the mouths of the Danube, and disappears beneath the strongly projecting arc of the Carpathians—further, the range of Sandomir in Poland, already faulted down in front of the border of the Carpathians, which has been regarded in this work as a foot range of the Sudetes, but may possibly prove to be an arching up of the Russian foreland produced by the Sudetes—finally the Bohemian mass, a fragment of a very ancient range, making its appearance within the Variscan arc, and deflecting the range of the Alpides.

We observe the rigefaction of the Altaides before the time of the uppermost Carboniferous, and the renewal and persistence of the folding in its subsidences. Thus the movements have been separated in space.

We have arrived at a boundary which belongs to the Altaides in respect to that part of its course formed by the south border of the Great Atlas and extending as far as the Jebel Bechar; from Jebel Bechar to the Adria it belongs to the Alpides, and from the Adria onwards as far as Djabekr it belongs to the Dinaro-Tauric marginal arcs. This boundary is followed in Africa by an ancient structure which extends through about 65 degrees of latitude and is devoid of any recent folding.

In the western Sahara the submeridional Saharides extend from the north to beyond the Niger; their folding is older than upper Silurian; we must thus regard them as older than the Caledonides, which in other respects they resemble. To the east of them, as far as Syria and Arabia, extends the Cretaceous and Tertiary desert plateau, to the south of them Archaean formations and the deposits of the Karoo, forming a complex comparable to the Indian peninsula. Long fissures, beset with volcanos, cut through the continent. Madagascar is a fragment of the ancient Gondwána land.

In the south a different scene is disclosed. Three fragments of folded mountain chains advance from three sides towards the Karoo. These folded ranges, however, were already rigid before the close of the Permian, and they form a southern pendant to the marginal arcs of Asia. Cape Agulhas is not so far from the equator as Crete or Cyprus, and if the north were submerged to the same extent as the south, the whole of Europe would lie beneath the Ocean, and of its complicated structure even less would be visible than of the southern structure on the borders of the Karoo.

Of the preceding the following facts deserve special attention: first, the intersection of an older structure (Caledonides, Saharides) by a younger (Altaides); next the rigefaction and subsidence of the latter; then the birth of new ranges, particularly the Alpides, within these subsidences; and, finally, the existence at the Cape of the fragments of a great folded system constructed like the periphery of Asia, but turned towards the north.—

We will again suppose that the earth has travelled on its course for six hours. The meridian of 15° E. has disappeared, and in its place the meridian of 75° W. now occupies the middle of the picture, but the great difference in longitude of North and South America obliges us to consider a broader section. Even the interval between 50° W. and 130° W. is not quite sufficient.

In the north we first observe, as it strikes obliquely across Ellesmere Land, the United States chain, a fragment of the Asiatic periphery, with the same rich Mesozoic succession, but extending beyond the pole. Then we reach the flat-lying lower Palaeozoic belt, and the ancient crystalline mass of Laurentia. Towards the north-east this mass includes Greenland, it may possibly extend through the whole breadth of the Atlantic Ocean to the Hebrides; in the south it forms the middle of the United States as far as Texas. In Laurentia, as in Africa and India, the absence of younger folding runs parallel with the absence of any well-marked development of marine Mesozoic beds. On its eastern side Newfoundland reveals to us once again the rias-coast, which withdrew itself from our view as Ireland and Brittany passed out of sight. It is a continuation of the western main branch of the Altaides, already rigid, in America also, before the Permian, but without inbreaks or other posthumous structures. Here it is known as the Appalachians; it forms the south-eastern and southern boundary of the foreland of Laurentia and dies away in Oklahoma.

A mighty range—the Rocky mountains—forms the western boundary. Its syntaxis, with the Alaskides, a range of purely Asiatic type, which takes place between the meridians of 146° and 147°, shows that it also belongs to the outrunners of the Asiatic system, which thus surrounds all the American part of Laurentia. This range which, over long intervals, presents an oblique, coulisse-like structure, is stowed in the south against the ancient block of the Colorado plateau, and dies out on its east side. Its folding came to an end after the upper Cretaceous. Yet another branch, the Elias range, proceeds from the syntaxis in meridian 147°. Just as in the Alaskides the Rocky mountains correspond to the Romanzov range, so the Elias range corresponds to the Kenai mountains, and is driven, like these, towards the Pacific Ocean; it is not rigefied; Tertiary beds are folded in it; and it is still subject to movement.

Between the Elias range and the Rocky mountains the Intermediate range makes its advance: it is a long zone characterized by a fairly rich Mesozoic series, by folding, disjunctive lines, troughs, and volcanos. To this range we assign the great Columbian batholite of granodiorite, the continuation of which forms the volcanic Cascade range, and a long tract of similar structure extending to the Basin ranges and the west side of the Colorado plateau. In Arizona this zone appears to be interrupted, but its characters are repeated by the Mexican sierras, which at the same time trend away to the south-east, decreasing in height up to the immediate neighbourhood of the gulf of Mexico.

The Californian coast ranges mark the first appearance of the colossal range of the Andes. Divided into a number of oblique coulisses they strike through upper California, across the Maria islands into the Mexican Sierra Maestra del Sur, the north side of which is accompanied by gigantic volcanos. Its further continuation runs unbroken across Tehuantepec to Guatemala. The branches become concave towards the north, while the western part of the Antilles forms a virgation which includes the main range of Cuba, of the line from the Sierra Maestra to north Haiti, and then of the line from Jamaica through south Haiti to Porto Rico; in Guatemala, on the other hand, the branches, concave towards the north, make a bend from the gulf of Amati across the island of Roatan into the direction of Jamaica. This is the first entry of the Andine structure into the Atlantic region. The above-mentioned virgation unites in the Lesser Antilles to form a single arc, which, subdivided into zones like the peripheral arcs of Asia, passes through Trinidad to Venezuela, and through Columbia and Ecuador back to the main range of the Andes.

In South America the Brazilian foreland plays a part similar to that of Laurentia in the north. Here, too, recent folds are absent, and almost all the marine Mesozoic beds. From the Carboniferous to the middle Cretaceous only extra-marine, plant-bearing beds are known. Towards the west, however, unusual conditions set in. The folding directed to the east, which characterizes a great part of the Andes, extends its influence to the stratified series of the foreland and the high mountains to the east of lake Titicaca, such as Illimani and its companions; the whole of the Cordillera Real and the Argentine Andes are formed of the same stratified series. It is not until we reach the west that we meet with marine Mesozoic beds in the Cordillera de los Andes, where they make their appearance as a long and narrow strip, with long disjunctive lines and troughs and the well-known gigantic volcanos, thus reproducing the principal features of the Intermediate range and the Basin ranges of North America. The western border is formed by a mountain range, which, as shown by the presence of superposed plant-bearing beds on its east side, formed part of a continent in Mesozoic times. The same superposition of plant-bearing beds is again seen in the Sierra Maestra del Sur of Mexico, in the heights of Honduras, in Chili, and down to the Antarctic region. Still further west the sea presents an important and elongated deep, but its relations to the Andes have unfortunately not yet been ascertained.

The view has been put forward that the southern Andine branches bend to the south-east, and then, diverging from one another, approach the sea between cape Corrientes and cape Horn in a similar manner to the Mexican sierras. The land, however, is little known, and this theory is contested. On the other hand, there is no doubt that the principal range of the Andes describes a curve about the south of Patagonia, which in a tectonic sense resembles the concave chains of Guatemala. Further away, the arrangement of the islands enables us to recognize a second advance of the Andine system. The analogy presented by the contours of Patagonia and Graham Land, and the volcanic arcs of the South Sandwich islands are indications of this advance, and the whole archipelago is termed, for want of a better name, the South Antilles.

An important foredeep may be supposed to exist outside the South Sandwich islands, and a foreland representing Brazil in the east of Graham Land.

The region just considered, extending from Ellesmere to Graham Land, is the only region on the globe which permits us to follow its structure from the Arctic to the Antarctic ice-fields.

We may again suppose six hours to have passed, and we reach the meridian 165° W. extending along the west coast of Alaska to Bering sea.

The great arc of the Alaskides is constructed on the Asiatic type, of which indeed it is one of the most perfect examples. The Romanzov range in the north, the Alaska range with the lofty mount McKinley, and the peninsula of Alaska with the volcanic arc of the Aleutian islands are the most important parts of the great virgation. Angara land, however, is not the backland, or at least is not visible as such; Bennet land is the last fairly well-known trace of a foreland.

Stewart peninsula, a segment entering between the branches of the virgation, is continued towards Asia, and the New Siberian islands are possibly one of the last traces of the backfolded Romanzov range.

The Alaskides form a true bridge between Asia and America, and as we have seen above, we assign the Rocky mountains and the St. Elias range to the Asiatic system.

To the south of the volcanic arc and the foredeep of the Aleutian islands the Pacific Ocean broadens out down to the south-easterly trending range of the Sima volcanos of Hawaii. With a few exceptions, the theory that the arcs of the Oceanides are parts of folded mountain ranges or their accompanying volcanos scarcely admits of doubt. An important exception is presented by Viti Levu, which is possibly the remains of a closed-in, unfolded segment.

The arcs are frequently interrupted. The first trifling indication of an arc is given by the atoll of Raroia and some occurrences of a similar kind, which are linked with the line of the Paumotu islands. The principal lines of the Polynesian region are formed by the Paumotu islands and Tahiti. In the Australian region we recognize three arcs: the first, bounded by a mighty foredeep, extends from the north-east of New Zealand, through the Kermadec and Tonga islands; the second, proceeding from it in virgation but less connected, includes the Caroline islands, Radak and Ralik; finally, the main arc includes the north-west of New Zealand, New Caledonia, the New Hebrides, the Solomon islands, and probably New Guinea.

The folding is directed mainly towards the north-east, in the periphery of Asia to the east and south-east, in the Alaskides to the south, in the St. Elias range (judging at least from the arrangement of the rocks) to the south-west.

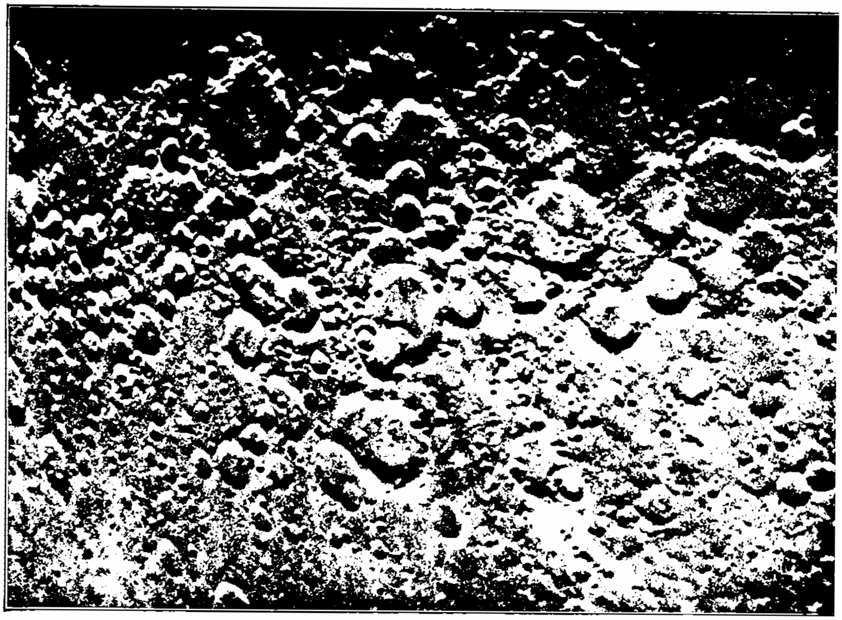
In the south of New Zealand, the islands which follow towards the south, and in Victoria Land, divergent Atlantic characters make their appearance.

In another six hours the great Asiatic system once more extends beneath our eyes. The earth has completed her day's journey.

Note to Pl. V. (In these figures the north lies below). Fig. 1 shows the coalescence of two of the seas which Loewy and Puiseux compare with the Mediterranean inbreaks, on the left the Mare Serenitatis, on the right the Mare Imbrium. The peninsulas separating them are above (in the south) the Apennines, and below the Caucasus. Three striking circumvallate rings rise from the Mare Imbrium, Archimedes, Autolycus, and Aristillus. The space between them and the steep scarp of the Apennines is the Palus Putredinis; it enters between the Caucasus and the Apennines; the latter bears here very high mountains, such as Mount Hadley, which are not volcanos but segments. On the other side of the gap between the Apennines and Caucasus, a faint white spot appears on the dark ground of the Mare Serenitatis. This is Linnaeus, in which recent alterations are believed to have taken place. A somewhat brighter white spot (alum ?) lies to the south of it, where the Apennines dip gently beneath the lava flow of the sea. Between the Caucasus and the border the great circumvallate plains Eudoxus and Aristotle occur. The mountains on the north border of the Mare Imbrium are the Alps; the valley of the Alps is visible as a straight cut. Fig. 2 shows above to the left and in some other places parts of the so-called 'ancient land,' namely, less altered parts of the lunar surface, to some extent comparable with the basaltic substratum of Iceland. Many 'riding' craters are visible. A beautiful example is seen below on the right; then follow in a submeridional series the three circumvallate plains, Purback overlapping into Regiomontanus, and Walther; then above on the right Orontes with two larger 'riding' craters following towards the left; the last is Nasreddin. To the left of Nasreddin lies Stoefler; above to the right and below to the right it presents small riding craters, above to the left the larger riding crater of Faraday, which is again followed by two generations, and so on. These occurrences show that there is every stage of transition between riding eruptive centres and circumvallate plains, and that the moon at its separation from the earth took with it many juvenile gases, although judging from the entire weight, 3·4, very little Nife can have gone with it.

After Loewy and Puiseux

Apennines, Caucasus, and Alps



After Loewy and Puiseux

Purback, Orontes, and Stoefler

PARTS OF THE SURFACE OF THE MOON

CHAPTER XVIII

LIFE

Introduction. The strand. History of the Caspian sea. Appearance of placental mammals. Asylums.

