CHAPTER II

THE EUROPEAN ALTAIDS AND THEIR CORRELATION TO THE ASIATIC STRUCTURE

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THE name Altaids was given by Suess to a system of mountain folds that comprises the main portion of Eurasia extending from the Vertex, or according to Gregory's expression, from the Nucleus of the Russian Altai through the central part of Asia to the mountainous plateau of Tibet. In the East Indies the extremities of this system comprise the Sunda Arc as far east as the Banda Sea. To the W. they include not only the remote branches of the Variscan and Armorican chains of Middle Europe, but also, across the Atlantic Ocean, the so-called American Altaids in the Appalachians, still traceable as far as the hills of Oklahoma, W. of the Mississippi. Even the Alpids, that is the Kainozoic mountain ranges of the Mediterranean, are regarded by Suess as a posthumous group of the Altaids, and their origin is attributed to the pressure of the older Altaid framework surrounding them. It should be borne in mind that when this classification was brought forward, stronger emphasis was laid on the importance in structural geology of trend-lines of strata than on the morphological outlines.

Grouping the different kinds of folds under one general term obviously implied their development by a common system of dynamical forces, arising from the Altai-Nucleus and spreading far to the S., E., and W. The limit between the Siberian tableland and the Central Asiatic region is a sharply-defined zone of fractures, divided into two projecting sinuosities—the Baikal or Primitive Nucleus, and the so-called Altai-Nucleus. The independence of the Western or Altai Nucleus is evident from its folding having continued into the Carboniferous Period, whereas the Primitive Nucleus is pre-Paleozoic.

The movements radiating from the Altai Nucleus spread far beyond the scope of the Primitive Nucleus and affect the bulk of the continent. They are not only separated in space from the Primitive Nucleus and its peripheral formations, but also belong to a different period of folding. Nevertheless, the question of the age of folding is not an essential element in Suess's conception of the Altaids, which differs in this respect from the French conception of the Caledonian and the Hercynian folding. Suess's word, Altaid, is not an extended application of the terms Variscan and Armorican, for it comprises the recent arcs of the Sunda Islands and Japan, and the Tsin-ling Shan is also considered as a branch of the waves radiating from the Altai Nucleus.

The dynamical sense of the conception is fully expressed in the comparison with the waves of a sheet of water stirred at a point between Irtisch and Tarbagatai and propagated with many deflections to the extreme E. and S. of Asia and to the remote Atlantic coast of Europe.[1]

The first comprehensive classification of this system incorporated and summarized the scientific knowledge available at the time; but recent progress has provided more exact distinctions. The different significance of the various trend-lines had then been indicated, but had not been fully worked out. The difference was referred to the lack of individuality in the crowded systems of folds, so that in the Nan Shan and elsewhere chains of gneiss and of sedimentary rocks appear alternately and are intruded by irregular bosses of granite. Such crowded ranges are regarded as waves belonging to a common movement, in contrast with the isolated younger chains, like the Alps and the Himalaya. These crowded ranges have a distinctive structure owing to the absence of an alien foreland, and they may be compared with the regular waves of the open sea in contrast with the confused breakers on a shore.

[1] Suess, *Face of the Earth*, Vol. III, p. 197.

It had also been found that some of the Asiatic mountain chains had each been elevated as a massive block.

Two conceptions that are developed in the sequel lead to a closer understanding of the Asiatic structure. The first is the just appreciation of morphological features as an effect of recent tectonic movements. The second is a sharper discrimination between the significance of the strike of the rocks which form part of a pronounced zone of folding (the so-called orogens), and of those which, after having been irregularly folded and usually intruded by batholiths, have subsequently been moved as a whole without further deformation. Rocks belonging to these two categories are distinguished by contrasted types of metamorphism.

Professor J. W. Gregory has directed attention to the first of these points[1] in his review of Suess's *Classification of Eurasian Mountains*. We ought not to neglect the fact that every morphology is of relatively recent date and is the effect of special tectonic movements, which may or may not coincide with the strike of younger or older folds. Furthermore, this idea is expressed in the term "Folded Mountainblock" (Faltenblockgebirge), which mountain type, according to Obruchev (*Geol. Siberien,* 1926), dominates the whole of Central Asia.

Argand's admirable synthesis of Asiatic structures is chiefly based on the same idea. One of the leading factors in Argand's explanation is the distinction of the "plis de fond" or "foundation-folds," or "ground-folds,"[2] and the "plis de couverture" or "cover-folds." The last-named are constructed out of "new material" that has not yet been used for mountain-making. It is the mass of pliable sediments of which the gently-folded recent cordilleras are formed. The ground-folds are geological phenomena of an incomparably larger style. They consist of the rigid older material that has been repeatedly worked up; and this material may besides be stiffened by crystallization and magmatic intrusion. As compared with cover-folds, ground-folds move much greater weights with much greater expenditure of

[1] *Geogr. Journ.*, Vol. XLV (1915), pp. 505-7.

[2] Mr. E. B. Bailey suggests "foundation-folds" instead of the usually adopted rendering, "ground-folds."

energy. This is shown by their greater breadth and greater radius of curvature. Older chains with an inner structure of the same type, as is shown by newly-folded material, are incorporated as inert masses in the ground-folds. Both systems, younger and older, may remain quite independent as regards their strike; they may run parallel or may cross each other.

