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ON THE TORSION-STRUCTURE OF THE DOLOMITES.

The TORSION-STRUCTURE *of the* DOLOMITES. By MARIA M. OGILVIE [MRS. GORDON], D.Sc. (Communicated by Prof. W. W. WATTS, M.A., Sec. G.S.)

[PLATE XL—MAP.]

CONTENTS.

I. INTRODUCTORY REMARKS.

THE Sella Massive at the time when I examined it (1891–1893) was one of the least visited of the Dolomite-mountains. Its remoteness from the main tourist-routes was the chief drawback to popularity. But, in 1894, a new driving-road was opened between Bruneck in the Puster Valley and Corvara in Enneberg (a village at the foot of the Gröden Pass and the Sella Massive). A shelter-hut was also built on the mountain-terrace below the Boe summit, and has since been satisfactorily conducted under the auspices of the Bamberg section of the German and Austrian Alpine Club. Thus, when I revisited the country in the season of 1898, I found that Enneberg and the Sella Massive had been brought well within the sphere of ordinary tourist intercourse, and that the physical difficulties of the long marches and ascents had been very materially reduced.

An historical epitome of the Geological Literature respecting the 'Dolomites' was given in my first paper on the subject, published in February 1893.[1] It will be sufficient here to note briefly the facts and opinions arrived at by geologists previous to the reading of the present paper, grouping them generally according as they deal, on the one hand with the stratigraphical, and on the other hand with the tectonic side of the question.

Stratigraphical.—The general succession of the Triassic rocks as laid down by Baron F. von Richthofen[2] for the region of the Dolomites is familiar to most geologists. The various members of the sequence occur in the following (ascending) order:—

(A) The Lower Trias or Werfen Series, subdivided locally into Seis Limestone and Campil Sandstone, with characteristic fossils.

(B) The Middle Trias or Muschelkalk Series, embracing a lower and more calcareous and fossiliferous horizon, and a higher and more

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[1] M. M. Ogilvie, 'Contributions to the Geology of the Wengen & St. Cassian Strata in Southern Tyrol,' Quart. Journ. Geol. Soc. vol. xlix (1893) pp. 1–78.

[2] 'Geognostische Beschreibung der Umgegend von Predazzo, St. Cassian etc.,' Gotha, 1860.

dolomitic horizon (the **Mendola Dolomite**), followed in Southern Tyrol by the **Buchenstein** banded limestones and conglomerates, with frequent occurrence of lavas and volcanic tuffs (especially the greenish **pietra verde**).

(C) The succeeding horizons—named by Richthofen **Wengen strata**, **Cassian strata**, and **Schlern Dolomite**—are more particularly those around which, together with the next horizon in the succession—the **Raibl strata**—the stratigraphical difficulties in the Dolomites have grouped themselves.

(D) The highest horizon of the Trias—namely, the **Dachstein Limestone** which follows—has long been quite definitely determined in the Dolomites.

With regard to the group of strata (C) below the Dachstein horizon, it will be remembered that when I first wrote upon the subject of the Dolomites, the questions at issue were mainly concerning the distribution of the different rock-facies in the region, namely:—

(1) Whether the massive **Schlern Dolomite** was the time-equivalent of the tufaceous shales and marls and thin-bedded limestones comprised as the Wengen and Cassian Series, etc.

(2) Whether the dolomitic rock-facies had been originally developed in thicknesses of 2000 or 3000 feet, forming precipitous mountain-walls, and then as suddenly dwindled down to nothing amid the surrounding deposits of earthy facies.

(3) And whether, if such were the case, the 'coral-reef' theory ascribing these enormous thicknesses of rock to coralline agency accounted for all the peculiarities of the district.

The coral-reef theory was merely suggested[1] by Baron F. von Richthofen in 1860 as a possible explanation of the curious stratigraphical features then not easily paralleled; but it entirely permeates the brilliant work of Mojsisovics,[2] and meets there with an elaboration of detail which would appear to carry conviction with it.

Certain peculiarities, however, remained unexplained to the minds of many, and Baron F. von Richthofen pointed out to me how and where some of the main problems might best be re-investigated, advising, above all, a minute search for fossils in the earthy strata of Enneberg, etc., and a detailed mapping of the fossiliferous zones round the base of a massive. This is the method which I have followed at every available opportunity since 1891.

In my papers, published in 1893 & 1894, I[3] established the following conclusions respecting the question of local lithological facies:—

(1) The **Schlern Dolomite** was originally a single sedimentary sheet overlying the earthy, thinly-bedded Wengen and Cassian strata throughout Gröden, Enneberg, and Ampezzo.

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[1] An account of the first enunciation of this theory by Richthofen, th opposition which it received at the hands of the late C. W. von Gümbel and Prof. Lepsius, and the strong support from E. von Mojsisovics, has been previously given by the present author, *op. cit.*, Quart. Journ. Geol. Soc. vol. xlix (1893) pp. 4-12.

[2] 'Die Dolomit-Riffe von Süd-Tirol u. Venetien,' Vienna, 1879.

[3] *Op. cit.* Quart. Journ. Geol. Soc. vol. xlix, p. 47; and 'Coral in th Dolomites,' Geol. Mag. 1894, pp. 1, 49.

(2) It rests conformably upon successively higher and higher palæontological zones of these thinly-bedded strata, when followed from south and south-west to north and north-east through the heart of that district.

(3) Its upper limit, with reference to the succeeding Raibl strata, varies at different localities[1] correspondingly, but more rapidly and somewhat more irregularly; in no case, however, do Raibl strata repose upon any other horizon than Schlern Dolomite.

(4) Fragmentary tufaceous material, associated with contemporaneous eruptive activity, is intermixed with all the thinly-bedded earthy series—Wengen, Cassian, and Raibl strata.

(5) Interstratified with the tufaceous deposits are lenticular beds, blocks, and thinly-spread banks (Cipit-Kalk) of coral-growth, both in Cassian and Raibl strata; on the other hand, such coral-growths were observed to be comparatively rare in the Schlern Dolomite itself. This was found to be a stratified marine deposit, in which remains of algal, molluscan, and echinoderm life (even if so much altered by dolomitization as merely to deserve the name of 'traces') prevailed far more largely than corals.

(6) The heteropism exhibited in the lithological facies presented by the palæontological zones of Wengen and Cassian strata led me to the conclusion that an ancient geographical limiting-line (now locally segmented) had extended in Triassic time east and west through the Dolomite-region. To the south of this line the earthy Wengen and Cassian strata disappear, giving place to thick masses of calcareous rock, namely, the Marmolata-Kalk; hence I concluded that the Schlern Dolomite of Gröden, etc. was the time-equivalent of the higher horizons of the calcareous Marmolata-facies to the south, while the earthy Wengen-Cassian strata represent in time the lower horizons of the southern calcareous series.

Having traced segments of the old geographical limit of Cassian and Wengen time along the exposures of igneous and tufaceous rock, from Mahlknecht through Duron, Rodella, Sasso di Mezzodi, etc., to Col di Lana, I explained the existence of such a limit as the result of a downthrow to the south during the time of deposition of the different Middle-Triassic facies; and stated that, in my opinion, 'contemporaneous faulting and volcanic action were the cause of mid-Triassic heteropism in South Tyrol.'[2]

These conclusions show distinctly that such palæontological and lithological evidence as is obtainable does not support the application of Darwin's theory of the origin of coral-reefs which had been made to this particular region of the Alps.

Tectonic.—The brilliant researches and conclusions of Mojsisovics, Suess, Vaček, Benecke, Bittner, and others respecting the complicated structure and tectonic accidents of the Peri-Adriatic region are familiar to students of Alpine geology. So long as little was known of the extraordinary effects of earth-crust movement in mountain-ranges, it was but natural that geologists should regard the peculiar forms of the Dolomite-massives in the Tyrol as original structures. But, with the growth of our knowledge of the complicated structures of mountain-regions during the last quarter of a

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[1] S. von Wöhrmann & Koken, 'Die Fauna der Raibler Schichten vom Schlernplateau,' Zeitschr. d. Deutsch. geol. Gesellsch. vol. xliv (1892) p. 167.

[2] Geol. Mag. 1894, p. 10.

century, the subject has gradually assumed a new aspect, and a tendency has been developed among geologists to regard these strange forms as of secondary origin—the results of the partial denudation of a mountain-region built up of normal rock-formations, which had been affected by excessive crust-movement. For example, it will be in the recollection of some of those who attended the Geological Section of the British Association at Edinburgh in 1892 that this point of view was taken by Prof. Lapworth, who, carrying out the principles dwelt upon in his Address,[1] urged, during one of the discussions, that the Dolomite-country was a typical region of cross-folding and faulting, and that its so-called reefs and other characteristic features were of secondary and tectonic origin due to Tertiary crust-movements, with which movements the injected bosses and sills (including even those of Predazzo) were probably connected.

Passing, therefore, to the tectonic side of the Dolomite question, it may here be briefly indicated that the chief structural conclusions worked out in my previous papers were as follows:—

(7) Some of the curious stratigraphical appearances round the base of the so-called 'reefs,' synonymous with the mountain-masses, are due to faults.

(8) A large proportion of these faults have inclined fault-planes, upon some of which overthrust, and upon others downthrow, has taken place.

(9) These inclined faults have been cut locally by subsequent transverse faults, causing horizontal displacement.

(10) Igneous rocks occur as injected sheets and dykes in some of the many anticlinal faults.

(11) The above-described system of overthrusting and cross-faulting in Enneberg and Ampezzo corresponds in all its characteristic features with the Judicarian-Asta system of faults demonstrated in the various parts of Southern Tyrol by Suess, Vaček, Benecke, Bittner, and Hœrnes. 'The same long flexures passing locally into faults occur, the same types of overthrusting, and the same swinging round of the Judicarian dislocations into those of the Asta series.' In fine, the areas mapped by the present author were characterized by a group of stratigraphical features in complete harmony with features previously identified in neighbouring areas; and these dominant stratigraphical features were quite independent of the Middle Triassic facies within region of the Dolomites.

(12) With regard to the geological age of these disturbances, the writer demonstrated the broken course of one main longitudinal fault or flexure of Triassic age; emphasized the presence of a number of parallel longitudinal faults, all containing eruptive injections, and all giving evidence that they had been important planes of movement since Mesozoic times, concluding that the predominating system of faults identified by her with the Judicarian-Asta system generally, must be of Tertiary age: these 'in some places coincided with, or crossed at varying angles, lines of Triassic disturbance,' a conspicuous example being the famous 'eruptive fault' of Monzoni-Fassa associated with the igneous injections of the neighbourhood of Predazzo.

The igneous dykes penetrate nowhere higher than Upper Triassic rock in the Dolomites, and even as late as 1894 I was unable

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[1] Brit. Assoc. Rep. 1892 (Edinburgh) pp. 699 *et seqq.*

to bring forward any conclusive evidence of the age of the younger injection-dykes in the longitudinal faults of Enneberg. The relationship in time of the younger injections with the younger system of faults was highly probable, but this did not limit the age of these injections to Tertiary time, as the crust-movements of the atest Alpine upheaval were already advancing through the Eastern Alps in Cretaceous time. Moreover, the dykes were found to be cut by the transverse faults, which are the youngest faults of the district. All that I was then in a position to say for Enneberg was that 'It would seem that the Judicarian-Asta system of faults followed largely ancient lines of weakness, which had been marked by the outbreak of lavas in Triassic time, or intrusions of porphyry of uncertain age.'[1]

Thus it remained to discover what was the relationship between Triassic and Tertiary movements in the areas under observation. Further, though overthrust-shearing might account for the lenticular shape of some of the mountains (as, for example, Sasso Pitschi), it would not altogether explain the constant recurrence of circular and elliptical mountain-shapes with precipitous walls of dolomite-rock, composed of younger Triassic rocks, sunk in appearance into the middle of swelling Alpine pasture-lands composed of older Triassic rocks; nor, again, the remarkable basin-shaped or C-shaped depressions in the very heart of the massives themselves, containing twisted masses of Jurassic or Cretaceous rocks in abnormal stratigraphical relations to the Dachstein Limestone of Upper Triassic age.

Three years' unabated work had only sufficed to show me that the coral-reef theory was wrong, and that the explanation of the phenomena by transverse and overthrust-faulting, so far as my observations disclosed, was insufficient. Clearly some greater, general cause lay behind all these features. I then spent two years in visiting and studying as many other parts of the Alps as possible, and thereupon returned to the Dolomites, to map, in fuller detail, the area that immediately adjoins my previously published map of Sett Sass and Prälongia.

Results obtained in recent years by other investigators.—Before entering upon the description of the district investigated and the new results obtained, it will be best to clear the ground by pointing out the present state of knowledge and opinion with reference to the facts and conclusions advanced in the author's previous papers, some of these conclusions having been strikingly corroborated by the circumstance that other observers in the same field have arrived at results either identical or in perfect agreement with them.

In 1894, Prof. Rothpletz published his description of a complete section across the Eastern Alps.[2] A part of this section

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[1] *Op. cit.* Geol. Mag. 1894, p. 58.

[2] 'Ein Geologischer Querschnitt durch die Ost-Alpen, nebst Anhang über die sog. Glarner Doppelfalte,' Stuttgart, 1894. The present author has, in previous works, acknowledged her indebtedness to Prof. Rothpletz, first as a student attending his lectures and afterwards in the free interchange of opinion.

passes through Seisser Alp and Schlern Mountain, and differs greatly from the Austrian Survey-work under E. von Mojsisovics. One chapter is devoted to the question of the origin of Schlern Dolomite; and Rothpletz concludes that it is a normal marine deposit and no coral-growth. Further, he gives sections showing that he had nowhere found (as asserted by the officers of the Austrian Survey) that Raibl strata sometimes rest conformably on Cassian beds.

In 1895, Dr. Salomon[1] published the results of his work on the Marmolata region, immediately south of the Enneberg district which had been part of the present author's field of observation. His results show, for this region, the existence of similar phenomena, and lead him to corresponding conclusions. Thus, he proved that (1) thrust-planes occur with overthrust to the south; (2) the overthrust-planes are cut by transverse faults; (3) the igneous dykes occasionally occur in fault-planes; and he concluded, upon palæontological and stratigraphical grounds, that the Marmolata Limestone was of Wengen and Cassian age in its lower members, and in its higher members the equivalent of the Schlern Dolomite. But whereas Dr. Salomon found the overthrusting to be towards the south in the Marmolata, I had found it to be towards the north in the Dürrenstein, etc., on the northern edge of the Dolomites, and in almost every direction within the Sella Group.

In 1895 also, Prof. W. C. Brögger[2] published the results of his observations among the igneous rocks of the Fleims-Fassa district, arranging the igneous rocks in that area in the following ascending order:—

(1) Basic dykes and flows (augite-porphyrite, tuffs, etc.), of Middle Triassic age.
(2) More acid rocks (particularly monzonite) associated with, but younger than, the foregoing.
(3) Red granite (at Predazzo) younger than 2, and probably associated with quartz-porphyry dykes.
(4) The youngest eruptions of the district, represented by a series of complementary dykes, partly of ultrabasic composition (camptonite, etc.) and partly of intermediate composition (liebenerite-porphyry, etc.). The last-named rock 'seems to represent quite the youngest eruptions of the whole district.'

(These conclusions appear to be in full accord with the results obtained by the present author in Enneberg and the Gröden Pass; where the youngest dykes belong to the last-named category, and a definite age can be assigned only to older basic dykes which are associated with the flows and tuffs demonstrably of Middle Triassic age.)

In 1897, Dr. Salomon[3] published a paper on the relations of the

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[1] 'Geologische u. paläontologische Studien über die Marmolata,' Palæontographica, vol. xlii, pp. 1–210.

[2] 'Die Eruptivgesteine des Kristianiagebietes: II. Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Süd-Tyrol,' Kristiania, 1895.

[3] 'Ueber Alter, Lagerungsform u. Entstehungsart d. periadriatischen granitischkörnigen Massen,' Tscherm. Min. u. Petr. Mitth. vol. xvii, pp. 109–283.

granite-grained masses round the Peri-Adriatic area of subsidence, agreeing with Prof. Brögger that the granite- and monzonite-masses and the liebenerite-dykes are younger than the Middle Triassic series; and stating that, 'in the present state of our knowledge, we cannot possibly say at present whether they are to be regarded as Upper Triassic, Jurassic, Cretaceous, or Tertiary.' He inclines, however, to the view that they are of Lower Tertiary age.

Conclusions arrived at in the present paper.—In the present paper I propose to show that the results obtained during my recent detailed survey of the Sella and Sett Sass district fully establish the following conclusions:—

(1) Faults and overfaults are far more prevalent in the Dolomite-country than has hitherto been supposed.
(2) The arrangement of these faults is typically a torsion-phenomenon.
(3) This phenomenon is the result of the superposition of a later upon an earlier strike of the rocks.
(4) The later crust-movement was of Middle Tertiary age, and one with the movement which gave origin to the 'Judicarian-Asta' phenomena, and more generally to the phenomena associated with the Oligocene-Miocene upheaval of the Alps.
(5) The youngest dykes and granitic masses are of this age, while the geographical position of both is the natural effect of the crust-torsion itself.
(6) The phenomenon of crust-torsion fully explains the special stratigraphical features of the Dolomites enumerated above, namely, the present isolation of the mountain-massives of dolomite-rock, the irregular shearing of various horizons of lower rocks around the base of the massives, the fanning-out of overthrust slices of the lower rocks in the intervening passes and valleys between the massives, and the presence of 'scoops' of Jurassic and Cretaceous rocks within the massives themselves.

II. THE ANTICLINE OF THE GRÖDEN PASS.

Previous description of the Gröden Pass area by the Austrian Geological Survey.—The strata of Gröden Pass and Sella Mountain have been described in outline in the Survey carried out by E. von Mojsisovics[1] and his colleagues. But as he recognizes in the Wengen and Cassian tufaceous, marly, and calcareous series at the base of the mountain-cliffs only the equivalent in time of the dolomite-rock that chiefly forms the cliffs, he calls the latter rock Wengen and Cassian 'coral-reef' dolomite, and maps it as if it thinned out all round the mountain into the supposed 'heteropic' facies of earthy deposits (see p. 562).

This standpoint completely differs from the present author's, and it would only obscure this paper to draw repeated comparisons between the observations published in Mojsisovics's 'Dolomit-Riffe' in 1879, and those now made by me in very much greater detail.

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[1] 'Die Dolomit-Riffe von Süd-Tirol u. Venetien,' 1879, chap. viii, p. 227.

Any comparison which seems desirable to the reader can be made independently; more especially would I call attention to several excellent photographs in the work just quoted.

General form of the Gröden Pass Anticline on the west side of the Pass.—Approaching the Pass from the Gröden Valley, the footpath for the ascent is reached at Plon (see General Map, Pl. XL[1]). The rocks in the stream beside the Plon Inn are fossiliferous *Bellerophon*-limestone strata. These Permian rocks are succeeded by a disturbed succession of Lower Triassic (Seis and Campil strata) and Muschelkalk horizons. The whole series represents an anticlinal form which we may term the Gröden Pass Anticline.

The anticline is here greatly contorted, and split into two unsymmetrical halves by a longitudinal fault directed west-south-west and east-north-east, and to this reference will be made as the Plon Fault. Minor transverse dislocations cross this longitudinal fault: one of these is well exposed where it penetrates Seis Limestone near a lateral waterfall, the limestone standing vertically.

The strike of the rocks in the northern fault-block of the anticline veers round from a north-westerly and south-easterly direction to west-south-west and east-north-east; the general dip is northward throughout, although the angle varies very frequently. The strike veers round similarly in the southern fault-block, where the dip, in spite of many small faults, holds southward. The crags and steep pastures of Pitzculatsch Hill represent the southern fault-block. They may be most conveniently examined by taking the path from Plon towards the Sella Pass, and diverging from it towards the numerous exposures on the hillside.

The Pitzculatsch Fault-dyke.—When a height of about 1800 metres is reached on the path, a steep gully will be found running up the hill, but it is practically hidden from the pathway by fir and brushwood. A dyke of igneous rock occupies the gully, and follows the course of a vertical fault east-north-eastward to the Gröden Pass. Muschelkalk strata, more particularly the Mendola Dolomite or upper horizons, are faulted on the north side of the fault against Wengen strata, and on the south side towards Sella (fig. 1, p. 568).

Origin of the so-called 'Buchenstein conglomeratic tuff' as a shear-and-contact breccia.—The strata on both sides show marked effects both of shear-slip and of contact-alteration. The rocks exhibit in a remarkable degree the result of mutual metamorphism of the intrusive and stratified masses. I observed here quite clearly that the so-called 'Buchenstein conglomeratic tuff' or 'Buchenstein agglomerate' has its origin as sheared and altered

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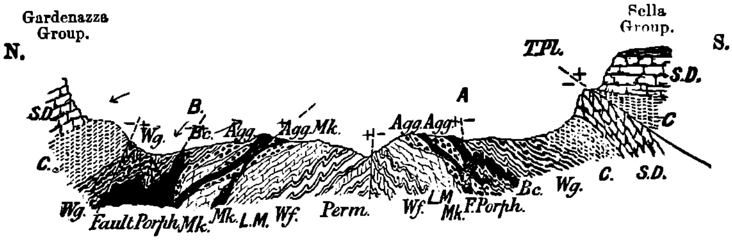
[1] The redrawing of the author's coloured map and original illustrations for reproduction in black and white was carried out by Miss E. M. R. Wood and Mr. F. Raw in the Research Section of the Geological Department of Mason University College, Birmingham, with the result that few practical detail have been lost, despite considerable reduction in size.

Fig. 1.—*Section through the anticlinal buckle of the Gröden Pass (western portion) on the scale of* $\frac{1}{50,000}$.



SD = Schlern Dolomite.
C = Cassian strata.
Wg = Wengen strata.
Bc = Buchenstein bedded rocks.
Mk = Muschelkalk (Mendola Dolomite).
L.M = Lower Muschelkalk.
Wf = Werfen strata.

Perm. = Permian.
Agg = So-called 'Buchenstein agglomerate,' author's 'shear-and-contact breccia.'
FP = Fault-porphyrite.
TPl = Thrust-plane.
A = Pitzculatsch Fault.
B = Vallbach Fault.

Fig. 2.—*Fold-form, west side of the Gröden Pass Anticline.*

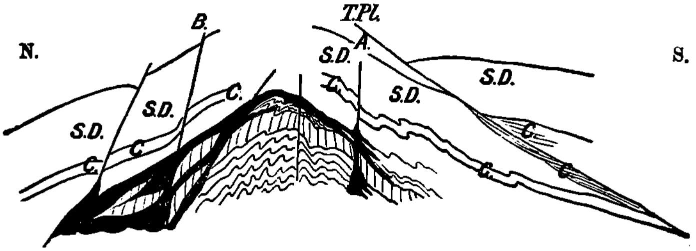
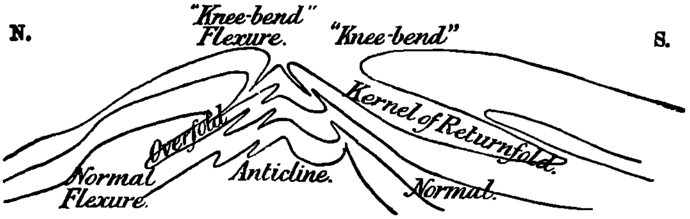


Fig. 3.—*Nomenclature of the fold-form, west side of the Gröden Pass Anticline.*



Mendola Dolomite. Structurally, it is a 'crush-breccia' (Bonney) dragged along with the intrusive dyke-material of the fault, and practically defining the outcrop of the fault-zone.

Brightly-banded and black, splintery, shaly masses are present on the south side of the fault-dyke, passing into greenish and whitish, crumbling 'paper-shales' in actual contact with the intrusive rock. This soft rock-material is a baked and altered representative of a thinly-bedded series of bituminous limestones, in which, at no very great distance, remains of the local Wengen flora and fauna are to be found.

A strip of characteristic light-grey limestone with siliceous nodules[1] intervenes at another part of the fault between the dyke and the wide outcrop of crumpled strata on the southern slope of the hill. The latter are the lower or 'Wengen' group of the Wengen-Cassian Series, and they contain abundant plant-remains, together with *Halobia Lommeli*, *Posidonomya wengensis*, and some badly-preserved *Ammonites*. The fossils show various degrees of compression and distortion. Tufaceous grits, black earthy tuffs, and thin lavas are interbedded with the fossiliferous strata.

Considerable patches of Wengen rocks occur caught in with the dyke-rock and lying in its midst, within the fault-zone. The results of contact-alteration and fault-shear are evidenced in the finest detail in those carried wedges. One fairly large wedge is represented on the map, situated where the Pitzculatsch fault-dyke widens out on the middle levels between Plon and the Pass height.

The fault-zone may be said to fork in two directions here, one branch twisting sharply north-north-eastward, in the direction of Spitz Kofl, the other branch continuing the main longitudinal direction east-north-eastward. The twisted branch is marked by the presence of sheared and brecciated rock chiefly composed of rock-masses and fragments belonging to the higher Muschelkalk horizon. This 'fault-rock' is brought against the various horizons of the Werfen and Lower Muschelkalk strata exposed in the Plon anticline on the west, and against the main fault-dyke and patches of Wengen strata on the east. The direct branch is marked by the presence of the porphyrite-dyke, which is here brought into contact on both sides with disturbed and altered Wengen strata.

The Vallbach fault-dykes and sills.—A glance at the map (Pl. XL) will show that other dykes branch out from this median area on the western slope of the Pass. These are dykes extending in an east-south-easterly to west-north-westerly direction towards Wolkenstein. Thick masses of the characteristic fault-breccias and altered tuff-rocks are present between the dykes, as well as unaltered but highly-tilted remnants of Lower Muschelkalk,

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[1] The 'siliceous limestone' belongs to a thin group of strata which marks in this district a limiting horizon between the 'Mendola Dolomite' and the Wengen Series. It represents the 'Buchenstein' horizon proper, and has in the more recent publications been referred to the Upper Muschelkalk.

