The Monzoni Group.

Frontispiece

THE GEOLOGICAL STRUCTURE

OF

MONZONI AND FASSA

BY

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WITH 14 PHOTOGRAPHS, 33 FIGURES, 4 GEOLOGICAL SECTIONS (BLACK AND WHITE), 8 GEOLOGICAL SECTIONS (COLOURED), 1 TABLE OF STRATIGRAPHICAL SUCCESSION, 1 COLOURED GEOLOGICAL MAP, AND 1 REFERENCE CONTOUR AND FAULT MAP.

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PREFATORY NOTE.

THE geological map which accompanies this paper was completed by me in *August* 1901 ; I have not since revisited the country. In *June* 1902, Professor Lapworth presented at the Royal Society of London my geological map and sections, a complete account of the geology of the Monzoni, Contrin, and Campagnazza area, and an *Abstract* of the paper ; the paper was officially "read" at the Society on June 19th of that year. On July 1st, 1902, a copy of the abstract appeared in the Geological Magazine. I then learnt that the publication of the abstract in another magazine previous to its publication in the Proceedings of the Royal Society might invalidate my paper at that Society. I at once set to work to write a new paper dealing with Rodella and the Donna Mountain, and also including the Monzoni area. That second paper was presented at the Royal Society by Professor Ray Lankester in *October* 1902, but in the end of *January* 1903 I was informed that it was rejected by the Geological Sectional Committee. At the same time I was told that the manuscript of my first paper on Monzoni would be kept in the Archives of the Royal Society, the scientific priority of my observations dating from its formal "*Reading*" *on June* 19th, 1902.

The Geological Society of Edinburgh called a special meeting on February 5th to hear and discuss my second paper, after which the Council resolved to publish it, with maps and illustrations, as a special number of the Transactions of that Society. I have to express my sincere gratitude to Dr Horne, F.R.S., of the Geological Survey of Scotland, for his inestimable assistance in getting my paper through the press ; also to Mr James Currie, Hon. Secretary, and to the Fellows of the Geological Society of Edinburgh for the interest they have displayed in the geological results of this paper, regarded from the general standpoint of structural geology.

In November and December 1902, I received authors' copies of papers on the Predazzo and Monzoni district by Professor

Doelter of Graz, and Professor Romberg of Berlin; in February 1903 another paper came from Professor Romberg describing field-observations made by him in Monzoni in the summer and autumn of 1902. As all my field-observations in that area had already been laid before the Royal Society in the foregoing June, my work naturally contains no reference to those papers.

It may be helpful to those geologists who intend to visit the neighbourhood on the occasion of the International Geological Congress at Vienna, if I mention that Herr Johann Trappmann, school teacher in Vigo, accompanied me throughout all my investigations in Monzoni and Fassa, carrying my camera, rücksack, etc. He knows accurately all the localities where I discovered good fossils, and I specially directed his attention to the places where I discovered the Wengen-Cassian strata, to the best occurrences of the new fossiliferous horizon of the passage-beds, and to the most important fault-dykes. I had hoped to commission him to collect more fossils for me in the event of a desire being expressed by Geheimrath von Zittel or Dr. Broili to have the new palæontological horizon completely investigated. But the Munich authorities had no wish to go farther in the work. And my own investigations at Monzoni which I had intended to continue in 1902 were practically stopped when I heard that both from German and from Austrian sides, revised geological maps of the area were being started.

February 1903.

CONTENTS.

PART I.

PART II.

PART III.

PART IV.

PART V.

PART VI.

LIST OF ILLUSTRATIONS.

PHOTOGRAPHS.

COLOURED GEOLOGICAL SECTIONS.

(Scale 1 : 25,000.)

At end of Volume.

INTRODUCTORY.

Study of Cross-Movements—Special Literature of the District—Author's Position in 1899—*Author's Advance since* 1899.

ELEVEN years have passed since, in 1891, I began my observations in the Dolomites, and in proportion as my geological experience has extended, I have been able to take a fuller grasp of the difficulties of that region. Each new paper that I have published marks a stage in advance of its predecessor; and all the facts obtained by me in the Dolomites lead towards the same general result.

The paper [1] published in 1893 included geological maps of three typical areas in the Dolomites. The map of Dürrenstein mountain (Map C, p. 32) and the sections (l.c. pp. 34 and 35) show that overthrusts and downslips had there taken place with E.N.E.-W.S.W. strike and low inclination towards S.S.E.; and that subsequently the inclined shear-planes and the overthrust and underlaid rock masses had been dragged and displaced by faults directed N.N.E.-S.S.W., N.N.W.-S.S.E., and nearly north-south; the downthrows were on the west of these diagonal and transverse faults, the thrust having acted from E.N.E. (l.c. fig. 9). The map of Falzarego Valley and Cortina (Map B, p. 28) shows a leading fault, curving from W.S.W.-E.N.E. direction to N.E. and N.N.E., and a group of N.N.W., N.W., W.N.W., and west-east faults radial in direction to this curve and intersecting it. In the tectonic chapter I pointed out that the strike of the strata in Falzarego Valley, like the curved fault, veered from an almost east-west direction and dip north to an almost north-south direction and dip west, and that the "bending-round" of the strata had been accomplished by means of these radial faults dislocating an older fault (l.c. p. 98). In the same paper a

[1] Miss Ogilvie, "Contributions to the Geology of the Wengen and Cassian Strata in Southern Tyrol," Quart. Journ. Geol. Soc., 1893.

section in Abtey Valley (fig. 5, p. 28) shows that a series of strata has been overcast towards the south and cut by a reverse fault inclined northward, so that whereas the overthrusts at Dürrenstein had been directed towards N.N.W., this was an example of an overthrust towards the south.

In the autumn of 1893, I laid before Professor Rothpletz my geological map of Sella Massive and Buchenstein Valley—the same which was published six years afterwards by the Geological Society of London (see footnote, p. 3). Professor Rothpletz disadvised the publication of this map in 1893 because the observations did not agree with any previously made in the Dolomites, and also because I had not determined whether the N.N.E.-S.S.W. fault on the east of Sella Massive continued across Gröden Pass. The novelty of my observations consisted chiefly in the evidence they afforded that within a comparatively small area a number of folds, overfolds, and inclined planes of overthrust and downslip had been developed along curved directions of strike, or crossing one another, and inclined towards quite different points of the compass. According to my map, the Sasso Pitschi thrust-plane on the south of Sella Massive inclined north, overthrust having taken place towards the south, but on the east side of Sella overthrusts had occurred towards the east, and on the north of Sella overthrust had been towards the N.N.W. These and certain observations of radiating fault-bundles, and of oblique faults cutting older thrust-planes, had more in common with Professor Lossen's work on the Harz mountains [1] than with any Alpine structures then known. My map and sections failed to convince Professor Rothpletz, and as I could give no sufficient explanation of the observed phenomena I agreed it was best to postpone their publication. I limited myself at that time to a brief statement of the chief tectonic and palæontological features, with some diagrams.[2]

During the next few years, observations of cross-movements began to be obtained in Switzerland. Dr Burckhardt's

[1] Professor Lossen, "Geol. u. Petrogr. Beiträge zur Kenntniss des Harzes," Jahrb. K. Pr. Geol. Landesanstalt in der Akad, 1882.

[2] Miss Ogilvie, "Coral in the Dolomites," Geological Magazine, Jan. and Feb. 1894.

work[1] on the Klön and Linth district made known the complex character of the folds that commenced to form in that district during late Eocene or Oligocene time. Dr Burckhardt showed that a system of folds overcast towards the north had developed in the southern part of the district but that in the area of the northern facies two obliquely intersecting fold-systems had been produced. Thus in Switzerland phenomena were described resembling those I had found in the Dolomites.

In 1897, Professor Rothpletz published a preliminary account[2] of his work on the structure of the Glarus Alps.

When I read these Swiss papers, I took courage to send my maps of Sella and Buchenstein to the Geological Society of London, spending three or four days at Gröden Pass to complete my investigation of the N.N.E.-S.S.W. fault and to confirm my previous observations on the distribution of the igneous rocks in the Pass; then going to Switzerland to see for myself how far my observations in the Dolomites corresponded with Swiss Alpine structures.

In 1898, a preliminary account of my paper on cross-folding in the Dolomites was given in the Proceedings of the Geological Society and in 1899 the full paper[3] appeared. It was entitled "Torsion-Structure" in deference to the resemblance between my observations and those to which Professor Lossen had applied the term "torsion."

Immediately after the publication of this paper I contributed to *Nature* (Sept. 7, 1899) a short article indicating the most striking features of general resemblance between the geological structures I had demonstrated in the Dolomites and those in other Alpine regions. In 1899, I also read two special papers[4] on the causes and effects of crust-torsion, at the British Association Meeting in Dover, and at the Inter-

[1] Burckhardt, "Monographie der Kreideketten zur Klönthal, Sihl, u. Linth," Beitr. zur Geol. Karte der Schweiz, 1896, Neue Folge, V. Lieferung.

[2] Rothpletz, "Ueber den Geol. Bau des Glärnisch," Zeitschr. d. D. Geol. Gesell. 1897.

[3] Mrs Ogilvie Gordon, "The Torsion-Structure of the Dolomites," Quart. Journ. Geol. Soc., 1899.

[4] Mrs Ogilvie Gordon, "On Sigmoidal Curves," Brit. Assoc. Reports, 1899. "The Crust-Basins of Southern Europe," Intern. Geogr. Congr. Report, Berlin, 1899.

national Geographical Congress in Berlin, showing different aspects of the subject of crust-deformation in relation to local intersecting directions of "strike" either simultaneously or successively induced, and illustrating these from several special areas in Southern Europe.

I purposely selected as the text upon which I demonstrated cross-movements in the Alps, not any area in the Dolomites, but the better known area of Glarus that had been made famous in geology by the researches of Professor Heim. I showed that Glarus was comprised in a local area of subsidence liable to subsidiary movements during or intermittently with the sequence of Alpine movements. I drew a sketch-map of the area that I defined as the Glarus Basin and showed the intersection of different folds and fault-systems, viz., the *leading Alpine strike* at this part directed N.E.-S.W., and the N.W.-S.E. and other *local strikes* following the smaller strike-curves of this Glarus Crust-Basin.

Passing from my illustrative sketch-map of Glarus, I discussed the subject of intersecting faults on general physical principles; showing how the leading strike-curve in any plicated region had reference to some basin of subsidence in the earth's crust, how in one and the same region strike-curves might form with reference to subsiding basins of quite different magnitudes, and that the subsidiary curves relating to the smaller local areas of subsidence were bound to intersect, and be intersected by, the major curves that related to some much wider area of subsidence. I defined the chief local crust-basins which had been determined in the Alpine and Mediterranean region, and demonstrated from my own results in the Dolomites how in all cases local strikes and strike-curves bore relation to local deformational movements initiated in virtue of the local subsidences, relative compression, and different resistances of rock-masses, and that such movements had occurred intermittently with the grander regional movements affecting Southern Europe. While a certain simultaneity of the local and regional movements must have been unavoidable, I emphasised the numerous evidences in the Dolomites that *intensity in the local adjustment movements,* the local inthrows, the local intrusions, was a characteristic which signalised the decadence period of some important regional movement.

Referring to my proofs that in the Dolomites a prolonged sequence of Tertiary movements had occurred, I led forward numerous evidences that cross-deformation with similar effects of crust-torsion had occurred throughout the Alps, and might be traced (1) to the inevitable *superposition of local and regional strains* in Alpine areas during regional Tertiary movements, seeing that the rock-developments in contiguous Alpine areas exhibited remarkable differences in their physical character; (2) to the superinduced *transversely or obliquely-acting* strains either local or regional in character initiated during a regional movement; (3) to the *periodic variations* in the intensity and horizontal direction of the thrusts causing the grander deformational movements themselves, or those causing subsidiary local movements at special areas, or at certain limited horizons of the crust.

I illustrated from my own maps the leading phenomena due to cross-movements in the Dolomites—such as the curved strikes and unequal thicknesses of the more yielding stratigraphical horizons; radiating fault-groups in the less yielding horizons; faults found to be inclined at varying angles to the horizontal as they are followed from place to place; fault-lines dying out in one direction and the line of throw continuing in a different direction; overfolded masses subjected to subsequent cross-deformation and segmentation, and the segments thrown back at some oblique angle to, or opposite to, the former direction of thrust; intersecting faults initiated at different ages, but along both, or all of which at a still later age differential shearing took place and gave rise to the loop-shaped, sickle or sigmoidal fault-curves, which might be regarded as the most notable tectonic feature in the Alps. In more general terms, I traced the marked effects of crust-torsion to the local deviations produced in virtue of local conditions when any powerful horizontal thrust from a particular direction affects an area that has already been folded and faulted along some other direction or directions of strike,—an area, that has within itself definite lines, localities, and horizons of special crust-weakness developed in virtue of crust-deformation, and quite additional to the original lines, localities, and horizons of crust-weakness that arise from the natural differences of rock-deposits, and the contiguity of areas with very different types and thicknesses of rock-formations.