The ground-folds may start as a low arch of any broad or elongated shape. But the further development will be governed by tangential stress, and will inevitably soon produce rupturing in rigid material. This rupturing will be followed by overthrusts which may here attain the largest proportions. But in the absence of pliable unfolded sediments, as true nappes of the Alpine type are not possible, the overthrusts are developed less conspicuously. In spite of perhaps far-reaching horizontal displacements they remain in this case as the so-called "Charriages à sec" or the "dry overthrusts" of Argand.

It would appear that the French interpretation of the term "plissement" comprises a greater variety of different kinds of dislocations than the English and German "folding" and "faltung." They call "plissement" any kind of deformation produced by tangential movement, so that the folded block-mountains of Obruchev, as well as warping, tilting, and faulting, belong to the phenomena of the "plissement de fond" of Argand.

Suess briefly threw out the idea that the whole southern border of Eurasia advances in a series of great folds towards Indo-Africa. He mentioned Griessbach's statement that, as one stands in front of the over-folded chains of the "Himalaya, there seems to have been a movement of the whole mass of Asia toward the S."

It was Taylor who, relying on Suess's interpretation of Asiatic structure, first explained the whole structure of Asia and that of other continents as the result of crust-creep from the poles, which acted with maximum deforming force in high latitudes, probably connected with the flattening of the lithosphere.

Argand's exposition of the continent has presented these crust-creep movements in a comprehensible form. The process is analysed in detail. He distinguishes a series of epochs of folding, or " cycles," as he calls them. The Caledonian Cycle is not clearly defined in Asia. The Hercynian Cycle is very conspicuous in the interior of the continent. The realm of the Tethys with Tibet, the Himalaya, the ranges of Iran, the Burmese and Malay Arcs, the eastern Asiatic island ranges, etc., all belong to the Alpine Cycle. Further investigations will probably show that these cycles are not strictly separable from each other, and that it is with the growing thickness of the sediments in the region of the Tethys that the younger folding becomes more prominent. The deeper-lying fold-systems, which Argand differentiates under the cycle of Paleozoic conformities, are not exhibited in the arrangement of the existing mountain formations of Central Asia. The folded blocks themselves, on the other hand, are an essential part in this arrangement.

The " Leitmotiv " of the Asiatic structure remains, according to Argand, the southward creep or flow of the whole continent. What is new in his conception is the separation of the recent movements from the anterior structure. He shows that the old structures, recognizable in the strike and trend of the schists, are not essential in the features that express the main movements of the continent, but are the Alpine ground-folds which have seized material of older or later date in Mesozoic or Kainozoic times. The whole continent becomes a unity of Alpine movement. It almost flows before our eyes. This conception is in harmony with the observations of the Russian and American geologists concerning the recent block-movements across the interior from the Primitive Nucleus to the Tibetan plateau.

The irregularities, the deviations and the distortions of the folds are produced by the lack of homogeneity in the continental block and by the intercalations of more rigid and less pliable portions.

Argand's conclusions are convincing[1] concerning the effect of the rigid Serindian platform (Eastern Turkestan) on the surrounding chains of the Tian Shan to the N. and of the Kuen Lun to the S.

[1] But *cf.* Prof. Mushketov's conclusions, p. 178; also pp. 14-15.

The resistance of the great Indian Peninsula not only caused an enormous deviation of the southward pressing continent, but also its partition into three main segments.

Suess and Argand agree in considering Europe as an appendix of Asia, and in the opinion that it has passed through the same history as Asia proper, so that in it there reappear the essential features of the Asiatic structure. But the reasoning of both authors is not identical.

According to Suess the Variscan and Armorican folds of middle and western Europe belong to the Altaids, owing to the common age of their folding, the common character of their structural features, and also owing to indications of their connection by tectonic lines that approach from the Caspian Sea through the Donetz Basin of southern Russia. Moreover, on account of a similarity of the structures and of marine transgressions, Suess included in the same class of chains the Cor-Sardinian block (Corsica and Sardinia), and even the mountains of the African Atlas to the S.

Argand, for his part, recognizes in the distribution of the horsts and basins of Europe the extremities of the Asiatic ground-folds with axes of elevation and subsidence. According to his view, processes of the same kind have produced the Kuen Lun in Asia and the Harz and the Teutoburger Forest in Europe. They work with diminished powers in the European areas, but the principles involved are the same. Both in Europe and in Asia the old material has been shaped by the younger bursting and breaking ground-folds. In both every vertical elevation is the effect of an extensive tangential movement.

On this point I venture to advance some considerations of my own, as I have personal knowledge of this subject. The region of the Variscan horsts is indeed small in comparison with Eurasia, but the investigation of its internal structure has advanced possibly further than in any other of the older parts of Eurasia. Though the so-called Hercynian or Variscan horsts, to which I wish especially to refer, belong to the oldest fields of geological investigation, yet recent years have brought a complete change of our views regarding them and a better understanding of their crystalline basement complex.

The more profound our insight into the texture and tissues of a single branch, the better is our understanding of the growth of the whole tree. If we are told that Europe is to be explained by Asia, it is also true that Europe can contribute to the understanding of the main problems of Asia.