IN the city of Vienna many thousands of human bodies must have passed, in the course of years, under the hands of Carl Rokitansky, one of the great founders of pathological anatomy. He watched the passing generations; he saw, outside the limits of the human race, repeating itself under the most diverse modifications, the same succession of birth, growth, propagation, and death. All life appeared to him as a single manifestation, and in summing up his observations he spoke not of unity, or of common origin, but of the *solidarity* of all life [1].

Lamarck and Darwin led the way to this conception, but now that it is reached it appears to us not as the final result of a comprehensive synthesis, but as the elementary physiological starting-point, to which these great investigators have led us back. It brings with it the idea of a biosphere, which assigns to life a place above the lithosphere, is concerned only with life on this planet and all the conditions in regard to temperature, chemical composition, and so forth, necessary for its existence, and leaves on one side all speculative hypotheses as to the possible presence of living beings on other heavenly bodies. Determined by these conditions, the biosphere is a phenomenon limited not only in space, but also in time.

We know nothing of the origin of life. The reduction and atrophy of the eyes of the Cambrian Trilobites show that these, although the earliest creatures known to us, are yet not actually the earliest that existed. Even the Xiphosures of the North American Belt Stage by no means present the character of primitive animals.

Little as we know as to the details of the beginning, equally little do we know as to those of the end, although this end is inevitable. Some vast prospective changes may be inferred from the tidal retardation of the planetary movements—in particular the final loss of sunlight over half the surface—but it will be seen from what follows that there may lie in the

[1] C. Rokitansky, Die Solidarität alles Thierlebens, Vortrag in der feierlichen Sitzung d. k. Akad. Wiss. Wien, 31. Mai 1869; Almanach k. Akad. Wiss. Wien, 1869, XIX, pp. 185–220.

very structure of the planet itself a source of danger threatening a not inconsiderable part of the living world.

Life is embodied in an almost infinite variety of forms. If we consider the wide distribution and uniformity of the freshwater fauna of the Devonian continent of Eria, or the floras of the Carboniferous, or the terrestrial fauna and flora of the Gondwána period, we shall readily admit that the variety has increased in the course of time. Physical influences have possibly remained unchanged, but their effects have accumulated. Even in comparatively early times there were glacial epochs; and the traces of warmer epochs date, even in Arctic regions, from periods as remote as the Palaeozoic aera. The sea of the coral-bearing Gosau beds was warmer than that of the contemporaneous Cretaceous of North Germany, and the coral sea of Castel Gomberto was warmer than that of the sands of Weinheim and Fontainebleau. Each new climatic phase was accompanied by a more greatly modified and, as a rule, more highly specialized fauna and flora. But the case is different when we turn to the face of the earth itself. For the whole of its existing state—with the outlines of the continents, the mountains and valleys, lakes and rivers, and the depths of the sea—is the product of an accumulated sum of different processes.

At the very outset, an attempt to consider the biosphere and the lithosphere simultaneously, shows that as the island of Trinidad, for example, presents throughout fluviatile fishes characteristic of South America, so even islands which are separated from the mainland by depths of several thousand meters, may yet possess many land and freshwater animals which are identical with those of the continent. Such an island cannot have been raised out of the sea, but the dividing deep must have been formed by subsidence. The islands containing such a fauna and flora are therefore horsts, and the theory of the permanence of oceanic basins represented by Wallace, is for this reason alone untenable.

The influence of external conditions is clearly manifest in the fact that changes do not always occur simultaneously in the marine, terrestrial, and freshwater animals. In the middle Cretaceous of the United States, for example, the existing dicotyledonous forests made their appearance and underwent a rapid development, while the ancient flora disappeared, and yet the ancient types of plant-eating reptiles persisted down to the close of the Cretaceous.

Richard Owen observed many years ago that if we add to the existing Australian marsupials those of their ancestors which became extinct in quite recent times we obtain a group presenting a subdivision into carnivorous, insectivorous, herbivorous and rodent-like animals similar to that presented by the great land faunas of Eurasia. The attempt has been made to show that a corresponding subdivision can be traced even in the Mesozoic reptilian faunas. Osborn has termed this phenomenon the law of adaptive radiation, and cites as an example the oldest Tertiary mammalian fauna—that of Puerco in New Mexico [1].

That the great units are subject to economic conditions—that a certain number of beasts of prey presuppose a certain number of plant-eating animals, and these a sufficient supply of food-plants—that the insect-eating animals presuppose insects, that certain insects are dependent on certain kinds of plants, and certain plants on insects—that coprophagous animals and parasites of every kind have their particular conditions of life—needs no explanation. It is equally obvious that in the relation of plant-eating animals to beasts of prey it is not the number of species, but of individuals, and the character of these individuals, which is of importance. It is a striking fact that in tracing the history of the Tertiary land faunas we by no means invariably find a continuous modification of the several species, such as we should expect from the undisturbed and persistent effect of natural selection, but that quite new faunas, whole economic units, as it were, follow each other in succession; a fact especially evident in the Miocene of Europe. It was the recognition of this that led to the theory of great migrations; and in this connexion the fundamental works of Lydekker and Depéret may be mentioned [2].

At the same time, however, there are isolated cases of still persisting relics and drifted colonies, such as exist, for example, on oceanic islands. For this reason Baur distinguished continental islands with an harmonious, and oceanic islands with a disharmonious, fauna and flora. Hedley has attempted to determine the limits of these two types of islands in the Pacific Ocean.[3]

In the following pages some examples on a larger scale will illustrate from the chorographic point of view only, the manner in which life adapts itself to the face of the earth. But so little do we know of the conditions which govern the life of marine animals, and the nature of the boundaries which determine their distribution, that we can only deal at present with the inhabitants of fresh water and the dry land.

The simplest case of this adaptation occurs among plants. Hooker, in his famous introduction to the Flora of Tasmania has already pointed out that varieties are most liable to occur on the boundaries of distributional

[1] H. F. Osborn, The Law of Adaptive Radiation, Am. Nat., 1902, XXXVI, pp. 353–363.

[2] L. Lydekker, Geographical History of Mammals, 8vo, Cambridge, 1896; A. C. Depéret, Transformation du monde animal, 8vo, Paris, 1907, and, in particular, communications in the C. R. Acad. Sci. Paris, June 5, 1905 (Évolution des mammifères tertiaires, méthodes et principes), Nov. 6, 1906 (Importance des migrations), further of Mar. 12 and Dec. 24, 1906.

[3] G. Baur, Origin of the Galápagos, Am. Nat., 1891, XXV, pp. 217–229, and 307–326; New Observations on the Origin of the Galápagos, with Remarks on the Age of the Pacific Ocean, op. cit., 1897, XXXI, pp. 661–680 et seq.; C. Hedley, Zoo-geographical Scheme for the Mid-Pacific, Proc. Linn. Soc. N.S.W., 1899, pp. 391–417, in particular p. 393.

provinces [1]. Lundström thinks it probable that near their northern boundary the willows of Nova Zembla are still forming new species [2]. Important investigations have been made by Wettstein, Engler, and others on the colonization of the peaks of high mountains [3]. These are supplemented by the instructive accounts given as to the gradual development of the vegetation of Scandinavia by J. Steenstrup, Andersson, Nathorst, Blyth, and others, from which much may be learnt concerning the origin of post-glacial variations. In all these cases the aggressive vanguard consists of the hardier varieties. If a severer climate were to return the mother plants would probably disappear and these varieties would survive as independent species.

We will now give some examples of a less simple character. We will first consider the life of a normal shore-line which is, as it were, at rest, then of a shore-line which is growing smaller and undergoing negative movement (Caspian sea), and finally of shore deposits with organic remains washed in from the land (appearance of placental animals).

The Strand. Chun placed the limit at which sunlight ceases to be visible at -400 meters. The broad zone extending from the shore to this depth, subject to continual changes in insolation, to storms and tides, and affected also more than any other part of the earth by displacements of the strand-line, is stamped by a number of characters which point to it as the region from which all the rest of the world has been colonized. From this region living creatures made their way up towards the sun, and down into the abysses, and sometimes it has received dwellers upon the land returning to a habitat in the sea.

The migration to the land was long ago recognized, and was described by Bronn, in 1860, as the 'terripetal movement', but it was also supposed that primitive forms still maintained their existence in the undisturbed regions of the deep sea. This view was opposed by Neumayr, whose objections were chiefly drawn from the distribution of the Echinidae. Subsequently Smith-Woodward concluded, from palaeontological studies, that a migration of fishes from the strand to the abysses, and indeed, the existence of deep-sea fishes in general, could not be traced backwards beyond the Cretaceous period [4].

[1] J. D. Hooker, On the Flora of Australia, being an introductory Essay to the Flora of Tasmania (Botany of the Antarctic Expedition III), 4to, London, 1859, cxxviii pp.

[2] Axel N. Lundström, Kritische Bemerkungen über die Weiden Nowaja Semlaas und ihren genetischen Zusammenhang, Nov. Act. R. Soc. Upsala, 1877 (Jubiläums-Band), p. 25: 'It is much more probable . . . that there, as von Baer says, although in a somewhat different sense, creation is still proceeding.'

[3] For this reason we have refrained from quoting the high-mountain floras of the Kilima Njaro, Cameroon, and other places (also Kinibalu in Borneo) as evidence of distant migration.

[4] H. G. Bronn, Stufengang des organischen Lebens von den Insel-Felsen des Oceans

The polymorphism of molluscan shells in waters of variable composition is well known. Not a few marine genera, such as Arca, Siliqua, and Cardium, occur in waters less salt than the sea, and indeed in almost fresh water. The most striking case is that of Trigonia. Some of the rivers of North America, South America, and China, contain sculptured Unios, with an ornamentation which presents every stage of transition down to that of Trigonia. The affinity of the two species was pointed out many years ago by Lamarck; Neumayr maintained that the Unionidae were derived from Trigonias. White showed that sculptured Unios occur as early as the brackish water Laramie stage, and that the existing species of the Mississippi are their direct descendants. We must therefore assume that Trigonias ascended the rivers and became Unionidae, and that sculptured Unios, such as are met with in the upper Tertiary beds of South Europe and up to Omsk in Siberia, and at other localities, cannot, as Steinmann justly concludes, be regarded as evidence of the continuity of the rivers[1].

The entrance of fish into the rivers takes place, as is well known, in a number of distinct steps. In addition to fish which are purely marine there are others which deposit their spawn in fresh water, but there are also regressive river fish, so to speak, which spawn in salt water; next, there are fish living in rivers, but whose nearest relations belong to salt water; then there are purely freshwater fish, and finally, a few ancient forms living in fluviatile marshes, such as Polypterus, which may still be included among the fishes, though they possess *lungs*.

In the terripetal movement no change is more characteristic than the development of the lung. It is not formed at the expense of the gills, but in the higher Vertebrates proceeds from the oesophagus, immediately behind the thyroid gland, as a completely independent organ. The gills may even continue their functions for a time side by side with the lung, as in the

bis auf die Festländer, 8vo, Stuttgart, 1860, Festrede, 31 pp.; M. Neumayr, Ueber den alterthümlichen Charakter der Tiefseefauna, N. J. f. Min., 1882, I, pp. 123–131; A. Smith-Woodward, Antiquity of Deep-Sea Fish-Fauna, Nat. Sci., 1898, XII, pp. 257–260.

[1] M. Neumayr, Herkunft der Unioniden, Sitzb. k. Akad. Wiss. Wien, 1889, XCVIII, pp. 1–23; G. Steinmann, Geologische Grundlage der Abstammungslehre, 8vo, Leipzig, 1908, pp. 99 et seq.; for North America in particular, C. A. White, Review of the non-marine fossil Mollusca of North America, Ann. Rep. U.S. Geol. Surv. (1881–1882), 1883, III, pp. 403–550. According to an earlier statement in Lycett (Monograph of British fossil Trigonia, Pal. Soc., 1872–1879, p. 233), it seems as though a greater development of the epidermal covering in brackish water may bring about a reduction of ornamentation in the living *Trigonia uniophora*. At the same time we may refer for example to *Unio Letsoni* from the Laramie of Montana (Whitfield, Ann. Mus. N.Y., 1907, XXVII, p. 627), and the very deeply folded Unionides from Baluchistán (Blandford, Mem. Geol. Surv. India, 1883, XX, p. 236 et seq.); also with regard to the Paludinas which are associated with these Unionides in Slavonia and their variability, reference may be made to what has been said by Monsuy, Ann. Mines, 1907, 10e sér., XI, p. 473 et seq., on their occurrence in Yunnan and the north of Kuang-si.

case of frogs. Finally, even in the highest mammals, a trace of the gills remains in embryonic life, as a mark of the common origin in the sea. The lung occurs in all terrestrial animals, the land snail, the reptile, the bird, and the mammal; the same need excites the same new growth.

We will not discuss here the modifications experienced by the extremities, but add a few words on the organs of sense.

In the ear of the toothed whale, that is, of a mammal which has returned to the sea, the auditory meatus is almost completely closed; the transmission of sound must take place through the body, since the tympanic membrane can scarcely receive sound waves. Dollo found that in the case of Plioplatecarpus, a Cretaceous Mosasaur, and Ichthyosaurus the transmission of sound also takes place through the substance of the body [1].

This case of the recurrence of the same modification in animals so different from one another, is frequently repeated in the case of the *eye*, and it is, in fact, difficult to understand these processes, without assuming—at least in the case of the eye—a unity in the system of sense organs, in accordance either with Haeckel's idea of sensillae, or with the results of investigation which have lately been made known. Eyes may, in fact, arise in the most diverse parts of the body, even within the mantle of cephalopods, and on the gills of certain bivalves [2]. Palaeontological researches leave no room for doubt that even the paired eyes of existing mammals are the result of a long-continued process of concentration.

In 1886 de Graaf found, in the case of *Anguis fragilis,* that the parietal foramen was occupied by an arrested eye; he regarded it as a reversion, and inferred from the occurrence of the parietal foramen in the Stegacephala that this group possessed a functional parietal eye. A little later Credner showed that in the Permian *Anthracosaurus raniceps* the scaly skin does not extend over the parietal foramen, and thus obtained confirmation of the original presence of an eye [3].

From further observations we derive the following facts.