In 1898 and 1900, Professor Rothpletz published his important works on the Glarus [1] and Rhaetikon [2] Alps. Professor Rothpletz showed that folds had formed in curved directions of strike, and had been overcast towards different points of the compass. A main Glarus Thrust-mass had travelled from the east or south-east. On the other hand in the Schild district in the west of Glarus, thrust-masses subsequently travelled from the N.W. direction. East of the Rhine Valley, Professor Rothpletz described a Rhaetikon Thrust-mass which had advanced from the east upon the eastward continuation of the Glarus Thrust-mass. As I reviewed these works in *Nature* (Jan. 24, 1901) it is not necessary to discuss them farther here.

At the close of 1900, Dr Lorenz published a highly interesting geological monograph of an area,[3] close to the Rhine Valley, between Glarus and the Rhaetikon. Dr Lorenz determined that cross-folds parallel with two strikes had been developed in this area, a N.W.-S.E. and a N.E.-S.W. strike. He associated the N.W.-S.E. strike with the curve round the north of a *local Glarus crust-basin*; the N.E.-S.W. strike with the Swiss-Alpine strike. Dr Lorenz inclined to the opinion that the determination of the local crust-basin was older than the regional Alpine folding in N.E.-S.W. direction of strike.

A more recent work [4] by Dr Lorenz treats the stratigraphy of an adjoining district in the Rhaetikon.

[1] Rothpletz, "Das Geotektonische Problem der Glarner Alpen," Jena 1898.

[2] Rothpletz, "Geol. Alpenforschungen I. Das Grenzgebiet zw. den Ost u. West Alpen u. die Rhätische Ueberschiebung," München, 1900.

[3] Lorenz, "Monographie des Fläscher Gebirges," Beitr. zur. Geol. Karte des Schweiz 1900, Neue Folge X. Lieferung.

[4] Lorenz, "Geol. Studien im Grenzgebiete zw. Helvetischer u. Ostalpiner Facies," II. Theil. "Südlicher Rhaetikon" (Ber. d. naturf. Gesells. zu Freiburg Bd. xii.) 1901.

Special Literature of the District.

The contributions to the geology and the mineralogy of this district have been very numerous. In the course of my researches I have had occasion to refer among the older standard works to these of Baron von Richthofen,[1] Professor Doelter,[2] Geh. Dr. von Mojsisovics;[3] among the newer works to those of Professor Broegger,[4] Professor Salomon,[5] Dr Weber,[6] Herr O. v. Huber,[7] Professor Romberg.[8] In July 1902 I published a short account of the sequence of the igneous intrusions in Monzoni and Upper Fassa, based upon my own researches in that district.[9]

Author's Position in 1899.

The sequence of the Triassic rocks in the Dolomites was given in detail in several of my papers; reference may be made to a special paper "On the Upper Cassian Zone"[10] wherein I pointed out that the horizons of Upper Cassian strata *above* the *Koninckina Leonhardti* and *Cardita crenata* zone ("Stuores" or Lower-Cassian zone) were those in which the faunas were most local in character and in which the occasional beds of coral reef limestone were most developed. This zone is succeeded in the Sella-Cassian area by a varying thickness of Schlern dolomite and Raibl strata.

[1] V. Richthofen, "Geogr. Karte der Umgegend von Predazzo," 1859.

[2] Doelter, "Der Geolog. Bau, die Gesteine und Mineralfundstätten des Monzonigebirges in Tirol," Jahrb. der k. k. Reichsanst, 1875.

[3] V. Mojsisovics, "Die Dolomit-Riffe von Süd-Tyrol u. Venetien," 1879.

[4] Broegger, "Die Eruptivgesteine des Kristiania-gebietes." II. "Die Eruptionsfolge der Triadischen Eruptivgesteine bei Predazzo in Süd-Tyrol," Kristiania, 1895.

[5] Salomon, "Geol. u. paläont. Studien über die Marmolata," Palæontographica, 1895, pp. 1-210. "Ueber Alter; Lagerungsform u. Entstehungsart der periadriatischen granitischkörnigen Massen," Tscherm. Min. u. Petr. Mitth. vol. xviii. pp. 109-283.

[6] Weber, "Die Contactvërhaltnisse vom Monzonithal nach Allochet." (Inaugural Dissertation) Würzburg, 1899.

[7] O. v. Huber, "Beitrag zu einer geolog. Karte des Fleimser Eruptivgebietes," Jahrb. der k. k. geol. Reichsanst, 1901.

[8] Romberg, "Vorarbeiten zur geol-petrogr. Untersuchung des gebietes von Predazzo (Südtyrol) Sitzungsber. der k. pr. Akad der Wiss," Berlin, 1901.

[9] Ogilvie Gordon, "Monzoni and Upper Fassa," Geological Magazine, 1902.

[10] Ogilvie Gordon, "Ueber die Obere Cassianer Zone an der Falzarego-Strasse" (Südtirol) Verhandl. der k. k. Geol. Reichsanst, Vienna, 1900. *Cf.* Geological Magazine, 1900.

The paper published by me in 1899 in the Quarterly Journal of the Geological Society of London was specially devoted to the tectonic problems, and to my mind proved the following propositions :—

(1) The only effusive and contemporaneous igneous rocks originally interbedded with the sediments are the contemporaneous tuffs and lavas in the Wengen-Cassian series.

(2) Large sheets and many small occurrences of augite porphyrite and the amygdaloidal "melaphyre" types are of subsequent age and are intrusive in the sediments as sills and dykes of Tertiary age. My map demonstration of the occurrences of these igneous rocks at the Gröden Pass in intersecting Tertiary faults, and at Col di Lana and in Buchenstein Valley also in Tertiary faults, as a system of dykes and sills, brought forward *the first proof of Tertiary porphyrites and melaphyres* in this region.

(3) The so-called "Buchenstein agglomerates" are not Triassic volcanic products, but shear-breccias or "fault-rock," sometimes formed from the Wengen mixed tuffs, lavas, and shales, sometimes from Mendola dolomite or Buchenstein calcareous horizons, and sometimes impregnated with ramifications from intrusive igneous material in the fault-zone.

(4) The sedimentary rocks of the Sella-Cassian country were folded by distinct regional crust-movements, an earlier East-Alpine series directed along an almost east-west strike and a later Asta-Judicarian series with a highly complex system of strikes in E.N.E.-W.S.W., N.E.-S.W., and N.N.E.-S.S.W. directions. The sedimentary rocks were during Asta-Judicarian epochs of movement subjected to complicated torsion phenomena, originating definite assemblages of torsion-lines, and faults and overfaults of curious types and effects. Interference phenomena were associated with local deformational movements around masses of more resisting rock such as the Permian Quartz Porphyry, or areas of local subsidence.

(5) The highest horizons of sedimentary rock preserved in the Sella-Cassian districts examined by me are the Jurassic deposits, and they were folded by both movements. In adjoining parts of the Dolomites and in the neighbouring

Adige Basin, the Asta-Judicarian faults, folds and thrusts have affected all the geological horizons, from Permian to Eocene inclusive, and cannot be older in initiation and development than the late-Eocene, Oligocene-Miocene, and later ages.

Author's Advance since 1899.

During the two summers, 1900-1901, I spent much time in mapping the region lying to the south of the Sella country, as far as the southern slopes of Monzoni, in order to ascertain if the structure of this southern region corresponded with that which I had already worked out to the north. I find that from end to end of this southern district, the geological, petrological, and structural phenomena are the natural expression of those in the Sella-Cassian country, and admit of the same interpretations. There is no evidence that the massive thicknesses of calcareous rock originated as *isolated* reef-growths, either coral or algal—they are marine formations and contain locally coral or algal remains, but also rich molluscan and other faunas; the calcareous rocks are ordinary erosion remnants of a wide sheet of deposit.

The sedimentary succession in the Fassa-Monzoni country is simply the extension of that in the Sella country, with the same lithological and palæontological individualities except in the case of the Wengen-Cassian horizons and the calcareo-dolomitic rocks above. The "Schlern Dolomite" is represented here by a bedded calcareous or calcareo-dolomitic series at whose base there is only a thinly-developed succession of Cassian shaly and impure limestone and of Wengen tuffs, lavas, tufaceous grits, marls, and plant shales. My discovery of Wengen-Cassian strata in this locality for the first time and of a definite fossiliferous horizon in the passage-bands between Upper Werfen strata and the horizon of Mendola Dolomite greatly aided the geological mapping (*cf.* pp. 20, 29).

Owing to the transitional state of the mineralogical nomenclature in the case of the monzonites and other igneous rocks of Monzoni, and to the fact that the best mineralogists in Berlin and Vienna were to revise the mineralogy of Monzoni and Predazzo, I made no attempt to distinguish the fine gradations of igneous varieties, but concentrated my attention on the relation of the leading types to the deformational lines of structure, and I discovered (*a*) that a very important fault-zone runs through Monzoni on the north slope from Allochet nearly to Malinverno, then bends to S.S.E., this line of fault being parallel with the limiting faults on the north and west of Monzoni; (*b*) that several cross-faults segment the Monzoni massive and are more particularly the seat of the youngest injections.[1]

By close attention to the cleavages, faults, and foldings in the different igneous rocks in Monzoni, and by comparison of these structural lines or forms with the structural lines and forms exhibited in the sedimentary strata, and in the augite porphyrite, augite and plagioclase porphyrite, and melaphyres of neighbouring areas, I devised a new method for that country of determining the ages of the intrusive masses and dykes, a method based upon their relation to the succession of deformational movements, of which I had for many years made a special study. The results obtained by this field-method can only be of a general character, and it is scarcely possible to compare them with the results obtained up to the present time along mineralogical lines. Moreover it would take several years to make a complete map of Monzoni; and not until both the cartography and mineralogy are exhaustively investigated in Monzoni and Fassa, can the results be entirely satisfactory. But, while I am thoroughly conscious of the inadequacy of my own individual work, it has at least the merit of demonstrating securely upon stratigraphical and upon structural grounds that the intrusions in Monzoni and Fassa were associated with that long series of Tertiary crust-movements, coming now from one direction, now from another, which gave rise to so many apparent anomalies of structure in the Dolomites.

In delineating the sequence of igneous rocks in Monzoni, I pointed out (*Geol. Mag.*, 1902) the great tectonic importance of distinguishing amongst the varieties of monzonite in Monzoni these biotite and augite varieties, which have always

[1] I made known these discoveries in June 1902 at the Royal Society of London, and they were published in the Abstract (*Geol. Mag.*, July 1902).

been regarded as the "normal type" of monzonite in Monzoni, from certain younger types, chiefly fine-grained, richly felspathic types and quartz-bearing varieties. I showed that whereas the "normal monzonite" had been at the leading fault-zone very much altered, sheared, and slickensided, and intercalated with copious injections of gabbros, diorites, and pyroxenites, the *younger* highly felspathic or quartz-bearing monzonites had been intruded very much later into fault and contact limits as veins or dykes in the gabbro, diorite and pyroxenite series as well as in the *older* monzonites. Their mode of distribution showed that the younger monzonite varieties belonged together with granite, quartz-syenite, syenite, and syenite porphyry intrusions to that advanced epoch in the history of the Judicarian cross-movement when the N.W.-S.E. and almost north-south faults were being developed in Monzoni, and *after* the copious sills of porphyrite had been intruded in the neighbouring area of Fassa.

With regard to the form assumed by the several intrusive masses in the Dolomites, I have throughout my whole series of papers avoided the use of any such term as *laccolite, batholite,* etc., as the cases examined by me do not correspond to any of the recognised descriptions of such masses. The forms assumed by the intrusive masses in the Dolomites are so varied that it is impossible to select any one form as a set standard. The igneous rocks have entered fault-zones and horizons of weakness in the sedimentary strata of the earth's crust, and are essentially *dyke-and-sill* systems. Where, as at Col Guschel, Pocol, Col Lares, Varos, and other places the covering strata above a copious sill of porphyrite are partially preserved, these are not gently arched, but are crumpled and tilted, brecciated or schistose, show contact alteration and are penetrated with finer sill-and-dyke ramifications from the larger sill. According to my observations, no large intrusive mass occurs except in the line of some pre-existing fault or faults, and I have found that from a comparatively narrow fault-zone in which the rock-magma has ascended, it has sent sill-ramifications of various sizes here and there into the successive horizons of the crust, the sills ascending both in bedding and cleavage-planes. The sills have spread most copiously at critical zones of weakness in the crust, more especially in the mixed Upper Werfen Series which had previously been very much split up by inclined fault and cleavage planes, and in the lower and upper limiting-horizons of the thick calcareous deposits, the calcareous rocks becoming locally engulfed or closely threaded with smaller sills and dykes. Sometimes the horizontal extension of the magma has taken place only on one side of a leading fault; *e.g.* at Monzoni, Col del Lares, Cherz Hill, Col di Lana, etc., where the extension of the sills has taken place on the south side of leading east-west faults. This is common in Fassa and Enneberg, because of the predominance of bedding-planes and inclined faults inclined towards north or north-west direction, hence, as seen in my geological sections, many of the sills lie wedge-shaped in the strata. Sometimes horizontal extension of the magma has taken place on both sides of a leading fault, not by any means equally, still in such a way as to give a certain resemblance to a saucer-shaped or cup-shaped intrusive mass, passing downward into one or more narrow fault-dykes; Mt. Donna is a fairly good example. Other local forms, such as the domal sill are called attention to in the course of the paper.