As is well known, the horsts, *i.e.* the Bohemian massif, the Harz, the Black Forest, the Vosges, the Central Plateau of France, and the Armorican Peninsula are fragments of the older Variscan and Armorican Arcs, and their actual outlines are quite independent of the fold-trends. The boundaries of the horsts cut across the lines of the old plan and are autonomous in direction. Recent investigations have brought evidence that the original Variscan mountain chain, of which now only scanty remains are left, was once not inferior in size and extension to the Alps of to-day, which are more completely preserved. Indeed, an additional important structural division was joined to the Variscan chain, of which there exists no corresponding equivalent in the Alps. Only the main features can here be briefly indicated.[1]

If we reconstruct from the existing horsts the trend-lines of the Variscan chains, of which the horsts are fragments, it can be shown that only a broad belt to the N. is comparable with the Alps. It is less than half the breadth of the whole structure, and lies between the outer zone in the coalfields of Westphalia and a line near the southern slope of the Erzgebirge. This belt consists of a true folded mountain chain or "orogen," exactly like the Alpine chain. Southwards from the outer border to the interior, the depth from which the outcrop has been lifted increases, and the degree of metamorphism is intensified. The outermost zone, approximately corresponding to the Alpine Flysch-zone, contains the well-known, extensive flat overthrusts of the Belgian and French Carboniferous. The next zone to the S. comprises the early Paleozoic sediments of the Rhenish Mountains and of the Harz; and Kossmat has added his view of the occurrence there of a huge folded overthrust to the known instances of far-reaching thrust-movements in

[1] *Cf.* F. E. Suess, *Intrusionstektonik und Wandertektonik im variszischen Grundgebirge* (1926).

the Taunus near Nauheim, and in the northern part of the Harz. He has confirmed what was expected in the region of Dill and Lahn near Marburg, on the eastern border of the Rhenish mass, from the close association of different facies of Silurian and Devonian sediments. The third zone has been pushed forward against the second zone. It is characterized by the predominance of the crystalline rocks; and there is overwhelming evidence that it consists of a system of overthrust sheets and of blocks piled up and driven northward. The core and the foundation is formed by the gneiss arches of the Saxon Erzgebirge, which are now recognized as a system of flat overthrust folds covering the altered cores of granite. The gneisses of the Erzgebirge resemble in their tectonic position and metamorphic structure the Pennine gneiss arches in the Simplon region, and the arched central gneisses of the Tauern with their "Schieferhülle." The gneiss arches of the Erzgebirge preserve the remains of what were once large thrust-blocks of highly crystalline rocks, that were transported from the S. by still more gigantic movements. The largest of these remains is the gneiss region of Münchberg in the western Fichtelgebirge. It is 20 miles (35 km.) long and 12½ miles (20 km.) broad, and its extremities lie upon the gneiss arches of the Erzgebirge exactly as the Silvretta (*i.e.* the fundamental block of the East Alpine Nappes, or Austrids according to Staub) rests on the Pennine Nappes in the Alps.

It may be inferred from the crystalline facies of the rocks that relatively small exposures of crystalline schists in the Spessart and in the northern portions of the Odenwald near Darmstadt also belong to the same zone of metamorphosed thrust-folds. That is all that has been left of a magnificent edifice which, in its former height and extent, was probably not inferior to the Central Alps from the Savoyan summits to the green hills of Styria at the border of the Hungarian Plain.

For various reasons, and especially because of the crystalline facies of the rocks, I am of the opinion that the so-called Saxon Granulitgebirge, south of Dresden, also belongs to masses that have migrated from the S. over the Erzgebirge.

The large blocks of gneiss are evidently derived from a crystalline region of another kind, that extended S. of the Erzgebirge. This southern tract occupies the whole of the Bohemian massif to beyond the Danube. Nearly the whole of the Black Forest and of the Vosges belongs to it, and the main portion of the French Central Plateau shows a structure of the same type. In the sedimentary complexes of this region, *i.e.* in the early Paleozoic and late pre-Cambrian rocks of Central Bohemia, there exists indeed a pronounced rather close folding with overthrusts; but it is far from being comparable with the overthrusts of Alpine type which dominate the Variscan Arc proper. Nowhere in this region has the folding been pushed to the stage of considerable attenuation and dynamo-metamorphism. Granitic intrusions, however, attain an enormous extension. They are surrounded by crystalline rocks that have suffered katametamorphism, *i.e.* a transformation caused not by stress and tangential movement, but by the influence of high temperature.[1] The strike of the rocks does not follow one or a few prevalent directions. It conforms, on the whole, but with various local irregular sinuosities, to the outlines of the greater granitic batholiths. The metamorphism and bedding of the rocks is evidently correlated with the adjacent granitic masses. Not the folding of the rocks, but the intrusion of the granitic magmas has obviously been the last formative process, and has produced the final and actual features of this wide region. Older tectonic and metamorphic facies have been obliterated through the influence of the intrusions and have been replaced by post-tectonic katametamorphism. For that reason I have called it the "*region of intrusion-tectonics.*"

The non-metamorphosed pre-Cambrian and early Paleozoic sediments of Central Bohemia belong to this region. They are remnants of its cover. Ordovician rocks are intruded over a long distance by the Central Bohemian granite and altered into contact-hornfels. For reasons into which I cannot enter here, I must assume that the sedimentary and igneous rocks of the Paleozoic and the pre-Cambrian of Central Bohemia—shales, sandstones, quartzites, limestones,

[1] The term katametamorphism is here used in the sense of Becke, and not in the exactly opposite sense for which it was proposed by van Hise.—[Ed.]

diabases, porphyries, etc.—are comprised in the kataschists of high-grade metamorphism. Parts of the cover have been overwhelmed by the granitic magma and drowned in it, and have suffered a sub-batholitic metamorphism.