During the Gondwána period, as we have frequently pointed out, the earth presented a number of extensive continents with a very widely

[1] L. Dollo, L'Audition chez les Ichthyosauriens, Bull. Soc. géol. Belge, 1907, XXI, Proc.-verb. pp. 157–163; also op. cit., 1904, XVIII, pp. 208–213, and XIX, 1905, pp. 125–131.

[2] Hoyle, Verh. V. intern. zool. Congr. Berlin, 1902, p. 774; P. Pelseneer, Yeux branchiaux des Lamellibranches, Bull. Acad. Sci. Brusxelles, 1908, pp. 773–778. Enslin states than Planaria are able to increase the number of their eyes; Jahresh. Ver. Naturk. Württ., 1906, LXII, pp. 306–360. Parker has found sensitive organs over the whole body of Protopterus; Proc. Roy. Soc., 1891, p. 549.

[3] All details are to be found in F. K. Studnička, Die Parietal-Organe (Oppel, Lehrbuch der vergleichenden mikroskopischen Anatomie, V), 8vo, Jena, 1905, 254 pp. No fossil with paired apertures is so far known, possibly however the scales of Anthracosaurus figured by Credner are an indication of this; Zeitschr. deutsch. geol. Ges., 1866, XXXVIII, pp. 592–596.

distributed flora and fauna. About this time there lived in places very remote from one another land reptiles in which the parietal aperture presented dimensions which have never since been attained; this was especially the case with the Anomodonta. Many years ago Cope was struck by the extraordinary size of this structure in the Diadectides from the Permian deposits of Texas [1]. Far from there, near Elgin, in the north-east of Scotland, beds of the age of the Gondwána fauna have furnished remains of the reptile *Gordonia Traquairi*, and in this the parietal aperture lies in an elongated depression. Its 'deep cup-like form', says Newton, 'is probably an indication that it lodged a well-developed eye' [2]. Seeley has described an incomplete skull of Deuterosaurus from the Permian of the Urals, in which the parietal aperture is connected with the cranial cavity by a canal three-quarters of an inch wide [3]. In the skull of Delphinognathus from South Africa the middle of the vertex rises in an independent cone, which bears the broad (almost 2 centimeters across) crater-like parietal aperture, surrounded by radiating vascular impressions [4]. In these cases the central organ itself may have possessed a very different form from that now existing.

Jaekel has collected similar observations from different formations. These show that in not a few Devonian fishes the aperture lies not in the parietal but in the frontal bones. Further, in Thursius and Diplopterus it is accompanied by a ring of small ossified plates which, notwithstanding

[1] Cope, Amer. Nat., 1880, XIV, p. 304, Skull of Empedocles; also Proc. Am. Phil. Soc. Philadelphia, 1882, XIX, p. 45.

[2] E. T. Newton, New Reptiles from the Elgin Sandstone, Phil. Trans. (1893), 1894, vol. 184, B, pp. 431–593, in particular p. 438. There is still a lack of complete agreement as to the age of these beds. Noetling and Hayden state that in Kashmir the beds with Gangamopteris, Archegosaurus, and other genera are overlain by marine upper Carboniferous. Hayden (Rec. Geol. Surv. India, 1907, XXXVI, pp. 23–29) and Amalitzky state that in North Russia the marine Zechstein rests upon the beds with Gangamopteris, Glossopteris, Dicynodon, and other genera, beneath these lies lower Permian with *Callio-pteris conferta*, and beneath this again marine lower Permian with *Productus cancrini* (Amalitzky, Excursion géologique, Exposé à la Société impériale naturaliste St. Pétersb., 1899, 25 pp.; also C. R. Acad. Sci. Paris, 4 mars 1901, et passim). Near Elgin at least two different horizons of the African Karoo are distinguished by Newton. We have included the accompanying glacial period in the Carboniferous; Tschernyschew does the same. Koken assigns it to the Permian (Indischer Perm und die Permische Eiszeit, N. J. f. Min., Festband, 1907, pp. 446–546, map); Arber (Catal. Glossopteris flora, Brit. Mus., 1905), unites the Glossopteris flora with the upper Carboniferous; Seward (Quart. Journ. Geol. Soc., 1908, LXIV, p. 111) points out that at Tete on the Zambesi the typical flora of the European upper Carboniferous occurs independently of the Glossopteris flora.

[3] H. G. Seeley, Research on Fossil Reptiles, VIII, Phil. Trans., 1894, vol. 185, B, pp. 663–717, in particular p. 677.

[4] H. G. Seeley, *Delphinognathus conocephalus* from Middle Karoo Beds, Cape Colony, Quart. Journ. Geol. Soc., 1892, XLVIII, pp. 469–475.

the doubts which have been raised, should be regarded in my opinion as a sclerotic ring [1].

In living reptiles two structures occur, lying one behind the other, these are the parietal organs with the parietal eye, and behind this the pineal organs; in certain cases the former alone enter a parietal aperture. That in these cases we are really dealing with the rudiment of a third eye is shown by the fact that in not a few Saurians the presence has been established of a refractive lens, a pigmented retina, and a special nerve which establishes connexion within the brain. Beside the Saurians, a particular interest attaches to Sphenodon (Hatteria), a remarkable relic of the Permian epoch, which still leads an isolated existence on some small islands in Cook's strait (New Zealand). Its third eye, with lens and retina, projects into the parietal aperture. In fully developed individuals this aperture is closed by connective tissue.

The rudiment appears to have been originally paired, and then to have become single, by selection of one of the two parts. Thus the pineal organ, almost the sole indication which remains of these structures in existing mammals, would represent a fourth eye. Even in man himself traces of a *nervus parietalis* have been found [2].

Of a different kind is the struggle of the eye with darkness. Even in the early days of the Palaeozoic aera the facetted eyes of Trilobites are affected sometimes by atrophy, sometimes by hypertrophy, and in the lower Silurian genus, Trinucleus, it may happen that young specimens have facetted eyes, while the adults are blind. But if we follow Exner's experiments on the migration of pigment in the facetted eye, and Chun's observations on the luminescent organs and the telescope eyes of deep sea animals, we arrive at wonderful physiological processes, and new growths, which have certainly been excited and educed by external circumstances, but to a degree far exceeding the powers of adaptation [3] as conceived by the simple views now prevalent.

The luminescent organs, once regarded as accessory eyes, are certainly aids to sight, but yet quite independent structures. Their autonomous origin, however, appears less wonderful than that of the lung, since eyes may be produced in such different parts of the body, but they occur, precisely like the lung, in animals of the most diverse kinds, Crustacea,

[1] O. Jaekel, Epiphyse und Hypophyse, Sitzb. Ges. naturf. Freunde, Berlin, 1903, pp. 27–58; the parietal aperture is here termed the epidyse; the epiphyse is the pineal body which will be mentioned later.

[2] O. Marburg, Normale und pathologische Histologie der Zirbeldrüse, Arbeiten aus dem neurologischen Institut der Wiener Universität, ed. by Obersteiner, 1908, XVII, pp. 217–279. Professor Zuckerkandl has drawn my attention to this fact.

[3] S. Exner, Die Physiologie der facettirten Augen von Krebsen und Insecten, 8vo, 1891, 206 pp.; C. Chun, Leuchtorgan und Facettenauge, Biol. Centralbl., 1893, XIII, pp. 554–571; also the works of the Valdivia expedition.

cephalopods, and fishes. Similar rudiments have even been observed in some of the mammals which have returned to the sea[1].

The lung is the product of life on land, the luminescent organ the product of the deep sea, and between them, as the place of departure, lies the strand. Certain classes of animals are permanently endowed with the ability to produce the same new formations under the same external circumstances. This indicates much more than a common descent. *It is not convergence, but persistent parallelism.* The earlier state disappears during embryonic life. New species, even new genera arise, yet along with this splitting up, identical organs are formed in different animals under the manifold influences which we are accustomed to include under the term 'adaptation'.

History of the Caspian sea. The strand, as we have just considered it, is free and open. But there are cases in which it becomes enclosed, restricted, and holds the inhabitants of the waters prisoner.

The face of the earth presents two examples of the remains of great seas, scarcely disturbed by tectonic phenomena. The descendant of the first is the dead salt basin of the Djouf in the western Sahara, and the moribund descendant of the second, which we may term the Palaeocaspian, is the Caspian sea. At the time of the upper Cretaceous both were covered by the marine transgression which extended from the Atlantic Ocean into the Tarim basin. Then separation occurred, partly owing to the excess of the negative displacements of the strand and partly owing to tectonic movements (Alps, Iran). The Djouf was separated off, solely, it would appear, by the retreat of the sea. The separation seems to have taken place from north-west to south-east, from the hills of Ahaggar, not very far from Bilma, in the direction of the mountains of Tibesti, thus dividing an Atlantic from a Libyan-Mediterranean basin (I, p. 359; IV, pp. 6, 89). By no means so clear, even in middle Tertiary times, was the boundary between the Palaeocaspian region and the Mediterranean, and while the Mediterranean still extended itself by subsidences, the Palaeocaspian remained a transgression-sea, divided by mountain structures, but not widening its bounds. For this reason it must be regarded simply as a late and transitory extension of the Tethys.

To the west, all the plains of the middle and lower Danube and the northern slopes of the Carpathians and the Caucasus belong to the Palaeocaspian sea. To the east, upper Cretaceous and Eocene reached Kashgár and Sánju, and it is a question whether the gypsums of the Pámir are not of Tertiary age. On the whole, however, the history of this sea remains for a long period bound up with that of the Mediterranean.

The fact that the southern borders of the Bohemian horst are sur-

[1] A. Pütter, Anpassung der Säugethieraugen an das Wasserleben, Verh. V. intern. zool. Congr. Berlin, 1901, pp. 613–620.

rounded only by litoral deposits of the first Mediterranean stage points to some decisive event, and we may take this region as the starting-point of our further studies. They will be based on what has already been said with regard to the history of the Mediterranean (I, p. 277), but will refer chiefly to the fauna. Notwithstanding this limitation, the subject remains so extensive that it is necessary to make a subdivision. We shall first consider briefly: (1) *Central and East Europe,* particularly with reference to the age of the faunas; we shall next make (2) a comparison with *India*; then (3) with *North Africa*; and finally (4) give a sketch of the existing conditions in the *Caspian.*

1. The above-mentioned litoral deposits of the Bohemian horst, resting on a brackish-water basement bed with *Cerithium margaritaceum* (beds of Molt, upper Aquitanian, according to Depéret) comprise the marine sands and Lithothamnium limestones of the first Mediterranean stage, and a land fauna, the correspondence of which with that of the sands of Orleans has been established by Depéret. This fauna is known as far as the lower course of the Tagus; its most characteristic genus is the great Suidine genus Brachyodus, but *Mastodon angustidens* is also said to occur[1].

After the deposition of these beds a great constriction of the sea occurred; its effects can be traced from Bavaria, through eastern Europe and a long way towards Asia. Salt and gypsum were deposited; this is the saline epoch of the Schlier, *the first harbinger of the end.* Besides Mediterranean species, a not inconsiderable number of new, endemic species occur in the associated marls; a whale also, 8 meters in length, has been found. No great changes would be required even at the present day to completely close up the Mediterranean together with the Pontus.

The period in which evaporation was in excess of precipitation came to an end. Brackish water Cardiums made their appearance. Freshwater beds with Oncophora were spread out from the west into Moravia. Leaves of the cinnamon tree were blown in by the wind; and on the east border of the Alps brown coal was formed. A horizon (Helvetian) characterized by *Cerithium lignitarum* marks the beginning of the second Mediterranean stage. The transgression was of moderate extent. Round about the margin of the sea the consequences of the dry period had by this time ceased to be manifest, and the whole of Central Europe was occupied by a rich land fauna. Brachyodus had disappeared; *Mastodon angustidens* still existed, and in addition Anthropoid apes, Amphicyon, Dinotherium, Anchitherium, Hyaemoschus, Prox, Palaeomeryx, Listriodon and other

[1] Depéret, Fauna von miocenen Wirbelthieren aus der I. Mediterran-Stufe von Eggenburg, Sitzb. k. Akad. Wiss. Wien, 1895, CIV, pp. 395–416; Le Néogène Continental dans la Basse Vallée du Tage, Paléontologie par F. Roman, Stratigraphie par A. Torres, Comm. serv. géol. Portugal, Lisbon, 1907, 108 pp., 4to.

genera. This fauna also extended towards the west as far as the lower course of the Tagus. Among the best-known fossil localities are Sansans, Steinheim, and the younger brown coals of Styria (Eibiswald).

In 1870 Oskar Fraas wrote that a study of the fossils of Steinheim leads irresistibly to the conclusion that this fauna is still living in the Indian archipelago. Not long afterwards A. von Pelzeln described it as *Malayan*[1]. We shall make use of this name, *not to imply that the Malayan regions were the original home of these animals, but only to indicate that at the present day Malay still possesses forms which exhibit a particularly close relationship with them.*

The area of deposition was again reduced, this time evidently by an extensive subsidence of the strandline. *The Palaeocaspian region was cut off from the Mediterranean, and has remained closed ever since.* The new, Sarmatian sea reached its western limit in lower Austria, and included in the east the sea of Aral. The composition of its waters ceased to be completely normal. The fauna was poor in species, but excessively rich in individuals. Certain Mediterranean relics still continued to exist beside the endemic fauna, in which marine mammals are conspicuous, and, among the molluscs, Trochus, Mactra, Cardium, and other genera. Cephalopods, Brachiopods, Echinids, and corals are absent, and no longer survived in the Caspian region.

This change in the contour of the sea and its fauna was not accompanied by any important change in the Malayan land fauna. Subaerial erosion of the Sarmatian deposits next occurred, and indicates a renewed negative movement; it was so considerable as to suggest that the strand of the Mediterranean may have lain lower than at present. The region previously marine, was now occupied by a chain of freshwater lakes; this is the period of the Pontic stage. Now for the first time the Malayan fauna disappears, and its successor bears a completely *African* stamp. Apes, Machairodus, Hyaena, *Mastodon longirostris*, *Dinotherium giganteum*, Hippotherium, Helladotherium, Camelopardalis, Gazella, Palaeoryx, Struthio and other genera are characteristic. It is known on the lower Tagus, at Concud (Spain), Eppelsheim (near Frankfort), in the Congeria beds of Vienna, and the Belvedere Schotter, near Balta (Podolia), Pikermi (not far from Athens), in the island of Samos, at Maragha (Persia), and many other places. Forms characteristic of the cape of Good Hope occur at the most remote localities, as, for example, Orycteropus found in Maragha and in Samos. Manis presents a similar case[2].