Mendola Dolomite, and of the next higher or 'Buchenstein' (see footnote, p. 569) horizon of limestones. An important dyke is exposed on the northern slopes of the Vallbach hill and in the bed of the stream. It marks a fault-line which penetrates the northern half of the anticline and lets down the Wengen strata to the north, just as the fault of the Pitzculatsch hill cuts the southern half and effects the downthrow of the Wengen strata to the south. These two faults are distinguished as A & B in the section (fig. 1, p. 568), and may be conveniently termed the Pitzculatsch and Vallbach Faults respectively.

Another intrusion on the summit and southern slope of the Vallbach hill presents a connected 'torsion-network' (Lossen) of dykes and sills, threaded through the Muschelkalk and Lower Trias in fault-planes inclined northward at various angles, and sometimes vertical (fig. 1, p. 568). The Vallbach intrusions occur in connexion with a series of faults that penetrate the northern wing of the anticline, and effect torsion of its strike round the dolomite-cliffs north of the Pass. I followed this network in all its detail, ascending the precipitous rocks facing the church of Sta. Maria, and discovering there very good examples of shear-and-contact metamorphism in horizons of Muschelkalk; then tracing the various threads round the slopes facing Plon and along the ridge of the Vallbach hill between the Vall and Frea streams. Altered and brecciated Muschelkalk-rocks in the form of the so-called 'Buchenstein agglomerate' accompany everywhere the igneous intrusions. It is quite impossible to show all the details in the map (Pl. XL), yet it is hoped that sufficient detail is there given to prove that the injection of igneous material has taken place in a fault-network associated with an actual twist in the strike of the rocks.

First in importance in this map I rank the demonstration that it gives of the intrusive rock running into and along the subordinate oblique and transverse faults on the Gröden Pass slopes, as well as into and along the main longitudinal, inclined planes of fault. The intrusive rock extends for a considerable distance in a north-and-south transverse fault between Wolkenstein and the Pass. This may be termed the Wolkenstein Fault, and it is one of the chief transverse faults of the district.

Fresh specimens of the intruded rock may be described as sometimes typical porphyrite of the district with augitic crystals, sometimes a plagioclase-porphyrite; amygdaloidal inclusions are frequent. What have hitherto been grouped as 'Buchenstein tuffs,' and attributed along with the augite-porphyrite to Middle Triassic age, are fault-rocks representing a compounded mass of fault-dyke material and fragments of the various stratified rocks affected in the planes of crust-movement. Slickenside appearances are very prevalent, while cleavage is another marked feature, extremely variable in the rocks nearest the sills and dykes.

The 'fold-form' of the western slope of the Gröden Pass (figs. 2 & 3,

p. 568) may be generally described as a distorted anticline with S-curvatures northward and southward, bent into the form of 'knee-bends' (Mojsisovics) and penetrated by injected igneous rock in the two opposite areas of the 'middle limbs' (Heim).

Structure of the central part of the Gröden Pass.—The outcrops of the Pitzculatsch, Plon, and Vallbach Faults converge towards the height of the Gröden Pass. The strata on the Pass-ridge are steeply contorted, bedded tuffs and lavas, tufaceous grits, marls and shales composing the Wengen Series. Numerous dislocations penetrate these soft rocks. The major dislocation that breaks the anticline is indicated by a line of blocks crossing the Pass-ridge continuously from the convergence-area of intrusive rock on the western side to an area on the eastern side where intrusive rock reappears. It then proceeds in a west-south-westerly and east-north-easterly direction towards Sass Songe, continuing therefore the direction of the Pitzculatsch Fault. It forms, however, the northern limit of the anticline on the eastern slopes of the Pass, similar in position to the Vallbach Fault on the western slopes, and, like it, is a normal fault with downthrow to the north, that is, towards the Tschampatsch and Sass Songe cliffs.

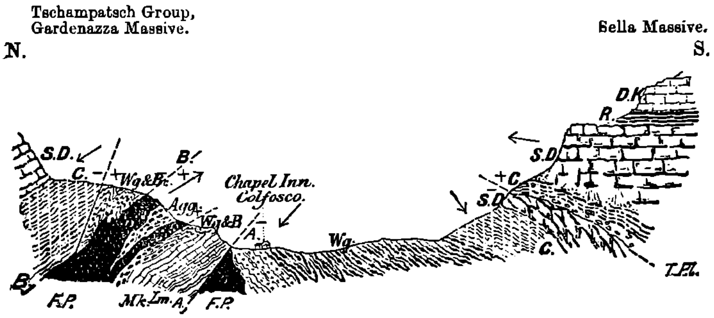
Another fault branches from the same high level on the eastern slopes, and continues the general east-and-west (slightly west-north-west to east-south-east) direction of the Vallbach Fault. But it corresponds with the Pitzculatsch Fault, in so far as it forms the southern limit of the anticline on the eastern side of the Pass. The southern fault is here distinctly reversed, with overthrust to the south (fig. 4, p. 572).

The combination of a normal and a reversed fault hading in the same direction is one which I have found to be a characteristic feature in the stratigraphy of the district, and its effect is to leave the outcrops of the downthrown strata on either side of the neutralizing faults practically at one and the same level (fig. 5, p. 572).

The 'Ruon' Rock.—About midway down the eastern slopes of the Pass near Ruon a prominent mass of Mendola Dolomite commands attention. This is a thick wedge caught in the midst of a fault-net of injected igneous rock, and the rock has been cleaved, sheared, and mutilated to such a degree that it is difficult to define any limit between the Mendola Dolomite and its burnt and sheared representative, the so-called 'Buchenstein agglomerate.' At the same time, small fragments of so-called 'Buchenstein banded shales and limestones,' representing, on the palæontological evidence, merely altered Wengen calcareous bands, are caught up in the shear-planes. One larger unaltered wedge of Wengen strata fills in the chief rupture-fissure on the eastern side of a transverse fault-dyke. This will be referred to later as the Ruon Dyke.

The whole complex is only a more striking case of the same general phenomena of dyke-injection associated with fault-shearing as those that I have described at the forking of the Pitzculatsch

Fig. 4.—*Section through the anticlinal buckle of the Gröden Pass (eastern portion) on the scale of* $\frac{1}{50,000}$.

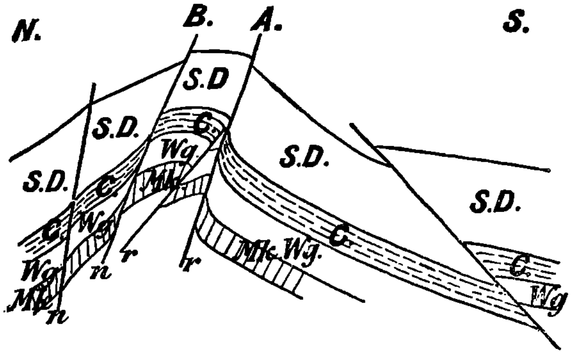


D.K=Dachstein Limestone.
R=Raibl marls & dolomitic flagstones.
S.D=Schlern Dolomite.
C=Cassian Marls and Cipit Limestone-beds.
Wg=Wengen earthy and tufaceous strata, with interbanded limestones.
Bc=Buchenstein flagstones, shales, banded and nodular limestones.

Mk=Muschelkalk: thickly-bedded limestone, partly dolomitic, poor in fossils.
Lm=Lower Muschelkalk; thinly-bedded fossiliferous limestones.
Agg=Shear-and-contact breccia.
F.P=Fault-porphyrite.

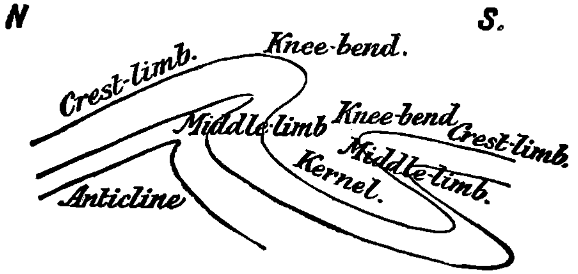
T.Pl=Peripheral overthrust-plane of the Sella Massive.
A=Pitzculatsch Fault.
B=Vallbach Fault.

Fig. 5.—*Fold-form, east side of the Gröden Pass Anticline.*



n=Normal fault; *r*=Reversed fault.

Fig. 6.—*Nomenclature of the fold-form, east side of the Gröden Pass Anticline.*



Fault on the western slopes of the Gröden Pass. The transverse dykes in both cases mark a strongly-twisted branch fault, running in a northerly, north-north-westerly, or north-north-easterly direction across the anticline. The twisted faults probably served to relieve the tension in areas where the strike-faults were tending to converge and even to intercross.

The distinctly 'knee-bent' shape of the Gröden Pass Anticline on the eastern slope is shown in fig. 6, p. 572. The northern wing has been overthrust south-south-eastward upon the 'reversed' fault-plane, and intrusive rocks have been injected not only into the normal and reversed limiting-faults, but also into the associated transverse and oblique dislocations.

The Colfosco section of the Gröden Pass Anticline.—The Colfosco (Kollfuschg) portion of the Gröden Pass Anticline is also limited to the 'knee-bent' strata of the northern wing, the full form of the anticline not appearing until the valley-level is reached below the hamlet of Pescosta.

The steep pastoral hill-ground between the hamlets of Colfosco and the cliffs of Tschampatsch and Sass Songe is composed of the lowest Wengen horizons, Upper and Lower Muschelkalk, Campil and Seis strata. The various horizons are met as one descends to Pescosta, the margin of outcrop representing the southern fault of the 'knee-bend.' The Mendola Dolomite is greatly cut up by dykes, whose direct connexion with the fault-sill B can be actually seen in tracing them both eastward to the stream-cutting above Colfosco. Contact-breccia again marks the contact-zone of the sill with the Mendola Dolomite, and patches of recognizable Wengen strata are found amid the sheared series between the fault-planes.

The Wengen strata north of the fault B are perpendicular, and highly altered near the intrusive rock. They form a contorted fragment, cut off against Cassian strata and Schlern Dolomite to the north by another normal fault hading northward.

Diagonal faults of the east side of the Gröden Pass.—The Pass segment is separated from the Enneberg Valley segment by an important diagonal fault passing from the west side of Sass Songe (Sett Sossander) in a north-north-westerly to south-south-easterly direction through Pescosta to Corvara. The fault-fissure is occupied by a thick mass of intrusive rock, the chief outcrop of which crosses eastward from the Pescosta slopes to those of Langs-da-Für between Corvara and St. Cassian. But dyke-threads may be said to radiate from the Pescosta centre in all directions. The chief threads are those which run westward into the Pass fault, and southward and south-south-eastward towards Corvara, Artara, and Campolungo. A branch of the southerly fault twists south-south-westward at the bend of the Rudort stream and continues as the chief fault east of Sella, with a westerly downthrow towards that mountain. Another branch continues the north-north-westerly to south-south-easterly direction of the Pescosta-Corvara Fault, has an easterly downthrow, and crosses between Cherz Hill and Prälongia into the Buchenstein Valley.

The diagonal fault of Pescosta-Corvara is parallel with another higher up the eastern slopes of the Gröden Pass, which crosses from the Tschampatsch dolomite-cliffs and through the Ruon fault-wedge to Crap de Sella. Its downthrow is also easterly, and the double throw of the Pescosta and the Ruon diagonal faults explains why Sass Songe is visibly more deeply depressed than the Tschampatsch, and much more than the Spitz Kofl group which occupies the head of the Pass.

The throw of the faults is increasing even at the present time. The weight of the Sass Songe dolomite-cliffs is continuously pressing forward and downward on the more yielding rocks of the anticline, separated from Sass Songe by longitudinal dislocation. Slipped rock from above fills in the transverse rupture between the Pescosta fault-dyke and the valley-segment of the anticline, just as Wengen rocks have filled the analogous transverse rupture next the fault-dyke at the higher (Ruon) slopes of the Pass (see p. 571).

Relations of the strata described to those of the massives north and south of the Gröden Pass.—(*a*) Although the downthrow of the dolomite in the cliffs north of the Gröden Pass is greatest at Sass Songe, the whole range of dolomite in the cliffs which form the face of the Gardenazza Massive is thrown down, relatively to the crumpled exposures of Wengen strata that accompany the northern limiting-fault of the Gröden Pass anticline. A normal fault (see figs. 1 & 4, pp. 568 & 572) sweeps in a curving direction over the Pass always near the base of the northern cliffs, and cuts off Wengen strata against different horizons of Cassian strata and Schlern Dolomite. It may be followed westward across the Langenthal towards the Ruine-Wolkenstein cliffs.

(*β*) The relation of the Gröden Pass Anticline to the dolomite-cliffs of the Sella Massive on the south of the Pass is so far similar. Faults have passed through the steep southern wing of the anticline, letting down the Sella region relatively to the Gröden Pass areas. But an overthrust has taken place northward from the Sella region on a reversed fault-plane, inclined away from the Pass and into the heart of the Sella Massive. The Sella overthrust is exposed in the Cassian or Schlern Dolomite horizons; while the Pass overthrust to the south-south-east is exposed chiefly in the Muschelkalk and Wengen horizons, and is accompanied by ramifying threads of intrusive dyke- and sill-rocks (figs. 4–6, p. 572).

The Sella overthrust will be dealt with later (p. 593), but almost any photographic panorama of the overthrust as shown on the eastern side of the Gröden Pass will serve to exhibit the shear-zone, where fragments of Cassian strata dipping outward are pushed above an irregular thickness of Schlern Dolomite dipping steeply inward. The reading given to these appearances in Mojsisovics's 'Dolomit-Riffe' was that of coral-built cliffs of calcareo-dolomitic rock thinning out into contemporaneous earthy deposits of Wengen age around the steep outer slopes of the 'reef.'

Cleavage-phenomena of the Pass.—The phenomena of cleavage are similar in the dolomite-cliffs on both sides of the Gröden Pass. Great cleavage-slabs of Schlern-Dolomite rock face west-north-westward with high inclination, the direction of strongest cleavage being north-north-easterly and south-south-westerly in the areas adjoining the Pass. In the north-eastern corner of the Sella Massive, however, the cleavage-planes are vertical and run almost due north and south.

A second set of cleavage-planes, also well developed although less assertive to the eye, cut the first set obliquely in a north-north-westerly and south-south-easterly direction, and are more constant in direction throughout the massives than the north-north-easterly and south-south-westerly planes (see fig. 21, p. 614).

These two series of cleavage-planes are also clearly developed in many of the harder stratified rocks comprised within the Gröden Pass anticline, but are scarcely decipherable as such in the softer, strongly-crumpled rocks. In the twisted wedges of Muschelkalk, I frequently distinguished east-and-west and east-north-east and west-south-west planes of cleavage.

The intercrossing in the directions of cleavages is an observation which I value as one in complete harmony with the intercrossing in the direction of the main faults over the Pass.

Diagonal disposition of the Dolomite Massives with respect to the Gröden Pass Anticline.—The imposing mountain-block of the Lang Kofl Massive rises west of the Sella Massive, separated from it only by the Sella Pass, and may be said to face the Gröden Pass on the south-west. The present author's familiarity with Pitzculatsch Hill (see p. 567) and the Sella Pass enable her to give some indication of the probable connexion between Lang Kofl and the Dolomite-mountains facing the Gröden Pass on the north-east.

The neighbouring areas are separated by the Wolkenstein cross-fault (see p. 570). The structural details differ on the two sides of the cross-fault, although the main directions of folding are retained. The Pitzculatsch strike-fault can be traced quite well across the Sella Pass slopes to the north or Gröden side of Lang Kofl. There it limits the now widened anticline, exposed on the Mont de Sora slopes, against the younger strata that compose the cliffs of Lang Kofl, the fault being accompanied throughout by intrusive porphyrite and an altered contact-zone of Muschelkalk and Wengen fault-rock.

The chief general feature to be observed is that the downthrow to the south of the fault is distinctly greater at Lang Kofl than at Sella; the fault is, just as at Pitzculatsch, a normal fault, inclined southward towards the mountain. Reversed faults, likewise hading southward, occur on the Mont de Sora slopes and in the Gröden Valley, so far neutralizing the effect of the Lang Kofl normal fault.

These relations at Lang Kofl are precisely analogous to the relations observed in detail, as existing between the Enneberg Valley segment and Sass Songe, and the analogy is presented in the case of Dolomite-mountains situated at diagonally opposite ends of the Gröden Pass fault-system (see fig. 7, p. 578).

RESULTS.

(A) Facts and Deductions confirmatory of the Results of previous Researches.

In summarizing the foregoing description of the geology of the Gröden Pass and its neighbourhood, the more general features will first be noted, in which the stratigraphy of the Pass bears out the result of recent researches in the Dolomites (p. 564), more widely considered, in the Peri-Adriatic area of the Alps.

(1) Combination of reversed and normal faults.—The fault-system of the Gröden Pass has been found to comprise faults inclined at various angles to the horizon as well as vertical faults. Some of the inclined fault-planes are typical planes of overthrust. The author would specially note the combination of the reversed and normal faults in two oppositely-inclined fault-groups, passing through the two opposite anticlinal wing-folds that have been overcast southward and northward. The oppositely-inclined planes of the Gröden Pass faults, if continued upward, would therefore meet each other as well as the vertical planes. The area is comparatively small, hence very involved stratigraphical relations must have ensued between the dovetailed parts of fault-blocks.

(2) Virgation of fault-lines.—The surface-outcrops of the faults diverge from the Pass height outward on both the western and eastern slopes. A divergent arrangement of fault-lines has been termed a 'virgating system' by American geologists, and a 'fan-shaped fault-bundle' by Austrian geologists. It is in association with the central convergence of the eastern and western fault-bundles that the main faults of the Gröden Pass anticline (namely, the Pitzculatsch-Colfosco Fault, and the Vallbach-Corvara Fault) have their throw reversed on the opposite sides of the Pass.

The faults may be conveniently distinguished, according to their geographical direction, as:—(*a*) Longitudinal or strike-faults, directed east and west, east-north-east and west-south-west, and east-south-east and west-north-west; (*b*) Diagonal or oblique faults, directed north-north-west and south-south-east, north-north-east and south-south-west, north-west and south-east, and north-east and south-west; (*c*) Transverse faults, directed north and south, or nearly so.

It must, however, be understood clearly that such grouping is arbitrary, since longitudinal faults give off branches in oblique or transverse directions, and fault-planes may at one part of thei:

force cross the strike, and at another part curve into the direction of strike. In short, the fault-system is pre-eminently a fault-network. Rapid variation in the throw of the fault is a marked feature, and is associated with the frequent branching of faults.

Similar features of overthrusting, rapid variation in the throw of faults and in the precise angle of inclination of the fault-planes, branching and curving of faults, have been demonstrated by the Austrian geologists to be characteristic of the Judicarian-Asta system [1] (*cf.* Suess) as presented in the Peri-Adriatic region of the Alps.

(B) New Facts and Deductions respecting the Geology of the Rocks of the Gröden Pass.

(1) The dyke-and-sill phenomena.—Evidences in the field and the author's map and sections afford proof of dyke-and-sill injections as an igneous network in the greater number of the fault-planes of the Gröden Pass, not only in the longitudinal or strike-faults,[2] but also in the diagonal and transverse faults. Evidence is everywhere to be obtained that the fault-shearing must have taken place while the igneous material was still a magma, and could solidify round carried wedges, torn blocks, and the finest fragments of faulted and invaded stratified rock. These shear-and-contact breccias are typical 'fault-rock'; they have been grouped hitherto by all observers as 'Buchenstein conglomerates and tuffs,' and referred to the Middle Triassic period as a distinct stratigraphical horizon.

The present author's observations go to show that the injection of the dykes and sills into fault-planes was associated with the origin of the coarse shear-and-contact breccias, and took place in the last epoch of intense crust-movements in the Gröden Pass neighbourhood. The development of the fault-system of the Gröden Pass and Enneberg generally was demonstrated in my previous papers to have been the Tertiary epoch of Alpine upheaval; therefore the date of origin of the so-called 'conglomeratic tuff' or 'agglomerate' is not Middle Triassic, but Tertiary. At the same time, there are true lava-flows interbedded with the lower horizons of the Wengen-Cassian Series, although of no great thickness. These cannot be regarded as a determining factor in the subsequent crumpling, shearing, and faulting of that soft and yielding series between the Mendola Dolomite and the Schlern Dolomite of this region.

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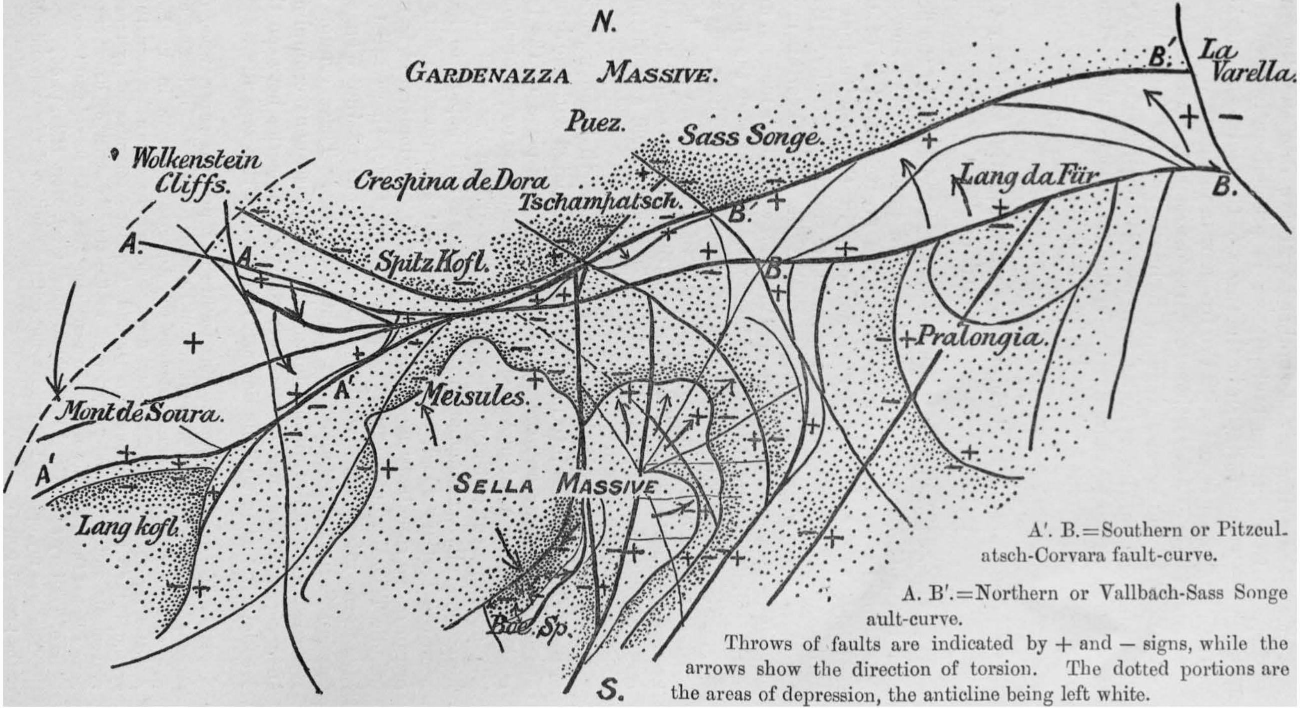
[1] The writer drew attention to this feature in a previous paper, when describing the analogy of the fault-systems of Enneberg with the Judicarian and Asta systems of faults, demonstrated by the Austrian geologists in the Peri-Adriatic region. 'No hard-and-fast distinction can be drawn between these systems; they pass into one another and form one complicated system of movements, which may be proved even in the small district of Enneberg to have affected the positions of both Triassic and Mesozoic rocks,' and therefore to be of Tertiary age ('Coral in the Dolomites,' Geol. Mag. 1894, p. 55)

[2] This was my opinion before carrying out the additional research embodied in the present paper.

Fig. 7.—*Torsion-system of the Gröden Pass, mapped on the scale of* $\frac{1}{25,000}$. (*Here reduced to* $\frac{1}{5}$.)



A'. B.=Southern or Pitzcul-atsch-Corvara fault-curve.

A. B'.=Northern or Vallbach-Sass Songe ault-curve.

Throws of faults are indicated by + and − signs, while the arrows show the direction of torsion. The dotted portions are the areas of depression, the anticline being left white.

(2) The torsion-phenomena.—Another new and far more striking feature in the geology of the Pass is the abundant evidence that the most conspicuous crust-movement has been one of crust-torsion.[1] My own observations illustrative of torsion at the Gröden Pass may now be classified, reference being understood to the scheme, map, and sections :—

1. Torsion of the strike of the strata.—The strike of the rocks in the various fault-blocks of the anticline veers round from longitudinal to oblique directions.

2. Distortion of the anticline.—The anticlinal 'buckle' (Lapworth) is asymmetric, divided into two unequal wings by the Plon fault. Both wings are well exposed on the western slope, where they form together an anticlinal fan of fault-blocks, expanding broadly in the Gröden Valley. On the eastern slope, the northern wing is well exposed on the Pass, but vanishes below Varda in the Enneberg Valley. While the southern wing is represented on the Pass only by the higher horizons of strata, it is fully exposed on the Langs-da-für hill above the Valley. The anticline, therefore, shows considerable variation within narrow spacial limits.