Above all, my previous paper in 1899 and this paper establish the fact that the earlier intrusions ran along the N.N.E.-S.S.W., N.E.-SW., and E.N.E.-W.S.W. lines of disturbance, as well as the E.-W. or W.N.W.-E.S.E. fault-lines, —in short, that they ascended intersecting faults. And where the magma spread on one side only of two intersecting faults, in an angle as it were, the intrusive mass was afterwards bounded by more or less curved or hook-shaped limits, and these limits were after the intrusion more than ever defined as places of differential strains. My new field-observations bring out more and more clearly the determining influence exercised by pre-existing planes of stratification, cleavage, or faulting, upon the particular local distribution of the igneous magma. It may be said generally that whether connected with longitudinal or cross-faults, the larger sills are limited in their east and west extension by some well-marked flexure of the sedimentary strata associated with the cross-plication of the rocks; and farther, that such flexures are proximal to or continuous with leading N.N.E.-S.S.W., N.E.-S.W., or E.N.E.-W.S.W. lines of disturbance, many of which were subject to differential movements subsequently to the earlier intrusions.

This all-important structural fact, viz., the intercalation of igneous material in the several Judicarian lines of disturbance and in the series of thrust-masses, as well as in the east-west faults, is really the key to the geological structure of the Dolomites. In the absence of any remnants of Eocene strata in the neighbourhood of Fassa, it alone gives direct evidence of the Tertiary age of the intrusions; for these faults belong to a system that cannot have begun to develop until the late-Eocene or Oligocene Alpine movements, and therefore the relation of the igneous rocks to them shows that the intrusions were at anyrate not earlier than that geological epoch. I brought forward in 1898-99 this evidence for the area of Enneberg and Sella, and now in 1902 am able to establish it for the far grander and, geologically, more widely known occurrences of igneous rock in Fassa and Monzoni.

Briefly stating the more general tectonic features regarding the intrusive rocks, all the massive sheets of igneous rock in the Fassa-Monzoni district are intrusive and were intercalated during the Asta-Judicarian epochs of movement, *i.e.* they are of Tertiary age. The chief intrusions took place at localities where the leading east-west or W.N.W.-E.S.E. faults were intersected by later faults and fault-groups. In the case of copious sill-flows, the igneous magma sought out more especially as its floor these critical horizons or bands of weakness in the crust which on account of the strongly contrasted physical characters of subjacent layers had been the seat of extreme differential strains during the previous crust-disturbances, and had been cut up by innumerable shear-planes. On these planes the torsion of individual rock-segments was slowly effected, and from time to time fresh fractures formed across them, to be followed by later intercalations from a still more specialised magma.

In the Fassa and Monzoni district there are the same evidences as in the Sella country of cross-folding and cross-thrusting. But now I furnish a mass of new evidence to show how greatly extended in time these movements were, how extremely complex in their deformational effects, and how essentially the history of intermittent intercalations of igneous material was knit up with a long history of local subsidences taking place within the Periadriatic region of the Alps and producing effects which inevitably interfered with the movements of Alpine distribution.

The Fassa and Monzoni district is essentially composed of a series of thrust-masses which represents a dislocated series of overcast folds with steep southern flexure. The fundamental strike of the strata in these thrust-masses is W.N.W., E.S.E. (N. 80° W.), nevertheless there are several leading faults which run due east-west, and appear to be of more ancient date. The stratified rocks of the thrust-masses have been gently folded parallel with the W.N.W.-E.S.E. strike, and dislocated by W.N.W.-E.S.E. strike-faults against which the compression has then been intensified. The strike-faults form a "step" series in Fassa, with downthrow on the north, so that subsequently to the intense epoch of thrust towards the south (or S.S.W.) there took place a certain reversal or relaxation of the north-south strains, and bands of rock slowly subsided in areas *over which previously crust-creep had advanced.*

This folding, step-faulting, and inthrowing of the thrust-masses *parallel with their strike* exercised an important retaining influence upon all subsequent deformational events. It was followed by intensified action of the crust-stresses *transverse or locally oblique to those previously-acting.* On the opposite sides of leading N.N.E.-S.S.W. faults cross-bands of the thrust-masses were vertically displaced, local basins of inthrow were defined, limited by the intersecting faults, and warped fold-systems formed following a curved strike round the south-east, and with steep knee-bent flexures facing the south-east or east. In addition to the leading N.N.E.-S.S.W. faults, fan-like groups of N.N.E., N.E., and E.N.E. faults were initiated, the area of convergence being always located where an older W.N.W.-E.S.E. or east-west fault was intersected by a later transverse fault. The strike of the strata in close proximity to any of the N.N.E., N.E., or E.N.E. faults shows a series of deflections from an east-west or almost east-west strike to the particular direction of the fault, and the strata are at these faults and at the W.N.W.-E.S.E. strike-faults closely folded and puckered, *but in a distorted way,* the folds like the strike undergoing rapid deflections, varying in form, and owing to the previous displacements affecting quite different horizons of the crust in adjacent localities. The phenomena of deformation attending the development of these fan-like groups of faults, and warped folds and over-folds, were those which I termed characteristic Torsion-phenomena.

During the more advanced stages of the transverse movement, there was, in the immediate proximity of areas of local subsidence of rock-masses, a marked tendency to overthrow of the steep flexures and distorted folds, and the development of reverse and normal fault-planes, followed by the inflow of rock magma into various horizons of the sedimentary mantle of strata. In Rodella and Fassa the chief over-thrusting at this period took place from N.N.W., N.W., or W.N.W. direction towards S.S.E., S.E., or E.S.E.; and normal fault-planes with downthrow towards N.N.W. or N.W. were then initiated, some of these having as low an inclination as 15° or 20°, so that the strains were essentially gliding and shearing strains at critical horizons of weakness in the crust. The resisting homogeneous groups of calcareous or calcareo-dolomitic strata were penetrated by systems of fine divisional planes inclined N.W. or S.E., many of which afterwards acted as planes of differential movement.

Over the old thrust-masses now much dislocated and distorted, and embodying invasions of igneous rock, there passed a folding-movement whose general strike was directed N. 40°-50° E., but was subject to local deflections. It was again followed by overthrusts, downslips, inthrows, and igneous intercalations, having relation to the newer and older directions of crust-fracture and to new local readjustments. As local differential strains transverse or oblique to the N.E.-S.W. strike increased in influence and the axes of elongation or least resistance altered, very curious effects were produced of back-folding and thrusting towards the directions opposite, or slightly oblique to, the former overfolds and overthrusts. The portions of the older thrust-masses that had in earlier stages swung round towards the N.E.-S.W. direction of strike and been thrust S.S.E. upon planes inclined N.N.W., were naturally specially susceptible of torsional movements at any fresh horizontal compressive stress in the crust. In the course of the N.E.-S.W. folding and subsequent deformation, they were crumpled, faulted and cleaved along N.E.-S.W. strike, and sheared slices locally glided or were carried back on planes inclined towards E.S.E., S.S.E., or S.S.W. In many cases these were gradually nipped laterally from all connection with the rest of the thrust-mass, and left as curious, isolated remnants resting upon low shear-planes, inclined oppositely or obliquely to one another. The shear-planes at a first glance might be very easily mistaken for mere bedding or cleavage planes. The reverse and normal fault-planes inclined S.S.E., S.E., or E.S.E. in the leading examples in this area, *e.g.* the faults round the north and west of Bufaure, Forca Alpe, Varos, Monzoni, are planes of differential movement between rocks of markedly different petrological character and elasticity.

The differential strains transverse to the N.E.-S.W. direction of strike also induced the development of local groups of torsion-faults roughly transverse to the N.N.E., N.E., and E.N.E. fault-bundles and therefore following W.N.W.-E.S.E., N.W.-S.E., and N.N.W.-S.S.E. directions. These have as a rule a very short course, merely from one of the older leading faults to the next on the south. The N.N.W.-S.S.E. lines of faults have sometimes a longer course. There likewise developed a vertical or high-dipping system of cleavage-planes or steep joints in N.N.W.-S.S.E. direction, sometimes almost north-south, well evinced in the igneous and calcareous rocks. A gentle roll of the strata parallel with some of these later fault-lines or parallel with older strike-directions has been subsequently developed in several localities, but this feature is merely an example of the fact that at any or all stages of the crust-deformation local plications were induced in the proximity of many of the pre-existing fault-lines. The Fassa-Monzoni district gives conclusive evidence of the influence of faults upon forms of deformation. After the fault-lines had developed in diverging bundles and in obliquely and rectangularly intersecting directions, there was little opportunity for the formation of linear and symmetrical folds; the recurrences of horizontal compression only effected partial and unsymmetrical plications following curved strikes determined by local conditions.

A marked feature throughout the whole sequence of deformation was the tendency for certain groups, or limited shear-slices, of the interbedded Werfen marls and marly or granular limestones to be nipped up as short folds, and strongly squeezed and attenuated between down-slipping masses of the calcareous, or in later stages the calcareous and igneous rocks, which were primarily above them in position in the crust. Such groups are preserved as irregular crush layers, lenticles or wedges wholly environed by the rocks into whose midst they were squeezed.

The streaming of the igneous magmas seems to have practically followed the same laws of movement as the rock-strata; the igneous material ascended in the crust at different periods in correlation with local dislocation and subsidence of rock-masses; the igneous inflows, while certain of them retained connection with the deeper-seated reservoirs, were enwrapt as lenticles or wedges of incompletely-consolidated magma amidst the Triassic succession; there undergoing still farther stages of segregation, alteration, consolidation, and deformation; and being repeatedly intercalated with fresh protrusions or threads ramifying in the fissures and cleavages. The crumpling, cleavage, faulting and thrusting followed the same directions in the igneous masses and in the sedimentary strata; but the igneous rocks tended at all surfaces to move differentially in relation to the sedimentary strata, and there were consequently formed those curious igneous and sedimentary breccias which occur here and there throughout the district. At the same time the large intrusive masses acquired schistose, gneissose, or brecciose structure at zones of contact and pressure within themselves.

The fossils which I collected in the field were very numerous, but, except the Wengen-Cassian fossils of Sella Pass, were almost all of them Werfen fossils. These have been identified for me by Dr Broili, Assistant-Custos in Munich Palæontological Museum; and I take this opportunity of thanking him for the kind assistance thus rendered to me. I desire also to thank Mr Gibb, Lecturer in Geology at Aberdeen University, for his careful microscopic examination of a number of thin sections prepared from my collection of igneous rock specimens. Throughout this paper Mr Gibb's descriptions are placed in inverted commas.

ESTIMATED THICKNESSES OF THE LOWER AND MIDDLE TRIASSIC STRATA IN THE FASSA VALLEY AND MONZONI DISTRICT—(SCALE 1 CM. = 50 MÈTRES.)

UPPER TRIAS ca. 370 mètres (as exposed in the vicinity of Fassa).		320 mètres Dachstein Limestone or Dolomite.	Massive calcareo-dolomitic zone, with *Megalodon triqueter*, etc.
		50 mètres Raibl marls, etc.	very mixed and varied series of breccias, sandstones, fine calcareous mud, etc. Sometimes gypsum beds; *Ostræa montis caprilis*, etc.
MIDDLE TRIAS ca. 510 mètres.	Salomon's "Marmolata Limestone."	350 mètres Schlern Dolomite or Dolomitic Limestone.	Massive calcareo-dolomitic zone, with Diplopores, corals and indefinite foraminiferal remains, locally molluscan faunas and brachiopods.
		"Cipit" Limestones.	blocks and beds of "Cipit limestone," with indef. coral remains and "*Evinospongia*" nodules.
		60 mètres. Cassian Marls.	*Encrinus cassianus*, *Cidaris dorsata*, etc.
		Wengen shales, tuffs, tufaceous grits and lavas.	*Halobia Lommeli*, *Posidonomya Wengensis*, etc.
		20-40 mètres Buchenstein Limestones.	banded limestone, and limestone with chert nodules.
	Salomon's Alpiner Muschelkalk.	40-60 mètres Mendola Limestone or Dolomite.	Massive calcareo-dolomitic zone with *Diplopore* remains. rauchwacke or limestone with lumpy bedding surfaces.
The Passage-Beds are the age-equivalent of the uppermost horizons of the "*Myophoria Beds*" or "*Reichenhall Limestone*" in the North Tyrol and Bavaria = (*Röth* horizon with salt, gypsum, etc.).		60-90 mètres Passage-Beds. Crinoid Limestone, Oolites, and Rauchwackes.	marls and fossilif. limestone. red limestone full of bivalve remains. yellow sandy and oolitic beds with fossils. red limestone full of fossils, badly preserved. red crinoid limestone. (*Pentacrinus* remains.) dolomite. purplish marly limestone with bivales—Macrodon, Avicula, Natica, Modiola, Myophoria, ind. species.
LOWER TRIAS ca. 500 mètres (maximum).	v. Richthofen's Campil Strata.	100-160 mètres Upper Werfen marls and marly limestone. (Naticella costata zone.)	Poikilitic series of sandy and marly limestones, cont. small Holopellas and indef. bivalves. highly fossiliferous zones yellow-grey and grey marls; variegated marls and thin-bedded limestone; purple and flecked oolitic and granular limestones: *Naticella costata*. *Turbo rectecostatus*. *Myophoria ovata*.
		35 mètres blue shales and marls.	blue marly limestone and shales streaked and veined with calcite; *Pseudomonotis aurita*.
		25 mètres Micaceous layers or rauchwackes.	arenaceous limestone (muscovite flecks) or rauchwackes; (traces of small bivalves.)
	v. Richthofen's Seisser Strata.	Lower Werfen. 130 mètres, red and grey marls and shales. (Pseudomonotis Clarai zone.)	bright red marls; *Pseudomonotis tridentina*. grey limestones and shales highly fossiliferous; *Pseudomonotis inaequicostata*. *Pseudomonotis Clarai*. *Pleuromya fassaensis*. *Myophoria ovata*, *and Naticiden*. bright red marls;
		20 metres. Lingula tenuissima zone.	yellowish and brownish marls and limestone; *Lingula tenuissima*. *Natica gregaria*.
		40 mètres. poikilitic marls and limestone. Natica gregaria.	dark shales; bright orange-grey limestones and red marls and marly limestones; *Pseudomonotis inaequicostata*. *Modiola* remains.
PERMIAN SEDIMENTS ca. 70 mètres.		"Bellerophon" Limestone gypsum, etc.	dark, bituminous limestone; grey and orange or creamy granular limestone; fetid shales, gypsum, etc.;
		Gröden Sandstones, quartzites, or breccias.	reddish and greenish sandy grits and sandstones interbedded quartziferous grits, grey, green, yellow and red series of sandstones with thin bands of nodular quartz.
PERMIAN PORPHYRY SHEET		Quartz Porphyry.	igneous contemporaneous rock.