The ascent of the magma was not limited to any special orogenetic phase; it has continued over an enormous period. The date of its beginning is unknown. As has been said, the intrusions have altered the Ordovician near Prague, and at other localities on the border and in the interior of the great granite mass of Central Bohemia. In the Black Forest the granites have penetrated the Culm-measures (Lower Carboniferous). In the Erzgebirge late thrusts have crossed the main thrust-surface and intruded into the zone of metamorphosed roof-structures. The latest tin-bearing bosses have there penetrated even the Permian porphyries.

The Bohemian basement complex is not an Archean block, as was believed when high metamorphism was held to be a significant character of geological age. The unconformities sometimes referred to between the pre-Cambrian (Algonkian) and the supposed Archean are only inferred and have not really been observed. The non-metamorphosed rocks are in some places in direct contact with the granite and show the usual intercalation of the contact-zone. Only in some tracts to the N. do the non-metamorphosed rocks pass gradually with increasing metamorphism into crystalline schists. The early Paleozoic rocks remain separated from the region of katagneisses in the whole extent of the territory from the Bohemian massif as far as the Central Plateau of France.

The portion of the region of "intrusion-tectonics" that belongs to the Bohemian massif is named the Moldanubian block. This has been moved as a large, relatively stiff unit against the series of "blanketing slices" which make up the Erzgebirge. The overthrust sheet of Münchberg, already mentioned, belongs to a part of the block which has been pushed farther.

The Moldanubian complex stands in approximately the same relationship to the folded Variscan region as the Dinarid mass stands to the Alpine structure proper. According to the Alpine structural geologists, Termier, Argand, Staub, etc., the front of the rigid Dinarid complex has over-ridden the

Pennine zone and the enormous pressure has converted the sediments and granites into a series of "blanketing slices." According to Staub's classification, the part pushed forward is now represented by the foundation block of the "Austrid-Nappes." To it belongs the crystalline mass of the Silvretta, and all the crystalline masses to the E. of the Brenner as far as the Hungarian Plain, except the Pennid and Grisonid windows of the Upper Engadine, of the Tauern and of the Semmering near Vienna. The ruins of the great overthrust sheet form towering mountains in the Alps; but in the Variscan ranges they have been removed and only scanty remnants have been left. In both cases the granitic intrusions are "post-tectonic," and have intruded into relatively shallow non-metamorphic fold-mountains. In this respect the Bohemian Paleozoic corresponds to the Mesozoic of the Alps of Bergamo, which have been intruded by the granites of the Adamello. In both the Alps and Variscan Mountains the granites have crossed the surface of principal overthrusts or zone of "roots," and have penetrated into the folded-zone or orogen proper. Thus the granites of the Veltlin and of the Bergeller massif in Switzerland behave like the granites of Karlsbad and Eibenstock in the Erzgebirge. It is to be assumed that the further advance of erosion in the Dinarids would likewise bring to view very extensive granite masses, and the accompanying schists would have dipped into the zone of regional katametamorphism.

In both the Alps and Variscan Mountains the travelling blocks have transported on their back a foreign stratigraphical facies; and the contrast between the Austrid facies of the East Alpine Mesozoic, so rich in limestone, and the monotonous Bundner-Schiefer has some analogy to the contrast between the so-called Bohemian or Hercynian facies of the early Paleozoic and that of the Rhenish facies with prevalent slates in the Ordovician, Gothlandian and Lower Devonian, which are the characteristic rocks of the non-metamorphic Variscan belt.

In both the Alps and Variscan Mountains the orogenetic process has continued for a very long period; notwithstanding it has been outlived by the period of intrusions. In both cases the rising mountain chains have been inundated by extensive transgressions, which seemingly divide the folding process into two phases. In the Variscan Mountains the widespread unconformity of the Culm or Dinantian overlaps the various deeply eroded elements, and its material consists in great measure of debris derived from the crystalline cores of the chain. In the Alps the Upper Cretaceous or Gosau beds lie unconformably upon the folds of the older phase. But in both cases the transgressions have no bearing on the orogenetic process itself. They are surely grand phenomena that extended over a great part of the earth's surface, although an adequate explanation is still wanting.

We may consider the Variscan chain, as well as the Alps, as continental-border-mountain-ranges. The so-called geo-synclines, with their massive sedimentary sequence, correspond in the one case with comprehensive series of the schistes lustrés of the Pennine Alps; in the other with the shales of the Rhenish zone. These sediments represent the filling of the foredeep, that migrates in front of the thrust block and becomes itself over-ridden during the orogenetic process.