What can be actually seen in the Pass structure is a number of separate fault-blocks, twisted obliquely away from a central convergent area; and the wider fault-gaps (and many of the narrower) filled up by intrusive rocks and fault-breccias. What may be deduced from the Pass structure is that if the intrusive rocks could be melted away, and the fault-blocks of stratified rock could be pulled back into line one with another on the opposite slopes of the Pass, the form obtained would be that of an anticlinal fold, the axis of which runs centrally along the Pass in the direction of its length, or, in other words, traverses the Pass in its meridional direction.

3. Opposite fold-arcs curving away one from another.—The distortion of the anticline in its several parts is such that no two sections through it show the same relations (compare figs. 1 & 4, pp. 568 & 572).

The northern wing curves from west-north-west round a southern arc to east-north-east, and has been overcast southward into the form of a knee-bend with overthrusts at different parts towards the south-south-west and south-south-east; normal faults curved in the same sense as the reversed faults have thrown down the strata to the north towards the Dolomite-cliffs of Spitz Kofl and Tschampatsch.

The southern wing curves from west-south-west round a northern arc to east-south-east, and is cut by the Pitzculatsch Fault. The adjoining cliffs of Sella exhibit a back-fold curved in the same sense, but rather more south-west and south-east. An overthrust-plane cuts this back-fold, the overthrust taking place towards the north-west, north-north-west, north-north-east and north-east. This is, therefore, a return overthrust to northward, compensating the overthrust to southward in the northern wing of the anticline.

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[1] The crust-movements concerned in bringing about the present structure of the Gröden Pass and the region of which it forms a part, embrace not only those of folding, faulting, overfolding, overthrusting, etc., as usually understood, but in addition, and even more conspicuously, those which are commonly grouped under the head of torsion.

Those geologists who are familiar, on the one hand, with the advances made during the last quarter of a century in knowledge and in speculation respecting crust-deformation, by means of folding and faulting, normal or overthrust in effect, and parallel, orthogonal, or oblique in direction; and, on the other hand, with the remarkable torsional results worked out by Daubrée in the laboratory, and by Lossen and others in the field, will have no difficulty in recognizing for themselves what tectonic principles and results are new in the present paper, and what have been derived from, or anticipated by, the work and deductions of others. As respects the terminology employed, reference may be made to the works of Heim, de Margerie, Suess, Bertrand, Lapworth, Peach & Horne, Daubrée, Lossen, etc.

4. Partial intersection of the opposite fold-arcs.—An area of curve-intersection of the opposite wings is present, which fairly corresponds with the central area of the Pass, and the upper part of the eastern slopes. The southern wing cuts off the exposure of part of the southern arc of the northern wing. Presented graphically, the fault-figure of intersection is like the figure 8 laid lengthways across the central area of the Pass, while the virgating faults branch outward from the two ends of the figure. As a matter of fact, the area of fold-intersection is marked on the ground by strongly-contorted rocks, by block-structure, by convergence of the ramifying threads of intrusive rock, and by frequently twisted cleavage—a combination of features sufficiently indicative of 'interference' crust-strains.

5. Cross-folding in its relation to torsion-forces.—Regarded from this central intersecting area, the strike of the radiating fore-folds and back-folds is directed to four points of the compass:—west-north-west, west-south-west, east-north-east, and east-south-east; and as the strike of a fold is rectangular to the forces producing it, we have to distinguish four directions from which forces were acting:—south-south-west, north-north-east, north-north-west, and south-south-east. They may be tabulated as follows:—

West side (northern wing), strike west-north-west and east-south-east.	Forces from north-north-east and south-south-west.
East side (southern wing), strike west-north-west and east-south-east.	Forces from north-north-east and south-south-west.
East side (northern wing), strike west-south-west and east-north-east.	Forces from north-north-west and south-south-east.
West side (southern wing), strike west-south-west and east-north-east.	Forces from north-north-west and south-south-east.

As the axis of the Gröden Pass Anticline itself lies slightly west-south-west and east-north-east, the forces from north-north-west and south-south-east have been stronger here than those from north-north-east and south-south-west. The phenomena of the converse curves of the opposite folds, the convergence of the anticlinal fault-blocks towards the median area of the Pass, and the divergence of the fault-blocks outward into more and more oblique positions, indicate that the forces did not act in straight lines across the area, but in some form of curves round the area, after the manner of force-couples. Clearly, also, the relative action of the forces must have been inward in the median area where the maximum compression is presented, and outward on the lower slopes where virgation is presented.

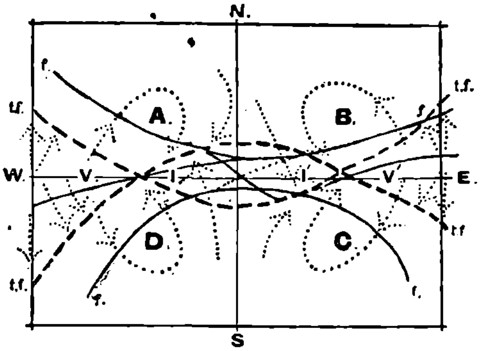
The following problem may be constructed in order to elucidate the probable action of the forces as indicated by the author's observations.

Imagine an almost straight line to be drawn across the Pass nearly east and west from Pescosta to Plon. Bisect this line by another at right angles. These divide the region roughly into four parts or quarters, which may be represented by A, B, C, & D in the accompanying diagram (fig. 8, p. 581). Let C & D be pushed northward, A & B be pushed southward, so as to form an anticline in the meridional direction. At the same time, or subsequently, imagine a motion of the nature of a twist to be given to each of these quarters: A & C to be moved counter-clockwise, B & D clockwise. The effect will be, therefore, as if every part within each quarter had received a combination of a forward motion and a twist; the resultant motion will be of the nature of a spiral for each quarter (epitrochoid).

Additional complications are indicated, such as a tilting of the southern quarters D & C, D rising and C being depressed, the raised portion D being pushed so far above A in the central area. The chief fact, however, is that the phenomena of the Gröden Pass indicate the combined action of a push and a twist—crust-compression and crust-torsion—resulting in contending spiral whirls.

We have, as it were, two dissimilar sets of force-couples acting on the Pass anticline, the more powerful set being north-north-west and south-south-east, and causing counter-clockwise torsion, the subsidiary set being north-north-east and suoth-south-west, and causing clockwise torsion. Consequently, there are two intercrossing torsion-strikes, a principal strike west-south-west and east-north-east, and a subsidiary strike west-north-west and east-south-east.

Fig. 8.—*Diagram illustrating the torsion-movements at the Gröden Pass.*



Such contending whirls of the forces seem to me to explain all the observed data—not only the phenomenon of an inner or median area of intertwining, correlated with lateral (east-and-west) outer areas of virgation, but also the phenomenon of associated longitudinal and diagonal buckling: since the resultants of the inner force-components pushing obliquely one towards another are the stronger resultants, and are those which would form curved longitudinal buckles; while the resultants of the outer force-components pushing obliquely away one from another are the weaker, and are those which would form curved diagonal buckles. The latter are, in this area, distinctly subordinate to the longitudinal anticlinal buckles in size, but are almost equally important in determining the general configuration of the crust.

The Pass structure thus affords an admirable example of cross-folding and buckling due to the conflicting action of force-components, forming two unequal sets of force-couples, directed obliquely one against the other.

6. Torsion-ellipsoid.—The axis of the anticline, which extends from Plon to Pescosta in a slightly west-south-westerly and east-north-easterly direction, is cut west of Plon by the Wolkenstein cross-fault, and east of Pescosta by the Pescosta (or Corvara) cross-fault. The two opposite centres of intrusive rock occur on the axial line, the western centre above the waterfall, the eastern centre above Ruon hamlet. With these two centres as foci and the anticlinal axis as a main axis, an elliptical figure may be drawn, which will embrace the torsion-phenomena of the Gröden Pass. For convenience I propose to term this figure a torsion-ellipsoid.

A straight line drawn at right angles to the major axis through the centre represents the minor axis of the ellipse, and, at the same time, the direction of the resultant forces acting inward on the anticlinal buckle, namely, in a direction slightly north-north-west and south-south-east.

The maximum 'interference' in the fold-formation has taken place between the foci, where the northern and southern fold-arcs have cut each other and interlocked.

7. Characteristic furcation of diagonal faults.—Furcation takes place in what may be called a dichotomous fashion. The main throw of a fault is taken up by the branch or branches in the new direction, while the throw either may be sensibly diminished in the continuation of the original direction, may die out. or may be replaced by a steep flexure or a series of contortions, according to the petrographical nature of the strata.

Two diagonal faults in a north-north-easterly and south-south-westerly direction, and a third in a northerly and southerly direction, cut the focal area in the western slope of the Pass. A main diagonal fault crosses between the Gröden Pass and the Wolkenstein, and passes south-south-westward over the Sella Pass, sending off a branch due south.

Upon the east side of the Pass, one diagonal fault crosses the focal area in a north-north-westerly and south-south-easterly direction, a branch passing due south into the Sella Massive. The Pescosta Fault is a main diagonal fault separating the Gröden Pass area from the Prälongia and St. Cassian area. The fault runs in a north-north-westerly and south-south-easterly direction, but a branch crosses the Pass north and south towards Crap di Sella. These three faults afterwards furcate to south-south-west. Still two other faults occur farther east—one, the north-north-west and south-south-east fault at St. Cassian; the other, the north-and-south fault which cuts off the Gröden Pass Anticline finally against the Centurinus group.

8. Correlation in form and structure between the anticline and the adjacent synclinal areas.—The diagonal faults of the Gröden Pass and their furcations sweep closely round, or pass into, the Dolomite-massives occupying the synclinal areas north and south of the Gröden Pass anticline. The geological map (Pl. XL) shows that the diagonal torsion-faults in springing across and away from the anticlinal buckle permitted the virgating fault-blocks to be twisted away from the directions of strike into increasingly oblique directions. The various oblique positions assumed by such torsion-offshoots from the Pass anticline have determined the boundaries of the synclinal areas immediately adjacent to the Pass.

Hence torsion-faulting is the basis of the correlation in form which obtains between the convex curves of the anticline and those of the adjacent Dolomite-massives. There is also a correlation in structure, since the opposite synclinal regions behind the main overthrusts and return overthrusts of the Pass anticline are clearly opposite regions of rock-distension, correlated with the Pass area of strong compression and even dovetailing of crust-folds. In the peripheral parts of the massives which immediately adjoin the anticline the rocks have undergone a thrust towards the anticline; while in the internal parts, remote from the anticline, the rocks have subsided into deep troughs.

A certain reciprocity of structure may be noted between individual synclinal basins on opposite sides of the anticline. It will be remembered that the synclines diagonally opposite each other have undergone the same direction of spiral twist. Thus the Spitz Kofl and Tschampatsch groups in the Gardenazza Massive are the reciprocals of the Pitz Kofl and Meisules groups in the Sella Massive. Again, a structural correlation has been indicated between the deep synclines of the Lang Kofl and Sass Songe mountains at diagonally opposite curves; and a correlation also exists between the shallow synclines of the Sta. Maria-Wolkenstein and the Prälongia meadows placed diagonally opposite each other at the north-western and south-eastern curves of the ellipsoid.

9. Torsion-figures. — Oblique fault-angles are formed (*a*) when a diagonal fault directed north-north-east and south-south-west meets or intersects a diagonal fault directed north-north-west and south-south-east; (*b*) when a north-and-south fault meets or intersects any diagonal fault; (*c*) in various cases of oblique intersection between longitudinal and cross-faults. The several possibilities o. coincidence and intersection can be verified in the accompanying map (Pl. XL), together with the consequent formation of distorted lozenge-shaped and polygonal figures.

Meantime, attention is simply called to such as occur in the Gröden Pass. The two limiting-faults AB' & A'B (fig. 7, p. 578) form an X shape, with elongated centre, disposed east and west across the Pass, while the areas between the arms of the X are laid out in long-sided V and W figures, with the intervention of small triangular wedges at sharp torsion-curves. These forms are similar to the characteristic torsion-figures which were obtained experimentally by Daubrée.

The chief joints and the cleavage-planes have the same oblique and intersecting directions as the diagonal faults, and, like the latter, these finer planes of rupture veer round to directions parallel with the curving strike of the Pass folds. In short, the present author's observations go to show that the torsion-figures, evident on a large scale in the general structure of the Pass, are equally demonstrable in the cleavage-phenomena of the rocks.

10. Superposition of the torsion-phenomena upon pre-existing crust-folds.—The intimate association of the longitudinal bundles of faults and the furcating diagonal or transverse faults is unmistakable. Not only do fault-dykes pass uninterruptedly from one to the other, but also the stratigraphy on the opposite sides of a diagonal fault shows that the

occurrence of the fault permitted the strata on the one side to be twisted and faulted with different degrees of complexity, and sometimes in a different sense from the strata on the other. Therefore I regard these faults as a simultaneously developed system of complex torsion-curves, due to the inertia of the rock-masses while undergoing torsion-deformation.

At the same time, it is noteworthy that the fundamental form of an anticline everywhere underlies the torsion-phenomena. Disregarding for the moment the diagonal buckles, one anticline can be followed west and east from the Gröden Valley to the Enneberg Valley. It has been cut by cross-faults at several points, and its axial line has been disjointed and displaced at such points, hence the anticlinal form would seem to be older than the cross-faults. The Gröden Pass area represents only one of the anticlinal segments, displaced laterally from its neighbours west and east by the Wolkenstein and Pescosta diagonal faults. Intrusive rocks are present in both of these faults, and are associated with the ramifying series of dykes which mark the system of torsion-faults in the anticline.

These data lead me to infer that torsion-deformation took place subsequently to the determination of a meridional anticlinal buckle. The probability is that the torsion-phenomena represent a later and more complex phase of crust-movements, superinduced upon a simpler phase characterized chiefly by lateral compression. The evidence is that the simpler folds in the Gröden-Enneberg area had their axes in almost meridional direction; whereas the more complex folds of the torsion-epoch have no straight axes. The torsion-folds are curved, and the torsion-faults lie in all possible oblique directions, displaying complicated phenomena of intersection and reversal.

The disposition of anticlinal buckles in curves circling round separate massives in the detached synclines is entirely a result of crust-torsion.

III. The Anticline of the Buchenstein Valley.

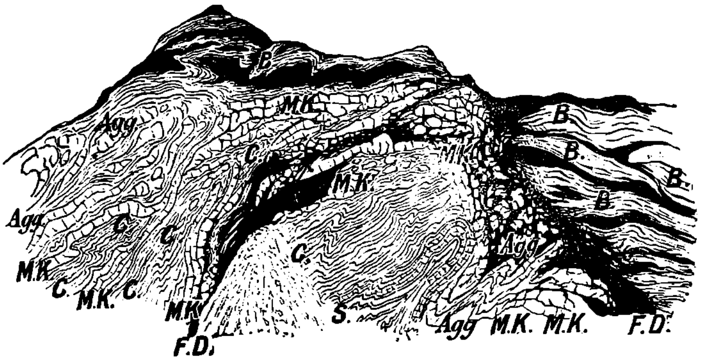
Northern slopes of the Buchenstein Valley.—Buchenstein Valley is the name given to the upper part of the Cordevole Valley (see Pl. XL). The Cordevole stream flows east-northeastward from the Pordoi Pass to Arabba, then bends east-south-east towards Pieve, and there curves sharply south-eastward. The curve described by the river is much the same as the curve described by the Gröden Pass round the northern base of the Sella Massive, and it will be shown to be due to the same structural feature of torsion.

The steep crags of Cherz Hill rise on the north of the valley. An old river-terrace occurs about 500 feet above the present river-level, where two groups of cottars' houses are perched, called respectively Varda and Cherz. Dark precipices rise 1400 feet higher to the summit (about 7000 feet), and it is chiefly among these precipices behind Varda and Cherz that instructive rock-exposures are to be found.

Southern slopes of the Buchenstein Valley.—The ridge of Belvedere and Sasso di Mezzodi shuts in the valley on the south. This is the ridge which has been already recognized on palæontological grounds (see p. 562) as corresponding generally in position with the geographical limit of the different facies in Enneberg and Fassa during the Wengen-Cassian time. Enneberg then, in my opinion, represented the submarine terrace, which was at once the upthrow side of a contemporaneous Middle Triassic fault or flexure, and part of the area over which Middle Triassic lavas and tuffs spread inward from the active zone of crust-movement. We have now to ascertain what changes were induced in this region of Middle Triassic disturbance during the Tertiary epoch of Alpine uprise.

Cherz Hill overthrusts.—The accompanying diagrammatic sketch (fig. 9) shows an exposure observed among the rocks above Varda. Werfen strata and Muschelkalk occur here **below** the augite-porphyrite of Cherz Hill, at a height of 1000 feet above their exposure in the valley at Soraruaz, and are overthrust **above** the augite-porphyrite of the Arabba area. The overthrust-plane hades northward.

Fig. 9.—*Cliff-exposure in the southern face of Cherz Hill, towards Varda, showing the origin of the so-called Buchenstein agglomerate.*



S=Seis Limestone. } Werfen Series.
C=Campil Sandstone and Shale. } Werfen Series.
B=Buchenstein banded limestone and plant-bearing shales.
FD=Fault-dyke.
Agg=Shear-and-contact breccia (so-called Buchenstein agglomerate).
MK=Muschelkalk.

[All the rocks are altered at the zones of contact; the Werfen strata are crushed and streaked into the 'agglomerate' at some points; the Muschelkalk is broken up into huge wedges of 'agglomerate' or dragged out into brittle paper-like laminæ; the Buchenstein limestone and shales have been changed into black earthy or banded rocks; while green 'pietra verde' and other highly altered rocks mark the zone of Buchenstein rocks actually next the main fault-dyke.]

Contact- and fault-alteration.—The overthrust series of rocks have been greatly compressed and sheared, the fossils found in the Werfen strata being squeezed and distorted. Patches of Werfen strata and greater masses of Muschelkalk have been rolled together with the intrusive rock into a shear-and-contact breccia. Here, as elsewhere, this mechanical complex has been regarded as a sedimentary series, the so-called 'Buchenstein conglomeratic limestone.' Fig. 9 displays the true relation of the rocks to the shear-and-contact breccia particularly well, since it shows wedges of various horizons, more especially large blocks of Mendola Dolomite still *in situ* in the midst of the brecciated shear-rock. Contact-alteration is everywhere evident along the many threads of intrusive igneous rock.

Specimens of the intrusive rocks have been kindly determined for me by Prof. Watts. They include augite-porphyrite, and a variety which might be described as olivine-melaphyre, together with a variety of liebenerite-porphyrite.

The chief occurrence of the intrusive rock is as a fault-sill between a normal fault inclined north and with northerly downthrow and a reversed fault inclined north with southerly overthrust. It has been injected into a ruptured 'knee-bend' flexure of the rocks, as at the Gröden Pass. The figure also exhibits a transverse fault cutting the inclined faults and seamed with a thread of intrusive rock. The strata on either side of the transverse dyke have been strongly sheared and altered. On the west side is the familiar shear-and-contact breccia of Lower and Middle Trias; on the east side the Wengen Series is present, comprising true interbedded dust-tuffs and lavas, as well as fossiliferous shales and shaly limestones. There is a contact-zone not more than 12 inches wide, in which the Wengen rocks have been altered to easily-powdered greenish pseudo-tuffs answering to the general appearance of pietra verde.

Oblique faulting across the Cherz overthrusts.—The main overthrust is exposed chiefly in Muschelkalk horizons. A lower overthrust can also be distinguished in some places, slicing contorted fragments of the Werfen rocks along with the Muschelkalk. Both are cut off on the middle slopes below Sella by the diagonal north-north-westerly and south-south-easterly, or Campolungo branch from the Pescosta Fault (p. 573).

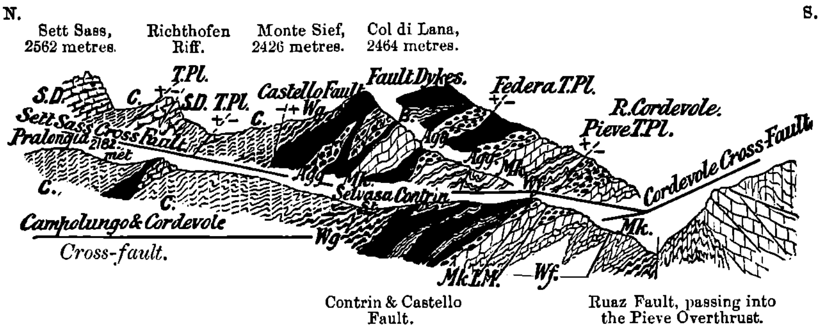
The most remarkable feature about the Cherz Hill overthrusts is that the rocks have not been sliced along continuous planes, but as a number of oblique torsion-wedges, each wedge showing a certain individuality in the precise stratigraphical relations of the inclined faults (see fig. 10, p. 586). A radiating bundle of these oblique faults occurs behind Varda, and has given the overthrust group of rocks the twist which has carried them round to the west-north-west.

The small area of Varda offers an example of a fold overcast primarily towards the south, but sliced obliquely across its strike into a number of movable pieces, capable of being twisted and set in a new direction of strike, at the same time that the strains of compression induced overthrusting.

The Prälongia-Soraruaz diagonal fault.—An important vertical diagonal fault cuts the Prälongia meadows in a north-and-south direction, crosses the Buchenstein Valley, and curves south-south-westward near Soraruaz. This fault runs parallel with the Campolungo Fault, and both throw down the strata on the west: that is, towards Sella. The Soraruaz Fault marks also the median line dividing the eastern and western portions in the torsion-system of the Buchenstein anticline.

Whereas the Arabba, or western part of the anticline, is characterized by the exposure of an intruded sheet of porphyrite in the

Fig. 10.—*Parallel sections from Monte Sief and Cherz Hill to the Buchenstein Valley, on the scale of* $\frac{1}{50,000}$.



SD = Schlern Dolomite.
C = Campil Sandstone and Shale.
Wg = Wengen strata.
B = Buchenstein limestone and shales.
Agg = Shear-and-contact breccia.
Mk = Muschelkalk.
LM = Lower Muschelkalk.
Wf = Werfen strata.
TPl = Thrust-planes.

[The western portion, between the Campolungo-Cordevole and the Prälongia-Soraruaz cross-faults, is twisted from the eastern portion, comprising Monte Sief and Pieve.]

Fig. 11.—*Faults in the fold-form of the Buchenstein Valley.*

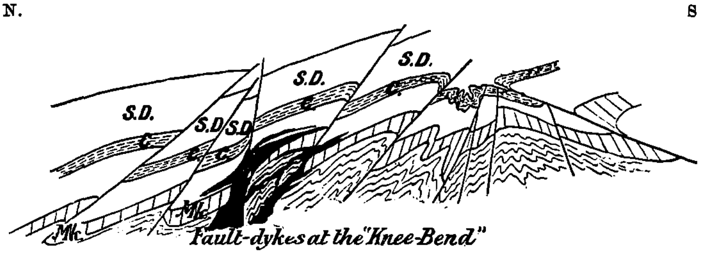
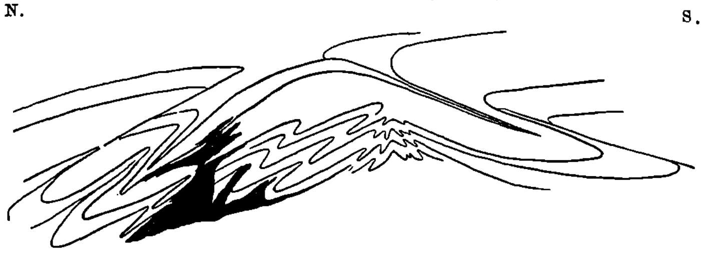


Fig. 12.—*Fold-form of the Buchenstein Valley and Sett Sass (for comparison with fig. 3, p. 568).*



main body of the fault-network, the Pieve, or eastern part, is characterized by wonderful exposures of highly-folded and strongly-sheared Werfen rocks and Muschelkalk (including the uppermost horizons representing true Buchenstein strata), arranged as a fan of fault-blocks virgating eastward.

The overthrusts in the Pieve area.—The uppermost of the Cherz Hill overthrusts is twisted eastward by the Soraruaz Fault into Col di Lana; the lower descends the Gliera slopes in a west-north-westerly and east-north-easterly direction, but it is twisted into a westerly and easterly direction near St. Johann by intersection with a subordinate oblique fault, and continues through the Federa fields into Col di Lana. The divergence of these overthrusts towards Col di Lana is in remarkable contrast with their overlapping position in the Varda area.

Another strike-fault runs south of these from Soraruaz, in a west-north-westerly and east-south-easterly direction, to the slopes of Col di Lana, immediately above Pieve. The throw of this fault is different on the east and west of its intersection with the St. Johann oblique fault.

It has thus been demonstrated that the crushed buckle of older Trias at Soraruaz and St. Johann is flanked on the northern wing by S-folds, with southerly overthrusts. Although the accompanying map (Pl. XL)[1] does not include a survey of the Belvedere ridge, the general northerly dip of the Muschelkalk rock in the middle and higher exposures of that range, as contrasted with the inward dip of the Muschelkalk in the lower hill-horizons, would seem to indicate the presence of a back-fold in the southern wing of the anticline.

The curved normal fault between the northern wing of the anticline and its correlated syncline.—Once more we find a steep flexure broken by a normal fault as the means by which a series of reversed faults has been neutralized. The flexure is best seen on the northern slopes of Monte Sief (fig. 10, p. 586). The Wengen strata strike north 40° east and dip 35° westward on the mountain, while the Wengen-Cassian Series of Prälongia, with a nearly east-and-west strike, and northerly dip, comes into contact with the bent series of Monte Sief along a flexure-fault with downthrow to the north. The fault describes a torsion-curve from west-north-west at Campolungo, round a southern arc through Monte Sief to east-north-east, where it is cut by the Valparola diagonal fault. This curved normal fault bounds the syncline of Prälongia and Sett Sass.