[1] O. Fraas, Fauna von Steinheim, Württ. naturw. Jahresh., 1870, XXVI, pp. 145-306, in particular p. 297; A. von Pelzeln, Africa-Indien, Verh. zool.-bot. Ges. Wien, 1875, XXV, pp. 33-62; Die malayische Säugethierfauna, Festschrift d. zool.-bot. Ges., 4to, Wien, 1876, pp. 50-74, map; observations on this by Blanford in Proc. Zool. Soc., 1879, pp. 631-634.

[2] Forsyth Major, Proc. Zool. Soc., 1893, p. 239.

With many changes of fortune the Holarctic fauna and flora then advanced from the north through Europe; Asiatic elements made their appearance; nevertheless, even at the present day, African relics exist in some parts of the northern coast regions of the Mediterranean.

2. The history of the Mediterranean has been happily completed by Pilgrim's investigations on the Persian gulf [1].

The conjectured secondary syntaxis, supposed to occur at Bender Abbas, actually takes place. One of the exterior chains of Iran which sink beneath the surface at Karáchi, reappears at Ras el Hadd in south-east Arabia. It strikes in an arc as a fairly high chain through Oman, and reaches cape Masandam opposite Bender Abbas. It consists of crystalline schist, Palaeozoic and Trias deposits, a thick basic intrusion, then Cretaceous and Tertiary. The gulf of Oman is thus not a fore-trough, but lies within the virgation of the chains of Sind, which is indicated in the east. The fore-trough of the Zagros chains does not begin until we reach the strait of Hormuzd, and it is supposed that the subsidence of the Persian gulf did not take place until very recent times. This conjecture rests on the fact that the Eocene sediments in the island of Bahrein are different from those of Persia.

On the Persian side the Cretaceous and Eocene are covered by the lower Nari stage of India (Oligocene), and this by the upper Nari, which corresponds with the deposits on lake Urmia, i.e. the first Mediterranean stage. Then follows widely distributed gypsum. It is overlain on the whole tract from Bushehr to Bender Abbas by the very thick equivalents of the second Mediterranean stage with *Pecten Virleti* and *Venus aglaurae*. Pilgrim consequently places the gypsum on the horizon of the Austrian Schlier.

The zone of *Pecten Vasseli*, or the coast-zone which now follows, is known from Kishm, along the Makrán coast as far as Karáchi. Strange to say it presents a fair number of endemic species [2].

The Bachtyári series, to all appearance an ancient river formation, now

[1] G. E. Pilgrim, Geology of the Persian Gulf, Mem. Geol. Surv. India, 1908, XXXIV, pt. 4, 177 pp., maps; Diener, Some Fossils from the Sedimentary Rocks of Oman (Arabia), Records, op. cit., 1908, XXXVI, pp. 156–163. Even at the time when the preceding page (p. 522) was in the press this work of Pilgrim's was unknown, and the syntaxis at Ormuz was therefore up to the present a matter of conjecture only; on this point see also I, p. 426, and III, pp. 288–297.

[2] I, p. 326. *Pecten Vasseli* was described by T. Fuchs from the material excavated from the Suez Canal between the Bitter lakes and Suez (Denkschr. k. Akad. Wiss. Wien, 1877, XXXVIII, p. 407). Blanckenhorn describes this species as one of the typical fossils of the upper Pliocene—Pleistocene coral reefs and coast deposits of the Gulf of Suez; it occurs in older (post-Miocene) coral structures on the south-east side of Mount Sinai (Hume, South-east Sinai, Survey Department, Egypt, 1906, p. 136) and in Pleistocene coast deposits near Tanger in East Africa (Koert, Monatsber. deutsch. geol. Ges., 1908, LX, pp. 326–328.

follows unconformably. Loftus has even traced it to Mosul on the Tigris; it was involved in the folding movements. One might well suppose that it had filled up an ancient fore-trough. Finally, a foraminiferal limestone (Miliolite) with oolitic structure occurs in horizontal beds; it is believed to have been formed by the wind. Consolidated shell beds, 'litoral concrete,' conclude the succession.

The 'blind alley' of the existing Persian gulf contains, like the zone of *Pecten Vatteli*, a number of endemic molluscs.

The most important changes in the middle Tertiary seas can be traced onwards—as we have previously pointed out, and as is shown more especially by the intercalation of gypsum and salt on a particular horizon —not only through Armenia and the high land of Iran to Chorassan, but also through Mesopotamia and at least as far as the strait of Hormuzd. Livingstone's account of the withdrawal of the elephants and rhinoceroses from regions which had become arid gives some idea of the possible influence of such a period on the fauna.

The Tertiary deposits of the Persian gulf are connected through Karáchi with those of the valley of the Indus.

The succession of land faunas in *India* precisely resembles that in South Europe. We will confine ourselves to a few isolated examples. In the Bugti mountains of east Baluchistán (southern foothills of Sewestán in the direction of the Indus) Blanford observed Brachyodus, and Unios with a remarkably folded ornamentation; Pilgrim has assigned them to the Aquitanian stage [1]. At Kushálgarh on the Indus (Ráwalpindi) the mammalian remains frequently referred to as the 'Attock fossils' occur. Dinotherium, Amphicyon, and Listriodon point to the Malayan fauna [2]. The rich Sewálik fauna of the foothills of the Himálaya bears the African stamp, like the other Pontic faunas at Pikermi and Maragha. It is also known on the Irawaddi in Burma.—

The question now arises as to what we are to understand by Malayan. Let us follow Blanford's classification of the distributional areas of India [3].

The Holarctic fauna comes down from the north and north-west and occupies the highland of Tibet, the Punjab, and the desert regions up to the Aravali mountains. The typical *Malayan* region begins at present in

[1] W. T. Blanford, Geological Notes on the Hills in the Neighbourhood of the Sind and Punjab Frontier between Quetta and Dera Ghazi Khan, Mem. Geol. Surv. India, 1883, XX, pp. 105–240, in particular p. 161 et seq., and p. 233 et seq.; G. E. Pilgrim, New Suidae from the Bugti Hills, Baluchistán, Records, op. cit., 1907, XXXVI, pp. 45–56. and Persian Gulf, Note to p. 33.

[2] Lydekker, Rec. Geol. Surv. India, 1876, IX, p. 91 et seq., and 1887, XX, pp. 51–63; Wynne, op. cit., 1877, X, p. 119; also in this work, I, p. 443, note 2.

[3] W. T. Blanford, Distribution of Vertebrate Animals in India, Ceylon, and Burma, Phil. Trans., vol. 194, B, pp. 335–436, map.

Tenasserim and extends far to the south-east. This adjoins on the north the *Transgangetic* region. The Transgangetic fauna occupies Burma, Assam, and the forest region of the Himálaya. But in this forest region an increasingly large admixture of Holarctic species makes its appearance as we proceed towards the west, and it seems as though the Transgangetic fauna had its original home here, then withdrew during a cold period, and returned again in quite recent times through the forests of Assam. It is these two faunas, that of Tenasserim and that of the Transgangetic region, which together form the Malayan fauna of Pelzeln; and it is in these that Lydekker recognized a difference from the Sewálik fauna and a resemblance to the Oligocene or Miocene faunas of Europe [1].

The *Cisgangetic region*, that is Hindustán proper, includes many genera of the Indo-Malayan (or Oriental) fauna, such as Semnopithecus, Elephas, and others, which dwell chiefly in the wooded parts of the peninsula, but it also contains elements of a second fauna, the *Aryan* fauna of Blanford, such as Melursus, Boselaphus, Antilope, and other genera, which are characteristic of tropical Africa, but are absent from North Africa and the adjacent parts of Asia. Precursors of both these faunas occur in the Sewálik.

Finally, we must distinguish from the Cisgangetic region the district of *Malabar*, which extends along the west coast of the peninsula and includes south-west Ceylon. Here not a few genera of the Transgangetic and Malayan fauna occur, which are not met with elsewhere on the peninsula. The correspondence is so striking that as early as 1870 Stoliczka raised the question whether the Malayan fauna might not once have been distributed over the whole peninsula [2]. Blanford distinguishes here traces of a third still older fauna, the Dravidic, which includes only a few mammals, and consists chiefly of reptiles and some land snails.

This division of India completely excludes the inhabitants of rivers. The gavial of the Sewálik beds lives in the Indus, Ganges, Brahmaputra, and Mahanadi; but it is also recorded from the river Koladyne (North Arakan). The subsidence of the gulf of Bengal, on the site of which the Ganges may once have flowed, is possibly a very recent event, as this distribution may perhaps suggest. The crocodile and *Emys tectum* of the Sewálik fauna still exist at the present day [3].

[1] R. Lydekker, Geographical History of Mammals, 8vo, Cambridge, 1896, p. 291.

[2] F. Stoliczka, Contribution to Malay Ornithology, Journ. Asiat. Soc. Bengal, 1870, XXXIX, pp. 277-334, in particular pp. 279, 280.

[3] The Tertiary Crocidilians of Malta and Gozo as well as of the first Mediterranean stage at Eggenburg belong to the genus Tomistoma at present existing only in Borneo. R. Lydekker, Notes on the fossil Mammalian Faunas of India and Burma, Rec. Geol. Surv. India, 1876, IX, pp. 86-106, in particular p. 97; Occurrence of the Crocodilian Genus Tomistoma in the Miocene of the Maltese Islands, Quart. Journ. Geol. Soc., 1886, XLII, pp. 20-22.

We will defer giving a synthesis of these details until we have considered the facts presented by North Africa.

3. The correspondence of the Mediterranean Atlas with Europe is well known. Depéret has shown that Pomel's Cartennian corresponds with the first Mediterranean stage, and that in Kabylia this stage contains *Mastodon angustidens*[1]. Pomel's Helvetian is the second Mediterranean stage, and the Sahèlian is probably a marine equivalent of the Pontic stage. In Oran and Constantine the land fauna of African character, which corresponds to the Pontic stage, has also been met with.

The ancient rocks forming the basement of Gondwána land extend from the southern half of Africa northwards, passing between the Nile and the Red sea, and in Sinai they cross over to Arabia. We have already mentioned that the fall of the Cretaceous sea-level brought about a separation of the seas of the Sahara, which ran approximately along the line from Ahaggar to Tibesti, and that on both sides of this line, Eocene and then Miocene sea-basins were left behind. In the Libyan basin the deposits of the Miocene coming from the lower Nile reach the existing seacoast near Tripoli, but they do not, it would seem, extend very far into the interior of the desert. Great rivers were discharged into this sea; the Wady Igharghar was probably the most important of them. None of these Tertiary rivers reach the sea at the present day.

The contours of the several groups of strata which succeed each other with a fair degree of regularity to the south and south-west of Cairo thus indicate so many contours of the north coast of the ancient continent, and the remarkable remains of terrestrial animals which occur here in fluvio-marine litoral beds simply represent a small part of the great variety of forms which at that time inhabited northern Gondwána land.

The palaeontological discoveries of Andrews, and the stratigraphical observations of Beadnell, show that in the *middle Eocene* (Mokattam stage) of the Fayûm the purely marine zone of *Nummulites Gizehensis* is overlain by white marls with fishes and Zeuglodon. Then follows an alternation of limestone, marl, and sandstone, with Moeritherium, Barytherium, a number of marine mammals, and fishes, especially roach. The *upper Eocene* (Barton stage) is fluvio-marine. Here the strange-looking Arsinotherium occurs, Palaeomastodon, a forerunner of the Elephants, and in addition to many forms unknown elsewhere, such genera as Hyaenodon, Procyon, and a few others, which show points of relation to the equally ancient land-fauna of Europe, which so far, however, is not known in anything like the same abundance. Here, too, numerous marine mammals have been found[2]. In the Fayûm other fluvio-marine deposits follow on, and in

[1] Depéret, Bull. Soc. géol. France, 1897, 3e sér., XXV, pp. 518–521.

[2] C. W. Andrews, Descriptive Catalogue of the Tertiary Vertebrates of the Fayûm, Egypt, 4to, London (British Museum), 1906, 324 pp.

their continuation near Moghara, 160 kilometers west of Cairo, Blanckenhorn discovered Brachyodus and Rhinoceros, and Beadnell, somewhat later, remains probably belonging to *Mastodon angustidens*. These fossils are associated with *Mytilus aquitanicus*, and correspond with the earliest representatives of the Malayan fauna. During the second Mediterranean stage a marine transgression occurs. Further away, in the Wady Natrûn, *Hipparion* aff. *gracile*, *Hippopotamus hipponensis*, Sus, *Hippotragus cordieri*, Samotherium (or Libytherium) have been found, as well as species of Mastodon; i. e. a fauna representing the *Pontic period* of Europe. It was during the Pontic period that the African type made its appearance, both in Europe and in India [1]. Finally, at Qasr-el-Sagha (Schweinfurth's Tempel) Beadnell obtained from the deposits left by the ancient extension of lake Moeris, to the north of the east end of the Fayûm, *Elephas africanus*, Hippopotamus and Bubalus, associated with Neolithic flints, that is, the *existing land-fauna*, although no Egyptian record mentions the elephant [2].

Here we may again call attention to the fact that the term Malayan or African fauna was not chosen in order to indicate the original habitat of this fauna, but its relationship to the existing faunas. In Africa a Malayan horizon is clearly intercalated between the mammalian horizons of the Fayûm and the existing animal world. It is by no means certain that a Malayan residue does not still survive in West Africa [3]. In that case the anthropoid Dryopithecus on Depéret's horizon of St. Gaudens (which is correlated approximately with the Sarmatian stage) would indicate a connexion between the orang of Borneo and the gorilla of West Africa. Thus, here again, we should have to separate off from the African fauna a Malayan residue, corresponding with the residue in Malabar.

4. Let us now attempt to sum up, completing our observations where they are deficient. We will begin with the Caspian region.