Another imposing and very remarkable phenomenon in the foundation of the European Altaids can only be briefly mentioned here. It has been shown elsewhere that the Moldanubian complex is thrust eastward over another entirely different structure which is called the Moravo-Silesian Mountain range. The boundary line between both complexes runs through the eastern borderland of the Bohemian massif from the Silesian plain south of Breslau almost as far as to the Danube W. of Vienna, over a distance of 150 miles (250 km.).

The Moravo-Silesian range is a true fold-range of Alpine type, with blanketed sheets of crystalline schists over gneiss cores. The distance to which the sheets have been transported is here probably even greater than in the Alps, for both the regions brought into contact are not only thoroughly different in structure, but also belong to different magmatic provinces.

The thrust-plane is accompanied by zones of deep lamination with development of real mica-schists by shearing. Nevertheless, the boundary line is quite definite and undivided. It is not crossed by any igneous boss or dyke at all. The wholly unexpected discovery of this remarkable system can hardly be brought into intelligible relation with the known general plan of the Variscan Arc.

As may be inferred from the preceding, the European Altaids are composed of very different elements. The middle region is that of the intrusion-tectonics structure. On the N. this region is attached to the Variscan fold-zone, and on the E. to the Moravo-Silesian fold-zone.

The main portion of the French Central Plateau belongs to the intrusion-tectonic zone, with large granitic batholiths and with katametamorphism. But, adjoining it on the W., beyond the great fault of Argentat, occurs a fragment with a foreign structure consisting of gneiss arches with different kinds of metamorphic "schists and phyllite." Its tectonic relation is not yet understood.[1]

I lay much stress on the general significance of the intrusion-tectonics. As stated previously, the intrusion-tectonic offers some characteristic features where the exposures show the deeper horizons. The lack of any general strike stands in obvious causal connection with the great extension of the batholiths and the post-tectonic crystallization of the schists with the mineralogical constituents of the katametamorphism. No trace of a crystalline axis is there discernible. The intrusion-tectonic belt not only exceeds in breadth any orogenetic zone, but also occupies large tracts outside the true mountain belts. To it belong the whole southern part of the Central Plateau and the West Alpine autochthonous massifs, from the St. Gothard and Mont Blanc as far as the Mercantour. Moreover, the Cor-Sardinian mass and great portions of the Iberian Meseta are likely to exhibit the same features. The observations on the Variscan horsts point to the probability that in Spain also great structural intricacies remain to be revealed.

Further examples of this kind of structure can be found in many an extensive region of crystalline schists, of course with many individual variations. For each region shows the peculiar features that correspond to its individual history.

[1] Mouret, *Bull. Soc. géol. Fr.*, XXVI (1898), p. 601; *Bull. Serv. Carte géol. Fr.*, XI (1899), p. 1; *C.R. Acad. Sci. Paris* (1917), p. 822.

Finland may be quoted as the best-known example of extensive reaction between the general widespread magmatic substratum and the covering "sclerosphere." There, too, in spite of manifold dislocations and certain fold-trends that run for some distance, a prevalent and dominating orogenetic strike is lacking. The complexes that are relatively less disturbed have dipped into the zone of regional katametamorphism with katacrystallization in a broader sense. This zone must be regarded as ubiquitous in the earth's crust at no extreme depth. Sederholm has already emphasized the differences of metamorphism between Finland and the Alps, which latter are characterized by the abundance of chloritic and sericitic phyllites and gneisses.

The process of metamorphism and magmatic fusion in Fennoscandia was not confined to one epoch. Periods of far-reaching denudation, that cut down to the crystalline substratum, were intercalated between the repeatedly revived phases of "Anatexis" (Sederholm).

Similar structures are certainly widespread in the Canadian Protaxis. William J. Miller, referring especially to the Grenville series in the Adirondack Mountains, has recently called attention to the fact that the trend in the old schists has no relation to folding, and that the deformation may reasonably be explained as "a direct result of magmatic intrusion or injection accompanied by not more than moderate compressive forces." According to these and other similar statements made by him,[1] I am inclined to take it for granted that in the Canadian basement complex, as well as in other supposed Archean regions, intrusion-tectonics play no inconsiderable part.

We may conclude from the known data of different regions that in any crystalline complex careful discrimination should be made between folded structures developed by tangential pressure and those accompanied by extensive magmatic intrusions; and that in any attempt to work out the geological structure of metamorphic territories, careful study of the so-called crystalline facies or the type of metamorphism is indispensable.

[1] W. J. Miller, *Bull. Geol. Soc. Amer.*, XXXIV (1923), p. 679.

Thus the experiences obtained from one of the supposed branches of the great Eurasian mountain system may teach us how many different kinds of structure may still be unrevealed in the large and little-known mountain areas, and warn us to be cautious in the interpretation of trend-lines in the pre-Carboniferous districts of Central Asia. We are justified in assuming as highly probable, that large portions of the metamorphosed regions in Asia do not belong to true fold-mountains or orogens, but that they will show the features of intrusion-tectonics. That is suggested by the frequency and extent of the granitic masses. I give as an example the reports of Berkey and Morris relative to the large batholith in Mongolia, of which the outliers even approach Peking.