The Buchenstein torsion-system.—The Pordoi-Pass area of this region represents a portion of the northern wing, very deeply sunk in comparison with the Varda portion of the same wing. It will be dealt with more conveniently on a subsequent page (p. 599). Sufficient data have been already given to afford a clue to the complete system of torsion in the Buchenstein region (see fig. 13, p. 588).

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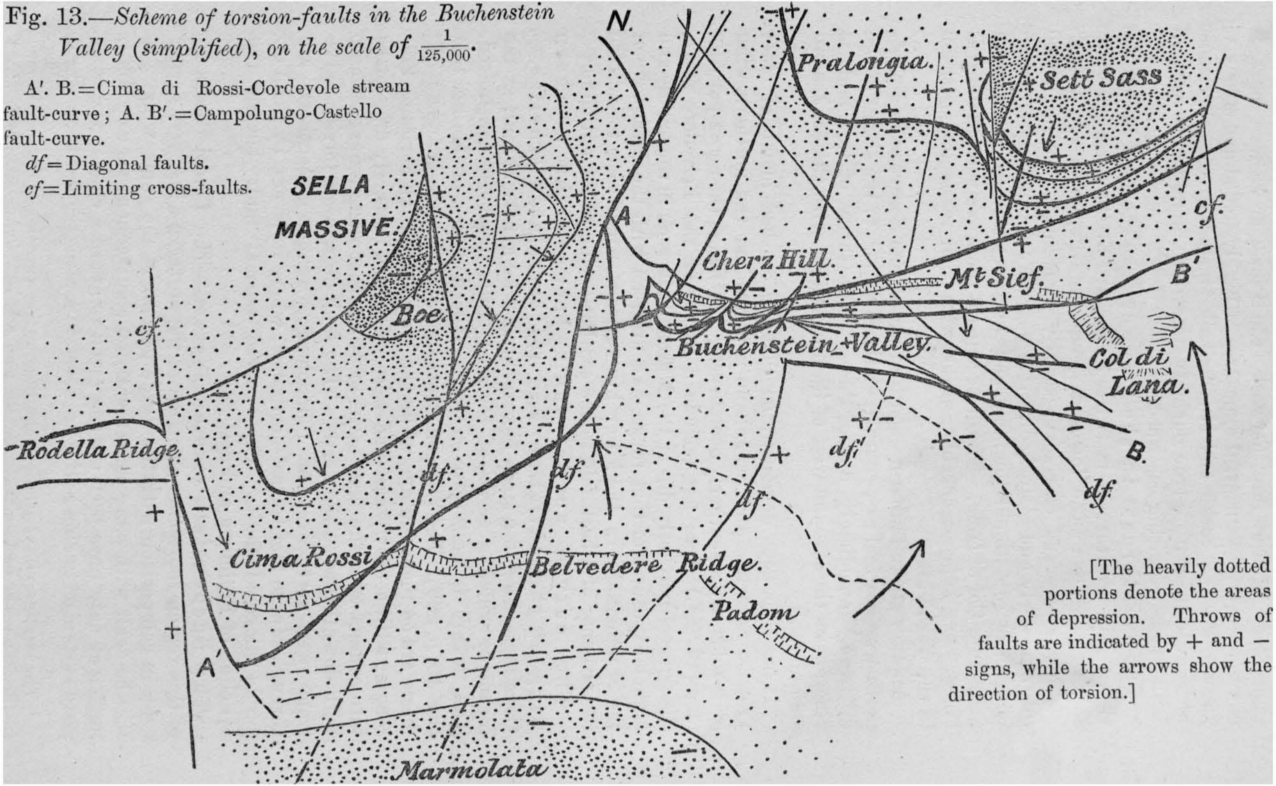
[1] The stratigraphical details of the Buchenstein virgating faults can be seen in the map; the paths marked on the map are old footpaths, now in great measure obliterated, owing to the building of fortifications and the laying-out of strategical roads at present going on in the valley.

Fig. 13.—*Scheme of torsion-faults in the Buchenstein Valley (simplified), on the scale of* $\frac{1}{125{,}000}$.

A′. B.=Cima di Rossi-Cordevole stream fault-curve; A. B′.=Campolungo-Castello fault-curve.

df=Diagonal faults.

cf=Limiting cross-faults.



[The heavily dotted portions denote the areas of depression. Throws of faults are indicated by + and − signs, while the arrows show the direction of torsion.]

First, one observes that the divergent faults east of the Soraruaz diagonal fault curve variously north-eastward and south-eastward, whereas the faults west of the Soraruaz Fault curve north-westward round Cherz, and south-westward through the Arabba Hills. Further, that the chief oblique faults intersecting the eastern fault-bundle are north-north-west and south-south-east in direction, whereas those across the western bundle are north-north-east and south-south-west in direction, becoming north-east and south-west and east-north-east and west-south-west in the strongly-compressed part of the Cherz Hill curve.

From a knowledge of the Gröden Pass and a comparison of figures, it is not difficult to recognize two opposite fold-arcs, meeting in a central area (Soraruaz) of fold-intersection and maximum torsion-shear. The torsion force-couples have induced clockwise torsion in the north-western and south-eastern quarters, counter-clockwise torsion in the north-eastern and south-western quarters.

If a straight line be now drawn from Canazei in the Avisio Valley, through the area of intersection and north of Monte Sief, to meet the Valparola stream, the line will have a west-south-westerly and east-north-easterly direction parallel with the line followed by the main torsion-fault of the Gröden Pass. Such a line, moreover, will be found to correspond with an actual line of contact in nature, between an intrusive igneous sheet and the Wengen strata exposed on the Pordoi, Sella, and Cherz slopes. The natural line varies from the drawn one only where the former follows the contours of Campolungo and Cherz above the Arabba stream. The line from Canazei to the Valparola stream is recognizable as the chief torsion-strike, while a subordinate torsion-strike runs from west-north-west (Cherz Hill curve) to east-south-east (Pieve and Cordevole Valley curve).

The complete torsion-system of Buchenstein may be embraced within an elliptical outline, and, just as in the case of the Gröden Pass, there are opposite areas of subsidence behind the northern and southern wings of the anticline respectively. Sella and Sett Sass represent two segmented portions of the northern synclinal area separated by the diagonal buckle of Campolungo, while the Marmolata mountain represents the southern synclinal area.

Relation of Col di Lana to the Belvedere ridge.—The petrographical similarity between the rocks of Col di Lana and Cherz Hill on the one hand, and those of the Belvedere ridge on the other, has been the subject of frequent comment by geologists. The apparent thickness of the rock-complex on Col di Lana and Cherz Hill is due to the occurrence of the overthrust-planes. Now, the system of torsion-faults set forth above explains Col di Lana and Cherz Hill as obliquely-twisted segments forming the northern fold-arc of the Buchenstein Anticline, whose southern fold-arc is formed by the Belvedere ridge. Thus, instead of Col di Lana representing an individual centre of eruption in Middle Triassic time, as suggested by some, it is shown by its stratigraphy to have been originally a homogeneous part of the Belvedere body of strata.

East-and-west cross-faults limiting the Buchenstein torsion-system.—The western extremity of the Belvedere ridge, named Cima di Rossi, is separated from the Rodella Hill complex of similar rocks by the fault over the Sella Pass (p. 570) towards Canazei. This transverse fault is accompanied here by a fault-dyke continuous with the intrusive sheet in the strike-shears. The Rodella fault-block west of the transverse fault has been twisted in counter-clockwise direction to the east-north-east, and the Cima di Rossi block, east of the transverse fault, has been twisted also in counter-clockwise direction, but to the west-south-west. Referring to the diagram of torsion (fig. 8, p. 581), the Rodella block and the Cima di Rossi block represent the B & D force-spirals respectively in two adjacent torsion-systems.

Again, the downthrow of the transverse fault is on the east side, towards Sella; the fault therefore neutralizes the sum of the diagonal faults through Soraruaz, Campolungo, and Bova Alp (p. 599), whose downthrow is in all three cases on the west side, towards Sella.

The limiting cross-fault east of the Buchenstein torsion-system is the Valparola Fault, with an easterly downthrow.

If we now in imagination turn back the intercrossing axes of the torsion-strikes into straight line one with another, Cima di Rossi would be brought into touch with Rodella at the western extremity and Col di Lana with Monte Padom at the eastern.

Superposition of Tertiary upon Triassic strike.—I previously pointed out the obliquity of Tertiary lines of crust-movement to pre-existing lines of Triassic disturbance (see p. 563). The probable relation of the later movements to the earlier may now be indicated, in accordance with the results obtained.

A Middle Triassic flexure or fault, with an east-and-west strike in this particular locality, was acted upon obliquely during the Tertiary upheaval by combined movements of compression and torsion, after the manner described in the case of the Gröden Pass. While the new movements apparently concentrated themselves along the pre-existing lines of crust-weakness, the new crust-buckles took shape across the former strike in the form of cross-folds, and the movements culminated in oblique shears and diagonal and transverse ruptures, accompanied by the injection of dykes and sheets in the curved faults. The overlapping or virgating shear-wedges of torsion then gradually adjusted themselves in the new directions of strike, while adjacent fault-blocks settled themselves on opposite sides of the diagonal and transverse ruptures, such movements of adjustment taking place along fault-planes primarily determined during the period of active torsion.

IV. THE SELLA MASSIVE.

The Sella Massive presents a highly characteristic type of the mountains in the Southern Tyrol Dolomites.

The geological map published by Mojsisovics[1] gives expression to the theory that Sella Mountain was pre-eminently a coral-reef

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[1] 'Die Dolomit-Riffe von Süd-Tirol u. Venetien,' 1879, chap. viii, pp. 227-240.

formation built during the Wengen, Cassian, and Raibl periods, having been formed in continuity with the 'Lang Kofl Reef' during Wengen and part of Cassian time. The following paragraphs give an account of the researches made and conclusions arrived at by the present author in the years 1892–1896.

Structural significance of the ravines of Val la Stries and Val di Mezzodi.—The Sella Massive occupies an area of subsidence, elliptical in outline. The Gröden Pass Anticline curves round it on the north, the Cima di Rossi portion of the Buchenstein Anticline curves round it on the south; the Campolungo diagonal buckle limits it on the east, and on the west the diagonal buckle of the Sella Pass dips towards it.

Two long narrow valleys with precipitous sides run up into the heart of the Sella Massive. The one is Pissadoi ravine, called also Val di Mezzodi, ascending from the Gröden Pass south-south-westward to the hanging glacier which descends from the Boe ridge; the other is Val la Stries, ascending from the Sella Pass eastward to the Boe ridge. Their axial lines would meet in the middle of the mountain at a wide angle, and the direction of curve which would thus be suggested is parallel with several important diagonal fault-curves through the east side of Sella. It is, moreover, practically the axis of the torsion-ellipsoid of Sella itself.

The line of section shown in fig. 14 (p. 592) runs north-west and south-east, as nearly as possible transverse to the direction of this curve. A second line of section is also given north and south, cutting transversely a subordinate direction of strike in the mountain (fig. 16, p. 594). The strike of the rocks curves round from one direction to another, holding parallel with the peripheral outline of the massive. The dip is, in the main body of the mountain, inward to the centre, but near the periphery the rocks, especially on the south and east sides, dip outward.

Pitzculatsch exposures.—The first part of the line of section (fig. 14, p. 592) passes from Plon over Pitzculatsch to that corner of Sella which is known as the Grüner Fleck, and thence over the high precipices of the Meisules terrace.

The Pitzculatsch Fault has been already described (p. 567). South of it, in its immediate neighbourhood, true 'Buchenstein limestone' (see footnote, p. 569) is wedged into the grass of the steep slopes in block-form, and probably represents sheared rock. The dark, banded limestone and tufaceous strata at the base of the Wengen Series have a considerable surface-outcrop, and can be examined in stream-courses. The general strike is north 60° to 65° east; the dip is about 50°, but diminishes to 30° nearer Sella.

A Cipit-Limestone horizon follows, which marks locally the limit between Wengen and Cassian strata, and has been previously termed 'Lower Cassian' by the present author on account of its containing the first indications of the Cassian fauna. Its character on the Pitzculatsch slope of Sella is precisely the same as that which is to be seen in the typical area of Prälongia.[1]

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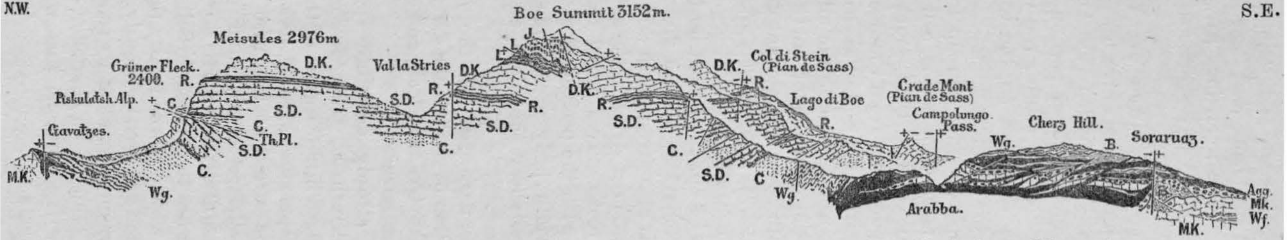
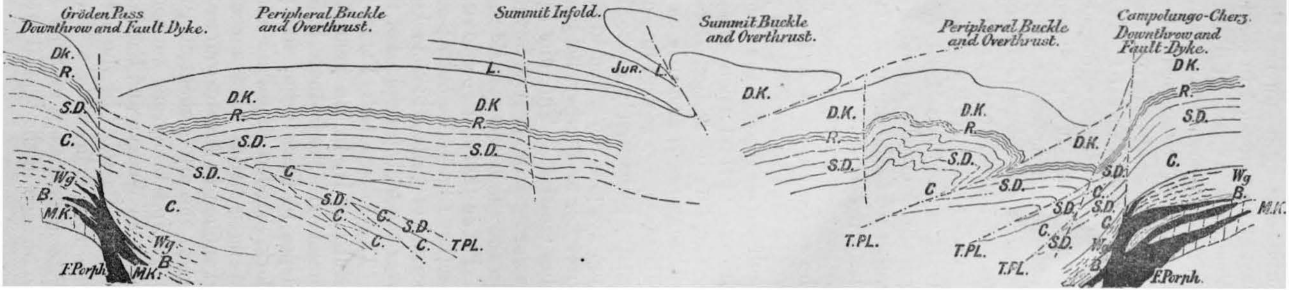
[1] Quart. Journ. Geol. Soc. vol. xlix (1893) p. 16.

Fig. 14.—*Transverse section through the Sella Massive, with parallel sections on the east side through Pian de Sass terrace, on the scale of* $\frac{1}{75{,}000}$.



Varda slopes of Lower & Middle Trias with fault-dykes and intrusive sheets.

Fig. 15.—*Fold-form of the Sella Massive (north-west to south-east).*



Large weathered blocks full of coral- and encrinite-remains are characteristic of the horizon, and were first described by Richthofen in the Cipit stream between Schlern and the Seisser Alp.

At Pitzculatsch there follows above this horizon a certain thickness of interbedded limestones and marls dipping about 30° towards the mountain. I found in these a typical 'Stuores' Cassian fauna, and followed the outcrop towards the Gröden Pass. Not only are the fossiliferous marls present, but also the higher horizons of more thickly-bedded brownish-yellow limestone, full of *Cidaris*-spines and other small fossils. The same zone of Cassian limestone is present on the ridge of Prälongia above the Stuores meadows.

Here, at Pitzculatsch, the yellow limestones are followed by thickly-bedded calcareous horizons with numerous encrinite-remains and blocks of coral-growth, and then succeeds the 'dolomite'-cliff of Grüner Fleck. But, so far as I could examine it, this last rock gave a distinctly acid reaction.

This section therefore proves a conformable succession of the rock called Schlern Dolomite (although largely calcareous in certain places) upon marls and limestone containing a typical 'Stuores' or Middle Cassian fauna. No individual zone is wanting which has been demonstrated and fixed palæontologically by the writer in the survey of the neighbouring typical area of Prälongia and Stuores. Hence there is no reason whatever for mapping the dolomitic limestone here as a 'reef-built facies' corresponding in age to a 'bedded facies' of earthy deposits. It succeeds the Wengen-Cassian Series conformably, and is therefore geologically younger than these strata.

Peripheral overthrust of Sella at the Grüner Fleck.—The precipitous cliffs of the Meisules group in Sella surmount the Pitzculatsch hill. Grüner Fleck is the name given to a grassy ledge midway up the rocks at the north-western corner. Even from below it can be observed that the 'Schlern-Dolomite' rocks below the Grüner Fleck dip steeply inward with the general dip of the Pitzculatsch succession, whereas the 'Schlern-Dolomite' rocks of Meisules are almost horizontal, and in their continuation towards the Gröden Pass dip outward from the mountain.

This difference becomes still more evident when an ascent is made to the Grüner Fleck. Cassian marls and calcareous rocks are present on the ledge, and share the strike-and-dip relations of the Meisules terrace. Both the Cassian marls of the Grüner Fleck and the overlying dolomite meet the lower dolomite along a disturbed shear-plane; an overthrust of certain horizons of the Cassian strata and the overlying Schlern Dolomite has taken place above the same horizons of rock in the Pitzculatsch conformable succession, upon a plane inclined south-eastward at an angle of about 50°. Confirmatory evidence of the thrust-plane is afforded in the cliffs facing the Gröden Pass.

Immediately east of the Grüner Fleck no Cassian strata are apparent in the overthrust-group. Farther round, however, Cassian strata come increasingly into evidence, while below the shear-plane

Fig. 16.—*Transverse section through the Sella Massive, on the scale of* $\frac{1}{75,000}$.

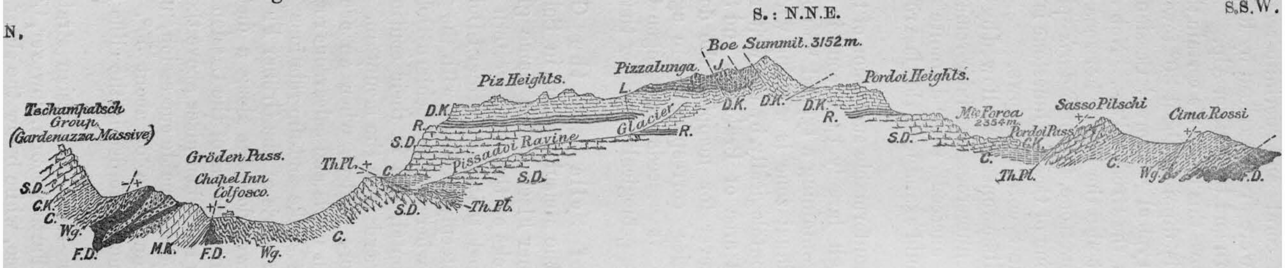
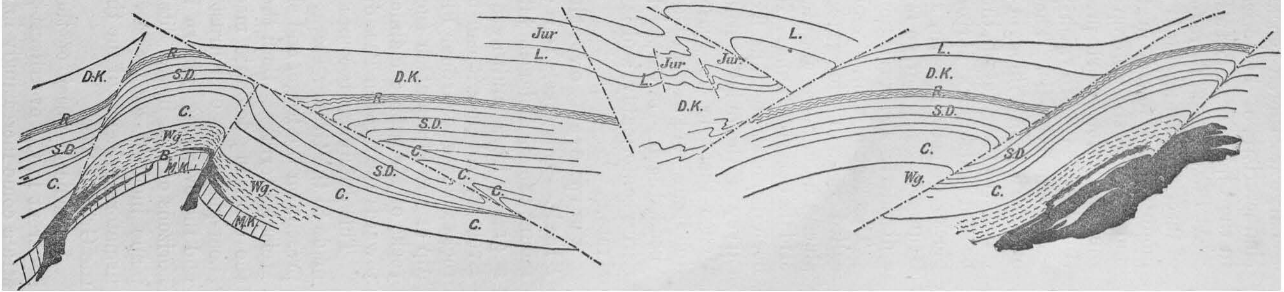


Fig. 17.—*Fold-form of the Sella Massive (north to south, then south-south-west).*



the Schlern Dolomite (which is not less than 500 feet thick below the Grüner Fleck) has been gradually cut away by the thrust-plane, so that it thins out to mere streaks of sheared and smashed rock.

Opposite the highest point of the Gröden Pass the Cassian strata above and below the shear-plane almost meet; but the difference in their dip-and-strike relations is perfectly distinct, since the Cassian strata above the shear-plane incline outward, and those below dip from 25° to 40° inward. The shear-plane descends from about the 2300-metre contour-line at the Grüner Fleck to 2200 opposite the Pass height, and to 2150 at its exposure in the Pissadoi Ravine.

In the direction of the ravine the dolomite again thickens below the shear-plane, a circumstance which is associated with the general west-south-westerly and east-north-easterly strike of the conformable succession of Wengen, Cassian, and Schlern-Dolomite strata on the Pass. The course of the shear-plane through the cliffs is marked by patches of vegetation, wherever the Cassian strata have been weathered out along the exposure of the plane.

While the Schlern Dolomite below the shear-plane is a variable factor with regard to thickness, that above the shear-plane is practically constant in this respect, and represents the complete thickness, where it has Cassian strata at its base and Raibl strata on the top of the Meisules terrace. This thickness may be estimated as 1100 feet at the most.

Immediately west of the Grüner Fleck the relations of the shear-plane are disturbed by a scree-slip, which seems, from the stratigraphical features on either side, to coincide with a small transverse fault. Beyond it, the precipitous walls of dolomite correspond to the similar precipices next the Grüner Fleck on the Gröden-Pass side. The position of the shear-plane, however, can be still determined by differential strike and dip, and is also indicated by a well-marked horizontal fissure through the rock.

The dolomite below the shear-plane forms an outjutting crag, named Buscatins on the local map. Together with the Cassian strata below it, the Schlern Dolomite of Buscatins strikes towards the Ciavatzes Alp, and is gradually cut out in that direction. On the top of Buscatins indications of Cassian limestone are present, but scree (and what is probably shear-breccia) cover the terrace between Buscatins and the western face of the Meisules cliffs. The line of scree continues southward into the midst of the Cassian strata exposed on the Sella Pass. These occupy the Pass-ridge from about the 2275-metre contour up to 2400 metres. The dip changes in this group of Cassian strata. The strata below the Sella Spitze have the almost horizontal position of the younger rocks forming these summits, whereas the Cassian strata on the Sella-Pass ridge have a steep and variable north-north-easterly dip. The Wengen strata, so widely exposed over the Sella Pass, are here highly contorted.

In the ravine of Val la Stries the Cassian strata are slightly inclined, as at the Sella Spitze. They correspond to the Meisules overthrust series, and are succeeded by Schlern Dolomite in its normal thickness of about 1100 feet. The overthrust-plane may be said to disappear from view when it enters the Cassian strata of the Sella Pass. Considerable tectonic disturbances are, however, evinced in the Wengen-Cassian group wherever exposures are found on the southern slopes of the Sella Pass towards the Salei stream, and on the steep descent of Val la Stries towards Roja. The soft strata are twisted in all directions, and riddled with small faults. This is the explanation of the wide surface-outcrop attained by Wengen and Cassian strata, more especially the former, on the south-west side of the Sella Massive.

The contorted Wengen-Cassian strata and the sheared fragments of Schlern Dolomite below the thrust-plane form part of the anticlinal group of strata belonging to the south-western quarter of the Gröden-Pass torsion-scheme, while the strata above the thrust-plane represent a back-fold from the correlated part of the Sella syncline. Differential movements of torsion have taken place here in superposed horizons of the earth's crust, the upper horizons having been twisted northward and north-westward, while the lower horizons were twisted southward and south-eastward. The shear-plane has passed spirally through the Wengen-Cassian Series of softer strata and also the more resisting Schlern Dolomite.

The torsion of the thrust-fold into an arc-shape is cognate with the torsion of the strike of the rocks. Thus the Meisules fold-arc forms a southern curve in the virgating group of torsion-curves demonstrated on the west of the Gröden Pass. The heaping-up of the calcareo-dolomitic strata towards the north and north-north-west is correlated with a general attenuation of these strata in the internal portion of the massive, and a consequent sinking of Jurassic strata along a curve parallel with the curve of the Meisules fold-arc.

The Pordoi Pass overthrust.—The Pordoi Pass forms what is usually regarded as the southern limit of the Sella Mountain. It extends east and west between two wide outcrops of the Wengen-Cassian Series, here, as at the Gröden Pass and the Sella Pass, strongly contorted and often faulted.

The Pordoi Spitze are southern summits of the Sella Massive which stand north of the Pass and exhibit an undisturbed succession of Schlern Dolomite, Raibl, and Dachstein-Limestone strata dipping slightly outward. On the south side of the Pordoi Pass the summit of Sasso Pitschi (Sasso Beccie) rises from the midst of the Wengen-Cassian Series. It is composed of Schlern-Dolomite rocks, not only dipping steeply north-westward, but also showing actual twists in the strata similar in direction to twist-curves which can be seen in the Dachstein Limestone that forms the highest summit (Boe) in the massive. The disturbed stratigraphy of Sasso Pitschi offers a marked contrast to the gentle outward dip of the strata on the opposite Pordoi summits.

The differential dips are separated by the Pordoi Pass overthrust-plane, which hades northward; I have described the details on a previous occasion.[1] Sasso Pitschi presents a lower slice of

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[1] Geol. Mag. 1894, pp. 53–54 & fig.

Schlern-Dolomite rock below the shear-plane, while the Cassian strata on the Pordoi Pass are above the shear-plane. Thus the same relations hold between Sasso Pitschi and the Pordoi summits as between the rocks of the Grüner Fleck and the Meisules group in the north-west of Sella. One important fact is that in every part of the circuit so far Wengen and Cassian strata have preserved precisely the same palæontological and petrographical features.