(*a*)' The genus Brachyodus dates from the Oligocene period; as a *harbinger of the Malayan fauna* we have *Mastodon angustidens*. This fauna is known throughout Central Europe, also in Baluchistán (Bugti) and west of Cairo (Moghara). The normal Mediterranean marine fauna extends from Central Europe and North Africa to Asia Minor and Persia (First Mediterranean stage = Burdigalien).

[1] Blanckenhorn, Zeitschr. deutsch. geol. Ges., 1901, pp. 55, 101; Andrews, Geol. Mag., 1899, Dec. IV, vol. VI, pp. 481-484, op. cit., 1900, VII, pp. 401-403, and Descriptive Catalogue, p. x et seq. F. Stromer mentions Brachyodus also from the Wady Faregh, Ber. Senckenb. Naturf. Ges., 1904, p. 112.

[2] Beadnell, Geol. Mag., 1903, 4th ser., vol. X, pp. 53-59; Andrews, tom. cit., p. 336; for the stratified succession in general, Barron, op. cit., 1904, 5th ser., I, pp. 603-608.

[3] For the views of Wallace and Lydekker on such relations see the latter's Geographical History of Mammals, p. 257; how the West-African Fauna following the great forest extends as far as the watershed, may be seen from Emin Pasha's account in Proc. Zool. Soc., 1888, part 1.

(*b*) *First closure of the sea*; salt and gypsum from the middle Danube to the highland of Persia, Hormuzd and Suez. Mediterranean shells along with endemic species (Schlier).

(*c*) Fluviomarine sediments, brown coal, then a moderate transgression with a normal Mediterranean fauna in central and South Europe and North Africa. *A rich Malayan mammalian fauna* in Central and South Europe, North Africa and on the Indus (Kushalgar). (Second Mediterranean stage = lower and middle Vindobonian = Helvetian and Tortonian.)

(*d*) *Second closure of the sea*, affecting the much more restricted area which extended from lower Austria across the sea of Aral, including the Troas on the south. First clearly marked appearance of the Palaeocaspian contour, which from this time onwards becomes increasingly restricted. Composition of the water not normal; numerous marine mammals; endemic molluscs with Mediterranean relics. Persistence of the Malayan land-fauna (Sarmatian stage = upper Vindobonian).

(*e*) The Malayan land-fauna now disappears from the whole region. It still exists at the present day in the Malay peninsula, and far towards the east; it also extends from Tenasserim through the Transgangetic region to the foot of the Himálaya, occurs in an isolated district in Malabar and south-west Ceylon; and possibly also, as a residue, in West Africa. Everywhere, through the whole of Central and Southern Europe, North Africa, and India it was displaced by *an African fauna*. The Sarmatian stage in Europe is immediately followed by a period in which the level of the strandline was low, and erosion occurred; it was at this time, apparently, that the African fauna made its entry. It extends over parts of Europe, occurs in Egypt (Wady Natrûn), reaches Persia (Maragha), India (Sewálik) and Burma. Everywhere it appears as the younger fauna, but on the Irawaddi the Malayan fauna afterwards again took possession of a region which during the Tertiary aera had borne an African fauna (Sewálik).

The eroded surface was first covered by Andrussow's *Maeotic* stage. In the north-west of Hungary, as Hoernes has shown, it corresponds with a zone characterized by *Melanopsis impressa*. Andrussow believes that at this time the Palaeocaspian region was already divided into several basins[1].

The last forefolding of the Himálaya and the Zagros chains, the subsidence of the gulf of Oman, the Persian gulf, the separation of Ceylon, the opening of Suez strait, and the Aegaean subsidence are more recent than the appearance of the African types. Very recent post-Pontic foldings

[1] The contours of the Maeotic basin in the Caspian region are described in Andrussow, Miocene of the Caspian regions, Bull. Com. géol. Russie, 1899, XVIII, pp. 339–369 at the end (in Russian), and in particular Maeotic stage; Verh. Min. Ges. St. Petersb., 1905, 2nd ser., XLIII, pp. 289–449, map. For north-western Hungary, R. Hoernes, Vorpontische Erosion, Sitzb. k. Akad. Wiss. Wien, 1900, CIX, pp. 811–857.

occur at the end of the Balkans, and on the border of the southern Carpathians, likewise in the Crimea; the Caucasus is accompanied by Sarmatian folds. Nevertheless the Sarmatian (at the same time Palaeocaspian) belt crosses over with flat bedding from Bukovina to Bessarabia, its north border reaches Ekaterinoslav, then the northern shore of the sea of Azov, and finally north of the Manytsh the Caspian sea [1].

(*f*) Great freshwater lakes make their appearance in the valley of the Danube with an endemic fauna (Cardium, Congeria, Melanopsis); traces of it also occur outside the Sarmatian contour, e.g. on the lower Rhone (Pontic stage).

Sabba Stefanescu's map shows very clearly that the Roumanian Tertiary deposits coming from the extreme west, almost from the point of exit of the Danube, follow the foot of the Carpathians in parallel zones, at the same time forming a basin closed in the west and open towards the south [2].

If in connexion with this we consider Andrussow's map of the Maeotic and Pontic deposits, we discover the existence of a vast sheet of water, which adjoins on the north the Sarmatian belt, and then advances towards the Manytsh, and then of a second sheet of water, which represents a Caspian sea very much extended towards the north. To the south-east of the Pontus, in the government of Kutaïs, Michailowski and Weber have also established the presence of Pontic deposits [3].

(*g*) The closing of the basin increased, but, in south Bessarabia, sands with *Cardium semisulcatum*, *C. novorossicum*, *Unio maximus*, and other shells characteristic of the steppe limestones of Odessa, still contain *Mastodon longirostris*, *Hippotherium gracile*, and other species of the African land fauna [4].

(*h*) The Levantine stage, which in Roumania, Hungary, and Austria represents the *horizon of Mastodon avernensis*, appears to be but little represented in the more restricted area between the Pontus and the sea of Aral. This species is recorded as occurring to the south-west of Taganrog, and Levantine shells are mentioned, but with some doubt, as occurring in Kutaïs.

(*i*) The *advance of the Holarctic fauna* now displaces the African fauna, but since the identity of *Elephas namadicus* and *Elephas antiquus* has been established by Pohlig, we see for how long a period the encroachment of some of the great African land animals into Europe and India must

[1] I, pl. V. I may refer to a little map by Sokolow in his History of the Steppes around the Black Sea, Pédologie, 1904, no. 3, 44 pp. (in Russian).

[2] Sabba Stefanescu, Étude sur le terrain tertiaire de Roumanie, 4to, Lille, 1897, 178 pp., map.

[3] G. Michailowski, The Pliocene of some regions of the West Caucasus, Verh. Min. Ges. St. Petersb., 1902, 2. Ser., XL, pp. 129–177 (in Russian).

[4] A. Wenjukow, Unterpliocene Säugethierfauna in den Sanden Süd-Bessarabiens, Verh. Min. Ges. St. Petersb., 1901, 2. Ser., XXXIX, pp. 31, 32.

have persisted. If we compare Pilgrim's description of the fauna of the alluvium of the Godavari, and of the caves of Karnul (on the Kistna where the remains of Manis still occur), with Boule's account of the stratified succession in the Grimaldi grottos (Monaco), we discover that man was a witness of this extension, both in Europe and in India [1]. In Europe it extends into the interglacial phase of the Chelléen. Numerous relics of the African fauna are still living at the present day in the south of Europe; in India similar relics survive as the Aryan element in the fauna of the cis-Gangetic region.

(*k*) We have now arrived at the *glacial epoch.* The ice advanced farthest in the valley of the Dnjepr, where it came down close to 48° 50′ N. The Volga represents a great line of drainage, along which the water from the melting ice flowed towards the Caspian. It now becomes possible to gather some information from the existing hydrographical relations. We will take as our guides the numerous and frequently-mentioned works of Andrussow, and two other admirable works—that of Sokolow on the liman of the Mjus near Taganrog, and Berg's monograph on the sea of Aral [2].

At the present day the level of the Black sea stands almost at the zero point, that of the Caspian at −25·4 meters, and of the sea of Aral at +50 meters.

The species of Cardium which characterize the Caspian fauna (*Didacna trigonoides*, *Adacna plicata*, and others) must be carefully distinguished from the allied species of the Levant and the Pontus. The Caspian species are known in a fossil state in all three seas, but it is only in the Caspian that they still survive.

The deposits in which they are found occur at the same height around the sea of Aral and the Caspian, that is 4 meters above the level of the existing sea of Aral, and almost 80 meters above the Caspian. At the time of this high level the two seas were connected on the east and south side

[1] Pohlig, Act. Nat. Curios., 1892, LVII, pp. 276 and 337; Pilgrim, Occurrence of *Elephas antiquus* (Namadicus) in the Godaveri Alluvium, Rec. Geol. Surv. India, 1905, XXXII, pp. 199–218; Les Grottes de Grimaldi, 4to, 1906; M. Boule, Géologie et Paléontologie, I, pp. 75–156.

[2] N. Sokolow, Der Mius-Liman und die Entstehungszeit der Limane, Verh. russ. Min. Ges., 1902, XL, pp. 35–112, maps; L. Berg, Der Aral-See, Attempt at a physico-geographical monograph (Wissenschaftliche Resultate der Aral-Expedition, IX), Izviestija of the Turkestan branch of the Imp. ross. Geogr. Obsch., 1908, V, 580, maps (in Russian). The figures giving the water-levels are according to the more recent measurements; cf. I, p. 346. The sea of Aral fluctuated in the summer of 1901 from +49·8 to 50·28 meters. The literature of this region begins with Herodotus. Pallas, with great penetration, gave a correct interpretation of many of the facts in the beginning of the nineteenth century. A number of publications followed, among them, in 1900, Brückner's studies on earlier fluctuations. The latest is probably that of E. Huntington, The Pulse of Asia, 8vo, London, 1907, 415 pp., maps.

of the dividing plateau of Ust-Urt through the Usboi and the Sary-Kamysh. The Caspian possessed some communication with the Pontus through the valley of the Manytsh. The Pontus, however, stood only a few meters above its existing level. Climatic influences produced a general subsidence of the water-levels. The seas became separated. The Manytsh dried up; the *Pontus* continued to sink, probably to a depth of 30 or 40 meters below its existing level. The mouths of its tributaries became elongated. The Dardanelles opened up; the salt water of the Mediterranean flowed in, raised the Pontic level to the zero point, flooded the river mouths (limans; these as they now exist have been regarded as a proof of continental subsidence) and killed the Caspian Cardium fauna in the Pontus.

The *Caspian* also continued to sink, but the new watershed exposed between it and the sea of Aral formed an imperfectly-bounded drainage area belonging to the Amu-darya, which had no opportunity to hollow out a normal bed, and, dividing into two main branches, discharged itself at this time into the Caspian. The completely isolated sea of Aral began to grow salt. Gradually, however, the Amu-darya diverted constantly increasing quantities of water into this sea, and quite recently, according to the Russian maps probably since the sixteenth century only, it has poured the whole of its waters into the sea of Aral. Subsequently, the Caspian doubtless sank to a still lower level; the sea of Aral, however, filled up, became very nearly fresh, and is probably rising at the present day.

The deposits with Caspian Cardiums which occur around the sea of Azov, and extend as far as the Dnjestr, contain the remains of *Elephas antiquus* and *Rhinoceros Mercki*, that is, the same fauna which has just been mentioned as belonging to the interglacial phase of the Chelléen. In the caves of Grimaldi it is accompanied by Hippopotamus, but besides these great African animals there appear here and there *Equus caballus, Cervus capreolus*, and other Holarctic species, including man. In the Pontus this brackish Cardium fauna was killed by the inflowing salt water of the Mediterranean, in the sea of Aral it was killed either by increasing salinity, or at a later time by the fresh water of the Amu. In the Caspian it still leads an isolated existence. The Caspian Phoca probably accompanied it; there are closely allied Sarmatian and Pontic seals, and it is not necessary to assume a northern origin. The fluviatile fauna of that time persists, however, in the rivers, and in part also in the seas. The sea of Aral was possibly repopulated with fishes from the rivers. The carp during times of high water-level even entered the Tshu and the Issyk-kul through the Sir-darya. Caspian Mysides seem to have travelled through the Volga to Yaroslav, 12 degrees of latitude above the existing mouth. It is now easy to understand how it happens that so many fishes are common to the Danube and the Asiatic rivers, and that, after changes of this kind, the fauna of the sea of Aral should be poor. Nevertheless some new endemic varieties and species make their appearance. Completely alien, and probably much more ancient, are the two species of sturgeon (Scaphirhynchus) occurring in the Amu-darya, a river which has long been inaccessible to any new immigration. The nearest relations of these two species live in North America. The river fauna has an independent history.

(*l*) Sokolow states that the *Loess* with *Elephas primigenius* is in part at least older than the submergence of the limans, and consequently than the opening of the Dardanelles. The aridity which gave rise to the Loess at the close of the glacial epoch has been brought into connexion with the sinking of the water-levels. In any case it does not seem to have come to an end. It manifested itself not only in the Caspian, but in the Dead sea, lake Rudolf, round about the Salt lake of Utah, on lake Titicaca, and, in short, on the most remote lakes without outflow. Recent French investigations in the Sahara lead us to conjecture that even in historic times the drying up of the Wadys had not progressed so far as at present. It is true that in this case the wind has exerted an effect by choking up with sand. From the ancient fluvial deposits of the Baringo, stone implements are recorded, and in the Kalahari desert the existing conditions were preceded by a pluvial epoch[1]. The effect of drought on the vegetation and through this on the fauna must be great. Indeed, the Edentates of South America have actually become smaller, so have the Lemurides of Madagascar and the non-placental mammals in Australia. Wallace concludes that we are living in an impoverished world.

The appearance of placental mammals. A great diversity of opinion has been expressed, *a priori*, on the circumstances which accompany a vertical movement of the strand-line. Distinguished investigators have even put forward the strange theory that sediments are only formed 'during subsidences', i.e. in positive periods. But the circumstances are in each case so different, that only observation and comparison can lead to any result. Comparison is rendered difficult by the fact that it must embrace very great surfaces, in order to answer the first question alone, that is, whether the change in the strand-line is general and eustatic, or connected with phenomena of gravitation, or only local and tectonic.