PART I.

The Stratigraphical Succession.

Lower Trias—The Upper Werfen Passage Beds—The Mendola and Buchenstein Horizons—The Wengen-Cassian Horizons—The Wengen-Cassian Series at Sella Pass—Schlern Dolomite—List I.: Fossils in the lower horizons of Cassian strata on the east side of Sella Pass—List II.: Fossils in Upper Cassian strata below the Schlern Dolomite of Sella Massive on the east side of Sella Pass—List III.: Fossils in Upper Cassian strata below the Schlern Dolomite of Langkofl Massive on the west side of Sella Pass—General Remarks.

The Sedimentary rocks exposed in Fassa Valley and the immediate neighbourhood of Monzoni belong to the Permian and Triassic series. The thicknesses of the successive deposits are represented to true scale in the accompanying Table (p. 19).

This Table marks certain advances upon all published accounts of the Triassic succession in the Fassa-Monzoni districts.

Two new fossiliferous zones are demonstrated:

(*a*) A fossiliferous zone at the base of the Mendola Limestone or dolomitic limestone horizon and above the *Naticella costata* zone, in so far as it has been previously defined in the Dolomites. This zone corresponds in stratigraphical position to the horizon of the "Myophoria Beds or Reichenhall Limestone in N. Tyrol and Bavaria.

(*b*) A fossiliferous zone at the base of the "Marmolata" Limestone or dolomitic-limestone and above the nodular limestone known as the "Buchenstein" horizon in this district. This fossiliferous zone answers to the Wengen-Cassian strata in other areas of the Dolomites and Eastern Alps generally.

Lower Trias.

Those geologists who are familiar with Alpine Trias will observe that the Werfen Strata or Lower Trias is estimated in the Table at a thickness more than double that which is usually accorded to it in this district; but the thickness of the individual horizons has been carefully calculated by me in the field and will be found to be approximately accurate. Very important results for the work of geological mapping were obtainable by means of close observation of the petrographical character as well as the typical fossils of each successive layer in the sequence of Werfen strata.

The number of fossils which I collected in the Werfen series was very large, but Dr Broili's identification shows that the fauna though exceedingly rich in the number of individuals is comparatively poor in the number of species. My fossil specimens have a special interest in so far as I not only collected well-preserved specimens with forms little affected by crush, but also distorted fossil forms showing the effects of the shearing and slickensiding of the sedimentary rocks.

The most frequently occurring fossils in the Werfen strata are the following:—

Natica gregaria Schl.
Naticella costata Mstr.
Turbo rectecostatus Hauer
Pseudomonotis aurita Hauer
Pseudomonotis Clarai Emm.
Pseudomonotis inaequicostata Ben.
Pseudomonotis tridentina Bittner.
Myophoria ovata Bronn
Pleuromya Fassaensis Wissm.

In the Naticella costata horizons I found several variations of the ordinary specific Werfen types as well as some new species. The upper horizons of Werfen strata have frequently been said to comprise conglomerates in this district. Within the area of Fassa, conglomerates occur locally at Pocol, Col Ombert, Rodella, Usel, but are all demonstrably shear conglomerates. I found no coarse conglomerate in the cases of conformable succession of the Werfen passage-beds and the Mendola calcareo-dolomitic horizon.

The Upper Werfen Passage Beds.

The feature of chief palæontological interest in the Lower Trias is the zone which I have called "passage-beds" in the Table of Succession. These beds have been described by previous authors as a mixed unfossiliferous series of dark and reddish-brown marls, marly limestones and dolomitic bands, *only occasionally* present.

Professor Salomon states that he had found no fossils in the beds of marl and dolomite and treats them as a *local facies* probably the equivalent in age of the lower portion of the "Mendola-dolomite"; he provisionally includes them in the "Horizon of Ceratites binodosus and trinodosus" or so-called "Alpine muschelkalk" (*cf.* Salomon, Palæontographica, 1895, p. 13).

As I found that the group of marls and oolites was often penetrated by shear-planes, I made these strata a special subject of investigation throughout the whole region and collected a fair number of fossils in them. Dr Broili identified all the fossils as Upper Werfen or nearly allied types; he thinks the strata containing them may probably be best regarded as the equivalent of the uppermost or "Röth horizon of the German Bunter Beds." I have seen no evidence in the field whatever in favour of the supposition that these fossiliferous passage-beds pass locally into a wholly calcareo-dolomitic facies. On the contrary the passage-beds are present as a distinct member of the succession in all undisturbed sections, and always have the same petrographical character—a mixed series of brown fine-grained limestones, sometimes with well preserved fossils, crystalline-granular limestones with beds full of sections of Lamellibranchs and Gastropods, reddish Crinoid limestones full of Pentacrinus remains, and bands of unfossiliferous rauchwacke or creamy dolomite. The layers of molluscan sections that occur in the oolitic and sandy limestones include species of Myophoria, Pseudomonotis, Macrodon, Avicula, Natica and Modiola, not yet described in detail by Dr. Broili. These layers are about 1-2 inches thick and are separated by intervening thicknesses of 1-3 feet of the crystalline-granular or arenaceous limestone to all appearance devoid of fossil remains.

The infilling of the fossils is in many cases entirely crystalline, indicating that similar mineralogical changes have been undergone by the rock and its fossil contents. The character of the passage-beds shows that this was a transitional period marked by fluctuations in the depth of the sea-floor.

The Mendola and Buchenstein Horizons.

The calcareous or calcareo-dolomitic series known as "Mendola Kalk" or "Mendola Dolomit" is in Fassa about 40-60 mètres thick and is succeeded by 20-40 mètres of the nodular siliceous limestones known as the Buchenstein horizons. The basal portion of the Mendola rocks is characterised by lumpy, irregular bedding surfaces and is always distinctly calcareous. Although variable in the degree of dolomitization the typical condition of the "Mendola" rock is a crystalline dolomite, with occasional appearances of minute algal fossils. Iron is present, and gives the reddish and warm pinky appearance to the weathered surfaces and veins. The Buchenstein horizon comprises banded limestone and coarse-grained, crystalline-granular magnesian limestone full of chert nodules. Iron and other impurities are present, yellow discoloration being frequent.

The Wengen-Cassian Horizons.

It has previously been supposed that the fossiliferous Wengen-Cassian mixed sèries of tuffs, marls and limestones deposited in Gröden, Enneberg and Ampezzo was entirely absent in Fassa, and that the contemporaneous rocks in Fassa were either extensive eruptive sheets of porphyrite or calcareous reef-growths and accumulations in the vicinity of these sheets. The calcareous facies was termed "Marmolata Limestone," and the upper portion of it was regarded as contemporaneous with the "Schlern Dolomite" reef facies in Gröden and Enneberg, or with the Cassian tufaceous and marly facies; while the lower horizons were similarly regarded as contemporaneous with the Wengen horizons of the tufaceous or marly facies and probably with the lower part of the Schlern Dolomite. In my former papers I showed that in Enneberg and Ampezzo, the Wengen-Cassian tufaceous and marly series is occasionally interbedded with and passes into the reef-growths which were called "Cipit Limestone" by Baron von Richthofen, but that the Wengen-Cassian series underlies the massive development of calcareo-dolomitic rock which was termed "Schlern-Dolomite" by Baron von Richthofen—that, in short, the Schlern Dolomite was not a coral-reef facies of the Wengen-Cassian fossiliferous marls and tuffs in the sense described in the work on "The Dolomite Reefs," by Geh. von Mojsisovics.

The Marmolata Mountain from which the massive calcareous rocks south of the Enneberg area take their name of "Marmolata Limestone" was not included in my geological map of Fassa, as it had undergone a searching examination in recent years by Professor Salomon. He found the "Marmolata Limestone" conformably above the Buchenstein horizon with which he included nodular and banded limestones and aphanitic tuffs (the latterly occasionally present). In view of the complete absence of the Wengen and Cassian tuffs and marls, Professor Salomon accepted the view that the Marmolata Limestone was a calcareous facies of these strata and of Schlern Dolomite. He explained it, however, not as a coral-reef structure but a local accumulation chiefly of algal skeletons, also of other marine organisms — contemporaneous with the neighbouring eruptive flows of porphyrite and deposits of Wengen-Cassian-Schlern horizons. In the area of Fassa which I have now examined,—in the Vallaccia Mountain-Massive, the Costabella Massive, and scattered occurrences between Contrin and Bufaure, —I have found *typical Wengen strata and a certain thickness of typical Cassian strata,* although not with the great development they have in the Enneberg area. Still, their presence at all is most important, for it proves that in Fassa the *Halobia Lommeli, Posidonomya Wengensis,* and *Cardita crenata* horizons of the Wengen-Cassian series are present conformably below massive developments of calcareous rock, the same developments that have been called "Marmolata Limestone" and been regarded as local, calcareous facies of the Wengen-Cassian tuffs and marls.

Taking the Vallaccia Massive on the north of Monzoni as an example, the Buchenstein cherty limestones are succeeded by Wengen tuffs, grits and shales, in which *Halobia Lommeli* and *Posidonomya Wengensis* occur. A thickness of about 40 mètres of the tufaceous Wengen beds is succeeded by yellowish limestone and fine calcareous and tufaceous breccias of the character of beach-rock. Layers of typical "Cipit Limestone" succeed, with *Cidaris dorsata*, coral remains, and *numerous Cassian species of gastropods and bivalves*, but the fossils do not weather out favourably. The limestone is exceedingly hard, and the only hope of seeing fossils is to examine the weathered bedding surfaces. There is no well-defined upper limit to the Cassian limestones. But the higher horizons of limestone when examined on the high terrace of Vallaccia have a quite different appearance, are crystalline and unfossiliferous, and often contain little patches of reddish marl that suggested the presence of Raibl Strata. But I searched the terrace in every part and could find no recognisable fossiliferous horizon.

Therefore the Wengen strata here are petrographically and palæontologically quite like the typical Wengen strata in the Enneberg district, but the lavas and tuffs are thinner. The Cassian strata are entirely calcareous, either fine breccias or Cipit Limestones; the thick development of interbedded tuffs and tufaceous marls in which the rich beds of fossils occur in Enneberg is here absent.

While the rock above the Cassian strata is undoubtedly the age-equivalent of *Schlern Dolomite*, it is distinctly a limestone. The lower horizons are very rich in "Evinospongia" nodular masses,[1] and these seem interbedded with banks of limestone containing corals and diplopores. Such banks have invariably the yellowish weathered surfaces characteristic of Cipit Limestone, and may thus be readily picked out in the field amidst the more clear and crystalline rock in which the nodules occur.

The Wengen-Cassian Series at Sella Pass.

The development of Wengen-Cassian strata at Sella Pass on the north slopes of Rodella Mountain is not within Fassa district, but had to be examined in connection with Rodella Mountain. The series occurs in east-west line with the Seiser Alpe, Buchenstein Valley, and Falzarego Valley in Ampezzo, and presents the same richly tufaceous character as the Wengen-Cassian strata in those areas (*cf.* Ogilvie, Q.J.G.S., 1893, p. 16 ff.).