The direction of the torsion-movements associated with the Pordoi overthrust is indicated by the change of strike and dip in the overthrust group on the east and west sides of the Pordoi summits. On the west side, towards Val la Stries, the Schlern Dolomite strikes almost due north-and-south, and dips from 5° to 10° inward. A small transverse fault east of the Pordoi summits marks a sharp curvature of the strike to west-north-west and east-south-east, and it then turns gradually eastward, while the dip is as much as 15° to 20° outward. The Sasso Pitschi fault-block has likewise a rapidly twisted strike, from west-south-west and east-north-east opposite Monte Forca to south-west and north-east a little lower down the Cordevole slopes. The dolomite-rocks of Sasso Pitschi show abundant evidence of shear-brecciation and slickensides.

The strike-torsion therefore describes an arc from west to east round the southern curve of the Sella Massive, comparable to the torsion-curve round the south of Cherz Hill opposite Arabba (p. 585). The shear-plane is also similarly inclined in the two places. These features indicate that the Pordoi portion of Sella represents a fold-arc in high horizons of the northern wing of the Buchenstein torsion-system. At the same time it is a sunken block occupying an area of tension between the two opposite and divergent torsion-curves of the main anticline, namely, the northern or Varda-Cherz curve and the southern or Belvedere–Cima di Rossi curve. The fold-arc has been broken, and the overlay and underlay of the fold have been twisted differently. The shear-zone occurs chiefly in the Wengen-Cassian Series, while the Schlern-Dolomite rocks that form Sasso Pitschi represent a torsion-wedge caught in an area of cross-movement and sharp curvature.

Recognition of rocks on the east side.—The eastern side of Sella, facing Campolungo Pass and Cherz Hill, proved an arduous field to examine. It is much cut up by faults, and the greatest care has to be exercised in identifying the rocks belonging to each fault-segment. The chief difficulty is in respect to the age of the dolomitic rock, as the Dachstein-Limestone horizon is in great measure dolomitic, and can be distinguished from Schlern Dolomite only by a persevering search for fossils. Fortunately *Megalodon triqueter*, the typical Dachstein fossil, occurs very numerously throughout the Dachstein rock-horizons in most parts of Sella, and the higher Dachstein horizons are full of smaller bivalves and gasteropods.

The Raibl strata are easily recognized from their petrographical character wherever they have been exposed to weather-action. Brownish fossiliferous sandstones at the base; rose-tinted or chalky-looking dolomitic flagstones, sometimes with beds of dolomite; brilliant red, violet, and greenish marls, and an interbedded fine, variegated, or pale breccia always form the series of Raibl strata as observed by me at Sella, Sett Sass, Sass Songe, and other localities. The few fossils found in this series on the Sella Mountain were typical Raibl species, and they were found in the brownish sandstones. *Ostrea montis-caprilis* and *Gervillia Bouëi* were the most characteristic types in these.

The Schlern-Dolomite rock proved often highly calcareous, and it was found to be comparatively easy to identify it on the east side, in spite of the disturbed stratigraphical relations, after the minute examination previously made on the west side up Val la Stries. It contains *Cidaris*-spines and highly-altered crystalline outlines of molluscan shells in great numbers; encrinite-remains and algal structures at all horizons; occasional banks of coral-growth; and sometimes good specimens of sponges. In the highest horizons the rock showed drusy cavities, with large gasteropoda in them resembling the *Chemnitzia* found in the Wetterstein limestone, although unfortunately I did not succeed in getting them out of the cliffs. Only fragments of these and of the bivalve-shells could be secured.

The Schlern Dolomite of the Sella Mountain is emphatically more calcareous and more fossiliferous than the Raibl Series. The latter is clearly a deposit which was originally magnesian. The fossiliferous sandstones at the base may be said to mark the gradual transition from the generally deeper-sea conditions of the previous period to the shallowing and variable conditions of Raibl time.[1]

Pian de Sass.—The name of 'Pian de Sass,' sometimes written 'Plan de Sass,' is given by the country-people to a shelving terrace on the east side of Sella. As often happens, the application of the name in the Government Survey map differs from the common usage in the district. That map (scale $\frac{1}{25,000}$) places the name opposite a rounded summit at the southern end of the terrace overlooking the Campolungo Pass. But the smaller Survey map, on the scale of $\frac{1}{75,000}$, places the name on another outstanding rock close to a ridge at the northern end of the terrace, where there is a col between Corvara and the Campolungo Pass.

I understand that this northern rock was the one visited by Prof. Rothpletz, and described by him[2] under the name of Pian de

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[1] 'Coral in the Dolomites,' Geol. Mag. 1894, p. 49 & pl. ii.

[2] 'Geol. Querschn. durch die Ost-Alpen,' 1894, p. 55. I may be allowed to remark that my own early observations on Pian de Sass were made in 1892–93 without any knowledge of those made by Prof. Rothpletz. In the course of subsequent conversation with him, I was pleased to find that our observations agreed in two important respects—(1) the identity of the Pian de Sass rock as Schlern Dolomite, and not Dachstein Dolomite, as mapped by Mojsisovics; (2) the existence of a transverse fault on the east side of Sella with downthrow to the west.

Sass. As a matter of fact, the rock at the northern end of the terrace is called Cra di Mont in the district, and that of the southern end is called Col di Stein, while the terrace is variously spoken of as Pian de Sass or as 'the Lago,' from the presence of a small tarn on it called Lago di Boe.

The torsion of the Pordoi overthrust at Bova Alp.—To return now to the circuit of Sella, the only means of tracing the Pordoi overthrust-fault eastward is by following the continuation of the different strike-and-dip systems of the Pordoi and the Sasso Pitschi fault-blocks, respectively above and below the shear-plane of the Pordoi Pass. In this way the fault may be traced in an east-north-easterly direction as far as the Bova-Alp corner of Sella, where the dolomite-rocks curve sharply northward. The curvature is very unexpected, since the strike of the Pordoi series is almost eastward and the dip slightly outward.

The sharp curvature takes place where the Pordoi overfold is intersected by a diagonal torsion-fault directed north-north-east and south-south-west, parallel with a diagonal buckle that runs through the eastern side of the mountain. The overfold is broken up into several shear-slices on that side.[1] The diagonal fault crosses the Cordevole Valley towards Col di Luc, but is subdivided into several branches where it enters Sella. The north-north-east and south-south-west branch passes through the mountain to the Gröden Pass; its downthrow is westerly. A north-north-west and south-south-east branch crosses the Pissadoi Ravine towards Ruon (p. 571); its downthrow also is westerly.

Strata below the shear-plane (east side).—The Wengen Cassian Series on the upthrow or east side of the Bova-Alp diagonal fault is thus raised high on the Bova Alp relatively to the Schlern Dolomite of the mountain. The Wengen strata are the typical tufaceous shales and succeeding calcareous horizons; the Cassian strata include the fossiliferous marls with interbedded banks of Cipit Limestone, and the high horizons of thick-bedded yellow limestones crammed with echinoderm-remains. The average reading of the strike in these strata between the Bova Alp and the Campolungo Pass is north 30°, 35° east, dip 40° west, which would indicate that the Wengen-Cassian Series here is the continuation of the group of

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[1] This is a case in point where a diagonal fault (which may be said to be transverse, as it cuts an overfold across its strike) cannot therefore be said to have originated subsequently. The phenomena of shearing differ on the opposite sides, hence the probability is that here is an example of contemporaneous faulting and shearing. I have treated this and similar cases in the Buchenstein Valley and the Gröden Pass as evidence of crust-torsion. The diagonal fault and the overthrust have both crossed obliquely an older east-and-west fold. I wish to emphasize this strongly, as in Alpine literature the great transverse (diagonal) faults of the Alps are considered to be in the main a set of phenomena subsequent to the thrusting in the Alps. But the transverse faults cannot be said to be of later origin, unless it can be proved that the thrust-phenomena on both sides of the fault are identical. In the Sella area virgating bundles of faults occur towards any geographical direction; some members of a bundle may be shear-faults, while others may be vertical, but there is every reason to consider them the result of one set of torsion crust-movements.

strata buckled below the peripheral shear-plane on the south of Sella.

Some thickness of Schlern Dolomite surmounts the Cassian strata on the Campolungo Pass, and has the same strike and dip as these strata. The dolomitic rock has been weathered into fantastic needles and large irregular blocks, cleavage-slabs of the rock forming the dominant structural feature, although in places the planes of stratification may be clearly distinguished. Cleavage has taken place parallel with the strike, and also in a north-and-south direction (see fig. 21, p. 614). These intersecting sets of cleavage-planes give evidence of an actual twist of the overfold at the Campolungo Pass.

The Campolungo-Pass outcrop of Schlern Dolomite thins out southward towards the Bova Alp, and is cut off on the north. At the same time, certain lenticular patches of Raibl strata are present at intervals on the top of the Schlern-Dolomite streak. The most vividly coloured and largest of these occurs on the mountain-slope immediately west of the needles of Schlern Dolomite, and at a higher level than the latter.

Strata above the shear-plane (east side).—A mountain-shelf composed of Schern Dolomite and Raibl strata rises above the Bova Alp, and the same horizons of rock continue throughout the east side of Sella in the form of a diagonal north-north-easterly and south-south-westerly anticlinal fold, with strata dipping eastward and westward. Schlern Dolomite, with a strike north and south, dipping 30° westward, and a slight easterly flexure, forms the prominent rounded summit of Col di Stein and the shelving terrace of Pian de Sass, north of Col di Stein. The upper surface both of the summit and terrace is wavy, and the strata show frequent contortions. Raibl rocks are present at the top of the terrace in complete succession, conformably overlying Schlern Dolomite. Large blocks of Dachstein Limestone are strewn over the terrace, some of them containing numerous specimens of *Megalodon triqueter*; there is, however, no Dachstein-rock *in situ* on the terrace.

The strike of the rocks curves round on the terrace from north and south to north-north-west and south-south-east in the upper part, where the dip is inward, and to north-north-east and south-south-west in the lower levels of the terrace, where the strata dip outward. The strata are, in short, twisted in different directions. The cleavage-planes cross each other in northerly and southerly and north-westerly and south-easterly directions.

The outward-dipping layers of Schlern Dolomite descend to the grassy slopes between the Campolungo Pass and the Corvara Pass, and meet there Cassian marls and limestones with a north-easterly strike and a steep dip towards the terrace.

Associated fold-fracture and strike-torsion. — I have frequently heard the opinion expressed that the Raibl patch west of the Campolungo Pass is merely a slipped fragment from the complete succession of Raibl strata on the Pian de Sass terrace above. But that by no means explains all the facts as they may be observed in the neighbourhood of the Bova Alp and Pian de Sass.

I regard the Campolungo-Pass exposure of Schlern Dolomite, together with the irregular appearances of Raibl rock above it, as fragments of underfolded strata which have been steeply tilted down to the north-west, and twisted obliquely beneath heavy overfolded masses with easterly flexure. The overlay of the fold comprises the strata on the Pian de Sass terrace and the summit of Col di Stein. The underlay of the fold comprises the strongly-sheared strata between the Campolungo Pass and the Bova Alp corner (fig. 14, p. 592).

According to this view, the needles of Schlern Dolomite which stand upon the Campolungo Pass would represent on the east of Sella another small sheared fragment below the peripheral overthrust, offering complete analogy with the southern dolomitic fragment of Sasso Pitschi; and neither of these abrupt summits can be said, upon the evidence of stratigraphy, to have arisen as individual coral-reefs.

Peripheral overthrust in the north-eastern part of the massive.—Immediately north of the Pian de Sass terrace an escarpment runs eastward from the imposing cliffs of Vallon to the grassy col between Corvara and Campolungo. The escarpment terminates abruptly against the small peak of Cra di Mont, the eastern corner (' Cra ') of the Sella Massive. The col below is sometimes called ' Corvara Col,' and sometimes erroneously ' Campolungo Pass' (p. 598). The escarpment is composed of the diagonal anticline of Schlern-Dolomite rock and Raibl horizons, faulted against the downthrown Raibl strata and Dachstein dolomitic limestone forming the high cliffs on the west. The strata of the escarpment are crumpled and broken at intervals by flexure-faults. One well-marked flexure occurs about the middle of the ridge, and bends the strata very steeply eastward. Lago di Boe lies in the hollow of that flexure, and is surrounded on all sides by Schlern Dolomite belonging to the same overthrust series as that on Pian de Sass.

Another and more twisted flexure-fault occurs at a lower level. In the hollow of it a small wedge of highly-tilted Cassian rock occurs, which can be determined as a high horizon of marls and encrinite-limestone. The Schlern-Dolomite peak of Cra di Mont crops out below the Cassian wedge, and the Schlern-Dolomite strata dip from 35° to 45° westward.

The position of the Cassian rocks upon the Schlern Dolomite indicates the passage of the peripheral overthrust-plane, which emerges here as a reversed fault-branch from the diagonal (north-north-east by south-south-west) fault between Pian de Sass and the Campolungo slopes. The diagonal fault continues its own direction below Cra di Mont, and leaves the mountain at this point. It penetrates Cassian and Wengen strata in a north-north-easterly direction, but soon furcates again, giving off another reversed fault-branch in a north-north-westerly direction between the Piz terrace and Crap de Sella, and itself continuing in a north-north-easterly direction to the Rudort stream opposite Corvara. The diagonal fault depresses the western portion, and is recognizable as one of the series of north-north-east and south-south-west faults, with westerly downthrow, which mark the east side of Sella.

The higher reversed fault-branch, above Cra di Mont, may be traced as a low overthrust-plane round the curvature of the mountain as far as Piz Kofl. It represents the return-fold from Sella in the south-eastern quarter of the Gröden-Pass torsion-system. The thrust-plane separates the outward-dipping Schlern Dolomite of the Piz terrace from numerous small twisted segments of the Schlern Dolomite and Cassian strata belonging to the underlay of the peripheral fold. The dip in these segments is always inward, and they correspond to the similar fragments on the Campolungo Pass and Corvara Col. It will be objected by some that these segments are all landslips and do not permit of a stratigraphical reading. To such objections I can only reply that minute investigations on the spot will convince an unbiased mind that the 'slips' are sheared slices through the middle limb and underlay of a twisted fold.[1]

The lower reversed fault, above Crap de Sella, has a high inclination and crosses the Gröden Pass almost vertically in a north-west to south-east direction. The summit of Crap de Sella is composed of the highest horizons of Cassian strata,—thick-bedded, yellowish limestones full of *Cidaris*-spines and encrinite-stems. A few block-remnants of dolomite weathered *in situ* show that the Cassian Series was followed by the conformable succession of Schlern Dolomite. Thus the Crap de Sella fault has effected a repetition of Cassian strata and Schlern Dolomite at a level of about 250 feet below the outcrop of the same horizons of rock on the Piz slopes, and is the lowest of the reversed faults on this side of Sella.

The overlapping of shear-planes in different horizons of the crust in the Bova-Alp region, as contrasted with the divergence of shear-planes in the Piz region, is a typical torsion-phenomenon, and points to relatively stronger oblique compression in the Bova-Alp region. It may be compared with the case in the northern fold-arc of the Buchenstein Valley, where the shear-planes overlap in the west and open out in the east of the centre of torsion.

The steep slopes below the 'Crap' present a complex network of faults in the Cassian and Wengen strata. The general tendency is to buckle up the strata along diverging torsion-curves parallel with the curve of the Piz terrace above. The faults are chiefly north-and-south, and they meet the main north-north-east and south-south-west diagonal fault of the Campolungo Pass. The curve described by the course of the Rudort stream precisely corresponds with the general direction of these torsion-curves.

The northern and southern fold-arcs in the peripheral overthrust.—A continuous series of peripheral overthrusts has now been traced completely round the Sella Massive.

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[1] The complete form of a torsion-curve is composed of a number of unit-shears; a shear in one direction dies out, as a shear in a new direction starts at a small angle with the other. Thus a curve of torsion-shears is formed on the principle of furcation previously enunciated (p. 581), and the precise angle of inclination differs in the several shear-planes.

In all cases overthrust has been outward from the heart of the mountain, and has served to neutralize steep inward and downward flexures of the strata from the twisted anticlinal buckles which surround the synclinal area of the mountain. Hence, no matter where a section is drawn through Sella, the same general lines will be obtained in the peripheral fold-form (figs. 15 & 17, pp. 592 & 594). The fold-form at once recalls the 'fan-structure' of the central massives of the Alps.

Cassian strata have been frequently carried along the overthrust-plane above Schlern Dolomite, while the Schlern Dolomite below the overthrust has been variously cut, as a continuous slice of irregular thickness in the north-west of the mountain, and as sheared wedge-shaped fragments at other parts of the periphery.

The peripheral overthrust-fold subdivides itself naturally into two fold-arcs, a northern and a southern, separated by a well-marked depression in the massive, from Pian de Sass westward across the central area. The northern arc is the wider and larger; it comprises the Meisules torsion-curve round the north-west of Sella, and the Piz-terrace torsion-curve round the north-east, overthrust being to the north-west and north-east respectively. The strata of the underlay thin out southward, in which direction therefore continuously lower horizons are sheared against the thrust-plane. The Meisules and Piz-terrace curves correspond to the D & C force-spirals in the Gröden-Pass scheme of torsion.

The southern fold-arc comprises the Pordoi torsion-curve round the south-south-west and the Bova-Alp curve round the south-south-east. This curve represents the sunken northern fold-arc corresponding to the A & B force-spirals in the Buchenstein-Valley torsion-system. Overthrust has taken place to the south-south-west and south-south-east. The underfolded strata have been dragged and sheared into a series of slices thinning out northward, and therefore continuously lower horizons occur next the thrust-plane as it twists towards Val la Stries and Bova Alp.

As these peripheral overthrusts have taken place in oblique compass-directions, the axis of maximum tension in the rocks composing the massive is a line dividing the D & A force-spirals on the west from the C & B force-spirals on the east. Such an axis would run, generally speaking, north and south from the Pissadoi Ravine to Monte Forca, immediately east of the Pordoi summits. The resultant forces of compression must have acted at right angles to this axis (see fig. 19, p. 607).

Considered from the aspect of the torsion-movements, the Sella Massive is a buckle occupying a torsion-basin between the cross-anticlines of the Sella Pass and the Campolungo Pass, and is itself directed north-north-east and south-south-west. But it occupies a synclinal area between the east-and-west anticlines of the Gröden Pass and of the Belvedere ridge. From this it would seem that there has been oblique folding in the Sella Massive, north-north-east and south-south-west, as well as meridional folding. These two fold-axes are denoted by the direction of two chief ravines in the massive, namely, the Pissadoi Ravine, north-north-east and south-south-west, and the Val la Stries Ravine, directed east and west.

Torsion-phenomena on the eastern side.—The strike of the strata, and the overthrusting in the peripheral fold, curve round an eastern arc from the Gröden Pass to the Cordevole Valley. The actual change of direction takes place at a sharp angle in the neighbourhood of Pian de Sass, and the influence of conflicting force-components at this part so far explains the confused position of the rocks. North of Pian de Sass the shear-planes diverge north and north-west; south of Pian de Sass they converge south-west towards the Bova Alp. While the overthrusts may be taken in themselves as a proof of lateral compression, the curvature of the shear-planes is a proof that the lateral compression was combined with horizontal torsion.

Further evidence of the crust-torsion is afforded by the presence of vertical faults radiating outward from the inner areas of Sella in north-easterly and south-easterly directions, and therefore intersecting the shear-planes. These faults are transverse to the several tangential shear-slices which compose the complete torsion-curve, and may be termed torsion-radii.

The chief rock-joints also form a radiating series on the east side, radiating to north-east, east, and south-east. They stand undoubtedly in torsion-correlation to an opposite series of fissures and slight faults which radiate from the higher horizons of Cherz Hill to the north-west, west, and south-west, round the Campolungo curve of the hill.

The Sella Series and the Cherz Series are separated by the Campolungo Fault, which limits the Sella synclinal area on the east side. On the downthrow or west side of the fault the Wengen-Cassian strata are tilted westward, and the strike is twisted to north-west and south-west. On the east or upthrow side there is a decided dip-flexure from west (facing Sella) to north-east (facing Prälongia), and the strike twists to north-north-east and to east-south-east.

The Campolungo Fault therefore traverses a diagonal anticline directed north-north-east and south-south-west, and dividing the deep Sella basin from the shallower syncline of Prälongia. The diagonal fault is met on the west side by curved torsion-faults from the two main east-and-west anticlines on the north and south, and also by torsion-radii diverging outward from the adjacent basins. These faults and curves are so intimately associated with the diagonal anticline that the latter is comprehensible only as the expression of a vertical movement contemporaneous with horizontal movements of torsion.

Cleavage-planes penetrate the rocks of the mountain, generally speaking, in two directions, north-north-west and south-south-east, and north-north-east and south-south-west. Round the eastern curve of the mountain, however, the arrangement is specialized in accordance with the sharp curvature and strong compression on this side. North-and-south cleavage-planes pass through all the rocks of the eastern side; they are intersected by planes at varying oblique angles to north-west in the north-eastern curve, and to south-west in the south-eastern curve.

Evidence of a former east-and-west strike.—Minor complications are present on the eastern side which bear testimony to a pre-existing strike. These are east-and-west flexures and flexure-faults. The Lago di Boe escarpment, in the middle of the eastern side, is an upthrow separated from two shelving terraces north and south by east-and-west faults. The northern is the Piz terrace, with flexure to the Gröden Pass; the southern terrace is that of Pian de Sass, which is separated from another upthrow, namely, that of Col di Stein, by an east-and-west fault parallel with those which limit the Lago-di-Boe upthrow. A southerly flexure of the strata descends from Col di Stein towards the Buchenstein Valley.

Thus the eastern side, taken from north to south, is composed of alternating arches and troughs. Such a series indicates crust-folding at some time from north and south.

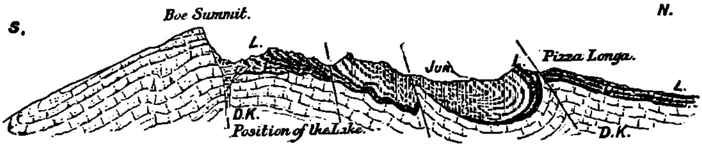
The same succession of east-and-west flexures is quite apparent throughout the mountain, but the component arches occur at wider intervals in the central downthrow of the mountain. Corresponding to the Pian-di-Sass trough, a broader trough runs through Vallon and the Pizza Longa to the inner basin of the west side of the mountain. The arch of the Lago-di-Boe escarpment is continued westward through the areas of the Pissadoi and Meisules summits. The Col-di-Stein arch, south of Pian de Sass, curves southward and runs through the Pordoi and Sella summits. The troughs external to these arches are indicated by the outward flexures, but the actual hollows of the outer troughs have been covered by the peripheral overthrust.

There is absolute stratigraphical evidence in all cases that this series of east-and-west flexures in Sella Mountain has been broken up by the various oblique shear-planes, the radiating faults and joints, and the cross-cleavages which I group together under the name of torsion-phenomena. Therefore we have to bear in mind that the forces which induced these phenomena had an already folded crust to work upon.

Stratigraphy at the Boe summit.—There is still the highest terrain of the Sella Massive to be discussed, which should, according to Mojsisovics's description in his 'Dolomit-Riffe,' be wholly occupied by 'Dachstein Limestone.' That is, however, not the case, as I showed in my paper in the Geological Magazine for 1894.

Ascending to the Boe summit from Val la Stries, the Dachstein horizon is met at a lower level than that mentioned by Mojsisovics. Abundant specimens of *Megalodon triqueter* were found by me in the rock at the 2600-metre contour-line. The strike was north-west and south-east, the dip very slight, about 8° or 10° towards the summit. Already from that horizon the eye was attracted by the appearance of bright, brick-red, earthy strata on the north side of the Boe summit. Viewed from a distance they seemed to rest conformably upon the Dachstein Limestone of the western side, and it was difficult to think how Dachstein Limestone could form the highest summit. Nearer investigation brought out rather complicated relations. Dachstein Limestone in its highest fossiliferous horizons forms the Boe summit. It is part of an overcast fold from the south and south-east, with the C-shaped curvature towards the north and north-west, while the brick-red earthy strata are part of an attenuated and sheared series of Jurassic rocks which lie in the trough of the overfold (fig. 18).

Fig. 18.—*Infold of Jurassic rocks, viewed from the east, and showing the compression and shearing of the strata.*



DK = Dachstein Kalk. | Jur = Jurassic.

The Jurassic infold is favourably exposed for examination. The Val la Stries or western aspect is at once the simplest and the most complete. The various horizons of Jurassic rock are found to be stretched, and therefore thinned, from north to south along a shear-plane of Dachstein Limestone. Thus, Liassic rocks occupy the terrain partially covered by the Pissadoi Glacier, while the younger brick-red marls (Fleckenmergel) and nodular shales and limestones of higher Jurassic horizons occur nearer the Boe summit. *Haploceras Stazyczii* (Zeuschn.) was met with in the higher horizons. The fossils found in the Liassic limestone-rocks were numerous, but badly preserved, chiefly ammonites belonging to the *Ægoceras angulatum*-zone. The shear-surface of the Dachstein rock is undulating, and is penetrated by several vertical chasms, some of which have undoubtedly a structural import.