There is no dearth of sections across the strand showing the marine series, and affording some conclusions with regard to the marine animals; an instructive example belonging to the Rhaetic period has already been given; this presented positive movement with terrestrial partings (II, p. 260). Sections which at the same time show the appearance of a fauna of

[1] Gregory, The Great Rift Valley, 8vo, 1896, p. 324; S. Passarge, Klimatische Verhältnisse Süd-Africas seit dem mittleren Mesozoicum, Zeitschr. Ges. Erdkunde, 1904, pp. 176–193, maps.

terrestrial mammals are rare, and many of these only indicate an unessential accident due to intercalation, and having no connexion whatever with a change of the strand-line.

The negative movements occurring between the Jurassic and Cretaceous had already begun during the Jurassic period. The Jurassic of Northern Switzerland affords the earliest evidence of the impoverishment of the marine fauna; the alternation of forest growth, freshwater and marine beds on the island of Purbeck marks the oscillations. Similar conditions are also revealed by the Atlantosaurus beds of the Black hills of Dakota, their erosion by flowing water, and the deposition of a coal-bearing series containing the Potomac flora in the valleys. The lithosphere was subsiding in fragments at places possibly remote from one another; the strand sinking by a eustatic movement; the vegetation advancing and struggling for the possession of new ground.

In like manner in North America the brackish water Laramie lake came into existence towards the close of the Cretaceous, and afterwards, in the basin of the Puerco river in New Mexico, a series was exposed, above the Laramie and beneath the Wahsatch stage, which contains the oldest remains of placental mammals so far known.

It is the same in Europe, where we find the uppermost beds of the Cretaceous, the Danian and Montian, restricted to a smaller area than the Senonian. The marls of Meudon, the sands of Rilly and Bracheux, the freshwater limestone of Rilly, the lignites and plastic clay, represent in the Paris basin the oscillations of the boundary.

Where the Cretaceous sea was of greater depth the results took a different form. In Istria and Dalmatia we find intercalated in the lowermost marine Eocene, close to the limit of the Cretaceous, lacustrine beds with tropical land and freshwater shells, Stache's Liburnian stage [1].

In the eastern Sahara the sea was still deeper; and the marine Eocene rests upon marine Cretaceous.

In New Mexico mammalian remains occur in the Puerco stage, the lowermost part of the Eocene, and some hundreds of feet higher on a second horizon, the Torrejon stage. They were first made known by Cope; the great progress which has since been made in their investigation we owe to Wortman and Matthew [2]. No species is common to both stages,

[1] G. Stache, in F. Sandberger, Land- und Süsswasser-Conchylien der Vorzeit, 4to, Wiesbaden, 1870–1875, pp. 120–139; and Die Liburnische Stufe, I, Abh. k. k. geol. Reichsanst., 1889, XIII, 170 pp., map.

[2] E. D. Cope, Synopsis of the Vertebrate-Fauna of the Puerco Series, Trans. Am. Phil. Soc. Philadelphia, 1890, new ser., XVI, pp. 298-360; J. L. Wortman, Ganodonta and their Relationship to the Edentata, Bull. Am. Mus. Nat. Hist, New York, 1897, IX, pp. 59–110; W. D. Matthew, Revision of the Puerco-Fauna, tom. cit., pp. 259-323; Torrejon has also been found in Montana; E. Douglass, Cretaceous and Lower Tertiary Section in South Central Montana, Proc. Am. Phil. Soc., 1902, XLI, pp. 207–224.

but the degree of general development is similar. Most of the animals are small; the predominance of arboreal animals is remarkable. The Multituberculata (Allotheria) belong to the Monotremes or Marsupials, and are of Mesozoic origin. The Primates (Lemurides), the creodont Carnivora, Rodents (?) and Ungulates are represented by primitive forms, but little differentiated, and the toes of the Ungulates are still divided, but besides these animals the family of the Ganodonts makes its appearance, and represents the Edentates, which have so far overtaken the other placentals in specialization that Wortman supposes they must have had Mesozoic ancestors.

At Cernay, not far from Rheims, Lemoine has discovered the Torrejon stage above the limestone of Rilly. The Multituberculata occur here also, and as in New Mexico are associated not only with Lemurids, Carnivores, and Ungulates, showing the same low degree of differentiation, but also with great ostrich-like birds.

In New Mexico the layers containing these faunas are intercalated in the midst of thick sediments; Torrejon in particular is a single layer of very inconsiderable thickness. Priem describes the series near Rheims as an alternation of litoral beds in which fluviatile fishes, such as Amia and Lepidosteus are associated with Silurides and Labrides. To the same alternation of beds belongs the rich flora of Sézanne which indicates a warmer climate [1].

From the preceding we perceive first, that the oldest known placental fauna is associated with a Mesozoic residuum, and, as is shown by the Ganodonts, does not include the oldest placentals; secondly, that we are dealing with forms accidentally washed in at times of high water, possibly swept out of a forest, a view supported by the occurrence in France of beds with driftwood and Unios; and last, that not only the correspondence of the land faunas, but the presence, in France in particular, of the genera Amia and Lepidosteus which occur in America both as Tertiary fossils and as living forms, points to a connexion between the continents.

The most instructive fact, however, is the close similarity in the differentiation and the systematic subdivision of the faunas on this ancient common continent. In America, as in Europe, the Coryphodon fauna is the

[1] Lemoine, Étude d'ensemble sur les dents des mammifères fossiles des environs de Reims, Bull. Soc. géol. de France, 1891, 3e sér., XIX, pp. 263–294, et passim; F. Priem, Poissons de l'Éocène inférieur des environs de Reims, op. cit., 1901, 4e sér., I, pp. 477–504; Saporta, Prodrome d'une flore fossile des Travertins anciens de Sézanne, Mém., op. cit., 2e sér., VIII, pp. 289–435, and in particular his Le Monde des Plantes, 8vo, Paris, 1879, p. 213 et seq.; M. Leriche, Sur l'âge des 'Sables à Unio et Térédines' des environs d'Épernay et sur la signification du terme Sparnacien, Bull., op. cit., 1904, 4e sér., IV, pp. 815–817. Rütimeyer has also discovered traces of the Torrejon stage in the bone earth of Egerkingen; here Calamodon probably represents the Edentates (Verh. naturf. Ges. Basel, 1890, IX, 34 pp.).

next to occupy the Eocene land. The close similarity reveals itself even in these fleeting glimpses—all that is granted to us—into the then prevailing conditions. In Patagonia we shall meet some confirmatory evidence on this point.

It is quite possible that eustatic movements have their effect upon the world of life, either by promoting terripetal migrations, or, in the opposite direction, by promoting a return migration; if they are rapid they may, indeed, cause the destruction of the whole litoral zone, but actual observations fail us on this point, and we cannot venture beyond the data furnished by Biology.

Places of refuge. The examples cited above, especially those illustrating the contrast between the processes taking place on the stable strand, and those affecting the Palaeocaspian sea, would certainly invite us to a closer examination of the question as to how far we must distinguish between active and passive changes. We cannot, however, embark upon such an inquiry, and must adhere to the chorographic method, nor can we enter into the question to what extent natural selection, hybridization, and heredity may have been concerned in the formation of the new species and genera which have come under our notice.

If, however, we consider carefully the actual surface of the earth, we shall perceive that there are tracts in which terrestrial forms of life have been protected from the action of such physical changes as transgressions and mountain building, for a very long period. There are regions which since the time of the great disturbances of the upper Carboniferous have been practically untouched by such movements, and the history of these—extending over a very long period, as a rule from the lower Gondwána down to the present day—is solely represented by the remains of successive land floras; marine sediments are completely absent. It is true that in these places life was not exempt from the influence of climatic changes, nor from economic disturbances produced by the immigration of invading organisms, nor even from the effects of complete subsidence beneath the sea; nevertheless floras followed one upon another in successive development, and the living world was less molested in these places than elsewhere: we shall term them therefore *asylums.*

From these places, after times of great disturbance, new colonies spread over the land, and for this reason we have compared them, in an earlier passage, to Linnaeus' island of Paradise (III, p. 149).

We distinguish in general four of these asylums. These are:

1. *Laurentia*, including the boundary of the northernmost part of the Atlantic Ocean.

2. *Angara land*, namely the tableland of East Siberia, up to the Arctic transgressions; possibly, also, parts of China.

3. *Gondwána land* (Arch-Amazonia + Arch-Helenis of Ihering; South

Atlantis + Gondwána land of Arldt),[1] i. e. the Indian peninsula, Madagascar, Africa, from the south border of the Karoo to the Sahara, and in the east to Sinai and beyond, and in addition great parts of Brazil and Argentina.

4. *Antarctis* with Australia and Patagonia.

With a few exceptions these regions have not been affected by folding movements since the close of the Carboniferous period; in the northern hemisphere they have formed the forelands or backlands to these movements. It is in these regions that we might be inclined to see indications of the permanence of continents, if it were not that three of them present obvious signs of having been broken up. The regions which were laid dry by the retreat of the Cretaceous, such as the Sahara, the Caspian, and the Laramie lake, belong to the periphery of such asylums and sometimes unite them or their fragments into larger continents. All the more recent mountain chains lie outside these asylums, but not all lie outside the region of the Gondwána flora. The Antarctic Andes are not included in Antarctis.

1. *Laurentia.* In North America the typical Gondwána flora has not yet been discovered. In that part known as Laurentia, the upper Carboniferous is followed, as in Germany, by the Permian Walchia-flora. The Newark-flora of the Keuper does not occur in Laurentia, but on the downthrown eastern side of the Appalachians, and this is also true of the Potomac-flora (Wealden) in Maryland. Some of its characteristic species continue to make their appearance as far as Texas, or again in West Canada, and probably as far to the north as cape Lisburne. They may perhaps indicate the margin of the Laurentian asylum. Many times in succession during the Cretaceous epoch this margin was submerged beneath the sea, but the centre has remained an asylum even down to the present day. There, the faunas of land and fresh water succeed each other in an unbroken series. Its history, however, differs in two respects from that of Europe. In the first place it has not experienced the repeated invasions of the sea which render the European systems so diversified and so instructive. Consequently, Lepidosteus, Amia, and the folded Unios were able to ascend from the Tertiary lakes into the existing rivers of North America; in Europe they disappear in the middle Tertiary. In the second place, the principal lines of the configuration strike in a meridional direction, so that climatic changes are manifested in a simple manner, and displacements of the faunas from and towards the Pole can be more clearly followed.

The oldest Tertiary sediments, Puerco, Torrejon, and Wahsatch (Coryphodon fauna) belong to the periphery of the Laurentian asylum.

The Torrejon stage and the Coryphodon fauna are repeated in France,

[1] H. von Ihering, Archhelenis und Archinotis, gesammelte Beiträge zur Geschichte der neotropischen Region, 8vo, Leipzig, 1907; T. Arldt, Entwicklung der Kontinente und ihrer Lebewelt, 8vo, Leipzig, 1907.

and the succeeding faunas also exhibit on both sides of the Ocean many connecting links; towards the Miocene these become rarer.

These correspondences point to a continuous continent in the north. The fact that Amia and Lepidosteus occur in the European Tertiary alone renders it altogether improbable that the only communication which served for all these rich faunas lay across Bering sea. This route could only have been followed by immigrating species of Asiatic type during glacial or post-glacial times.

In regard to communication across the North Atlantic we are in possession of the following facts: Extending far from the south, almost to lat. 42° N., a marine selvage (IV, p. 75, fig. 11) extends along the western coast, which shows that during the Tertiary aera the continent did not extend over this region into the existing sea. From lat. 42° N. towards the north the coasts are bare. On the island of Disko, with the exception of a few trifling intercalations representing the Senonian sea, terrestrial floras succeed each other from the lower Cretaceous to the Tertiary, almost as though this were an asylum. The coast around cape Farewell is bare. At the beginning of the Miocene epoch a bridge of basaltic flows connected this coast with Iceland, the Faeröes and Scotland [1]. It was covered with forest, the leaves of which are preserved in the associated tuffs.

From this point onwards the situation is changed.

On the peninsula of Tjörnes (north Iceland) the plant-bearing series is underlain by a marine bed, which is correlated with the English Crag [2]. On the coast of Greenland, in lat. 69° 24′ N. and also near lat. 75° N., Miocene deposits occur which are perhaps parts of a surrounding border. They are repeated in Spitzbergen, intercalated between plant-bearing beds, and beneath this series lies a similar alternation of marine and plant-bearing beds but of Jurassic age. A precisely similar alternation also occurs in the Carboniferous, and marks repeated shallow-water transgressions.

Finally there follow in the whole region the circumpolar, post-glacial transgressions under which Iceland was also submerged.

In the North, Eocene marine deposits are entirely absent.

Thus to the north of Iceland there did probably exist a temporary communication which was frequently interrupted by transgressions. Since the time of the Eocene no communication has taken place across the Ocean south of lat. 42° N. in the west, and south of lat. 52° N. in the east, though on this side islands of considerable size may have lain near the periphery. In the south of England and in Belgium the lowermost Eocene (Thanetian) is represented both by marine and plant-bearing beds.

[1] T. Thoroddsen, Hypotesen om en postglacial Landbro over Island og Færöerne set fra en geologisk Synspunkt, Ymer, 1904, pp. 392–399.

[2] II, p. 67; Nathorst, Zeitschr. deutsch. geol. Ges., 1896, XLVIII, pp. 983-986; H. Pjeturss, Zeitschr. Ges. Erdk.. 1908, p. 455 et seq.

These results only give us limits, and it is possible that Iceland was separated from the continent before the existence of its basalt bridge, as this bridge itself seems to indicate. The whole of Laurentia, however, is evidently a natural unit, a foreland to the United States chain as well as to the Appalachians, with a flat Palaeozoic belt, only submerged by later seas on its margin, and never folded since the Cambrian epoch. It possibly also formed, in the western Hebrides, a Caledonian foreland. At the same time, in the west as in the east, we see the subsiding rias coasts of the western Altaides, which once extended across the Ocean, representing the remains of a second natural unit. Both are broken up.