[1] I sent some specimens to Dr Hinde, and his microscopic examination confirmed them as the so-called "Evinospongia" nodules, but no further insight could be obtained into their origin.

At Sella Pass, the Buchenstein horizon is succeeded by dark shales with Halobia beds and with numerous plant remains. The development is precisely the same as at Corvara, and is succeeded by dark limestone, sometimes banded black and brown. The shales and limestones are succeeded by a thick series of interbedded lavas, tuffs, ashy grits, plant shales and greenish bands; this tufaceous series is succeeded by the thin-bedded sandstones, shaly limestones, and shales containing innumerable individuals of the small *Posidonomya Wengensis.* The whole thickness of the Wengen strata here might be estimated at 60 mètres.

The lavas are of two distinct kinds (*a*) a close-grained augite porphyrite, with conchoidal fracture, and dark-grey in the fresh state; (*b*) a loose-textured porphyrite with abundant plagioclastic as well as augitic elements, and remarkable for its regular spheroidal weathering; it weathers brown and is often full of amygdaloids, nearly always showing advanced stages of decomposition. The thickness of the lavas varies from ½-3 mètres The banded, sometimes flaked appearance of the sedimentary rock is well-marked where it has formed the floor of a lava flow; but the beds immediately above the lavas are not altered.

In Mojsisovics' description of the "Sedimentär-Tuffe," blocks of porphyrite are described as "rolled" in appearance and the explanation suggested that they represented ejecta of "bomb" form that had been rolled on the sea-floor before they were finally buried amidst the contemporaneous sediments. But so far as I have observed the Wengen series, these "blocks of porphyrite" are merely joint-blocks weathered in situ. As observed in the field, the body of a loose-textured lava is made up of one or more layers of spheroidal masses of a granular porphyrite; each spheroidal mass is surrounded by envelope after envelope of *decomposed residue of the same rock* that composes the firmer central mass. The decomposition may have proceeded so far that little of the original rock-material is left. And then, as the layers of spheroidal blocks simulate bedding, it seems at first sight as if one had merely an accumulation of crumbly tufaceous sediment to deal with, or some kind of volcanic conglomerate. But in my opinion, the block-structure in the Wengen "Sedimentary Tuffs" is an entirely subsequent condition, due to spheroidal weathering along divisional planes; planes parallel with the bedding-planes of the interbedded sediments, and intersecting sets of vertical planes.

The spheroidal structure is developed in the Wengen tufaceous grits as well as in the true volcanic flows and is equally developed in the Cassian horizons of similar petrographical character. The examples shown in fig. 11 were drawn from the

Wengen Tuffs above the inclined Rodella Fault-Plane, near the place where the Sallei stream cuts through the fault-zone between Rodella and Roja. They show clearly that the concretionary structure is *superinduced*, as the coarser layers of sedimentation can be traced through neighbouring concretionary blocks (*cf.* Sir A. Geikie, "Text-Book of Geology," 1893, p. 513).

The upper Wengen horizons show a cessation of contemporaneous volcanic activity, but the incoming of the Cassian fauna was associated with local renewal of volcanic conditions.

As in the case of Enneberg and Ampezzo, the Cassian strata at Sella Pass can be subdivided in two well-marked palæontological zones, the *lower* horizons containing a typical "Stuores" fauna, such as has so long been known to occur on the Stuores meadows beside St Cassian, and the *upper* horizons containing the mixed Cassian-Raibl fauna such as I found at Ampezzo for the first time and made the basis of an *Upper Cassian* palæontological zone.

A complete section of Cassian strata is obtained by ascending from Sella Pass at 2218 mètres eastward to the Sella Spitze (see fig. 12). The Stuores-Cassian fossils are found in the marls, tuffs and Cipit limestones on the hill immediately east of the Sella Pass Club-Hut, and in numerous excellent exposures provided by slight landslips up to about the 2300 mètres' contour. Above that horizon the thin lavas interbedded with the Cipit limestones are much more basic and the tuffs are full of iron-ore nodules; the tufaceous breccias and calcareous beds are rich in the Upper Cassian fauna. The term "concretionary tuffs" used below has reference to the spheroidal character of the weathering.

The Cipit limestones have their usual development as calcareous banks of irregular thickness, containing chiefly branching coral remains and Cidaris spines, but also sponges, brachiopods and gastropods.

The interbedding of the irregular calcareous rocks and the more yielding tufaceous sediments has made these strata particularly subject to distortion and deformation of all kinds. Together with the Wengen strata, they represent the horizon of maximum subsequent deformation in all the areas where the tufaceous facies is developed. On the other hand, in Fassa where the Cassian series is more uniform in its development, the deformational effects of the strains during the crust-movements have been concentrated *mainly* in the upper Werfen and Passage-Beds, and have in a subordinate measure affected the Wengen-Cassian horizons.

An observation which may frequently be made in the Sella Pass area is that vertical or steeply-inclined planes of shear-slip or jointing have been filled by material fallen from higher horizons. The widening of joints, and inslips from above may in some cases have been partially due to the recurrences of cross-compression. As Section 12 shows, the rocks of Sella Pass have been waved transversely to the original strike, a fact which gives them an apparently greater thickness than they actually possess. Their thickness is probably not over-estimated at 250 mètres. In Val la Stries, the highest Cassian horizons conformably underlie a thickness of nearly 300 mètres of Schlern Dolomite.

Briefly tabulated, the Cassian succession at Sella Pass is as follows :—

Schlern Dolomite.

Reddish Cipit Limestone interbedded with reddish nodular iron ore (Bohnerz), tufaceous marls, concretionary tuffs and breccias, with *Upper Cassian* fauna (List II).

Light-grey crags of Cipit Limestone interbedded with brown or black-weathering concretionary tuffs and lavas; richly fossiliferous, fine ashy beds, and greenish breccias full of worn and decomposed augites; grits and shales; containing the *Upper Cassian* fauna as in List II.

Smaller developments of grey Cipit Limestone interbedded with fossiliferous marls, thin-bedded shales and limestones; brown-weathering concretionary lavas and tuffs, felsitic grits and breccias, containing the typical "Stuores" or *Lower Cassian* faunas in List I. In addition to abundance of Stuores types, this horizon contains at Sella Pass as in Seiser Alpe numerous individuals of *Pachycardia rugosa.*

LIST I.—Fossils *in the lower horizons of Cassian strata on the East side of Sella Pass.*

Epitheles astroides Mstr.
Encrinus varians Mstr., *granulosus* Mstr., *cassianus* Lbe, sp.
Pentacrinus propinquus Mstr., *Fuchsi* Lbe;
Cidaris subcoronata Mstr., *scrobiculata* Mstr., *trigona* Mstr., *Brauni* Desor., cf. *Klipsteini* Desor., *dorsata* Braun, *linearis* Mstr., *Hausmanni* Wissm., *decorata* Mstr.
Spirigera quadriplecta Mstr., *Wissmanni* Mstr.
Rhynconella semiplecta Mstr.
Terebratula neglecta Bittn.
Palæoneilo lineata Goldf.
Nucula subobliqua d'Orb.; sp. n.
Cassianella Beyrichi Bittn., sp.
Cardita crenata Goldf.
Pecten Zitteli Wöhrm.
Pachycardia rugosa Hauer

Mysidioptera Emiliae Bittner, sp.
Patella sp.
Clanculus cassianus Wissm.
Worthenia coronata Mstr., sp.; *canalifera* Laube.
Neritopsis armata Mstr., sp.
Trochus, sp.
Cf. *Scalaria supranodosa* Klipst.
Hologyra alpina Koken, *Schizogonium serratum* Mstr.
Palæonarica sp., *Turritella* sp., *Euomphalus dentatus* Mstr.
Naticopsis neritacea Mstr., and div. sp.
Chemnitzia solida Koken.
Cœlostylina conica Mstr.; div. sp.
Eustylus Konincki Mstr.
Loxonema sp. indet.
Goniogyra sp.
Flemingia bistriata Mstr.
Promathildia sp.
Orthoceras sp.
Trachyceras? furcatum Mstr.

LIST II.—Fossils *in Upper Cassian strata below the Schlern Dolomite of Sella Massive on the East side of Sella Pass.*

Epitheles astroides Mstr.
Montlivaltia granulata Mstr.
Rhabdophyllia cf. *recondita* Lbe.
Pentacrinus subcrenatus Mstr., *Fuchsi* Lbe.
Encrinus cassianus Lbe, *granulosus* Mstr.
Cidaris subcoronata Mstr., *dorsata* Braun, *trigona* Mstr., *alata* Agassiz, *Brauni* Desor., *decorata* Mstr., *scrobiculata* Mstr.; sp.
Nucula subobliqua d'Orb, *strigillata* Goldf.,
Palæoneilo præacuta Klipst.
Trigonodus rablensis Gredler
Pachycardia rugosa Hauer
Myophoriopis Richthofeni Wöhrm.
Amauropsis paludinaris Mstr., *tyrolensis* Lbe.
Neritopsis armata Mstr., sp.
Euomphalus cf. *venustus* Mstr.
Cf. *Natica Bernwerthi* Kittl
Hologyra and *Neritaria* div. sp.
Scalaria supranodosa Klipst., sp.
Clanculus cassianus Wissm.
Worthenia coronata Mstr., *canalifera* Klipst.
Joannis Austriæ Klipst.
Eustylus Konincki Mstr., *ladinus* Kittl
Cœlostylina conica Mstr.
Spirostylus cf. *subcolumnaris* Mstr.
Cheilostoma cf. *Blumi* Mstr.

Turritella cf. *fasciata* Kittl
Loxonema tenuis Mstr., sp.
Turbo subcarinatus Mstr.
Orthoceras ellipticum Kittl
Trachyceras Aon Mstr.

LIST III.—Fossils in *Upper Cassian* strata below the Schlern Dolomite of Langkofl Massive on the west side of Sella Pass.

Encrinus varians Mstr., *granulosus* Mstr.
Cidaris decorata Mstr., *dorsata* Braun, *Brauni* Desor., *subcoronata* Mstr.
Rhynconella semiplecta Mstr., *semicostata* Mstr.
Spirigera quadriplecta Mstr., *indistincta* Beyr.
Cassianella Beyrichi Bittn.
Myoconcha Maximiliani Leuchtenbergensis Klipst., *parvula* v. Wöhrm, sp. indet.
Opis affinis Laube
Trigonodus costatus Gredler
Pachycardia rugosa Hauer
Mysidioptera Zitteli Broili; sp. indet., cf. *Emiliæ* Bittn.
Palæoneilo elliptica Goldf., *lineata* Goldf.
Arcoptera vide *arcata Broili*
? *Arcoptera* sp.
Macrodon sp. indet.
Prospondylus crassus Broili
Worthenia sp. indet.
Clanculus cassianus Wissm.
Platychilina Wöhrmanni, Koken
Naticopsis neritacea Mstr.; *cf. ladina* Kittl; div. sp.
Neritaria similis Koken
Palæonarica concentrica Mstr.
Chemnitzia solida Koken
Cœlostylina conica Mstr.; div. sp.
Pustularia alpina Eichw.
Tretospira multistriata v. Wöhrm.
? *Purpuroidea* sp.
Trochus sp.
Orthoceras sp.
Celtites sp.

General Remarks.

The establishment of the "passage-beds" as a definite stratigraphical zone at once brings the Trias of Fassa, and it may safely be said of the Dolomites, into closer touch with that of other areas. For the horizon of the passage-beds precisely corresponds to that passage-zone in N. Tyrol which has been variously termed "Reichenhall Limestone" and "Myophoria Beds," and probably also to the well-known "Röth" in the North German Trias.

As has been mentioned above (p. 20), the strata of the passage-beds were previously regarded as an occasional particular facies, sometimes present, sometimes absent in Fassa, while the Wengen-Cassian facies was unknown. It is all-important to the compilation of a correct geological map to know whether a band of rock is an abnormal facies or a constant zone. And naturally my map, based upon these two advances in the knowledge of the stratigraphical succession, gives a different presentation of the geological structure in Fassa. All the more are these advances of interest when the tectonic value of the horizons is realised. For, throughout the crust-movements in the Dolomites, these two particular horizons have been the leading crush-zones within the Triassic succession.

The zone of the "passage-beds" occurs in Fassa *below* a massive development of calcareous rocks, and *above* an almost equal thickness of mixed deposits; it is therefore a well-marked "critical" zone within the earth's crust, interleaved between rock material presenting strongly contrasted physical characters. During the action of crust-strains, the maximum deformational effects are attained at such *critical* zones. While the "passage-beds" represent in Fassa the chief critical zone, a *subsidiary deformational zone* is presented by the Wengen tufaceous sediments and the Cassian "Cipit limestones." These are mixed deposits occurring between the development of Mendola dolomite and hard cherty Buchenstein limestones, and the massive development of the "Schlern" horizon of calcareous deposit. Situated between these two uniformly calcareous or calcareo-dolomitic horizons the Wengen-Cassian beds have offered a zone of easier yielding, and have consequently like the passage-beds been largely sliced by the planes of differential movement, and strongly crumpled, dragged, and distorted.