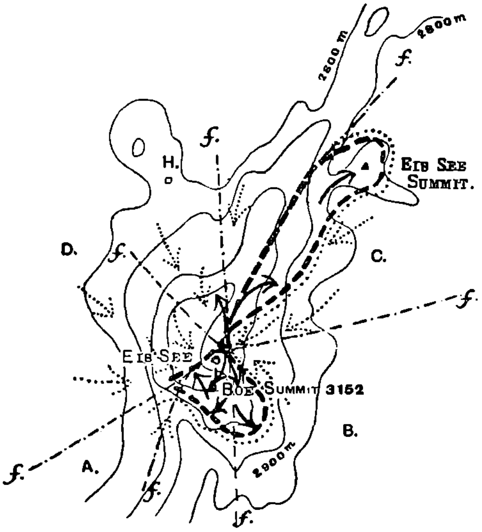
A well-marked fissure separates the Dachstein-rocks of the Boe summit from the contorted Jurassic marls immediately north of it. The fissure denotes the reverse plane of movement with downthrow on the side of the marls. Radial dislocations penetrate the infolded strata, radiating westward. These meet the reversed fault of the Boe summit in a basin of Dachstein strata on the east side of the ridge. The basin is occupied by a small lake, the Eis See.

Just as in the case of intersection of a shear-plane at the Bova Alp, the plane of the overthrust undergoes a sharp curvature at the point of intersection, and is twisted almost due north, slightly north-north-east. The reverse plane becomes then almost vertical, and faults Dachstein Dolomite against Liassic and other Jurassic strata. The Jurassic strata thin out from west to south, where the radiating faults diverge, but are strongly crumpled and compressed on the east, where the faults converge. The radiating faults through them are radii to the western curve limiting the outcrop of the Jurassic strata, a curve parallel with the torsion-curve round the western periphery of the mountain (see Pl. XL).

A diagonal buckle, directed north-north-east, extends from the Boe summit towards the Eis See summit, and is composed of the highest horizons of the Dachstein Series. The summit-buckle, which is fractured lengthways, with downthrow to the west, is overthrust eastward and southward upon the main mass of Dachstein Dolomite forming the eastern part of Sella.

The occurrence of Jurassic strata west of the summit-buckle is highly significant. It is demonstrative of a central subsidence-area within the wider subsidence-area occupied by the whole massive. The highest strata may be said to have collapsed into the space afforded centrally as a result of the outthrust and overthrust of the rocks of the massive all round the periphery. This phenomenon confirms the correctness of the observations already detailed. The Jurassic strata are, moreover, present in a trough directed north-north-east and south-south-west, parallel with the leading diagonal buckles in the Sella area.

Fig. 19.—*Diagram of torsion at the Boe summit.*



[The general outline of the summit-buckle and overthrust is shown by strong broken lines. The heavy arrows represent the evolute movements of the overlay, the dotted arrows represent the involute movements of the underlay.]

ff=Radial faults. H.=Bamberg shelter-hut (Alpine Club).

The summit-buckle is parallel with the two buckles on the eastern side which have been already discussed, namely, the diagonal anticline exposed in Raibl and Schlern-Dolomite rocks north-north-east and south-south-west through the mountain from the Piz terrace to the Bova Alp, and the diagonal anticline which runs across the Campolungo Pass exposed in Wengen-Cassian strata. Both of these lower anticlines, as well as the summit-buckle, are traversed by diagonal faults, with downthrow to the west.

Evolute and involute torsion-movements at the summit.—The Jurassic strata have subsided upon a sliding-plane and have been twisted south-eastward in proportion as the underlying Dachstein-rocks have been in their main body overthrust to the north-west towards the periphery, and in smaller mass twisted south-eastward along with the Jurassic strata. At the same time the Dachstein rocks of Vallon below the Eis-See summit have been twisted south-westward, a movement precisely the converse of that which has taken place in the higher rocks between the Boe and Eis-See summits. This movement round the Eis-See summit repeats the C-spiral movement characteristic of the south-eastern quarter in the Gröden-Pass scheme, while the movement in the Jurassic infold and Boe ridge repeats the movement of the D-spiral in the south-western quarter of the Gröden-Pass scheme.

The southern part of the summit-buckle is overthrust round a small southern fold-arc parallel with the Pordoi and Bova-Alp fold-arc in the southern periphery of the mountain. The underlay of the Dachstein-rock has been tilted inward and sliced northward, while the overlay has been thinned towards the south-west and south-east. These complex movements repeat the A & B spiral movements already demonstrated in the southern part of the peripheral overthrust. (See fig. 19, p. 607.)

The similar appearance presented by the curved masses of calcareo-dolomitic strata at Sasso Pitschi and the southern part of the Boe summit-ridge is therefore no chance resemblance, but a result of precisely similar crust-torsion at the one place and at the other.

The same spiral directions of twisting movement, therefore, explain the position of the strata in the main mass of the mountain and in the summit-area. Centrifugal forces have pushed outward and upward the Dachstein horizons of the summit-buckle, while centripetal forces have pressed inward and tilted downward the Dachstein and Jurassic horizons of the summit-trough. Thus crust-movements which may be termed 'evolute' and 'involute' have taken place in reference to a central area upon which the Eis See rests. The lake-area is that in which radiating faults converge, and apparently denotes the superposition of a diagonal arch upon an earlier east-and-west arch.

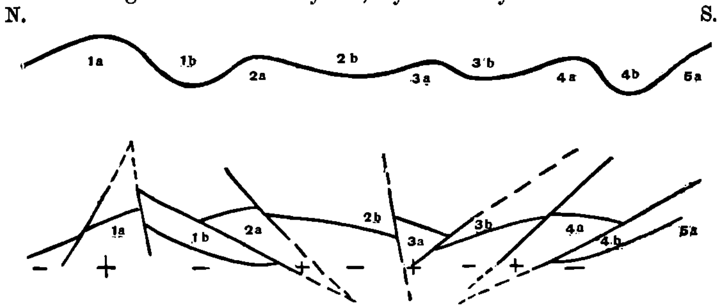
Fan-structure.—The Dachstein buckle on the top of Sella affords a miniature example of Alpine fan-structure. It rises from the midst of a circumferential trough much elongated in shape. The fundamental fact is that its position here is the result of combined translatory and rotatory movements. The older rocks have been twined above younger horizons.

In the same way the peripheral overthrust-rocks of the Sella Massive have been twined in different directions outward and upward relatively to inward and downward flexures of younger strata. These flexures represent the synclinal curves corresponding to anticlinal curves round the mountain. Hence the mass of rocks composing the overlay of the peripheral overthrust rises from a circumferential trough proportionately larger than the trough below the summit-buckle, but similarly elongated in shape with reference to a north-north-easterly and south-south-westerly axis.

The mountain-massive of Sella may be described as an elliptical basin or sag.

Rock-twining and dolomitization.—The main body of Dachstein-Raibl-Schlern-Dolomite rocks is disposed as an elliptical 'tier' of rock which may be termed a *rock-whorl*. In each part of the whorl corresponding to an individual spiral movement the upper horizons of the whorl have been twisted and bent in opposite directions from the lower horizons. *The mass has therefore undergone twining-strains to a very great degree.* The lines dividing parts of the rock-whorl which move in opposite directions are 'nodal lines' in respect of the crust-movements. Dynamo-metamorphic changes undoubtedly have taken place in rocks undergoing such powerful strains, and the processes which brought about the dolomitization of the 'Dachstein' and 'Schlern' calcareous masses may have been directed or greatly aided by these torsion-strains.

Fig. 20.—*The Sella folds, before and after torsion.*



Character of the two movements.—The effect of the earlier movement has been described above as a simple wrinkling of the crust into a series of folds with east-and-west strike (p. 605).

I have distinguished five folds in the region examined:—

1 (*a*) Gröden-Pass arch; (*b*) Gröden-Pass trough, now involved in the thrust-plane of the northern fold-arc of the Sella Massive.
2 (*a*) Arch of Meisules-Pissadoi-Zehner summits and the Lago di Boe escarpment; (*b*) corresponding trough through the heart of the mountain, including the Jurassic infold.
3 (*a*) Boe summit; (*b*) trough between Boe and Pordoi.
4 (*a*) Arch of Sella-Pordoi-Col di Stein summits; (*b*) southern trough, including Val la Stries, Monte Forca, Bova Alp.
5 (*a*) Cima-di-Rossi portion of the Belvedere-Buchenstein arch.

The later movement was locally one of compression from west-north-westerly and east-south-easterly directions. Had there been no previous folds the result would presumably have been the formation of crust-folds directed north-north-east and south-south-west.

Distorted folds in that direction can be traced upon the basis of dip-flexures as follows:—

1 (*a*) Sella-Pass arch; (*b*) Ciavatzes trough and the underthrust on the western side.
2 (*a*) Arch of the Meisules terrace in the direction from the Meisules to the Sella summits; (*b*) parallel inward flexure towards the centre.
3 (*a*) Pissadoi and Pordoi arch crossing the centre in the neighbourhood of the shelter-hut; (*b*) diagonal central trough (Jurassic inthrow).
4 (*a*) Arch from the Eissee summit to the Boe summit; (*b*) trough from the Vallon downthrow inward to the summit-ridge.
5 (*a*) Arch of the eastern side; (*b*) trough mostly concealed in the underthrust, inward flexures apparent at Cra di Mont and the Campolungo Pass.
6 (*a*) Main arch across Campolungo.

It is quite in accordance with our knowledge of crust-movement that a crumpling and contraction of the crust from east and west should succeed a crumpling and contraction from north and south. The whole interest lies in the investigation of the details; in determining firstly, which was the earlier of the movements in any given area; secondly, how far the late movements were modified by the pre-existing crust-folds.

What actually took place in the Enneberg area during the later movement was the subsidence of elliptical areas of the crust, associated with converse torsion-movements in different horizons of the crust. In the areas of subsidence, crust-whorl above crust-whorl was arranged in tighter and more contracted positions than would have been possible without torsion-movements.

Torsion-buckles.—The presumptive geographical direction and particular local position that would have been assumed by diagonal folds if the crust had been more mobile have been determined by the writer not only upon the basis of dip-flexures and diagonal faults parallel with them, but also upon the evidence of series of torsion-buckles. These buckles are distorted periclinal bulgings of the crust at places where diagonal arches of the later movement have interfered with and crossed arches of the earlier movement. The maximum torsion-effects are apparent in the crossing of the chief anticlines in the older system, namely, those of the Gröden Pass and Belvedere-Buchenstein. The bulgings are typically lozenge-shaped in ground-plan, with a longer axis in some oblique east-and-west direction, and a short axis in some oblique north-and-south direction, but not rectangular to the other.

As an example, take the torsion-buckle at Plon, on the west of the Gröden Pass (see map, Pl. XL). The diagonal north-north-east and south-south-west arch across the Sella Pass has intersected there the Gröden-Pass Anticline, and the effect has been the determination of a local centre of crust-weakness and cross-ruptures. The chief crust-rupture has occurred along (*a*) the west side of the diagonal arch, and is marked by an intrusive dyke. (*b*) Oblique torsion-faults are associated with the chief ruptures; they form two opposite virgating bundles, the one converging eastward towards the height of the Gröden Pass, the other converging westward round the Champinoi slopes below Lang Kofl. (*c*) Intrusive sills penetrate the fault-planes in the opposite bundles, and are continuous with the cross-dyke. The sill-intrusions are predominant in the inclined planes hading north in the Vallbach area of downthrow towards the Spitz Kofl group north of the Gröden Pass, and in the inclined planes hading south in the Champinoi area of downthrow towards the Lang Kofl group on the west side of the cross-arch. (*d*) The cross-axes of the buckle are directed east-north east and west-south-west (from the Gröden-Pass apex of virgating faults to the Lang-Kofl apex), and north and south. Another example of a torsion cross-buckle occurs at Pescosta.

Owing to the inelastic nature of the crust, deformation of the east-and-west folds was the essential condition upon which new crust-forms could be carried out. The virgating fault-curves which turn away from the cross-buckles on all sides show that these areas were individual centres of evolute movements in deep layers of the crust. The term 'evolute' has special reference to a compensating 'involute' movement (p. 608). The intrusion of igneous rock into the cross-buckle shows that the molten layers below the crust had involute movement towards such centres. The greater the compression at any given area, the wider would the buckle become and the greater would be the mass of intruded rock.

The northern synclinal curves of Sella have reference to these two cross-buckles on the Gröden-Pass Anticline; while the southern synclinal curves of Sella have reference to two other cross-buckles formed at the areas where the same diagonal anticlines (Sella Pass and Campolungo Pass) have been superposed on the Belvedere-Buchenstein Anticline.

A general law may be thus stated:—The chief torsion-buckles in a system of torsion-folds are formed where the cross-anticlines are superposed upon main anticlines of the pre-existing series of crust-folds; such areas of superposition are of necessity major centres of crust-weakness, peculiarly liable to invasions of molten rock during the active period of crust-torsion.

Torsion as affected by, and affecting, petrographical conditions.—All round Sella the Wengen-Cassian Series has been let down by faults from the anticlinal cross-buckles, and has been at the same time twisted downward into the underlay of the peripheral overthrust of the massive. The series has therefore sunk relatively to both the great masses of calcareous rock—Middle Triassic limestones below and Upper Triassic limestones above. The intermediate Wengen-Cassian Series would inevitably have been buried at some parts had the twisting and compression been greater (see fig. 20, p. 609).

The same danger threatened the mixed series of Jurassic strata, comprising marls, breccias, and thin nodular limestones. They were bent inward and twisted downward beneath portions of Dachstein Limestone moving outward and upward. Curious variations in thickness were effected, both in the case of the Wengen-Cassian Series and the Jurassic rocks. Such appearances have been attributed to natural causes—ground-inequalities during deposition, coral-growth, etc.; but any striking cases observed at Sella are results of the complex shearing movements during crust-torsion and compression.

While the crust-strains can be always demonstrated in the fragmental rocks by means of the contorted and fractured strata, less stratigraphical disturbance is visible in the calcareous horizons. Sufficient proof, however, of crust-strains through the calcareous rocks is presented by the significant fact of their dolomitization. It may be added that the earthy Raibl strata which occur beween the two calcareous horizons of Upper Trias very frequently show contortions and fractures when the calcareous horizons seem comparatively little disturbed.

Strike-torsion.—The fault-blocks composed of the lower geological horizons and extending between the old anticlines and the later diagonal anticlines have a small torsion-angle relative to the original strike. For example, taking the D-quarter of the Gröden Pass as a type (Pl. XL), we find that the Muschelkalk block of Pitzculatsch Hill has a torsion-angle of strike of about 20°, while the Upper Triassic rocks in the massive have a greater torsion-angle, about 35° to 40°. It is only in the highest horizons that the strike-torsion has reached an angle of 50° to 70°.

The Gröden-Pass scheme will show how two cross-directions of strike are always co-ordinated as a necessary result of the action of the torsion-forces. A west-south-west and east-north-east strike at one part of a torsion-curve is responded to by a west-north-west and east-south-east strike in the other part of the curve; similarly, a south-west and north-east strike is responded to by a north-west and south-east strike in the other portion, and a south-south-west and north-north-east strike is co-ordinated with a north-north-west and south-south-east strike.

Summary.—Briefly summarizing, we note that

(1) The synclinal basin of Sella is included within a polygon of faults whose planes incline inward.

(2) Steep downthrow-faults or flexures from the surrounding anticlines are neutralized by peripheral overthrusts from the synclinal basin. The Wengen-Cassian Series is sunk, strongly contorted and mutilated between these corresponding faults round the massive.

(3) Torsion has taken place in different directions in the overlay and underlay of the peripheral overthrust.

(4) The same horizons of Dachstein strata that bend outward in the peripheral overthrust bend inward to form the underlay of a summit-overthrust, but the underlay has been twisted in opposite directions from the twisting in the overlay. The overlay of the summit-overthrust repeats the same directions of twist as the overlay of the peripheral overthrusts.

(5) Thus the Upper Trias of the massive is arranged in two whorls, as a result of combined movements of torsion and compression.

(6) The Lower and Middle Triassic strata are heaped up in torsion-buckles situated at the four oblique corners of the massive: Plon, Pescosta, Arabba, and Rodella. These have been local centres of eruption during torsion-movements.

V. SETT SASS AND PRÄLONGIA.

The Sett-Sass and Prälongia area a companion to the Sella Syncline.—The Dolomite-mountain of Sett Sass, together with the meadows of Prälongia and Stuores, form a broken-up synclinal area on the southern side of the Langs-da-Für Anticline and on the northern side of the Buchenstein Anticline. The diagonal buckle of the Campolungo Pass extends from the Gröden Pass to the Buchenstein Anticline, and separates the Sett Sass and Prälongia Syncline from the companion syncline of Sella.

On the western side of the diagonal buckle three parallel faults have already been traced in a north-north-easterly and south-south-westerly direction, all having downthrow to the west, and therefore lowering continuously younger rocks towards the central depression of the Sella Massive (pp. 590 & 604). My earlier work showed that the Prälongia ridge was cut by faults with downthrow to the east, that is, towards Sett Sass; only one fault was traced on the west side of the Prälongia ridge with downthrow to the west.[1]

Eastern flexure-fault of the Campolungo-Pass Anticline.—The subsequent examination of the Buchenstein Valley has disclosed the southerly continuation of these cross-faults penetrating the Prälongia ridge. The diagonal fault between Prälongia and the Ruones slopes is parallel with the Campolungo and Pian-de-Sass Faults. It continues with the same north-north-easterly and south-south-westerly direction through the buckled-up Wengen rocks of the Cherz and Campolungo slopes. It separates two general strike-systems in the rocks of Cherz Hill, the fault-block on the west side having a north-easterly and south-westerly strike and dip to north-west, the other on the east side of the fault having a north-westerly and south-easterly strike and dip towards the north-east. The fault may be said to cut off the east-and-west Varda overthrusts on its east side from the Muschelkalk, augite-porphyrite, and Wengen rocks composing the diagonal fault-block of the Campolungo Pass. This fault passes through the steep flexure of the rocks from the diagonal arch of the Campolungo Pass towards the Selvaza and Ruones hollows on the east side.

The oblique torsion-faults which slice the Varda overthrusts round the south-west of Cherz Hill meet the north-north-east and south-south-west Campolungo Fault. It is impossible to trace these oblique torsion-faults northward through the Wengen rocks of Cherz Hill, as these are largely grass-grown. But it may be noted that a continuation in that direction would mean a general convergence of the fault-lines towards the Selvaza hollow. All the exposures of Wengen strata which can be found on the Selvaza slopes show considerable contortions in the rocks, and prove strong compression.

These features indicate a radiating bundle of small oblique torsion-faults through the curved overthrusts round the south-west of Cherz Hill. The correlation of these torsion-fault curves and radii with the

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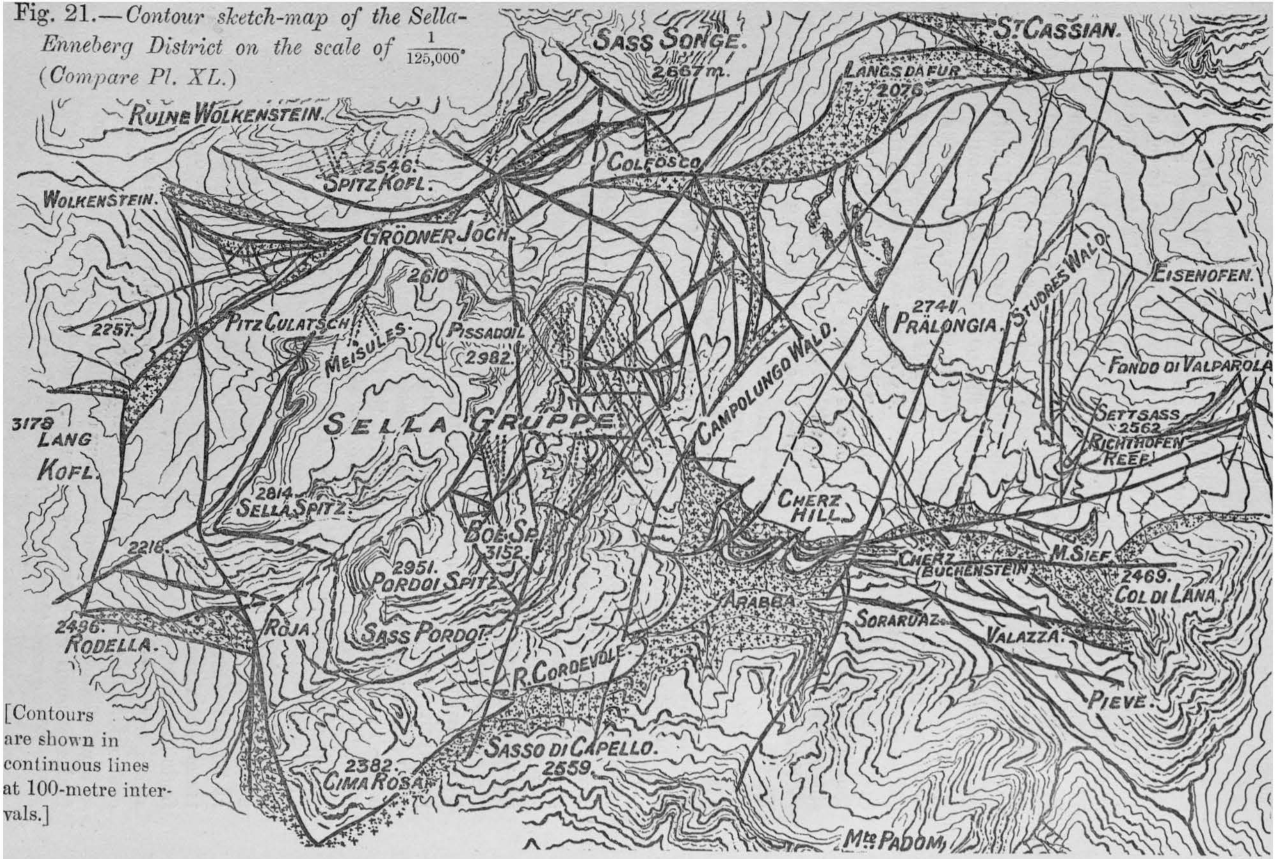
[1] Quart. Journ. Geol. Soc. vol. xlix (1893) p. 18 & map A.

Fig. 21.—*Contour sketch-map of the Sella-Enneberg District on the scale of* $\frac{1}{125,000}$. (*Compare Pl. XL.*)



[Contours are shown in continuous lines at 100-metre intervals.]

The heavy black lines indicate the chief faults; the cleavage-directions are shown by short lines of heavy dots. ++ = Intrusive rocks.

converse curves and oppositely radiating faults on the eastern side of Sella has been pointed out above (p. 604).

Prälongia Fault.—The next diagonal fault that I determined on the Prälongia ridge is the Prälongia Fault, which divides a central portion of the ridge, including the highest point (2182 metres), from a western wing, where a cross stands upon a slightly lower summit (2141 metres). The western wing is thrown down, and large blocks and standing pieces of the highest thickly-bedded Cassian limestones are preserved on it; whereas the fossiliferous marls representing an older palæontological zone than these limestones are exposed on the high central segments at Stuores.

This Prälongia Fault may be traced northward along a line of landslips as far as Corisell on the right bank of the Sore stream. There it meets the eastern extremity of the southerly limiting-fault of the Gröden-Pass Anticline. Traced southward, the Prälongia Fault causes marked disturbance in the strata of the southern slopes at the 2000-metre and 1900-metre contour-lines. It is continued through the overthrusts of Cherz Hill and across the Buchenstein Valley to the Soraruaz area, whence it curves towards Sasso di Mezzodi. This fault throughout has a downthrow to the west.

Stuores bundle of diagonal faults.—Another diagonal fault cuts the Prälongia ridge, separating the central part with its summit at 2182 metres from an eastern wing with its summit at 2172 metres. Downthrow is to the east; hence the central part of the Prälongia ridge corresponds to a diagonal north-north-east and south-south-west arch with flexure-faults on the opposite sides. This fault is a branch from the more important diagonal fault which limits the Stuores meadows against the western side of Sett Sass, with considerable downthrow to the east. Between these two faults others are present with similar effect, converging towards the north of the Stuores meadows. The bundle of Stuores faults intersects the southern overthrusts, and the latter curve at the area of intersection from a west-north-westerly and east-south-easterly to a west-south-westerly and east-north-easterly direction. The analogy between the Stuores bundle and the Bova-Alp bundle of diagonal faults (p. 604) will be at once apparent.

The chief fault of the bundle between Stuores and Sett Sass is continued northward along the western side of the Kreuz-Kofl dolomite-mountains.[1] The main Stuores Fault marks as great a downthrow of the strata on the east side of the Prälongia meadows as that which has taken place on the west side, where a west-south-west and east-north-east curved torsion-fault limits the Langs-da-Für Anticline against the syncline of Siadu, and in both cases the downthrow is eastward.

These two faults form the two sides of a triangle whose wide base is formed by the uptilted Wengen strata of Campolungo and Cherz

[1] See my paper in Quart. Journ. Geol. Soc. vol. xlix (1893) pp. 64–66, and Rothpletz, 'Geol. Querschnitt durch die Ost-Alpen,' 1894, p. 57.

Hill. The three faults across the Prälongia ridge diverge at almost equal distances one from another within the triangle, and demonstrate alternate cross-buckling and depression of the strata entirely analogous to that observed on the east side of Sella; but here the general downthrow is eastward, while at Sella it is westward. The base of the triangle is an anticlinal curve round the south-west, towards which direction the diagonal faults of Prälongia diverge.

Strike-torsion round Prälongia and Sett Sass.—The wide triangular exposure of Cassian strata at Prälongia is characterized on the south side by a torsion of the strata from a north-easterly and south-westerly strike at Monte Sief, an easterly and westerly direction of strike on the Selvaza slopes, to a northerly and southerly direction of strike on the Ruones slopes; on the north side, by a torsion of the strata from a west-north-westerly and east-south-easterly direction at Eisenofen, and an east-north-easterly and west-south-westerly direction in the lower slopes between the Piccol and Stuores streams, to a northerly and southerly direction in the upper Piccol slopes.