2. *Angara land* (III, p. 19). This asylum has not been reduced to fragments. The Lena and Yenisei form its boundary for long stretches; towards the south it comprises the amphitheatre of Irkutsk; towards the north the ancient tableland sinks gradually beneath the northern transgressions. On all the three great rivers which flow from the amphitheatre to the Yenisei—the Angara, the Stony, and the Lower Tunguska—we meet with the Tungusian or lower Gondwána flora; Jurassic and Tertiary floras are known at many localities, but nowhere a marine deposit since the time of the lower Palaeozoic beds, which have remained horizontal. Here we may expect great discoveries of fossil land-animals.

3. *Gondwána land* (I, p. 387; IV, p. 471). This vast continent extended from the east side of India into the west of Brazil, and to the Argentine cordilleras. Only in its westernmost part was it involved in folding. Up to the most remote points, on the east and on the west, we find representatives of the different stages of the Gondwána flora, and from India to South America we meet with reptiles which have reached a similar level of development. With the exception of certain encroachments of the upper Cretaceous, no sea has extended over this continent, now broken into fragments, since the Carboniferous period.

The Gondwána flora also extended, however, into the region of the Tethys, though perhaps it occurred only in islands of that sea. In Kashmir it makes its appearance between upper Palaeozoic beds, and on the pass of Bamián, in the heart of the Hindu-Kush, as the base of the Mesozoic series; it is also continued, in some places, as far as east Chorasan. It has been discovered even on the Dwina in North Russia, where it is associated with similar reptiles to those found in the south, and forms perhaps a colony derived either from Angara land or Gondwána land. None of these last-mentioned localities, extending from Kashmir to the Dwina, can be taken into account when considering asylums, since they were all subsequently exposed to inundations.

Gondwána land has been so frequently discussed in this work that we will now confine ourselves to the consideration of a particular question, namely the manner in which this continent was broken into by the Atlantic Ocean (I, p. 288).

The Loire, the Gironde, the Tagus, and the Guadalquivir present in the lower part of their course so complete a resemblance to ordinary bays of the sea, that notwithstanding the occurrence of granite on the Berlengas (off the coast of Estremadura) the supposition of continuity with a much vaster continent situated in the existing Atlantic region can hardly be entertained. Santa Maria, in the Azores, Madeira and Porto Santo are engirdled by the second Mediterranean stage; during the deposition of this stage no continuous continent existed here, and if any settlement of these islands took place from Europe it must have occurred previously, unless it were caused by drift [1].

From lat. 42° N. towards the south, as we have seen above, junction with an Atlantic continent is excluded during the Tertiary aera. This probably holds good for the region extending to the Orinoco. Although in the west of the European Mediterranean the Germanic facies of the Trias is dominant, and thus some doubt may arise as to its connexion with the Trias of Mexico, yet the Mexican Alamitos stage throughout its course from the Rio Grande to the Durango completely corresponds with the European Kimeridge. The Gosau facies of the upper Cretaceous, with its Actaeonellas and Hippurites, occurs in an unmistakable manner in Jamaica and North Coahuila (in the latter beneath the Laramie beds). In the case of the Eocene it would be more difficult to establish correspondence. We may, however, correlate the Lepidocyclina stage of Florida, Nicaragua, and Panama with the first Mediterranean stage (Brito or Vicksburg stage). About this time communication with the Pacific was open both across lake Nicaragua and across Panama (here at a later time also). We must thus assume that the Tethys, during at least a part of its existence, extended across the existing Atlantic Ocean.

It is more difficult to follow the situation in the south.

After a close examination of all the facts connected with the distribution of the African flora, Engler concludes that they would be best explained if we could establish the existence of fairly large islands or a continuous tract of land *between the north of Brazil, south-east of the estuary of the Amazon, and the bight of Biafra* [2]. Let us examine this conclusion.

[1] J. C. Berkeley Cotter, Nota de alg. fosseis terciar. do Archip. da Madeira, Commun. da Commiss. d. Trab. geol. de Portugal, 1888–1892, II, pp. 232–254; and Nota de alg. fosseis terciar. da Ilha de S. Maria no Archip. d. Açores, tom. cit., pp. 255–287. In Vol. I, p. 302, misled by the resemblance of the Turitellae of St. Gallen, I correlated the Swiss marine molasse, the type of the Helvetian, with the horizon of Gauderndorf in the first Mediterranean stage. It corresponds to the horizon of Grund at the base of the second Mediterranean stage. Thus what has been said in I, p. 288 on the border of Atlantic islands needs correction.

[2] A. A. Engler, Floristische Verwandtschaften zwischen dem tropischen Africa und

Broadly speaking, the mouth of the Orinoco may be taken as the northern boundary of the South American part of Gondwána land, and the mouth of the La Plata or cape Corrientes as its southern boundary.

The coasts of Guiana are little known, and probably consist only of the ancient rocks of the interior. They are succeeded by the broad alluvial plains of the Amazon. From Para (lat. 1° S.) to *Cabo Frio*, i.e. through 22 degrees of latitude, patches of the upper Cretaceous transgression accompany the shore. In some places they also extend further inland, and must probably be regarded, not as a selvage, but as the remains of a sheet. On the Abrolhos islands (lat. 18° S.) Derby mentions a similar patch of sediments, associated with basic rocks, which also occur on the mainland [1]. Similar relations doubtless prevail as far as the La Plata.

These facts correspond with those observed on the border of the ancient Archaean plateau, a fragment of the great asylum. They also correspond completely with those observed on the border which Ihering supposes to adjoin his downthrown continent of Arch-Helenis from the Amazon to the La Plata. No Tertiary border is present; Ihering mentions a post-Tertiary litoral zone which extends from San Paolo towards the south [2].

Let us now turn to the east side of the Ocean. As far as the Wady Draa no junction with a continent is to be expected. The region extending to cape Bojador is little known. In Rio de Oro ancient rocks and Palaeozoic beds advance to the sea. From lat. 23° N. onwards a bed with Ostrea and Tellina is mentioned as occurring, and further south, according to the last communication which I owe to the kindness of M. Chudeau, a broad bay opens up; it extends far into the interior and also towards the south as far as the mouth of the Senegal and beyond. M. Chudeau inquires whether this bay may not correspond with the Marginella beds of Timbuctu. We may assume that the coast from lat. 23° N. onwards to at least lat. 15° N. belongs to the middle Tertiary inland sea which extended from this point towards Central Africa (IV, p. 89).

At cape Verd volcanic rock rises out of recent alluvial land; the islands of the same name are probably formed by a continuation of these rocks. On one of them ancient rocks are said to occur, and such rocks are widely

America, sowie über die Annahme eines versunkenen brasilianisch-aethiopischen Continentes, Sitzb. k. preuss. Akad. Wiss. Berlin, 1905, pp. 180–231, in particular pp. 229.

[1] O. Derby, Sedimentary Belt of the Coast of Brazil, Am. Journ. Geol., 1907, XV, pp. 218–237. Tertiary beds are also mentioned, but no fossils are known with certainty. South of Bahia, brackish beds with plant-remains and Dinosaurs rest upon limestone with Neithea; this should indicate the negative phase at the close of the Cretaceous, which may be recognized into the Argentine Andes. Thus it is doubtful whether the Abrolhos must be included among volcanic islands.

[2] H. v. Ihering, Les mollusques fossiles du Tertiaire et du Crétacé supérieur de l'Argentine, An. Mus. Nac. Buenos Ayres, 1907, XIV, 611 pp., in particular p. 483.

distributed over this part of the mainland. It is here, then, near cape Verd, that a possible junction first makes its appearance.

The following tract of coast as far as Cameroon belongs to that fragment of the ancient crust which was probably separated from Africa during the upper Cretaceous period or even later. In Cameroon, Eocene, as well as Cretaceous, has been met with[1]. The line of volcanos which extends to Anno Bom indicates the continuation of the continental structure beneath the Ocean. From this point (lat. 4° N.) onwards there is unfortunately a dearth of observations nearly as far as Landana (lat. 5° S.), and then, as far as lat. 16° S., there follows a border of upper Cretaceous and Tertiary (chiefly with Lepidocyclina) which so far has been determined at only a few localities[2]. In German south-west Africa the coasts appear to be bare rock.

These data, although fragmentary, are yet sufficient to show that a possible continental junction may be sought between lats. 15° and 4° N., that is, in the bight of B afra and to the north of it, but the possibility of its existence as far as lat. 5° S. is not excluded. To the south of lat. 16° S. the situation is still obscure. These facts show that it is the two parts of South America and Africa at present projecting farthest into the Ocean which afford the strongest suggestion of having been originally connected.

The correspondence of these results with those obtained by Engler is striking. Scharff also places the connecting land to the south of the Atlantic groups of islands[3]. Ihering places the north boundary of his downthrown continent of Arch-Helenis remarkably far to the south. Kobelt, basing his views on the land snails, has discovered many African characters in the Azores; at the same time the European Miocene is generally represented on the islands, and for this reason he looks for the connexion further to the north[4]. It is possible that at some future time some significance will be found in the fact that the girdle which occurs

[1] IV, p. 92. Chautard conjectures that the separation continued into the Eocene, and points to the Eocene of Cameroon; Matériel pour la géologie et la minéralogie de l'Afrique occidentale française, I, Gorea, 1906, 8vo, 15 pp.

[2] P. Choffat, Contribution à la connaissance géologique des Colonies portugaises de l'Afrique, II, Nouvelles données sur la zone littorale d'Angola, Commission géologique du Portugal, 4to, 1905, 78 pp. There is at my disposal no evidence on the existence of ancient mainland from Tristan d'Acunha. The island is volcanic; a loose block of gneiss of no importance; E. H. L. Schwarz, The Rocks of Tristan d'Acunha, with their bearing on the question of the permanence of Ocean basins; Trans. S. African Phil. Soc., 1905, XVI, pp. 9–51; and The former land-connexion between Africa and South America, Journ. Geol. Chicago, 1906, XIV, pp. 81–90.

[3] R. F. Scharff, Some Remarks on the Atlantis Problem, Proc. Roy. Irish Acad., 1903, XXIV, B, pp. 268–302, in particular p. 279.

[4] W. Kobelt, Verhältniss der europäischen Landmollusken-Fauna zur west-indischen und centralamerikanischen, Nachrichtenblatt d. deutsch. Malakoz. Ges., 1887, pp. 145–148.

around some of these islands belongs to so late a period as the second Mediterranean.

4. *Antarctis.* That Australia and Patagonia were once connected by mainland has long been repeatedly asserted by biologists. Hedley, as the result of a detailed investigation, is led to assume the past existence of a region with a mild climate, extending across the south of Tierra Fuego to Tasmania. Osborn has even attempted a restoration based on the 1000-fathom isobaths[1]. These speculations have received support from palaeontological discoveries, but the extensive breaking-up of the Polar regions and our slight knowledge of them render it difficult for the geologist to arrive at any decided opinion on this point.

(*a*) *Australia* (II, p. 149; IV, p. 291). The eastern part of the continent presents the same succession of floras as that which characterizes the asylums from the time of the lower Gondwána onwards; and the glacial phenomena which accompany the beginning of this series in India and South Africa are also met with on this side of the continent; towards the west, however, marine transgressions set in. The granites of the Australian Cordillera cross Torres Strait into the south of New Guinea, and Australian Unios inhabit the Fly river. The east coast is bare rock and has been formed by a series of longitudinal faults of comparatively recent date; the sea on the east may be regarded as a recent subsidence. The south coast is accompanied by Tertiary sediments and is probably a slightly older fracture.

Tasmania is a southerly continuation of Australia. The recent geological observations made in Auckland and the adjacent islands reveal continental conditions and an original connexion with the south, possibly also with the south-west of New Zealand, which together with Stewart island is distinguished from the New Zealand mountains by a divergent structure[2]. This was possibly the route by which the Tertiary giant penguins (Palaeeudyptes) reached Otago[3]. They show, along with the great Tertiary penguins of Seymour island, both the original connexion of these remote points, and the age at which these exclusively Antarctic animals existed[4]. The horned tortoise, Miolania, an inhabitant of land or marshes, occurs on the little island of Lord Howe, as well as in recent sediments in Queensland, and an allied species is found in the older sandstones of Patagonia[5].

[1] C. Hedley, Considerations on the Surviving Refugees in Austral Lands of Ancient Antarctic Life, Proc. R. Soc. N.S.W., 1895, pp. 197–206, in particular p. 203; Osborn, Correlation between Tertiary Mammal Horizons of Europe and America, Ann. Acad. Sci. New York, 1900-1901, XIII, pp. 1–72, in particular p. 52.

[2] See addendum at foot of p. 327 (IV).

[3] Hector, Quart. Journ. Geol. Soc., 1876, XXXII, p. 53.

[4] Wiman, Bull. Geol. Inst. Upsala, 1905, VI, pp. 247-252.

[5] The existing accounts are collected in A. Smith-Woodward, Some Extinct Reptiles from Patagonia, Proc. Zool. Soc., 1901, new ser., I, pp. 169-184 (II, p. 162; Megalania was originally regarded as a Lacerta).

The numerous works which have recently appeared on the existing fauna of Australia do not yet seem to have led to a fresh classification; we will retain Hedley's subdivision, according to which we must distinguish: 1. The oldest autochthonous fauna (*Eyrean*, Spencer), chiefly in the extreme south-west; 2. The second endemic fauna (*Euronotian*, Tate) with the typical Monotremes, Marsupials, and so on, distributed over the whole continent, and extending in isolated representatives to New Guinea and the Solomon Islands; 3. As the most recent element, the *Papuan* fauna, which advances from New Guinea chiefly along the east coast of Queensland[1].

Let us recall the fact that the series of land floras is preserved only in the east; as regards the relative importance of the freshwater fauna and the transgressions, it must be observed that Ceratodus still lives in Queensland, and is also met with in South Victoria in Mesozoic beds[2]. Thus relics of the Antarctic fauna, and the entirely alien, more highly differentiated, Papuan fauna are found together.