As is shown in the Bohemian massif, in regions of this type non-metamorphic rocks and rocks of high-grade katametamorphism, both of the same age, may appear at quite short distances from each other. I am inclined to consider it not impossible that some of the crystalline schists in the Altaid region of Suess may have to be raised in the scale of the Paleozoic strata as high as the Lower Carboniferous (Mississippian).

The Moldanubian block and the other fields of intrusion-tectonics in the European horsts represent one gigantic chip splintered from the roof above the " Sal " and pushed forward by great tangential forces. During the movement it has proved resistant to true folding, and remained relatively rigid; but that has not prevented its reaction to powerful tangential thrusts. Sliding movements of an earlier period, perhaps contemporaneous with the folding of the outer sedimentary arc, have produced intercalations of certain types of micæous gneisses and mica-schists in the deeper interior parts of the block. Movements of later periods are preserved in the form of thrust-planes, mostly accompanied by zones of foliation and phyllonites,[1] diaphtorites,[2] and mylonites.

[1] Rocks of different origins from true phyllites, which have acquired the mineralogical and textural characters of phyllites by stress at lower temperature.—[Ed.]

[2] This name was given by Becke to rocks in which constituents have been replaced by mineral species characteristic of a less extreme metamorphism, such as biotite replaced by chlorite, or orthoclase by quartz and mica.—[Ed.]

To this younger phase belong the great overthrusts near St. Etienne in the Central Plateau and others described by Termier,[1] and the flat fault-thrust with broad zones of mylonite in the southern Black Forest and in the Vosges (Bubnoff,[2] Cohen, Young,[3] etc.). They are themselves traversed by the latest granitic intrusions.

We are fully justified in considering the transgression of the terrestrial Upper Pennsylvanian (Stephanian) and the Permian (Rotliegendes) as the final stage of the main orogenetic process, although the magmas continued to rise as porphyritic effusions. In later periods the regions were still exposed to the action of tangential forces from different directions.

Certain prevailing systems may be distinguished in these later periods:—

1. The *Rhine* direction; 2. The direction of the *Erzgebirgian* trough; and 3. The system of the so-called *Karpinskian* or *Asiatic* direction. The Rhenish system is irregularly distributed, and apparently signifies a "breaking" of western Europe N. of the Iberian Peninsula against the Atlantic. Its most prominent feature, the Rift Valley of the Rhine (Rheingraben), has obviously been produced by tension and disruption of the superficial crust, which has occasionally given access to the ascending magma in volcanic vents such as that of the Kaiserstuhl. Its diminished and deflected continuation can be followed northward through the Leine Valley near Göttingen to the western slope of the Harz Mountains. It is accompanied by the more extensive eruptions of the Vogelsberg and the neighbourhood of Kassel. Approximately parallel to this great shattered zone is the broader, and much younger, belt of volcanoes that traverses the Central Plateau of France from the Allier Valley southward and attains the Mediterranean coast near Agde.

The second system, that of the Erzgebirge trough, also includes dislocations of different ages. Its direction is W.S.W. The great fault in the southern slope of the Erzgebirge and the adjoining trench, from which the great effusive masses of

[1] *C.R. Congr. Géol.* (1923), p. 585.
[2] *N. Jahr. Min., B.B.*, XLV (1921).
[3] *C.R. Acad. Sci. Paris* (1922), p. 1377.

the Bohemian Mittelgebirge were extruded, are both Miocene. The shatter-zone continues below the Mesozoic cover of the Swabian Plateau, as is revealed by various Miocene eruptions. Among these are the large explosive vent of Ries near Nordlingen, the group of the tiny so-called embryo volcanoes south of Stuttgart, and further on the Hegau volcanoes to the south of the Black Forest. Numerous other eruptions of Miocene age have made their appearance through other shatter-zones of most irregular distribution.

The third system we have to consider especially. It penetrates intimately the structures of the whole of western Europe from Scania to the Pyrenees; how conspicuously its general trend to the N.W. and W.N.W. becomes visible on some boundary lines of the horsts has often been emphasized; for instance, at the boundary of the Sudeten mountains S. of Breslau, on both sides of the Thüringer Forest, at the slope of the Fichtelgebirge as far as N. of Regensburg, at the minor horsts of Central Germany up to the Teutoburger Forest, at the south-western border of the Central Plateau of France and in the Pyrenees themselves.

It is well known that Suess comprised this system under the name Asiatic lines or Karpinski lines, because he recognized a connection between them and some extensive dislocations that come from Asia, traverse the Caspian Sea, and apparently continue through the W.N.W. dislocations of the Donetz basin and to the mountains of Sandomir in Poland. Thus they pass without perceptible demarcation into the European system of a similar trend.

There is ample evidence that this Asiatic system of faults in Europe is produced by tangential compression acting in general from N.E. to S.W. One of the most remarkable facts is the entire lack of volcanic occurrences on these lines. Even the Pyrenees, which follow the same direction, are remarkably poor in younger volcanic rocks, compared with some other Kainozoic chains.