Thus two torsion-arcs limit the shallow syncline of the Prälongia meadows—a northern arc from Ruones to the lower Piccol district, and a southern arc from Corvara round Cherz Hill to Monte Sief. As in the case of the Sella syncline, D & C spiral movements have been followed in the northern arc, and A & B spiral movements through the southern arc. But whereas the northern arc and the associated torsion-movements form the greater part of Sella, it is the southern arc which is the larger round Prälongia and Sett Sass, so that torsion-curves corresponding with the A & B spiral movements predominate in this area (see fig. 8, p. 581).

Northward continuation of the diagonal Campolungo Anticline.—Although the Langs-da-Für Anticline crosses the Prälongia system between Corvara and St. Cassian, it is evident that the north-north-easterly and south-south-westerly strike continues down the Abtey Valley, and that Campolungo and Abtey form a main diagonal anticlinal buckle between two opposite synclinal areas occupied by Dolomite-massives.[1] Prälongia was part of a long syncline limited north and south by two earlier east-and-west anticlines (Langs-da-Für and Buchenstein) and afterwards crossed obliquely by the superposed anticline of the Campolungo Pass. Torsion-curves pass from the east-and-west anticlines towards the north-north-east and south-south-west anticlines.

Relation of the Sett-Sass Syncline to Prälongia.—Minor complications within the Prälongia Syncline have arisen, owing to the presence of another diagonal anticline, namely that of Prälongia, parallel with the Campolungo Anticline. This cross-arch has broken up the original syncline into two troughs, of which that occupied by Sett Sass is the deeper. Again, in the Sett-Sass Syncline another cross-arch is apparent, parallel with those of Prälongia and Campolungo. It forms that part of Sett Sass which

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[1] Quart. Journ. Geol. Soc. vol. xlix (1893) p. 27 & fig. 4.

includes the south-western summit (2434 metres) and is continued northward to the Eisenofen huts. Flexure-faults directed north-north-eastward and south-south-westward are again present—the western with downthrow to the west, the eastern with downthrow to the east. The most deeply sunk part of Sett Sass is the western wing, which is wedged between the diagonal arches of Prälongia and Eisenofen.

Relation of the Sett-Sass Syncline to the Buchenstein Anticline.—Sett Sass represents a synclinal basin as deep as that of Sella, and, like it, bounded by a polygon of faults with downthrow to the mountain. As the map (Pl. XL) shows, Monte Sief and Col di Lana are at the east-north-eastern end of the twisted Belvedere-Buchenstein Anticline, while Cima di Rossi is at the west-south-western end. A steep northward flexure of the strata marks the whole northern face of this anticline.

In its proximity to this anticline on its south side, and in its downthrow from the Cassian strata of Prälongia, Sett Sass offers a precise analogy with the conditions affecting the south and east of the Sella Massive. The resemblance became evident to me while engaged in mapping the area of Sasso Pitschi, Pordoi Pass, and Pian de Sass; and it suggested a clearer interpretation of the geology of Sett Sass than had occurred to me from my more limited standpoint of 1892.

The writer's map[1] was reduced from the original survey, and several of the details were omitted for the sake of clearness in the reduced map. The accompanying map of the west and south sides of Sett Sass is therefore given, with all the details as originally entered on the Survey map on the scale of $\frac{1}{25,000}$ (Pl. XL).

Peripheral overthrust round the southern curve of Sett Sass.—The chief feature of the south side is the rock which was called 'Richthofen Riff' by Mojsisovics and portrayed by him in an excellent photograph.[2] This so-called reef may be explained in precisely the same way as the present writer explained Sasso Pitschi,[3] namely as a slice of Schlern Dolomite below an overthrust-plane.

Careful collection of the fossils in the Cassian marls overlying the Richthofen Reef, and as careful comparison of these with the fossils found in the Cassian marls below the Reef and upon Prälongia and Stuores meadows, made it impossible to determine any zonal distinction. In short, the Cassian marls above and below the Richthofen Reef are identical both in respect of their fauna and their petrographical character.

With regard to the relations of strike and dip, these vary considerably when they are followed round the southern curve of the mountain. The Schlern-Dolomite rocks of Sett Sass strike east and west, and dip 12° northward. The Cassian strata dip regularly below

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[1] Quart. Journ. Geol. Soc. vol. xlix (1893), map A.

[2] 'Dolomit-Riffe,' 1879, p. 248.

[3] 'Coral in the Dolomites,' Geol. Mag. 1894, p. 53.

Sett Sass, but assume irregular relations with respect to the Richthofen Reef. The strike-readings are north 45° west above the Richthofen Reef, veering to north 60° west a little eastward, and to east and west still farther east. The dip varies from 25° northward above the Richthofen Reef to 60° farther east; and still farther east the strata are tilted almost vertically. The Schlern-Dolomite rock of the Richthofen Reef is really at a higher level than that occupied by the Cassian strata in the col between the Reef and Sett Sass. Such rapid variation along the plane between the Cassian strata and the underlying Schlern Dolomite would in itself suggest some stratigraphical disturbance of the nature of a thrust-plane.

'Dolomite'-rock forms only the upper half of the Reef, and very rapidly thins out eastward. The lower half of the Reef is separated from the upper half by an inclined joint-plane. The lower half consists of the brownish-yellow limestones which mark the uppermost horizons of Cassian rocks all round Sella, at Crap de Sella, on Prälongia, and elsewhere.

Another joint separates this lower half of the Reef-rock from a thin basal grey limestone. I followed all three horizons of the reef both eastward and westward, and found that soft Cassian marls gradually appeared along the continuation of these inclined 'joints'; I regard the inclined joints as subordinate shear-planes associated with a main overthrust-plane above the Richthofen Reef, upon which the fossiliferous soft-bedded Cassian marls have been overthrust southward above the higher horizons of Cassian limestone at some points, and for the most part, and above Schlern Dolomite at the Richthofen Reef.

The map (Pl. XL) and section (fig. 10, p. 586) perhaps explain the relations better than a verbal description. Combined with the overthrust there has been a differential twining movement in the sense of the B-spiral. The overlay of the fold has been twisted south-eastward, while the underlay has been twisted north-westward. The easterly shear-faults denote segmentation of the underlay due to torsion.

Peripheral overthrust round the west of Sett Sass.—A curvature of the peripheral overthrusts takes place where the diagonal Eisenofen arch (p. 617) crosses the overthrust. The mode of torsion of a thrust-plane under such conditions has been demonstrated already in several cases. Here torsion of the strike of the strata has been effected from east and west on the south to north-west and south-east on the west, while the shear-faults run north and south.

A series of narrow ridges diverge from the diagonal fault on the west side of the Eisenofen arch. They radiate from the curvature of the cliffs westward and north-westward, and are composed of Raibl strata, massive Dachstein-Limestone blocks, and, in less number, Schlern-Dolomite blocks. The Raibl rocks are clearly in their true position, as they may be followed at about the same level along the base of the western cliffs. The Dolomite-blocks are largely fallen masses.

Cassian strata are present round the base of the mountain above the level of these ridges, and a good exposure is met with farther north above a steep crag of Dachstein Limestone in its true position with Raibl strata at its base. This exposure proves the peripheral overthrust at the west side; it occurs at about the 2250-metre contour-line, about midway between the two western summits marked 2334 and 2434 metres in the map. Subordinate shears also pass through this part of the peripheral overthrust, and may be traced to the divergent series of ridges at the angle of curvature or south-western corner of the mountain.

The presence of Cassian strata above successively higher horizons of Upper Trias from south to north proves how strong the shearing has been in the underlay of the peripheral folds. The effect is one which can be explained only on the basis of differential twists in the overlay and underlay of a fold —the overlay having been twisted south-westward while it was thrust outward, and the underlay having been tilted steeply with easterly dip and simultaneously twisted north-eastward. Thus continuously higher horizons of the underlay would be brought at the shear-plane into contact with continuously lower horizons of the overlay.

Although the rocks succeeding the Cassian strata above the shear-plane are less disturbed than those below, they show strong compression and the thinning-out of the various horizons along the shear-plane. Schlern Dolomite represents a small wedge between Raibl strata above and below. The Raibl strata below occur in bedded fragments, of various horizons, much as in the case of Pian de Sass (p. 597). The strata comprise (*a*) sandstones with *Myophoria Kefersteinii*; (*b*) red and violet marls; (*c*) pale dolomitic sandstones and breccias; (*d*) red, violet, and greenish marls and dolomitic flagstones. The usual opinion about the western face of Sett Sass is that the rocks are mostly rock-slips and screes, with the exception of the succession of Raibl strata just quoted and the Dachstein Limestone above it.

I have devoted several days of toilsome work to the 'screes' and 'slips,' and have seen in many places clear evidence that the strata had been primarily sheared and twisted into their present position. Small surface-slips have taken place along original lines of fault-shear, but this is a feature characteristic of the whole district, and merely demonstrates adjustment along the lines of weakness.

Prälongia and Castello thrust-plane.—The exposure of Cassian strata on the Montagna della Corte Pass, between the two summits of Richthofen Riff and Monte Sief, shows another repetition of the fossiliferous marly horizons and succeeding *Cidaris*-limestones. This subordinate thrust-plane may be traced eastward towards Castello along a ridge of block-scree which is chiefly composed of shear-fragments of Cassian strata and Schlern Dolomite weathered *in situ*. The fault-plane passes east-north-eastward through the meadows, as far as the transverse fault of the Valparola stream. The Valparola Fault is a westerly one limiting another diagonal arch, that of Lagazuoi and Sasso di Stria, parallel with the Sett-Sass and Prälongia diagonal arches.

Westward from Montagna della Corte, the lower thrust-plane may be traced through the southern slopes of Prälongia. A wedge of dolomitic limestone is again present at about the 1950- and 2000-metre contour-lines immediately south of the Prälongia summit, and is here associated with an intrusive sill of porphyrite. The fault-plane curves sharply northward through the Ruones meadows, still accompanied by the intrusive sill, and gradually assumes a higher angle of inclination (70° to 80°). Its further continuation is round a north-western arc between Langs-da-Für and Siadu, with downthrow to Siadu. The intrusive sill round Prälongia is therefore a thread from the Pescosta and Langs-da-Für intrusive mass.

The Prälongia-Castello thrust-plane describes a wider torsion-arc round the south-west than the higher thrust-plane above the Richthofen Reef, but it is characterized by the same A & B spiral movements which are found to answer generally for the southern torsion-arcs in this neighbourhood. The Castello portion represents the B-spiral, where the underlay has been tilted with a steep inward dip and twisted northward and north-westward, while the overlay has been twisted almost horizontally outward to south and south-east. The Prälongia portion represents the A-spiral, where the underlay has been steeply tilted with a north-easterly dip and twisted in that direction, while the overlay has been twisted south-westward. The overlay of the Prälongia overthrust comprises the strata of the Prälongia ridge, which on the other side of the ridge form the underlay of the peripheral overthrust of Sett Sass. Therefore the strata of the Prälongia thrust-whorl have endured twining strains of the same nature as those described on a preceding page for the main whorl of the Sella Massive.

The normal fault of Monte Sief.—The flexure of the Monte-Sief strata towards the north is very marked. The Wengen rocks strike north 40° east, and dip 35° north-westward. The flexure is cut by a highly-inclined normal fault, with downthrow towards Sett Sass. As the angle of inclination is much greater than the inclination of the reversed fault-planes of Montagna della Corte and the Richthofen Reef, the three fault-planes would meet if continued upward. Thus the tendency of compression was to bring the overthrust mass of Sett Sass always closer to the Middle Triassic anticline of Monte Sief and Col di Lana.

Once more it is the softer Wengen-Cassian Series which has been chiefly crumpled, sliced, and torn, together with small shear-fragments of the overlying calcareous rock, between the advancing overthrust mass of Upper Trias and the upwardly-bulged mass of Middle Triassic limestone (see fig. 10, p. 586).

The normal fault of Sett Sass.—The Schlern-Dolomite rock of Sett Sass, which has a scarcely perceptible dip (about 8° to 10°) above the Richthofen Reef, makes a steep flexure on the north side of the mountain, cut by a slight flexure-fault. The Raibl and

Dachstein strata lie in the hollow of this flexure at the Eisenofen huts. Immediately north of the huts and of Lake Valparola, Cassian strata are dislocated by a steep fault and brought, along with Schlern Dolomite, into complex stratigraphical relations with the Raibl strata and Dachstein rock in the Sett-Sass basin.

This Eisenofen-Valparola Fault with southerly downthrow was previously demonstrated by the writer to be a curved continuation of the east-and-west Falzarego Fault which runs from the Tra-i-Sassi Pass to the Ampezzo Valley. In its portion north of Sett Sass this fault may be regarded as a reversed one limiting the northern side of the basin, and neutralizing the steep flexure-fault of Monte Sief which limits the Sett-Sass basin on the south. The Monte-Sief and Sett-Sass Faults give expression to a general overcasting of earlier east-and-west anticlines towards the south during the later torsion-movements. At the same time we have seen how compensating overcasts took place towards the north in the Langs-da-Für Anticline north of Siadu.

The northern fold-arc of Prälongia and Sett Sass.—A northern fold-arc is presented in the curved form of the Langs-da-Für Anticline, but the anticline is cut off from the basin of Siadu by the intrusion of porphyrite continuous with that of the Pescosta centre (p. 583). The Siadu basin is cut off from a corresponding basin on the opposite side of the Sore stream by the diagonal arch of Prälongia continued northward between Ru and the Centurinus Dolomite-group. The downthrow from this arch towards the Centurinus group is part of the long downthrow from the north-north-west and south-south-east fault-shears between Abtey and the Dolomite-group of Kreuz Kofl and La Varella.

Cross-arches.—The anticlines of the earlier epoch of compression are the easterly continuation of the arches demonstrated in the Sella area, and will now be briefly mentioned in the same order, to facilitate comparison (p. 609):—

1 (*a*) Langs-da-Für limiting anticline; (*b*) Siadu trough.
2 (*a*) Ruones-Piccol-Tra-i-Sassi arch; (*b*) Stuores and Sett-Sass trough (Fondo di Valparola).
3 (*a*) and (*b*) [wanting].
4 (*a*) Southern arch of Prälongia and Sett Sass; (*b*) southern trough (underlay of southern overthrusts).
5 (*a*) Monte-Sief and Col-di-Lana limiting anticline.

The diagonal series of cross-buckles, and the torsion-curves and torsion-radii associated with them, indicate two later diagonal arches across the middle of the area—the Prälongia-Soraruaz arch and the Eisenofen-Sett Sass arch (2434 metres).

The main diagonal anticline is that of Campolungo, limiting the area on the west, and the eastern limit is the diagonal arch crossing Tra i Sassi, and forming a natural boundary between the two distinct torsion-systems of Enneberg and Ampezzo.

If we consider now the position of the strata in the Sett-Sass area previous to the torsion-movements, clearly the Cassian strata occupied a relatively high position in the arches north and south of that area, while the Upper Triassic limestones were well depressed in the Sett-Sass trough. It was therefore natural that, during oblique compression and overcasting in the later period of folding, reversed faults should carry to a certain extent lower horizons in the arches above higher horizons in the troughs.

Compensating torsion-movements in companion basins.—The chief diagonal anticline is that of the Campolungo Pass, and the predominating torsion-phenomena have distinct reference to the torsion-buckles formed at its superposition upon the Gröden-Pass and Buchenstein Anticlines.

The leading torsion-curves of Sella are determined by the oblique and divergent faults which pass south-eastward from the Gröden Pass to the Campolungo arch, and by the oblique faults which pass north-eastward, from the Cima-di-Rossi and Col-di-Luc portions of the southern anticline, towards the Campolungo arch.

The leading torsion-curves of Prälongia and Sett Sass are determined by the oblique faults which pass south-westward from the Langs-da-Für Anticline to the Campolungo arch, and by the north-western faults which pass from the Buchenstein Valley to the Campolungo arch. Both the basins east and west of the arch are elliptical, but the long axis of the Sella basin is directed north-north-east and south-south-west; while the long axis of the Prälongia and Sett-Sass basin is directed north-north-west and south-south-east, parallel with the leading torsion-curves (Corvara-Contrin, Ruones-Castello, Piccol-Lake Valparola).

Whereas the torsion of the strike in the anticlines has only been through a small angle of about 20°, here, as at Sella, the strike-torsion is greater in the higher horizons occupying the syncline, where it is north-east and south-west and north-north-east to south-south-west, in the immediate neighbourhood of the diagonal arches west of Sett Sass, veering to north-west and south-east in the Castello meadow.

Conclusions.

(1) The area of Sett Sass and Prälongia originally formed part of a main east-and-west syncline situated between a Gröden-Enneberg anticline on the north and a Belvedere-Buchenstein anticline on the south, and dating from an early period of crust-movement so far begun in Middle Triassic time (see 'Coral in the Dolomites,' Geol. Mag. 1894).

(2) During the great Middle Tertiary epoch of crust-compression this syncline was thrown into a series of cross-arches and troughs oblique to the former synclinal axis; the chief diagonal arch was that of the Campolungo Pass, which subdivided the original syncline into two adjacent basins, Sella on the west and Prälongia and Sett Sass on the east, and whose superposition on the Gröden-Pass Anticline has been accompanied by igneous intrusions.

(3) During the continuance of crust-compression neutralizing flexure and overthrust-faults took place in the combined sense of the earlier and the later movements; thus torsion fault-curves were formed and were associated with fault-radii across the curves. The fault-curves of Prälongia and Sett Sass describe an arc round the south-west, while the fault-radii diverge from a northern area of convergence towards westerly, west-south-westerly, south-westerly, south-south-westerly, and southerly directions.

(4) A series of four crust-whorls was determined by the inclined planes of the fault-curves. The lowest whorl is exposed in Middle Trias, and partly in Lower Trias; it passes through Langs-da-Für, Campolungo, Cherz, Monte Sief, to Castello, and is characterized by inclined faults towards the Prälongia and Sett Sass basin, and intrusive porphyrite in the faults. The succeeding whorl is exposed in the Wengen-Cassian Series and passes through the Ruones, Prälongia, Montagna della Corte, and Castello meadows. It is characterized by overthrust southward, and steep flexure northward towards Stuores and the southern curve of Sett Sass. The next whorl is fragmentary, being represented by the Cassian and Schlern-Dolomite rocks composing the Richthofen Reef and the continuation of that slice round the western and southern curvature of Sett Sass. This fragment also shows overthrust southward and steep northward flexure. The highest whorl in this basin is that of the Upper Trias composing Sett Sass, which has been overthrust southward above the Richthofen Reef and bent steeply northward towards Eisenofen. All four whorls are incomplete on the east side of the basin, where they are cut by cross-faults.

(5) The most important tectonic feature is the result of the particular combination of normal and reversed faults similarly inclined, but with very different angles of inclination. The most compressed portion of the area is at Monte Sief and Sett Sass, where the series of faults is as follows:—

Planes meet upward.	*a.* Highly	inclined	normal	fault	at Monte Sief.
	b. Moderately	„	reversed	„	at Montagna della Corte.
	c. Slightly	„	„	„	at the Richthofen Reef.
Planes meet downward.	*d.* Moderately	„	normal	„	in Sett Sass.
	e. Highly	„	reversed	„	at Eisenofen.

The grouping of these inclined faults is such that increased compression tended to bring the mass of strata composing Sett Sass nearer the strata of Monte Sief and Col di Lana.

Appendix.

Analogy of Monte Sief with Rodella Hill.—The diagonal fault between Sasso di Stria and Sett Sass has effected a lateral southward displacement of the strata which composed the east-and-west anticline of Cima di Rossi, Belvedere, and Col di Lana. The eastward continuation of this anticlinal buckle of older Trias and lava must be sought some distance south of the Nuvolau and Carnera Dolomite-massives.

The diagonal fault west of the Sasso di Stria arch is parallel with the diagonal fault of the Sella arch, and these two faults form the eastern and western limits respectively of the area of torsion described in the foregoing pages. These are definite confines, which limit a four-sided area, influenced by the Gröden-Pass torsion-system on the north and the Buchenstein torsion-system on the south. The area is a typical torsion-unit in the Dolomites, and displays in a marked degree the phenomena of interference cross-faults, cutting a series of peripheral overthrusts round the synclines, and parallel flexure-faults between the anticlinal buckles and the synclinal basins.

Both the limiting diagonal faults displace the outcrop of the Belvedere-Buchenstein Anticline towards the south: that is, they effect downthrow on their east side. Rodella is present, west of the Sella Fault, as a curious torsion-block of older rock in the immediate vicinity of the torsion-basin occupied by the Platt-Kofl and

Lang-Kofl group. Similarly, Monte Sief is left west of the Sasso-di-Stria faults, as a torsion-block of older strata in close proximity to the Sett-Sass basin.

Lake Alleghe.—Lake Alleghe seems to be an area of convergence for several diagonal faults. The north-north-westerly and south-south-easterly fault from Corvara to Contrin continues down the Cordevole Valley towards Caprile and Lake Alleghe. The faults on both sides of the diagonal arch of Sasso di Stria, as well as a diagonal fault west of the next diagonal arch of Travernenzes and Nuvolau, all tend to converge if continued southward towards Lake Alleghe. Hence the lake seems to be a chief centre of torsion-radii in the district (see fig. 22, p. 630).

The Cortina area.—I should wish here to indicate briefly how the laws of torsion may be also applied to the stratigraphy of two other localities which I examined and mapped geologically.[1]

The Falzarego Valley represents an older east-and-west anticline which has been twisted round the southern arc of the Tofana group. The fault-curves hade northward and pass obliquely north-westward through Tra i Sassi and north-eastward round the Cortina meadows. The chief diagonal arch which has crossed the anticline is that of the Ampezzo Valley. A sharp curvature of the strike from the Falzarego to the Ampezzo Valley is again the seat of intersection of normal and reversed faults by a group of radiating faults. These faults radiate southward and eastward from the Tofana massive at Verviers, Lake Majorera, and Romerlo. The Tofana bundle of fault-radii is therefore, in its south-easterly direction, compensatory to the Centurinus bundle north of Prälongia, where the fault-radii are directed towards the west and south-west.

Dürrenstein Mountain.—The present author's map of Dürrenstein Mountain[2] exhibits a complicated system of faults. The leading fault-curves describe a narrow northern fold-arc round the mountain, and hade southward.

The Dürrenstein Massive denotes cross-buckling superposed upon an older east-and-west trough. The east-and-west anticline on the north has been penetrated by a series of reversed faults, slicing chiefly Muschelkalk and Wengen strata. A steep northward flexure at the Sarl Köfele has been cut by a normal fault letting down the Cassian and Schlern-Dolomite strata of Dürrenstein. The latter are cut into several shear-slices in the part next Sarl Köfele, so that the section from the anticlinal arch to the synclinal basin would closely resemble that of the equally compressed area of Col di Lana, Monte Sief, and Sett Sass. The central portion of the Dürrenstein Massive represents part of the original trough, round which older strata have been twined; the inthrow is on Plätz meadow. The general strike is north-west to south-east, in the central part of the area, but in the torsion-arcs north of it the strike veers round from north-east and south-west to north-west and south-east.

Two features deserve special attention in this area: one is that

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[1] Quart. Journ. Geol. Soc. vol. xlix (1893) map B, pp. 28–32 & pp. 68–69.

[2] *Ibid.* map C, facing p. 32.

overthrusts have taken place towards the north; the other is the torsion of the strike in a north-westerly and south-easterly direction.

With regard to the northward overthrusts, the Dürrenstein area resembles the Gröden-Valley and Seis-Alp area farther west. Both areas are proximal to the schists of the Central Alps. The inclined faults therefore hade away from the main anticline of the Alps, so far as it is represented by the flanking schists. This is quite in accord with my experience within the Dolomites—the inclined planes hade away from torsion-buckles and towards the chief synclinal basins within the areas specially examined.

With regard to the south-easterly torsion of the strike at Dürrenstein, it corresponds with the general torsion which the district of the Dolomites undergoes in the neighbourhood of the Sexten Valley. It is explained as a strike compensatory to, and co-ordinated with, the crust-torsion in the direction of the north-north-western and south-south-eastern arches of the Gröden and Enneberg area.

VI. Application of the Principles of Torsion in the Dolomites and in the Judicarian-Asta Region.

Correlation of anticlines and synclines.—So far as the observations of the present author go, there is one general law which governs the inclination of the fault-planes in the torsion-structure of the Dolomites. Whether overthrust-planes or normal fault-planes, if they are parallel with the strike of the rocks, they incline towards the areas of subsidence in the particular localities.

Hence at Dürrenstein and the Prags margin the inclination of the fault-planes is south and south-west towards the broad synclinal area of Dachstein Dolomite, comprising the Rothwand, Pfanes, Tofana, and Cristallo groups. Round the southern curve of the same synclinal area, my observations in the Falzarego and Cortina district showed that the fault-planes incline northward and north-westward.

Again, it has been found in Enneberg that the chief anticlines have distinct reference to the particular synclines north of them. The knee-bend flexures facing south are the most strongly compressed. Overthrust-fractures have occurred, while torsion has, at the same time, produced a fan of obliquely-set anticlinal slices at varying angles of obliquity to the original anticlinal axis. Corresponding phenomena have taken place where return knee-bends formed facing the north, and were twisted in the diagonally opposite direction. The squeezed and shattered anticlines are pierced by intrusive rocks, for the most part injected along fault-planes.