(*b*) *Patagonia.* The discoveries of the brothers Ameghino, and the works of Hatcher, Ortman, Gaudry, Sinclair, and other investigators in Patagonia have made us familiar with a series of faunas which seem to have no relations with the mammals of the northern hemisphere. It is possible that no single genus is common to both regions, and yet there is a certain parallelism of development. Unfortunately the stratigraphical data are not in complete accordance. The latest observations of Roth confirm the much-contested statement that Dinosaurs occur along with the oldest mammalian fauna (Notostylops-fauna); this is never the case in North America or Europe[3]. The Carnivores are without exception Creodonts; the Edentates are already represented by one great form (Palaeopeltis). The occurrence of Ganodonts in the Puerco fauna of New Mexico would lead us to expect ancestral Edentates at still earlier horizons.

We will not enter into details respecting this remarkable fauna. In North America and Europe the negative movements on the boundary between the Jurassic and Cretaceous and between the Cretaceous and Tertiary were oscillatory, and an earlier phase of such oscillations may, according to Roth's data, have occurred in Patagonia.

The Pyrotherium fauna, which comes next, contains numerous animals, some of them of large size, and the various groups continue their evolution into the third or Santa Cruz fauna which is assigned to the upper Oligocene

[1] Hedley, A zoogeographical Scheme for the Mid-Pacific, Proc. Linn. Soc. N.S.W., 1899, pp. 391-417.

[2] Smith-Woodward, Tooth of Ceratodus and a Dinosaurian Claw from Lower Jurassic, Victoria, Ann. Mag. Nat. Hist., 1906, ser. 7, XVIII, pp. 1-3.

[3] Santiago Roth, Beitrag zur Gliederung der Sedimentablagerungen in Patagonien und der Pampas-Region, N. J. f. Min., 1908, Beilage-Band XXVI, pp. 92-150; this also serves to correct what has been said in Vol. II, p. 305 on the Tertiary formation of Patagonia.

or Miocene, but here too the Carnivora are all small and Creodont; neither Proboscidians nor Ruminants occur; but the Edentates are already in possession of their immense claws. Still higher follows the much younger Pampas fauna with Megatherium, Glyptodon, and other genera, the gigantic descendants of the older Edentates.

The habitat of the three older Patagonian faunas by no means presents the characters of an ancient asylum. Cretaceous transgressions are known, and the ancient floras are absent. Doubtless we have here, as in New Mexico, only the border of a continent. Gaudry has justly pointed out that this diversified fauna presupposes a much wider distributional area than is afforded by existing Patagonia [1]. The adjacent Falkland islands, however, actually present the most characteristic feature of an asylum. In these islands the lower Gondwána flora does in fact lie upon ancient rock, and we are led to conjecture that the home of Notostylops, Pyrotherium, and the rest of these strange-looking animals must have extended out towards the Ocean far beyond existing Patagonia.

The fauna of Santa Cruz is doubtless much older than the Eurynotic fauna of Australia, the gigantic ancestors of which scarcely reach back as far as the Tertiary aera. In the Santa Cruz fauna, however, we already discern an increasing resemblance with that of Australia. Sinclair has recognized among the marsupials of the Patagonian fauna the ancestors or relations of such Australian groups as the Thylacinidae and the Diprotodonts, and along with these the ancestors of the existing Didelphidae of South America [2].

Hedley has attempted to represent on a map the boundary between the continental islands of Australia, populated by original connexion with the mainland, and the Oceanic islands colonized by drift. The boundary coincides with that between the two inner Australian arcs, but also includes Viti Levu. The Papuan fauna is shown as streaming out of New Guinea on the south, to Australia, and south-east to the New Hebrides. A second stream, the origin of which is believed to be Antarctic, proceeds from New Zealand through Norfolk island to New Caledonia. The facts previously referred to in connexion with Palaeeudyptes and penguins may be regarded as a confirmation of this view. As we have already seen, a further trace of Antarctic life, which has possibly come across Auckland, may very well be present. Hedley regards this residue as older than the Eurynotic fauna of Australia, and thus arrives at the conclusion that this Eurynotic fauna, with its abundance of Implacentalia, which we have always been accustomed to regard as one of the oldest of living faunas, is

[1] A. Gaudry, Étude sur une portion du monde antarctique, Ann. d. Paléontologie, 1906, I, fasc. 3, pp. 1-43, in particular p. 8.

[2] W. J. Sinclair, Marsupial Fauna of the Santa Cruz Beds, Proc. Am. Phil. Soc., 1905, XLIX, pp. 73-81. For a comparison with Europe cf. Depéret, Transformation, p. 318 et seq.

in fact younger than the faunas of Patagonia and New Zealand, and so far represents the latest fossil member of the evolutional series in Antarctis. We may suppose that its peculiarities have been preserved by isolation.

This first survey of the Pacific arcs shows that here, in contrast to the Atlantic region, the task which presents itself is that of following out long lines. The only exception occurs in the east of the Pacific, where the islands are arranged in groups, after the Atlantic type; and in this connexion it may be pointed out that the Galápagos are possibly a panzerhorst, like Iceland and Kerguelen; a view which accords with Baur's, who regards their fauna as continental [1].

The Pacific arcs, particularly the island-festoons, as well as the northern Antilles, present a number of connexions and separations which it is impossible at present to disentangle. Herr Steindachner informs me that *Cobitis taenia*, well known as one of the commonest European river fish, lives not only in Japan, but also in Formosa. The presence of mastodons in Borneo, Banca, Sumatra and Java affords another example of connexion; the attempt of the brothers Sarasin to determine the order in which successive faunas entered Celebes reveals the difficulties of the problem [2].

The great asylums of land animals also serve as asylums for land floras and inhabitants of rivers, but for each group in a different manner. For the sea we have at present no means of making similar observations. Even in the case of the land, there may have been still other regions besides those cited here; Borneo, and high mountain ranges for example, have certainly served at times as places of refuge. Whether the older conception of 'centres of creation' can be applied to asylums is a question difficult to answer, since, as the preceding examples show, species and genera may arise under a great variety of circumstances, and at the most diverse places, and may then migrate or perish together. What we observe, is an extremely uniform distribution of an upper Carboniferous-Permian flora and fauna over most of these asylums, and even where this is absent, as for example in Laurentia, there is yet a very concordant phase of organic development in the Permian land fauna. There is yet more to be seen. The independence of the Tertiary faunas of Antarctis (Australia + Patagonia) is undeniable, as is also the fact, however, that its starting-point, or apparently oldest element as represented by the Monotremes or Marsupials, does not differ essentially from that of the faunas of the northern hemisphere; that even the nature of the differentiation in its

[1] G. Baur, IV, p. 324, note 4.

[2] P. and F. Sarasin, Geologische Geschichte der Insel Celebes auf Grund der Thierverbreitung (Material zur Naturgeschichte der Insel Celebes, III, 4to, Wiesbaden, 1901), and K. Martin, Zweiter Beitrag zur Frage nach der Entstehung des ostindischen Archipels, Geogr. Zeitschr., 1907, XIII, pp. 425-438; H. Höfer, Das polynesische alteozoische Festland, Sitzb. k. Akad. Wiss. Wien, 1908, CXVII, pp. 513-518.

Edentates, Ungulates, and other orders is similar in both cases,—that both types of fauna, the northern and equatorial on the one hand, and the southern on the other, approach the same goal by similar routes, but the southern, even in its most recent member, the Eurynotic fauna, has not reached the same stage of development as the widely extended northern and equatorial faunas. This is shown by the contrast to the Papuan fauna presented by the north and east of Australia.

Without entering further into these biological questions, let us again turn our attention to the nature of the asylums. They coincide partly, but not wholly, with tectonic units. Although the north of European Russia presents us with horizontal Cambrian sediments, and the fauna and flora of Gondwána, yet it cannot be included among the asylums on account of the marine transgressions which followed. Other examples are not hard to find.

Asylums reveal themselves as ancient lands both by their structure and by the fauna of their rivers. Lakes without overflow are almost entirely absent, unless in fault-troughs. Even Victoria Nyanza is probably a local subsidence. In Africa, outside the Sahara, the sources of rivers have been brought so near together by retrogression, and their upper courses have mutually influenced each other to such an extent, that the fluviatile fauna has become uniform. This is Boulenger's Megapotamic sub-region, including the Nile, Niger, Gambia, Senegal, Congo, and Zambesi rivers, and lake Chad. In the bay of Bengal, as we have seen, the rivers of its east and west sides may once have been tributary to a prolongation of the Ganges, which has since foundered in. All the oldest types of fishes live in asylums, as for example, Ceratodus in Australia (Antarctis), Polypterus and Protopterus in Africa (east Gondwána land), Lepidosiren in Brazil (west Gondwána land) and finally Amia and Lepidosteus in North America (Laurentia).

The residue of a Sarmatian fauna now living in lake Baikal indicates an asylum situated close outside Angara land in a trough. A similar asylum in a trough is lake Tanganyika. Moore regards the remarkable relic-fauna of this lake as the remains of a Jurassic marine transgression; Boulanger is inclined to regard it rather as an Eocene transgression; since the discovery of the Medusa of lake Tanganyika in Victoria Nyanza, and in the river Niger, the idea suggests itself with increasing force that a similar migration from the sea may still take place at the present day. On an earlier page similar facts have been stated with regard to the Mysidae of the Volga. We will content ourselves for the present with the observation that so far neither a Jurassic nor an Eocene transgression is known to approach within great distances of lake Tanganyika; further, that even the upper Cretaceous transgression, the most widely distributed in Central Africa, is not known in the region of the East African troughs. Nor, according to Bornhardt's observations (Makonde beds), does it ascend from the east over the ancient highland in which lake Nyassa is let down. On the other hand, Pyrgulifera (Moore's Paramelania), a genus found in lake Tanganyika, is widely distributed both in Europe and in North America *in fresh or brackish water deposits of upper Cretaceous age.* In Hungary, especially, it occurs abundantly, associated with coal-beds of the Gosau formation [1].

The river systems of the asylums are discharged almost exclusively into the Atlantic or the Arctic Ocean. The Atlantic hemisphere, with its widely extended watershed, is that of the dry land, the Pacific that of the sea, and, considering the trifling age of the Atlantic Ocean, the subsidences which divide up the asylums in that region appear almost like an endeavour to establish planetary equilibrium.

In our survey of Asia (III, p. 311) we stated that all the ancient regions possess well-developed river-systems and a free outflow to the sea. This is true of all asylums. Regions such as the Caspian or the Gobi do not occur among them. The Djouf of the Sahara rests upon the Cretaceous mantle. The distinction between central and peripheral regions, and the difference in their value in respect to living beings, have been clearly pointed out by Richthofen. *According to Richthofen, all asylums are peripheral regions.* There are also regions outside the asylums which possess a peripheral position, such as that of lake Laramie and most of the Mediterranean lands. At the same time the Polar parts of the asylums, owing to their climate, have ceased to serve as places of refuge since the Tertiary aera. The other asylums, however, are *regions of maximum value for colonization.*

When a subsidence occurs towards the middle of an ocean it is followed by a negative eustatic movement of the strand and an extension of the mainland. Similar subsidences, however, have often encroached upon the mainland, and the gain in land laid dry has been counterbalanced by loss through submergence. But gain or loss, so far as it affects the living world, is not measured merely by the extent of the area exposed, but also by its nature. If we imagine that a pan-Thalassa originally covered the planet, then every change at that time would mean a gain for the mainland. With continued development of the seas the situation had become changed to such an extent that at the present day only 0·28 of the surface of the planet is dry land. Any further loss in asylums (except in polar regions) is a loss of valuable ground, and the nature of the surfaces gained has not always

[1] A survey is given by C. Gravier, La Méduse du Tanganyika et du Victoria Nyanza, sa dispersion en Afrique, Bull. Mus. Hist. nat. Paris, 1907, pp. 218-224, map; W. J. Sollas, Freshwater Faunas in the Age of the Earth, London, 1905, pp. 208–215; G. A. Boulenger, Distribution of African Freshwater Fishes (South African Meeting British Association), Nature, Aug. 24, 1905, pp. 413–421; Tausch, Ueber einige Conchylien des Tanganyika-Sees, Sitzb. k. Akad. Wiss. Wien, 1885, XC, pp. 56-70.

been equal in value to that of those which have been lost. On the whole, however, the loss of surface has exceeded the gain; this is shown by the trifling extent of the existing remains, and the terraced islands of the Pacific do not indicate that the process is at an end. The comprehensive biological work of the *Challenger* led Murray to conjecture that in the Palaeozoic aera the Oceans were not so deep as at present and were strewn with numerous islands; later, the continental land became more continuous and higher, while the Oceans were more circumscribed and grew deeper[1].

This conclusion the geologist may accept in all essential points. The Oceans have become more restricted and deeper, and at the same time the continents have become higher as a consequence of subsidences. For the same reason, as is shown by the Sahara and the Caspian, the continents have become more continuous, but this is due to the radial effects of contraction; in addition, we have the mountain chains as the result of tangential action, and these acquired especial importance at the time when the Tethys was incorporated. Leading investigators of the moon have attempted to distinguish definite lunar diameters corresponding with phases of contraction. On the earth such phases cannot be recognized (IV, 599), but in spite of the risk attaching to averages we may point out as a remarkable fact that the mean depths of the Atlantic (—3858 meters), the Indian (—3929 meters), and the Pacific Ocean (—4097 meters) lie very near a common mean of about —4000 meters.

If there were even a remote tendency in the contraction of the planet to establish a new, uniform radius, if the Atlantic subsidences which cut through our most valuable asylums, have actually been produced by an effort to establish planetary equilibrium, then we should have to fear a progressive diminution of the area inhabitable by land and freshwater animals. Not life itself, but a very important, and indeed the most highly organized part of it would be doomed to final destruction, and would be restored to the pan-Thalassa.

In face of these open questions let us rejoice in the sunshine, the starry firmament and all the manifold diversity of the Face of our Earth, which has been produced by these very processes, recognizing, at the same time, to how great a degree life is controlled by the nature of the planet and its fortunes.

[1] J. Murray, Report on the Scientific Results of the Voyage of H.M.S. *Challenger*, Summary II, 1895, p. 1462.

CORRIGENDA

Page 26, line 8. The term 'rich in graphite,' refers to the Moldanubian zones near the Moravian region; the dislocation on the upper March lies within the Sudetes.

Page 194, line 1, *for* Eastern *read* Western.