According to my geological mapping, these two bands—the Upper Werfen passage-beds and the Wengen-Cassian—were the main sliding-zones in the Fassa-Monzoni district during the Tertiary crust-movements. Innumerable overthrust and normal fault-planes developed within these bands, some with no more than 10°-20° inclination, others with steeper angles of inclination. *Subsequently*, irruptions of molten rock found their way locally into these deformational zones and consolidated there in the form of sheets or sills, such sheets and sills being connected with dykes and breccias in steeper fractures.

This paper therefore confirms the conclusion I previously formed when I investigated Enneberg and Buchenstein, viz., that the copious flows of augite porphyrite regarded as extrusive were in reality *intrusive*, and had been intruded pre-eminently into fault-planes and lines or horizons of weakness and crust-deformation. The previous investigators of Fassa valley failed to recognise the presence of the innumerable crush-planes with extremely low hade, and the branch-connection of many of them with leading cross-faults, and consequently overlooked the correlation of the igneous invasions with pre-existent deformational structures.

As the presence of igneous rock undergoing consolidation amidst the Triassic succession only served to still farther accentuate and concentrate the differential strains at special horizons of the crust during the Tertiary movements, the same crush-zones were again and again the seat of crust-movements, and were invaded afresh by molten material. In the immediate vicinity of the larger igneous masses, the sedimentary deposits tended to subside; thus the local horizontal crust-strains increased in intensity. During protracted periods of crush and deformation, the earlier intrusions suffered, together with the original thrust-masses and downslip-slices. They were cleaved and faulted, locally altered, sheared or fragmented just as their sedimentary roof and floor. Later dykes and veins ramified in them and in the environing sediments, and the direction of these later dykes often gives valuable evidence of the local horizontal crust-strains associated with the continued local subsidences.

PART II.

Rodella and Mt. Donna.

The Duron Valley—The Pozzale Section—Cross-Deformation at Pozzale—Relation of the Porphyrite Intrusions to the Cross-Deformation—The Transverse Fault-Blocks of Rodella—The Piav Fault-Block—The Central Fault-Block of Rodella—The Eastern Fault-Block—Canazei—Types of Porphyrite—The North Fault-Zone of Rodella—Comparison of the Rodella and Buchenstein Areas—Sella Pass—The term "Asta-Judicarian"—The Crush-Conglomerates of Rodella—Additional Evidences of the Epoch of Porphyrite Intrusions—Alba—The Intrusions in the neighbourhood of Penia—Mount Donna—The Rocks of the Mount Donna Thrust-Mass—The South Aspect of Mount Donna—Mendola Dolomite—Deformation of the old Thrust-slices of Mount Donna—The N.N.W.-S.S.E. Faults—Summary—The Clapaja Slopes between Mazzin and Campitello—The Clapaja Slopes opposite Canazei and Alba—The Campaz and S. Bufaure Thrust-Mass—The Mairin Wand—The Peripheral Shear and Contact Zone of Bufaure—General Interpretation regarding the Bufaure Porphyrite.

The Duron Valley.

Probably the best insight into the structure of Rodella mountain is obtained by the section exposed in the Pozzale stream which joins the Duron River nearly a mile west of Campitello. The Werfen strata through which the Duron River runs, have near Campitello a general W.N.W. strike and southward dip (strike N. 70°-80° W.; dip, 10°-15° S., but steepening to 40°-50° on north bank). The fossils are *Pseudomonotis Clarai Em.*, *Pleuromya fassaensis* Wissm., and *Myophoria ovata* Br. The "Clarai Zone" is conformably succeeded by variegated marls and marly limestone containing *Pseudomonotis inæquicostata and Pleuromya fassaensis.*

The fossils of the next higher horizon are plentiful, but are so much distorted and altered by pressure that the species are seldom recognisable; *Naticella costata* and *Myophoria ovata* are the most common types.

The "*Naticella costata*" limestone is succeeded by the "passage-beds" of red oolites, grey marls, and limestone with uneven bedding surfaces; but both the "passage-beds" and the "Mendola dolomite" succeeding them are cut on the north and south valley slopes by steep strike-faults (figs. 1, 2). The fault-block north of the Duron valley-segment is thrown down relatively to the valley-segment, and the valley-segment is itself thrown down relative to the next fault-block of Mt. Donna on the south. The lower part of the valley is crossed by several transverse faults directed N.N.E. and S.S.W. which have displaced the strike-faults, and were therefore of later date. The most important of the transverse faults is one which keeps fairly close to the Pozzale stream and may be called the "Pozzale fault." It throws down the western fault-block comprising the rocks in the upper portion of the Duron valley. The general strike of the Werfen strata in the valley, on the west of the fault is E.N.E., the dip is N.N.W., and the calcareo-dolomitic and porphyritic rocks on the south bank near Campitello display a well-marked system of cleavage-planes directed N.N.W.-S.S.E., *i.e.* parallel with the dip of the down-thrown fault-block.

The Pozzale Section.

On the north valley slope, the strike-fault is exposed a little distance up the Pozzale stream. An overcast arch of Upper Werfen and Mendola dolomite horizons is present north of the fault. It has been cut by an inclined fault with ca. 20° inclination to the north. A large fault-wedge of Upper Werfen, Mendola and Buchenstein horizons occupies an inthrow between the strike-fault and the N.N.E.-S.S.W. Pozzale fault. The most important feature here is the presence of a crush-conglomerate *within the "knee-bend" of the overcast arch,* and the evidence that the crush-conglomerate has been subsequently slashed by joint and shear-slip planes in N.N.E.-S.S.W. and N.N.W.-S.S.E. directions.

The accompanying sections show the position of the crush-conglomerate relative to the bent and down-slipped fragment of

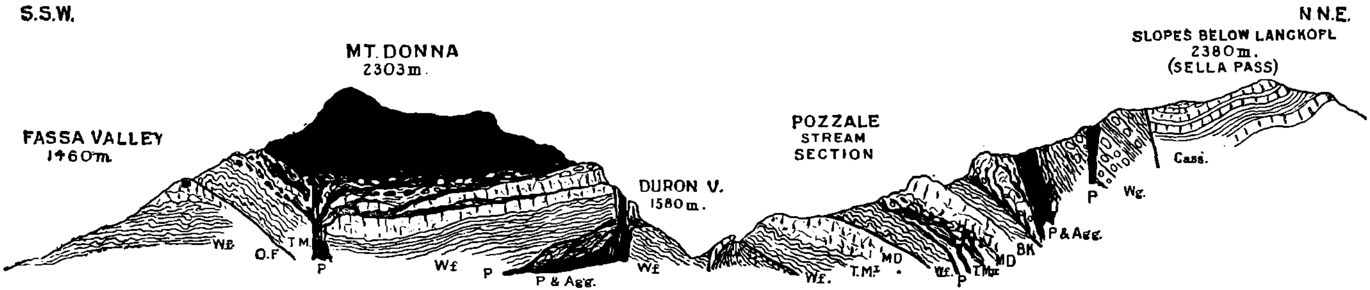


FIG. 1.

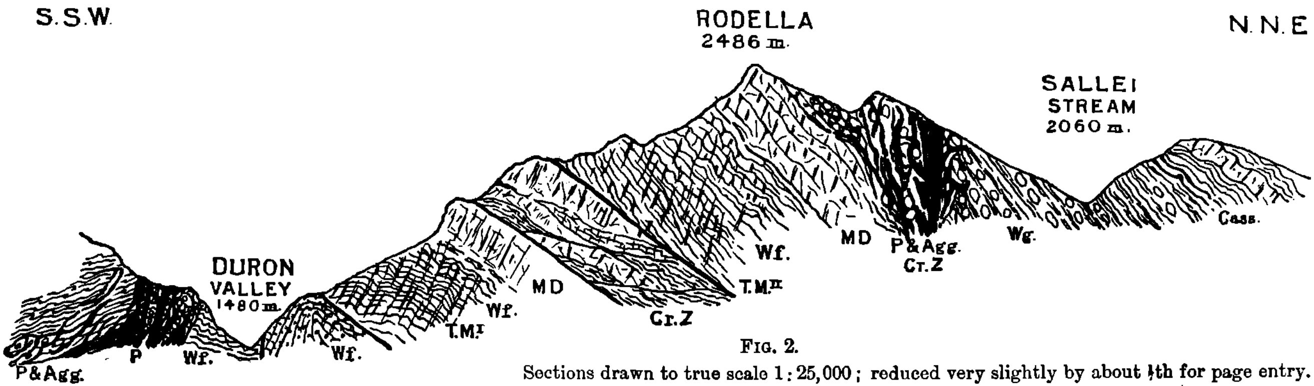


FIG. 2.

Sections drawn to true scale 1 : 25,000 ; reduced very slightly by about ⅛th for page entry.

FIG. 1.—Section through the area on the *West* of the N.N.E.-S.S.W. Pozzale Fault (for the sake of clearness the N.N.W.-S.S.E. faults are omitted in Mt. Donna).

FIG. 2.—Section through Rodella Mt. on the *East* of the N.N.E.-S.S.W. Pozzale Fault.

Cass. = Cassian Tuffs and Limestones.
Wg. = Wengen Tuffs, Lavas, and Plant-Shales.
Bk. = Buchenstein nodular and banded limestones.
MD. = Mendola Dolomite,
Wf. = Werfen marly limestones, marls, etc.
P. = Augite Porphyrite (intrusive) ; for varieties, see text.
P. & AGG. = Aug. Porphyrite and contact-breccia.
TM I. = Lower Thrust-Mass of Rodella.
TM II. = Upper Thrust-Mass of Rodella.
Cr. Z. = Crush-Zone of Rodella.
O. F. = Overthrust Fault on the South Face of Mt. Donna.

"Mendola" rock at Pozzale, and to the steep south-dipping strata occupying the lower slopes of Rodella mountain. Thus an overcast arch may be traced along the north slope of Duron valley to Fassa valley.

The Pozzale crush-conglomerate is about 8 or 10 mètres thick; it encloses rock fragments of all sizes from large blocks to small pebbles; and many of these fragments have fossils in them, and the fossils as well as the rock-varieties show that the fragments were collected from various horizons of the Werfen series—more especially from the brightly-coloured marly limestones with *Myophoria ovata*, and from *Naticella costata* limestones. Many of the fragments have striated and polished or deeply-fluted surfaces veined with calcite, and the pebbles have occasionally marks of indentation caused by neighbouring fragments; the whole appearance of the conglomerate is curiously like a "scratched Nagelflue."

The downslip shear-plane between the crush-conglomerate and the Mendola rock is steeply inclined to the south, and strikes N. 45° E.; the shear-plane on the north is an important thrust-plane, and is occupied by altered shales with slaty cleavage. Brick-red coloration is developed along all pressure-planes, and is most strongly marked in the actual shear-planes.

The thrust-mass that succeeds the crush-conglomerate comprises at the Pozzale area Upper Werfen and Mendola dolomite horizons; but further east on the Rodella slopes much lower horizons of the Werfen strata crop out on the thrust-plane. This first thrust-mass at Pozzale is succeeded by crumpled and sheared fragments of Lower and Upper Werfen strata. The shear-plane itself is not well exposed, but the crumpled Werfen strata of thrust-mass II. are exposed in the stream ravine at the height of 1760 mètres, and are succeeded at about 1825 mètres by the Mendola dolomite. Intrusive porphyrite rock is present in the limiting-zone of the "passage beds" between the crumpled Werfen strata and the dolomitic rock, and innumerable threads impregnate the lower horizons of the "Mendola" rock, so that the latter has the appearance of a fine igneous and calcareous breccia. Instead of having been crumpled like the soft Werfen strata, the dolomitic rock has been *split up by coarsely-developed cleavage-planes*; these are directed N.N.E.-S.S.W., being roughly parallel with the Pozzale fault and the accompanying subordinate fault-fissures.

The precipitous cliffs of the calcareo-dolomitic rock rise for over 2000 mètres, and the whole thickness might easily be taken for Mendola dolomite. But midway in the precipitous cliffs at about the 1900 contour line, there is another thrust-plane, which can be quite well examined in the stream ravine, and for some distance to the west of it. A third thrust-slice of Mendola dolomite has been driven southward over thrust-mass II. Below the thrust-plane there are sheared fragmentary occurrences of the lower Wengen plant shales, and the Buchenstein banded and nodular limestone. Again, just as in the case of the Werfen strata below the Mendola dolomite rock of thrust-mass II. the soft shaly limestones and dark shales of the lower Wengen horizons have been brecciated and rendered finely fissile in the crush-plane, and also display a series of small cross undulations. Thus independent deformational effects are demonstrated in subjacent layers of rock according to their physical character.

The horizons in the thrust-plane and the Mendola dolomite of the thrust-mass above the fault-plane have been intercalated with intrusive porphyrite as a net-work of sills, dykes, and vein-like threads. This network runs continuously from the outcrops on the west of the Pozzale stream to the S.S.W.-N.N.E. fault and there intercalates the sheared and brecciated fault-rock.