Evidence of horizontal thrusts have long been known at various localities. The most frequently cited is the thrust of granite over Jurassic on the great Lausitz-fault at the slope of the Riesengebirge on the Saxon-Bohemian boundary. Analogous to it are the parallel overthrusts at several localities along the Danube between Regensburg and the Austrian boundary, where granite or Permian rocks overlie Jurassic and Cretaceous sediments.

Movements of the same tendency but of far greater extension are recognizable in the division of the so-called Sudeten mountains into a series of thrust-blocks limited by approximately straight lines. That the blocks must have been brought into their present position by great horizontal movements is proved by the difference of structure in each of them. The innermost block contains the large granitic masses and crystalline schists of the Riesengebirge and the Isergebirge. The second or middle block contains the Paleozoic of the Boberkatzbachgebirge, overlain by the overthrust gneiss masses of the Eulengebirge and the Spieglitzer Schneegebirge; these masses are the remains, and give evidence of a far-reaching overthrust structure, previous to the partition of the second block into thrust-blocks with a north-westerly direction. The third block consists of the crystalline and Palæozoic hills in the Silesian Plain.

The youth of this straight-lined partition of the folded range is proved by the irregularities of its relief. In this region stands the highest mountain of the Bohemian massif, the granitic Schneekoppe (5260 ft.), near the Cretaceous Heuscheuer (3639 ft.) and the gneissose Spieglitzer Schneeberg, and between these mountains lies the flat Permian basin of Braunau. We find here also confirmation of the fact that in the outer relief of the earth's crust, the greatest heights and depths are produced by relatively young tectonic movements; and it is uncertain to what degree the heights in the southern Bohemian massif, and perhaps in the Black Forest also, are due to vertical elevation in consequence of the Cretaceous and post-Cretaceous tangential compression.

Besides the larger fractures, uplifts and fault-troughs, we find widespread evidence of dynamic alteration of the rocks due to regional tangential compression. In any part of this vast region, where investigation has advanced sufficiently, innumerable smaller dislocations are found to exist. Thus the detailed maps of the Bohemian Paleozoic of the Thuringian fold-zone, as well as of the unfolded Mesozoic basin of Swabia, show a lattice of straight fault-lines with a great prevalence of the north-westerly direction, and crossed by a comparatively small number of faults with other trends.

The well-known quartz-ridge called the great "Pfahl" runs with astonishing straightness for more than 100 miles (160 km.) from Amberg in Bavaria to beyond the Austrian frontier. It has been produced by the filling of a long cleft with material derived from the decomposition of crushed felspars into quartz and sericite. The long rupture is accompanied by a broad band of mylonites and thinly foliated sericitic schists, alteration products due to the intense shearing along the disruption.

Overwhelming evidence of the enormous pressure suffered by the whole of the mountain block is afforded by the innumerable fissures and joint-plains and by a minute foliation that becomes visible on fractures. It traverses in straight parallel directions all kinds of crystalline rocks, granites, and gneisses, not only in the vicinity of the great fault, but also far off from it over almost the whole south-western part of the massif.

The unilateral push from the N.E. which is distinctly marked by the prevailing number of N.W. to S.E. faults, leads us to infer that this area has not been affected by crustal contraction but by pressures operating from outside. Deviations are produced by the irregularities of the older structure.

Suess has emphasized that this system of faults is connected with another that was described by Karpinski, and traverses, on lines that are approximately parallel, the main part of southern Russia. It comes from the Alai mountains in Asia; its continuation forms the anticline of the Mangishlak Peninsula in the Caspian Sea. Along the same line, farther on, lie the foldings of the Carboniferous deposits of the Donetz. They are on both sides accompanied by a broad belt of parallel subsidiary features, which continues to the mountains of Sandomir in Poland, and there reach the Middle European System. The assumption is well justified that all these lines, as they have a common trend for enormous distances, are of common origin. If we admit that the Asiatic folded blocks are produced by a great tangential push related to the southward creep of the enormous crustal sheet, we must also consider the north-western fault-system of western Europe as the deflected and diminished effect of the same process.

Let us now return to Argand's analysis. He divides the structure of western Europe into seven ground-folds belonging to the Alpine Cycle. The first of them consists, according to him, of the ancient Helvetian massifs in the Alps, from St. Gothard to the Mercantour. In my opinion these masses ought to be separated from the true horsts. They may be built up of the same ancient material, but their elevation is due to other causes, and is not only incomparably greater, but also younger than that of the horsts. Only the Alpine thrust, caused by the advance of the African continent, has been powerful enough to raise the basement complex to the lofty summits of Mont Blanc and the Jungfrau.

The north-western dislocations or Variscan lines are not recognizable in the Alps themselves. In the region of the Helvetian massifs the Variscan lines may have been effaced by the Alpine movement, while the crystalline basement complex of the so-called East-Alpine Nappes or Austrids belongs to another continental complex, as Argand himself assumes.

The other ground-folds—Nos. 2 to 5 of Argand—have raised the principal horsts, which he has arranged according to the distribution of the main elevations, as follows :—

2. The French Central Plateau and the broad domes of the Vosges and the Black Forest.

3. The Armorican massif.

4. Cornwall in England, the Ardennes and the Rhenish Paleozoic mountains.

5. The Teutoburger Forest, the Harz, the north-eastern part of the Bohemian massif, the Silesian mountains, and the Lysa Gora (mountains of Sandomir) with the intercalated troughs. This ground-fold sinks rapidly below the Oligocene, Neogene, and Quaternary of the North German Plain, where deep borings have revealed the persistence of structures similar to that of the neighbouring horsts.