The Gröden-Pass Anticline has the Spitz-Kofl and Sass-Songe mountain-group as the corresponding syncline of the northern wing, and this syncline is marked by attenuation of the strata towards the Puez Alp, where Jurassic and Cretaceous rocks are present. The anticline of the Buchenstein Valley has on the south and south-east Sella and Sett Sass, as the corresponding syncline of the northern wing. Both these synclines are characterized by a similar attenuation of the rocks towards an inner depression, containing inthrown high horizons of Upper Triassic or even Jurassic rock.

The relations would be extremely simple, had they not been complicated by the diagonal torsion-folds. The diagonal anticline of Enneberg is that which forms the Abtey Valley, and is recognized again in the Corvara, Ruones, Campolungo, and Cherz-Hill buckle crossing from the Gröden-Pass Anticline to that of the Buchenstein Valley (see map, Pl. XL).

It is the combination of longitudinal and diagonal buckling which has marked out the separate synclinal areas in Enneberg; and this combination has been explained fully as the result of the curving torsion fold-arcs formed in diagonally opposite senses. Those of any one torsion-system combine with those of adjacent torsion-systems to produce a whorl-shaped arrangement of anticlines round separate synclinal areas.

Anticlines have been twisted round synclines, and the rocks in the synclines have themselves been twisted and distorted, buckled up and depressed, overthrust and faulted normally, cross-faulted and cleaved, to an extent that has not hitherto been realized.

Tiers-Duron torsion-system.—We may apply the principles of torsion throughout the Dolomites. And, first, to recur to the continuous east-and-west ridge from Mahlknecht to Col di Lana, which I replaced in imagination above (p. 562). The ridge as there reconstituted was supposed to have been once an actual line of Middle Triassic flexure and lava-outflow, limiting an ancient submarine terrace to the north of a wide sea-basin. The same line may be traced westward through Botzen and eastward towards Pieve di Cadore, Tolmezzo, Raibl, etc. (see fig. 22, p. 630).

The continuity of the ridge was described as having been broken in the Tertiary period of Alpine upheaval by the influence of the torsion-forces demonstrated in the case of the Buchenstein part of the ridge (§ III, pp. 587–590).

In the area immediately west of the Buchenstein Anticline I would distinguish a torsion-system extending through the broken anticlines of the Tiers and Duron Valleys, with the Schlern and Platt Kofl Mountains as northern synclines, and Rosengarten as the southern syncline. The cross-buckle of Mahlknecht separates the adjacent synclines of Schlern and Platt Kofl, much as the Campolungo buckle separates the adjacent synclines of Sella and Sett Sass. The anticlinal axis of the Tiers-Duron system is set west-south-west and east-north-east. The Rodella portion has been twisted northward, and the Tiers portion southward.

The opposite Dolomite-mountains represent torsion-segments curving away one from the other and from the torsion-axis along the various correlated oblique directions, as already demonstrated in the cases of Sella and Sett Sass. These examples of oblique torsion-systems along one and the same original line of strike suffice to prove the general application of torsion to the complicated stratigraphy of the neighbourhood. The complications would not have arisen, had not Permian and Middle Triassic flexures previously existed in another direction of strike than that called forth by the horizontal forces acting during the later uprise of the Alps.

On the other hand, all the faults are reduced to order, when it is recognized that the area has been broken up into a number of individual torsion-systems in each of which the strike has undergone the necessary change. Adjacent systems are separated by cross-faults, many of which give evidence of having continued to act as planes of adjustment after torsion had taken place (see also p. 574).

Strike-torsion at Fassa.—In order to investigate further the action of the later horizontal forces of compression and torsion, one of the torsion-axes of strike must be followed. The new strike-axis of Col di Lana and Cima di Rossi, which lie east-north-east and west-south-west across the Buchenstein Valley, curves south-west at Canazei and passes obliquely across the Fassa Valley. There it forms the torsion-axis of a system in which the southern spurs of Rosengarten branch at the north-western area of subsidence, and the diagonally opposite, south-eastern area is occupied by the Vallaccia and Monzoni group (fig. 22, p. 630). The Buchenstein and the Fassa axes form together one torsion-curve veering from west-south-west to south-west. A parallel axis of torsion farther south passes through the 'eruptive' area of Fleims and Predazzo. The torsion-axis may be said to lie in the eruptive rocks, while areas of subsidence are present all round the eruptive centre except on the south-east side. The Latemar group occupies the area of subsidence on the north-west side of the Fleims axis, and the dolomite-rocks of Viezzena and Dosso Capello lie south of the axis. The torsion-curve in both these cases is a curve which is characteristic of the Judicarian-Asta system of faults (pp. 577 & 602, footnotes).

The angle of torsion through which the old east-and-west strike was shifted was much greater at Fassa and Fleims than at Buchenstein; and the eruptive group of Viezzena and Predazzo occurs where the torsion-curve crosses the original strike at an angle of about 45°, that is, where the torsion was unusually pronounced. At the same time, the area is proximal to the Permian porphyry. The inevitable conclusion is that eruptive activity broke out in that area afresh as a result of torsion, and must therefore have occurred at a fairly advanced stage of the torsion. The latest outbreaks in the area may be identified with the most acute phase of torsion, since the transverse, as well as the diagonal, faults which cut the main overthrusts and torsion strike-faults of the Gröden-Pass and the Buchenstein-Valley systems are occupied by fault-dykes, radially arranged with regard to the Viezzena and Predazzo area. They pass from it in a south-south-westerly and north-north-easterly direction to Buchenstein, more north-and-south at Rodella and the Sella Pass, and more south-south-east and north-north-west towards Rosengarten, the varying direction agreeing with the reciprocating character of torsion-faults.

This arrangement shows the radiating faults to have been initiated in association with eruptive outbreaks in the area next the resisting mass of Permian eruptive rock. Also, they clearly mark a relatively late phase in the torsion, since they frequently cut less curved faults belonging to the Asta system, although in other cases they pass into them and form a Judicarian-Asta curve (see footnote, p. 577). Such a curve, however, is no simple tectonic line, but the result of cross-folding.

Torsional eruptivity.—Upon the basis of the observations detailed above, we have to distinguish different phases in the protracted history of torsion, marked by progressive phases in the collateral history of eruptivity.

The 'middle limb' between the anticlines and synclines of the earlier east-and-west Alps presented a series of septal lines of crust-weakness, to which were added in the Judicarian district north-and-south lines of crust-weakness attendant upon the earlier Permian intrusive mass. These were the special lines which determined the form of the later peri-Adriatic depression.

The history of torsion starts with oblique fracture of the old septal lines along correlated diagonal lines (see p. 571). Escape of the underlying molten rock along the old fold-septa, inrush towards and spreading out of the underlying rock within the torsion-buckles, which took shape as torsion proceeded, and injection of dyke-material into torsion-faults in course of formation may be regarded as progressive stages of torsional eruptivity during mountain-upheaval. Eruptivity is a necessary part of the regional dynamic phenomena (see p. 611). The later phases of decadence have reference more especially to the synclinal torsion-basins. The demarcation of a torsion-basin, the heaping-up of the strata peripherally, and their attenuation centrally are results of torsion-movement. And the local escape of underlying rock at the rim or within attenuated central areas denotes a further stage of torsion.

Thus torsional eruptive activity may be said to have marked time in a history of Alpine movement, which extends from the later Cretaceous to the present age.

Characteristic stratigraphical features in the Judicarian-Asta district.—The geology of the Adige Basin and the Cima d'Asta area has been made known in a series of able works by Suess, Lepsius, Vaček, Bittner, and other well-known Austrian geologists. A brilliant chapter by Suess, in his 'Antlitz der Erde,' summarizes the facts as known in 1885, and leads the reader clearly and carefully through the intricacies of the Adriatic Subsidence. Cima d'Asta was described by Suess as a Horst, since the investigations of Mojsisovics had pointed out the repeated appearance in the Dolomites of northwardly-inclined normal flexures passing into faults with downthrow on the north; whereas Suess, Bittner, and other geologists had traced overfolds and thrusts towards the south and south-east in the area south of Cima d'Asta, and in the Judicarian district.

The present author and Dr. Salomon (see p. 565) showed the existence of overfolds and overthrusts within the Dolomites whose direction agreed with that demonstrated in the Judicarian and Asta areas. Now this paper shows that a characteristic feature of the Dolomites is the repeated combination of flexures and flexure-faults, towards the north and north-west, in the sense demonstrated by Mojsisovics, with overfolds and overthrust-faults towards the south and south-east: that is, in the Judicarian-Asta sense. The inclination of the planes is in both cases precisely the same, but the actual combined result is so far neutral.

The neutralizing action of similarly-inclined normal and reversed faults whose direction is curved, explains the recurrence of Dolomite-massives with the same strata and the same tectonic features over a wide area.

A further fact brought out in this paper is equally significant for the structure of the Dolomites, namely, the relation of return-folds and overthrusting to the original fold-system. The strike-faults on the southern and inner portion of the Dolomites mostly produce overthrust southward; the strike-faults along the northern rim (as, for example, Dürrenstein) are overthrust northward.

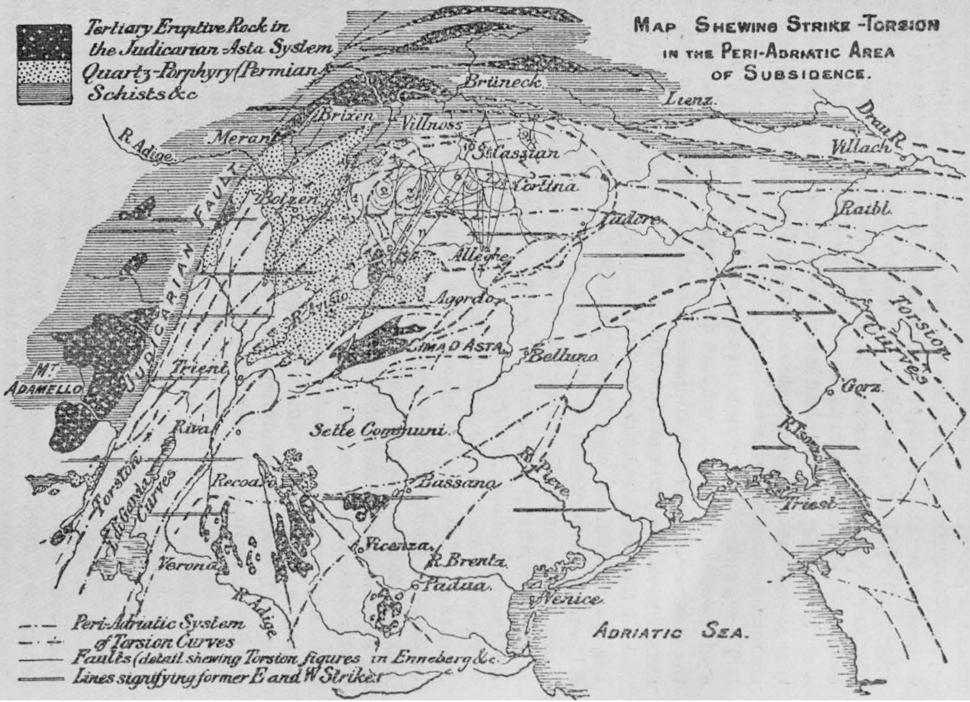
This want of uniformity is paralleled by the researches of Bittner and Vaček in the Adige Basin. There the chief fault is the Judicarian Fault, ranging north-north-east and south-south-west, and with it the occurrences of eruptive rock are associated. Along this western limit and throughout the mountains, the overcasting and overthrusting are eastward; whereas along the eastern limit of the same area the quartz-porphyry has been overthrust westward over the rocks of the Adige Basin. The occurrence of fold and back-fold, the frequent obliquity in the shape of folds, the variation of the same lines of disturbance from gentle flexures into sharp faults, and the relations between strike and diagonal faults are identical.

The Judicarian Faults, north-north-east and south-south-west, are said to be crossed by Asta Faults, which come from the Lombardy Plain, both in an east-south-easterly and east-north-easterly direction, or are likewise associated with dykes. Certain sharp north-and-south faults, sometimes more north-north-west and south-south-east, cut the others. The virgation of faults is still another feature common to the Dolomites and to the Judicarian-Asta region; while the latter area also confirms the observation, made with respect to the eruptive rocks in Fassa, Fleims Valley, Buchenstein, and Enneberg, that the bosses and dykes are present pre-eminently in twisted anticlines and along diagonal lines of fault where torsion has been greatest (fig. 22, p. 630).

Fig. 22.

INDEX.

1 = Schlern.
2 = Lang Kofl.
3 = Sella.
4 = Gröden.
5 = Buchenstein.
6 = Prälongia.
7 = Tofana.
8 = Cristallo.
9 = Dürrenstein.
10 = Kreuz Kofl.
11 = Marmolata.
12 = Predazzo.



MAP SHEWING STRIKE-TORSION IN THE PERI-ADRIATIC AREA OF SUBSIDENCE.

NOTE.

[The disposition of the eruptive rocks is shown in this map to be along lines and curves where the former strike of the strata has undergone the greatest twist. If a north-and-south line be drawn across the map passing through the masses of Cima d'Asta and Predazzo, it will be seen that the eruptive rocks occur at intervals along this line.]

The identity in the tectonic character of the adjacent neighbourhoods is unmistakable; and if torsion can be applied correctly as an explanation of these features in Enneberg, there is every reason to suppose that it can be applied for the whole area.

Age of acute torsion.—The Judicarian or north-north-east and south-south-west system of folds and faults in the adjacent neighbourhood affects the whole series of rocks, from Permian to Middle Tertiary. Hence the oldest period which can be adduced for the acute stage of torsion and the injection of the eruptive rocks along the chief torsion fault-lines and curves is Middle Tertiary.

In a word, the outbreak of the more acid series of eruptive rocks in Southern Tyrol marked an advanced phase in the phenomena of strike-torsion in that region, and was associated with an important system of diagonal and transverse faults, some of which in all probability still act as planes of lateral displacement and crust-adjustment.

It is worthy of remark, that the recurrences of eruptive activity in Southern Tyrol would thus be proved to have been always associated with great crust-movements: (1) those of Permian uprise and mountain-making; (2) those of Triassic depression; (3) those of Tertiary torsion and mountain-making, inducing and followed by local subsidences.

During the period of torsional uprise, the eruptive activity chiefly took the form of central bosses and laccolithic expansions in the characteristic crust-buckles, and was accompanied by fault-dykes and sills. During the subsequent period of local depression the activity has largely taken the form of superficial flows and volcanic outbursts.

It is just possible that some of the interrupted north-and-south lines of fault in the Judicarian-Asta region (fig. 22, p. 630), as well as the north-and-south exposures of Permian eruptive rocks, in which again Tertiary rocks burst through, may correspond in position to ancient transverse lines and valleys in the pre-Permian and Permian Alps. This seems especially worthy of attention in the occurrence of the Tertiary rocks in the Vicentine area, Asta, and Fleims-Fassa centres. These areas occur along a north-and-south line, and in each case the eruptions are associated with outcrops of old schist-rocks or of older eruptive rocks. In Scotland, it has been proved that fresh outbreaks of eruptive rocks in many cases followed old valleys.[1]

Peri-Adriatic torsion-curves.—The sketch-map of the Judicarian-Asta area given by Suess[2] has been taken by the present author as the basis of a new diagram (fig. 22). Torsion-curves have been drawn through the area in accordance with the principles laid down in the present paper. Generally considered, it depicts a region folded in one geological age along east-and-west

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[1] A. Geikie, 'Anc. Volc. Gr. Brit.' vol. ii (1897) pp. 61, 65, 96.

[2] 'Antlitz der Erde,' vol. i (1885) p. 322.

lines, and in a much later geological age folded obliquely to the old lines—cross-folding and crust-contraction having followed longitudinal folding and contraction.

The Judicarian strike in the western area is north-north-east and south-south-west, parallel with the strike of the new folds at Sella; and the development of this series has been accompanied by the development of a correlated series in a north-north-westerly and south-south-easterly direction (see p. 612), shown in the Trieste strike. Torsion of old anticlines has taken place in these directions, with the development of northern and southern fold-arcs round individual basins. The curve from Schlern to the Sexten Valley describes a northern torsion-arc round the basin of the Dolomites, while the curve from Cima d'Asta to Pieve di Cadore and Auronzo describes a southern torsion-arc round the Dolomites.

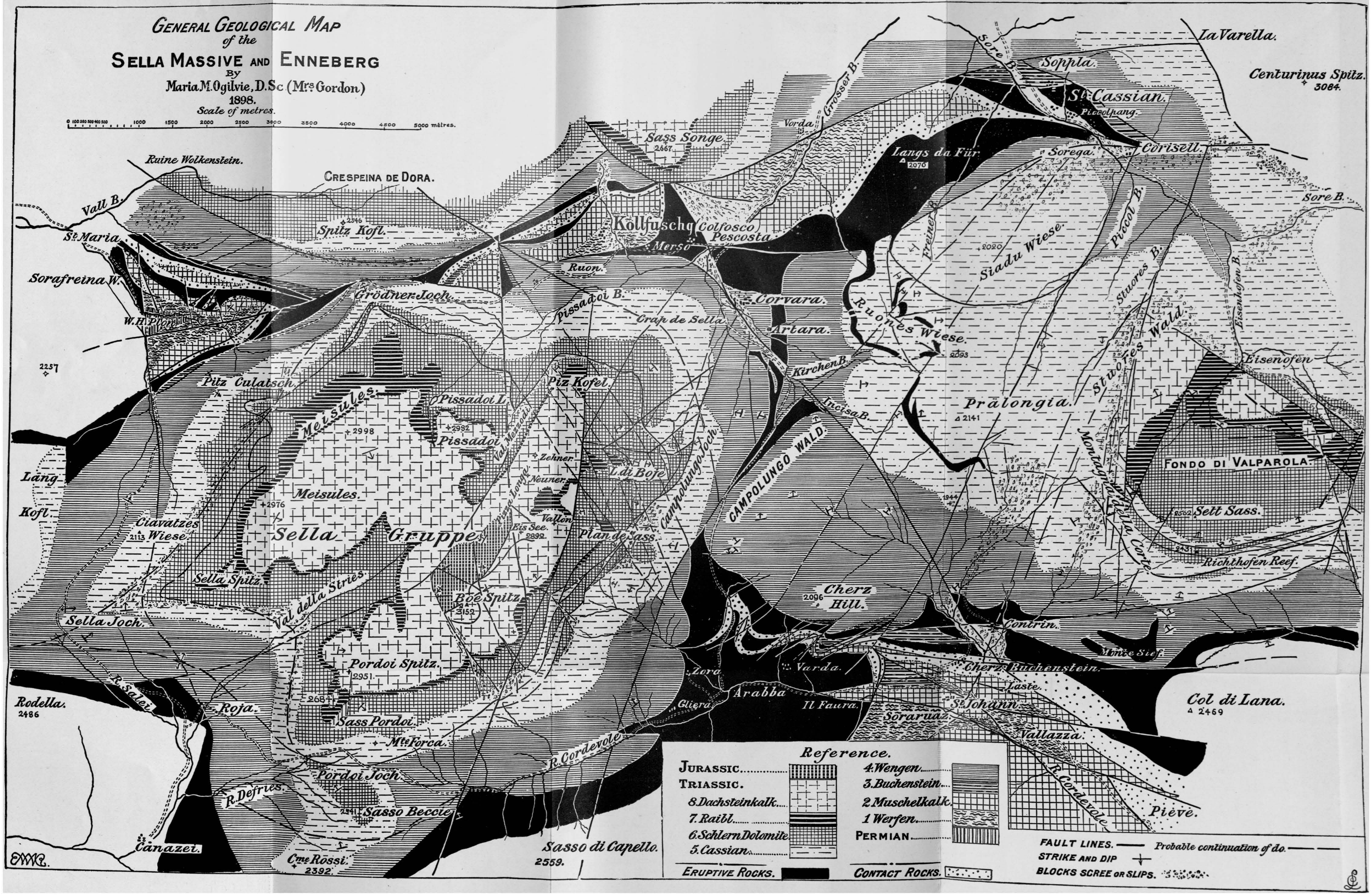
The leading curves of the torsion-system trend from west to south-west and south-south-west in the Adige and Judicarian area, and from east to south-east and south-south-east in the Carinthian and Trieste area. The large sheet of Permian porphyry presents a disturbing element in the course of the torsion-curves, dividing the Adige torsion-basin from the basin of the Dolomites and deflecting the curves round its southern edge.

The diagram shows at a glance an important general correlation. Short lines in an east-and-west direction have been drawn by the writer to indicate the existence of an older strike, as inferred above and in a former paper. These east-and-west lines are crossed by the torsion-curves at increasingly oblique angles where the curves trend south-westward and south-south-westward, and it is there where Tertiary eruptive activity has been displayed in the Judicarian region—a region of earlier Permian eruptivity.

The relation of the peri-Adriatic system of torsion-curves to the torsion-phenomena of the Alps generally cannot be discussed here. In my opinion, the principles of crust-torsion exemplified in the region of the Dolomites can be shown to be equally applicable to the structure of the entire Alpine system. This I propose to deal with elsewhere.

I cannot conclude without giving expression to a deep feeling of personal indebtedness to the writings of Prof. Suess and Dr. Bittner. The classical works in which the former has traced the great curves of the Alps and its related mountain-systems, taken together with the persistent demonstration by Dr. Bittner of the characteristics of the complicated fault-system in various regions of the Eastern Alps, lead almost inevitably to the conception of crust-torsion on a grand scale.

I must again gratefully acknowledge my great indebtedness to Baron F. von Richthofen, whose original interpretation of the Triassic succession in the Dolomite country has not only formed the foundation for the researches made by me and all other workers in the same field, but stands to-day undisturbed after forty years of controversy.



GENERAL GEOLOGICAL MAP
of the
SELLA MASSIVE AND ENNEBERG
By
Maria M. Ogilvie, D.Sc (Mrs Gordon)
1898.

My grateful thanks are especially due to Prof. Lapworth, who, with his unfailing kindness to workers in geology, has freely extended to me advice and encouragement. The reader will have gathered for himself to what extent the general inferences drawn by Prof. Lapworth accord with my own detailed field-work; and it was a matter of especial gratification to me when he consented to read this paper on my behalf at the present meeting of the Geological Society.

Finally, my cordial thanks are also due to Prof. Watts for his kindness in communicating this paper, as well as for his careful microscopic examination of the specimens of igneous rock brought by me from various localities in Enneberg.

EXPLANATION OF PLATE XL.

General Geological Map of the Sella Massive and Enneberg, on the scale of $\frac{1}{50,000}$, or about 1·267 inches to the mile.

It will be noted that a small area north-east of Vallon, left white in error, should have been shaded as Schlern Dolomite.

Discussion.

Prof. Bonney said that he had not visited the region since 1880, and then had not passed over the precise area examined. The hypothesis advanced by the Author explained many difficulties, but he had doubts about the date assigned to the eruptions, for he felt convinced that these were of Triassic age. Also he much doubted the ages assigned to the movements, namely, whether the east-and-west foldings were the earlier. He had pointed out more than ten years ago that in the Alps, most strongly in the eastern and western portions, foldings could be traced from north-north-east to south-south-west modifying the east-and-west foldings, which, however, had an even boundary on the north. The former foldings agree with post-Carboniferous and pre-Mesozoic folds, of which he gave instances. The Alps, in fact, were regions of repeated movements, and greatly as he was impressed by the ability of the paper, he must suspend his judgment till he could read and consider it thoroughly

Prof. Sollas expressed his admiration of this brilliant and solid piece of work, which had been rendered intelligible to the meanest capacity by the lucid explanation of Prof. Lapworth. In the course of the exposition we had witnessed with mingled feelings the dissolution of Richthofen's coral-reefs, as they disappeared in a chaos of thrusts and overfolds, and the evolution of a new system which was more wonderful than the old. The structure of the Dolomites still seemed to the speaker suggestive of coral-reefs, which could not have been mere fringes, but were comparable to barriers and atolls; and it was possible that in the Tyrol we were confronted with mixed phenomena. If so, the disturbances of the district could not be regarded as affecting a homogeneous system of sheets, and account should be taken of the original inequalities of the sea-floor, which might find a parallel in the tropical Pacific. The tuffs of the district could not all belong to the Tertiary era; on this point the evidence of contemporaneous Triassic corals seemed conclusive.

Prof. WATTS pointed out that, among the rocks submitted to him, there were some undoubted tuffs, some augite-porphyrites and labradorite-porphyrites, the constituents of which occurred in the tuffs, and one example of a rock which appears to be related to liebenerite-porphyrites.

Dr. J. W. GREGORY expressed his congratulations to the Author on the brilliant results attained by the combined application of stratigraphy and palæontology. He doubted whether the coral-reef theory would have been proposed had any detailed study of the corals been then made. The resemblances between the dolomites in the Eastern and Western Alps was of much interest: in the latter area the principal Triassic dolomite-mass was similarly isolated by faults and intersected by thrust-planes, and the reef-corals described from it were of Upper Mesozoic age and had been let down into the dolomites by trough-faults. With reference to the age of the volcanic rocks, it had been proved in the Cottians that they belonged to more than one age. Along the great bow of the Western Alps there were outcrops of massive igneous rocks in positions analogous to those along the Judicarian line, and the speaker had endeavoured to show that they were later than the Middle Kainozoic.

Prof. LAPWORTH pointed out that the Author recognized the existence of contemporaneous igneous rocks and tuffs in the Buchenstein-Cassian succession of Triassic age; but she claimed that the igneous rocks occurring in the fault-lines were intrusive, and were of Tertiary date. This paper was the result of several seasons of hard field-work in a critical area of the Dolomite country, by one who had previously made herself familiar with all the stratigraphical zones. He was himself prepared to accept her description of the complex folding and faulting in the area covered by her work in the field; and he looked upon her map and sections of that area as a most important and suggestive contribution to our knowledge of Alpine stratigraphy.