The Mendola dolomite of thrust-mass III. has quite a conglomeratic appearance owing to the excessive intercalation of igneous material. The original bedding-planes can still be detected with strike N. 75°-80° W. and dip N. ca. 30° ; there is a system of high cleavage-planes with the same strike, but inclined S. at 70°-80°, and these are intersected by a cross-system of high cleavage-planes with strike N. 10° E., and dip 50°-60° west; these again by another system with strike N. 20°-30 °W., and standing almost vertical.

The Mendola dolomite is succeeded by patches of Buchenstein strata and the lower Wengen *Halobia* and plant shales; these are cut off by a group of shear-planes that strike W.S.W.-E.N.E., and are inclined northward; but in this case the fault-segments north of the shear-planes have slipped down relatively to those south of the shear-planes. The W.S.W.-E.N.E. normal faults are occupied by fault breccias, closely threaded with igneous rock material continuous with the intrusive threads in the Pozzale fault.

The fault-breccia between the Pozzale thrust-mass III. and the Wengen series corresponds in character to that which used to be treated as an interbedded mid-Triassic volcanic agglomerate, and called a "Buchenstein Agglomerate." But as a matter of fact, there are patches of the same fossiliferous Lower Wengen horizon above and below it, and fragments of these strata as well as of the calcareo-dolomitic rocks are contained in the breccia. So that, quite apart from all the evidence of strike and dip there is absolute palæontological evidence against the old idea that these coarse breccias formed contemporaneously with mid-Triassic eruptions.

The *structural* evidence is equally conclusive. For the intrusive rock enters continuously (*a*) the W.S.W.-E.N.E. fault with downthrow on the north, (*b*) the Pozzale S.S.W.-N.N.E. fault with downthrow on the west, and (*c*) the thrust-planes that are present in the western or Pozzale fault-block. These thrust-planes are cut by the W.S.W.-E.N.E. fault and by the S.S.W.-N.N.E. "Pozzale" fault, therefore the whole Pozzale series of thrust-masses had been piled up in the crust previous to the cross-slicing by the E.N.E. and N.N.E. faults. And as the Porphyrite intrusions most richly invade the cross-faults, it follows that the intrusions certainly are no older than the *age of initiation of these faults.* The term "age of initiation" is used because these faults were further developed *after* the first formation of fault-breccias and the first consolidation of the intrusive magma that was admitted into the zones of shear-slip and brecciation.

The Wengen strata on the north of the W.S.W.-E.N.E. fault strike against it at different horizons. The strike in the Wengen strata near the main fault is N. 80° E. and dip 50° N. and the strata are cut by numerous companion shear-slip faults with a general E.W. direction. The Lower Wengen series comprises from below upwards banded limestones and shales containing *Halobia Lommeli*, compact concretionary lava weathering in spheroidal blocks, plant shales full of coaly fragments, vesicular close-grained augitic and plagioclastic porphyrite as a thick flow, shales with plant remains interbedded with several thin tuffs and lavas. The full succession of Wengen strata is not present; one steps from highly tilted or plicated plant shales to a fairly high horizon in the Cassian with *Pachycardia rugosa*, *Cardita crenata*, etc. These have a N.E.-S.W. strike, and dip N.W., but a little higher the strata strike N. 80° E. and dip gently southward. The dip flexures are associated with the many small bendings in the Wengen-Cassian strata on the south of Langkofl Massive. The complete development of the Wengen-Cassian Series is present in the Sella Pass fault-block on the east or up-throw side of the Pozzale N.N.E.-S.S.W. fault.

Cross-Deformation at Pozzale.

Cross-folding of the thrust-masses is very well seen in the upper reaches of the Pozzale stream, between it and the pathway to Sella Pass (Sketch, fig. 3). The axes of the cross-folds run N. 10° E. and the Pozzale fault runs parallel with this direction.

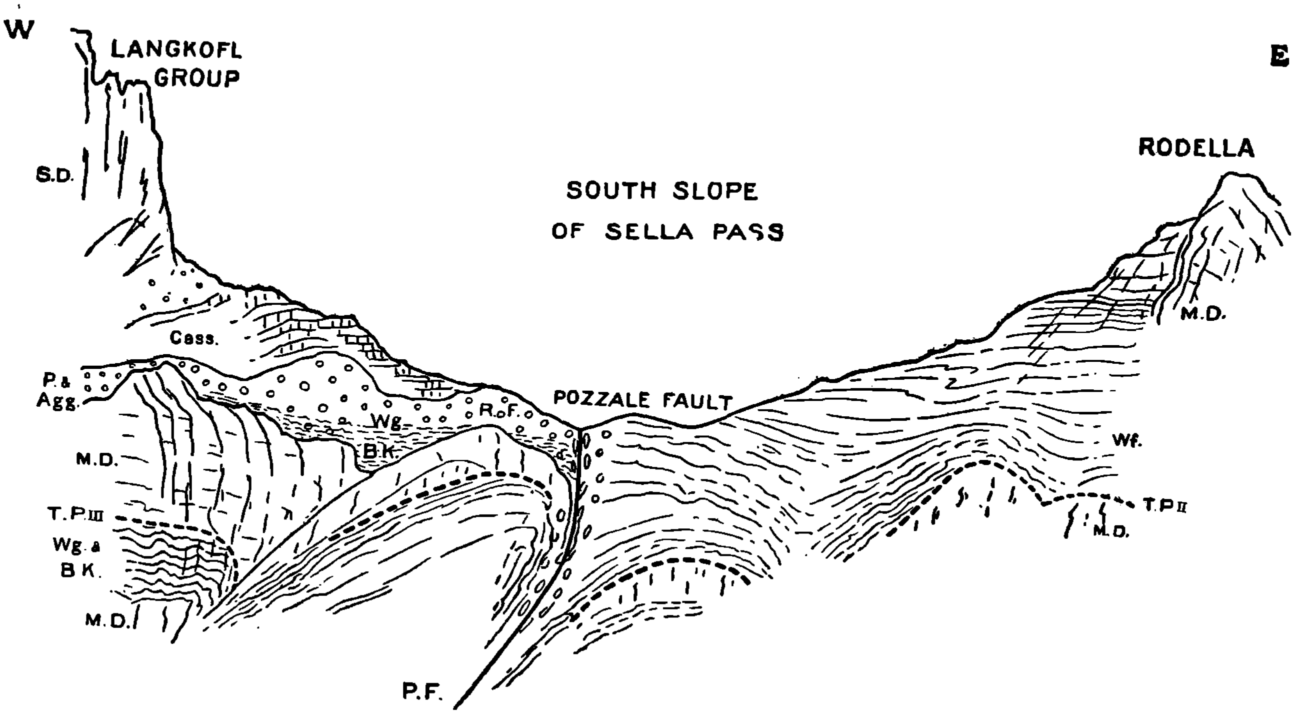


FIG. 3.—Cross-bending and fracture of the old Thrust-Masses and Thrust-Planes with W.N.W.-E.S.E. strike and dip N.; TP II = 2nd Thrust-Plane of Rodella; TP III = 3rd Thrust-Plane; Wf. = Werfen; MD. = Mendola; BK. = Buchenstein; Wg. = Wengen; Cass. = Cassian; S D. = Schlern Dolomite; Horizons P. and Agg. = Intrusive Augite Porphyrite and fault and contact breccias; P. F. = N.N.E.-S.S.W. Pozzale Fault with downthrow on the West; R.F. = Rodella Fault-zone with downthrow on the North.

The cross-undulations in the neighbourhood of the Pass are best developed in the softer rock varieties—namely in the Wengen strata below the "Mendola horizon" and in the Wengen strata at the Pass level. In the thick homogeneous mass of calcareo-dolomitic rock enclosed wedge-like in the thrust-masses, there are cleavage-planes whose direction is parallel with the axes of cross-undulation in the softer rock varieties. The differences of elasticity of the subjacent rock-horizons within the crust answers for the different effects produced as well as for the origination of numerous crust-interstices and inclined fractures between the rocks of strongly contrasted physical characters.

The bent thrust-plane shown in the sketch (fig. 3) on the east of the Pozzale fault is that between thrust-mass I. and thrust-mass II., but its outcrop on this upthrow side is more than 200 mètres higher and a kilomètre farther north than its outcrop on the west or downthrow side of the Pozzale fault.

The Mendola Dolomite of thrust-mass I. has been torn at the cross-fault; the Werfen strata of thrust-mass II. have been thrown into short, distorted plications and dragged horizontally southward at subordinate shear-planes;[1] and certain parts have subsided from time to time along the fault line. Thus there is evidence that differential movements in horizontal sense went on along the line of this N.N.E.-S.S.W. fault in addition to the differential movements in vertical sense attested by the actual downthrow of the whole western fault-block.

On comparison of typical sections east and west of the Pozzale fault and reference to the map it will further be apparent that while the same thrust-masses are present on both sides of the fault, the whole series has been crushed into much smaller horizontal space from north to south on the west side of the fault than on the east. But, as the sketch shows, the down-sinking strata on the west side of the Pozzale fault have been crushed back, as it were, against the cross-fault itself, and that is still more evident in the field where one can survey a wide terrain. From that observation it may be concluded that the numerous E.N.E.-W.S.W. branch-faults which are associated with the Pozzale fault, as well as the superinduced E.N.E.-W.S.W. strike, give expression to the horizontal

[1] The local superinduced strike is roughly parallel with the curved outcrop of the dolomite cliffs of Langkofl Massive, but this correspondence can in nowise be regarded as a proof that there was originally a coral reef in the Langkofl area which thinned out in contemporaneous sediment and afterwards during erosion tended to sink in virtue of its weight and so to exert pressure on the surrounding soft strata (see Dr Diener's criticism of my paper in 1899) within the crust. The importance of local differential strains is insisted upon in all my papers, but the local complexities here were initiated by the tendency not of original reef-like structures but of definitely limited fault-blocks to subside.

thrusts which were acting IN the downthrown fault-block during and in consequence of its insinking. The strata were stemmed back against the main N.N.E.-S.S.W. fault and *at the*

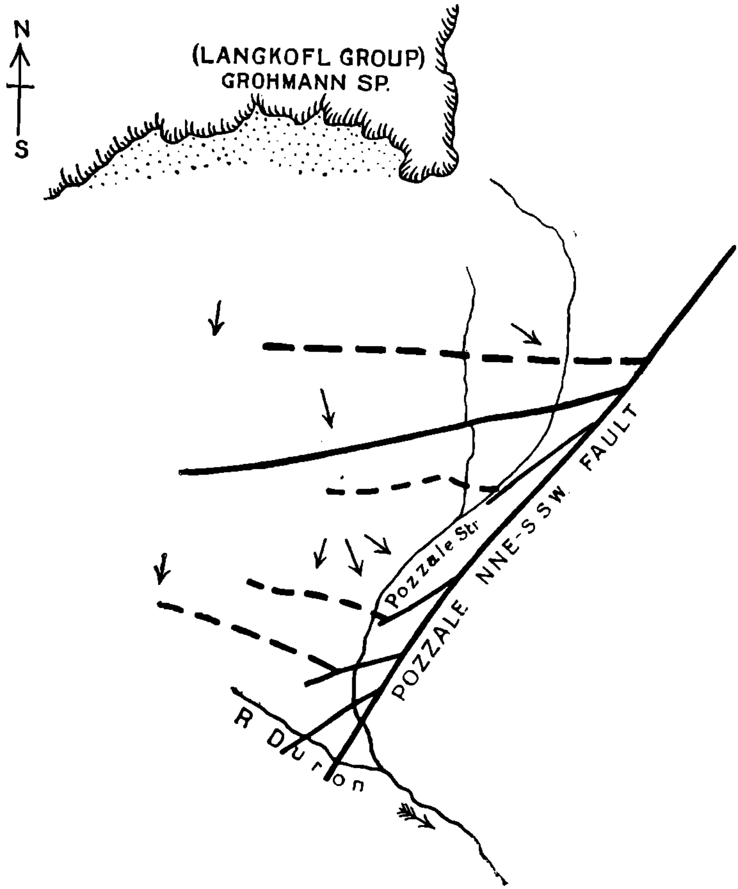


FIG 4.—Sketch-Map of the Pozzale Fault and the branch-faults in the down thrown "west" segment. — — — older faults W.N.W.-E.S.E. or W.-E. Pozzale faults E.N.E.-W.S.W., N.E.-S.W. or N.N.E.-S.S.W. ↓ the local horizontal forces of compression.

same time against the strike-fault on the north of the Duron Valley (*cf.* below, p. 63), and consequently set themselves along curving resultant strikes. The leading strike-curve for the Pozzale inthrown area is therefore from the original W.N.W.-E.S.E. strike round the south to W.S.W.-E.N.E., S.W.-N.E., S.S.W.-N.N.E. parallel with the Pozzale fault.

The strike-curvature at Pozzale can be readily demonstrated to have been correlated with the direction of the actual local resultant, for the axis of the local cross-crumpling shows that the local horizontal thrust in the proximity of the N.N.E.-S.S.W. Pozzale fault acted rectangularly to that fault, *i.e.* in a W.N.W.-E.S.E. direction; the narrowing of the outcrops on the west of the Pozzale fault together with their southward lateral displacement shows that a local horizontal thrust acted along N.N.E.-S.S.W. direction in that subsiding area which was limited by the older W.N.W.-E.S.E. fault north of the Duron River; consequently the *resultant local horizontal thrust* for the triangular area of the Pozzale fault-block was directed N.W.-S.E. (fig. 4). With continued subsidence of the downthrow fault-block, this local resultant thrust of necessity became more intense.