6. The flat ridges of the smoothly vaulted Upper Cretaceous and Kainozoic in Denmark. Its great radius of curvature is attributed to the stiffness of the underlying rocks that belong either to the Baltic Shield or to a hidden branch of the Caledonian Chains.

7. Scania and Bornholm are considered as a seventh zone. Their great radius of curvature is referred to the stiffness of the pre-Paleozoic basement that has been worked into this ground-fold.

8. The broad elevation of southern Sweden is considered as possibly an eighth zone.

To this conception we may remark first that these assumed ground-folds are internally divided into strips by approximately parallel faults or overthrusts. It has been stated above that these dividing lines are of different ages. One of the most prominent lines between the fold of the Erzgebirge and the granitic masses and schists of the Lausitz is of pre-Permian age. It separates two very different structures, and it is obviously of great importance.

The partition of the eroded Variscan structures must have started comparatively soon after the close of the folding process, that is about late Carboniferous time. It has persisted, of course, with many irregularities and interruptions, at least into the early Kainozoic. Naturally, it is the younger post-Cretaceous series of movements which has formed the main features of the actual morphology and the ridges and basins of Argand's ground-folds. It would be hardly possible to refer their development to one definite cycle of mountain-building. They are also related to the development of the Asiatic folded blocks or ground-folds, so far as has been ascertained from repeated movements on great fault-lines radiating outward from the bulk of the continent.

Of course, the temporary occurrences of strainings and crushings in other directions, especially those of the Erzgebirge and Rhenish trends, participate in a very conspicuous manner in the determination of modern morphology.

Concluding Remarks.—It is difficult to establish definite connecting lines between the pre-Permian structures that have been distinguished as the European and Asiatic Altaids. What is called the Variscan range contains large crust-sheets of the type of the intrusion-tectonics. This range is cut off on the E. and thrust over a structure of Alpine type—the so-called Moravo-Silesian Chain—of which the principal trend is from N.N.E. to S.S.W. We can expect that the pre-Permian basement complex of Central Asia will also contain a great variety of structures, and that a considerable portion of them will have to be explained as examples of intrusion-tectonics. In such regions with abundant crystalline rocks the determination of regional structural connections, and the age of the mountain chains cannot be based on the mere trend-lines without special investigation of the position and the crystalline facies of the schists. Very likely, in large areas, the trend-lines will have no relation to the true fold ranges, as is the case in the Canadian Protaxis and elsewhere.

In Europe, as in Asia, the old structures have been overwhelmed by the younger tangential movement, and here as in many parts of Central Asia the actual morphology is related to transverse disturbances sometimes of great extent.

The history of the European-folded blocks has been, of course, in some respects different from that of the Asiatic blocks. The steep fault-scarps of the horst-ridges have been better preserved in the almost continuous desert climates of Central Asia than in the humid climate of Europe. These areas have also been traversed by peneplanes of different ages, and especially by planes of wave-erosion, due to the repeated invasions of the Miocene and older Kainozoic Sea.

The mobility of the earth's crust is not throughout restricted to the relatively narrow belt of the Kainozoic orogens. The large creeping sheet of the Asiatic continent is crushed and distorted in a very considerable degree. The " dry overthrusts " which occur in the interior of the continent arise from the same general impulse as the more striking chains of the new pliable strata of the Tethys. The " continental border chains," above all, have elevated the thickest and most complete sedimentary series.

The unifying attribute of the Altaids is accordingly their common pre-Upper Carboniferous or pre-Permian age, and the unconformable cover of mostly late Carboniferous or Permian sediments. But they may contain structures of various trends and of various ages. The transgressions of the Upper Carboniferous and the Permian Seas extend over great parts of Asia, of Europe, of Northern Africa and North America ; and it is observed as well in the mountain chains of the Alps and of the Atlas, as over the forelands of Variscan age. The nearly contemporaneous exposure, over so great a portion of the earth's crust, of structures of different ages cannot be referred to processes that are strictly orogenetic. Like the great marine transgressions of the Upper Jurassic and of the Upper Cretaceous, this phenomenon is not dependent on the processes of mountain-building proper. It is true, the older and the younger orogens have their own stratigraphy, which is different from that in the forelands. Nevertheless, even in the more ample stratigraphical sequence of the orogens one can observe indications of the general rising and sinking of the ocean-level. In the Alps, for instance, the coals of the Carnian (Lunz sandstone) are the equivalent of the coals of the extra-Alpine Keuper. The rising of the sea during the Upper Trias, Rhætic and Lias is seen in the Alps as well as in Germany. The transgression of the Gosau beds in the Alps corresponds to the general Upper Cretaceous transgression.

Phenomena of this kind, to which also belongs the great transgression that separates the Altaids from the younger mountain systems, must be connected with events of a more universal character; such as the creeping of continental masses in the sense of Wegener's hypothesis, or variations in the form of the hydrosphere or other still unknown causes.