Relation of the Porphyrite Intrusions to the Cross-Deformation.

The distribution of the intrusive igneous rocks at Pozzale displays a very definite relation to the cross-crumpling of the thrust-masses. The magma has gained ingress chiefly at planes or bands of crust-weakness between subjacent rocks of different physical character, into the interstices created at these planes in virtue of the tendency of certain rock-horizons (*e.g.* the Werfen or Wengen strata) to *cross-fold*, as contrasted with the tendency of the calcareo-dolomitic horizons to *resist cross-deformation* except by means of a rearrangement of the component rock-minerals and development of a system of cleavage-planes. The cleavage-planes superinduced in the calcareo-dolomitic rocks in the Pozzale area are W.N.W.-E.S.E. or almost west-east with high dip south, N.N.E.-S.S.W. (N. 10° E.) with inclination to the west sometimes as low as 40°, and crossing these there is a N.N.W.-S.S.E. system. More especially the magma has ascended in volume into the group of normal faults associated with the downslipping of the rock-material on the northern dip slope of the older thrust-masses. The fault-breccias of intrusive and sedimentary rocks at the downslip zone and in the N.N.E.-S.S.W. Pozzale fault have been subsequently intercalated with small dykes, and veins of the nature of "contemporaneous veins." These later injections, as well as numerous slickensided joint-planes in the fault breccias, denote that differential movement took place at these faults during protracted epochs, probably recurring intermittently. Mineralogically considered, the later injections are augite porphyrite of more close-grained texture than the earlier invasions, and with more magnetite; olivine is sometimes present, and these rocks alter and weather as typical amygdaloidal melaphyres. A dyke high up the Pozzale stream in Lower Wengen rocks may be taken as an example:—examined microscopically, it shows—

"a typical pilotaxitic ground-mass consisting of a web of minute Felspars, Magnetite and Augite granules, composing more than half of the rock; there are numerous phenocrysts of striped Felspar and of a very pale green Augite, which is at times fresh, at times replaced by pseudomorphs of Calcite, or Calcite and Serpentine, or Serpentine alone. Quartz is not evident; there is much secondary Magnetite."

The N.N.E.-S.S.W. Pozzale fault continues southward across Duron Valley and enters the slopes of Mt. Donna as the fault-plane occupied by the intrusive augite porphyrite of the higher levels of Mt. Donna. Different horizons of the sedimentary rocks of the lower slopes of Mt. Donna are cut off against the fault, and the nature of the fault-breccia varies accordingly.

The Transverse Fault-Blocks of Rodella.

The actual horizontal compression sustained by the rock-masses of the downthrown fault-block west of the Pozzale fault in a direction parallel with that fault is best demonstrated by a comparison of the Pozzale section with a typical section through Rodella east of the Pozzale fault (fig. 2). Roughly speaking, the horizontal distance from the W.N.W.-E.S.E. strike-fault north of Duron Valley to the downslip fault that throws down the Wengen-Cassian strata of Sella Pass is about 1¼ kilomètres on the west of the Pozzale fault, and nearly 2 kilomètres in a section through Rodella summit. The thrust-masses on the east side have correspondingly wider outcrops than those on the west of the Pozzale fault.

Thrust-plane I. is exposed at about the same contour-line in the fault-block west of the Pozzale fault and in the fault-block between that fault and the hamlet of Piav on the Rodella slope opposite Campitello. It cannot be traced farther east than Piav, as the next portion of Rodella in the east has been downthrown relatively to the Piav fault-block along a N.N.E.-S.S.W. fault parallel with the Pozzale fault, and the lower levels of the mountain are grass-grown or covered with rock débris. The N.N.E.-S.S.W. fault east of Piav hamlet cuts the piled up thrust-masses and may be traced through the highest rocks of Rodella, which it cuts a little eastward from the summit.

The *Central* portion of the Rodella Mountain is included between the Piav fault and a north-south fault nearer Gries;

the *Eastern* portion of Rodella Mountain is included between the fault west of Gries and a parallel north-south fault, the "Roja Fault," which I had occasion to mention in my former papers as the western fault-limit of the downthrown area of Pordoi Pass and Sasso Beccie (*cf.* Map, Q.J.G.S. 1899). The *Eastern* portion of Rodella may be termed the Canazei fault-block.

Thus I distinguish in Rodella Mountain three main transverse fault-blocks: (1) the Eastern or Canazei; (2) the Central fault-block; (3) the Piav fault-block. The width from east to west of any one of these is not more than 1 kilomètre, and within that short distance there are in each fault-block several subsidiary faults. Relatively to the Pozzale area on the west and the Pordoi area on the east, the three fault-blocks of Rodella Mountain form together an upthrow; relatively to one another the Piav fault-block is the highest, the central block is downthrown from it, and again the eastern block is downthrown from the central (*cf.* fig. 6).

The Piav Fault-Block.

In all three fault-blocks of Rodella mountain the same structural type is present as has been described for the Pozzale area; the superposed thrust-masses can be distinguished in all, and with their general W.N.W.-E.S.E. strike, although this strike is always distorted in the vicinity of the subsequent transverse and diagonal faults. In the Piav fault-block the Werfen strata of thrust-mass I show marked disturbance near the strike-fault. They strike N. 60° W. and dip 80° N. or are vertical, the bedding surfaces are waved and fluted parallel with the strike. These bedding-planes are cut by a system of cleavage-planes which strike N. 85° E. and dip steeply to the south. There are also two intersecting diagonal cleavage-systems with strikes N. 10°-15° E. and N.N.W.-S.S.E., but the diagonal systems in the Werfen strata have the effect rather of a rough jointing than of regularly developed slaty cleavage such as has been effected along the E.N.E. direction. The slabs facing the S.S.E. are readily weathered away and the Werfen strata of the thrust-mass are thus in a constant state of landslip. The disturbances along the middle levels where thrust-plane II. crops out cannot therefore be taken into account. In the higher levels occupied by thrust-mass II. the Werfen strata have been strongly twisted so that they strike almost N.W. on the slopes immediately below Sella Pass on the west face of the mountain, but E.N.E. on the steep slopes beneath the precipitous south face of the summit. At and near the Pozzale fault dykes and ramifying veins penetrate a fault-breccia of Werfen rock material. The Mendola-Dolomite of thrust-mass II. forms the highest precipices of Rodella Mountain; the bedding surfaces of Upper Werfen passage-beds below the high precipices on the west side are slickensided and fluted and intercalated with augite porphyrite. The mapping on the west face of the summit is very complicated; I carried it out in detail, but it was impossible to do more than indicate the complications on the scale of my geological map, 1:25,000.

The calcareo-dolomitic rocks are cut by cleavage-planes and prominent joints, and many of these fissures have served as planes of intercalation of intrusive magma, or of differential movements, or of both. The Buchenstein limestone with chert nodules, and the Lower Wengen plant shales which are preserved as crushed remnants on the *north* slope of the Rodella crags farther east, have, near the Pozzale fault, been sharply bent towards the west and have slipped into *fissures in the dolomite rock formed during cross-movement*, and subsequently been cross-cleaved, jointed, torn, and intercalated with igneous material *along with the calcareo-dolomitic rock.* Crush and contact breccias ramify in this face of Rodella almost like veins, and are very instructive, representing various grades of metamorphic rock material from a calcareous gneissose breccia to a calcareous schist. A fault-bundle from N.E. to S.W. direction radiates southward in the summit rocks from the place at which there is the steep westward bend of the rocks.

The bedding-planes of the summit crags at this part strike N. 80° W. and dip 45°-50° N. The cleavage or "divisional" planes are developed in intersecting directions N. 12°-20° E. and N. 30° W. The N.N.E. planes are those along which the surfaces have been chiefly slickensided, waved, striated, or polished; the N.N.W. planes have a fresher aspect. But the intrusive porphyrite has entered planes of fission in any direction, and has intercalated the contiguous rocks with fine igneous threads that in the field look merely like fine cracks, but a rock specimen shows under the microscope that there are minute trails of porphyrite in these cracks, usually serpentinised in Rodella.

Just as in the Pozzale area, it is clear that these intrusions of augite porphyrite did not begin to take place until the old thrust-masses had been cross-bent and faulted in N.N.E.-S.S.W. direction, and intermittent intrusions must have continued throughout long epochs of localised subsidences when local resultants were the chief determining factors in the deformational structures. For the N.N.W.-S.S.E. system of divisional planes has been developed in the first intrusions of augite porphyrite that took place in the Pozzale area, and was therefore later than these intrusions and the associated breccias; fresh intercalations of porphyrite occurred into the N.N.E. and N.N.W. divisional planes, and underwent crust-strains in these planes.

The Central Fault-Block of Rodella.

In the proximity of the Piav N.N.E.-S.S.W. fault, the cleavage-slabs in the Werfen strata of the Piav fault-block turn round so that the strike of these slaty slabs follows a curve from E.N.E. round the south to N.N.E. Now it is extremely important to observe that the slaty cleavage has been developed parallel with this curve, as the parallelism with the curve gives a definite geological date to the development of the cleavage. The fissility in the rock is shown to have been developed in association with the same cross-strains under whose influence the N.N.E.-S.S.W. Piav fault developed. And just as in the case of the fault-planes the inclination of the cleavage-planes although high is demonstrated here to have been towards the south-south-east or south-east, *i.e.* towards a direction of local downthrow. If in an adjoining part of Rodella one sees augite porphyrite dykes occupying this superinduced system of divisional planes, surely that dates the age of these particular intrusions as not earlier than the age of the cross-crumpling and faulting of the older thrust-masses (*cf.* below, p. 45).

Again, the direction of the strike-curve of the planes of slaty cleavage indicates that correlated local horizontal thrusts or forces of compression were acting along N.W.-S.E. (resp. N.N.W.-S.S.E.) direction, *i.e.* in the same direction as local resultant horizontal forces acted in the Pozzale area. And it was in this direction that a later cleavage-system developed. Thus we can recognise the N.W.-S.E. direction as one along which, during the sequence of movements, local strains effected *in the first instance, strike-cleavage, i.e.* N.E.-S.W. or E.N.E.-W.S.W. cleavage, and *in the second instance* "*cross*" or "*dip*"-*cleavage* relatively to the earlier strike-cleavage.

The Mendola Dolomite of thrust-mass I. forms imposing precipices in the central fault-block, and is succeeded by portions of the Buchenstein horizon, but these are cut by thrust-plane II. The outcrop of this thrust-plane is exposed for some distance between the 2000 and 1900 mèt. contours, but descends to the 1900 mèt. contour near the eastern fault-limit. Crumpled and fragmentary patches of both the Mendola and Buchenstein horizons are present in the shear-plane.

Several N.W.-S.E. threads of porphyrite invade the brecciated Werfen strata above the thrust-plane. These occur on a ridge to the west of a high pasture and Alpe Hut. The N.N.E.-S.S.W. Piav cross-fault continues northward through fossiliferous Upper Werfen strata and passage-beds to the summit precipices. The highest summit of Rodella occurs in the Piav fault-block between this fault and another parallel fault at the west end of the precipices. Porphyritic intrusive threads have been intercalated into both these faults, and the neighbouring calcareous fault-rock is entirely impregnated and altered. The Piav fault cannot be traced further north than the strike-fault between Rodella and Sella Pass. It may have continued southward across Fassa Valley, parallel with the other N.N.E.-S.S.W. fault that is filled with dyke material on the west of Campitello, but it is impossible to establish this on account of the valley débris.

The *eastern* fault-limit of the central fault-block of Rodella is a marked north-south line of disturbance in the mountain; as viewed from Fassa Valley the topographical aspect of the mountain east and west of this fault is very different; the contrast is mainly owing to the abundance of porphyrite in the eastern or Gries fault-block and its rarity in the central summit portion of Rodella. In the occurrence of the porphyrite the Gries fault-block resembles the Bufaure Mountain Massive on the south side of Fassa Valley; and the porphyritic intrusions in the Gries area are mineralogically remarkably similar to the porphyritic masses on the west of the Clapaja slopes (or northern part of Bufaure), having the same characteristic "block-structure." Moreover, the same sharp topographical contrast presents itself on the opposite sides of Fassa Valley below Campitello as obtains in the case of the central and eastern fault-blocks of Rodella Mountain. The opinion I have formed from knowledge of both areas is that the transverse fault between these fault-blocks in Rodella intersected the W.N.W.-E.S.E. strike-fault at the base of Rodella and originally continued in S.S.W. direction into the Clapaja area. In any case the original cross-fault was here *lost to observation in consequence of the subsequent massive intrusion of porphyrite* in the Clapaja area and still later inthrow of the same area. But from Fontanazza southward, the sill-floor is quite apparent. It is the inclined plane between the Mendola Dolomite on the east of Fassa Valley and the intrusive Augite Porphyrite of Bufaure Massive. Referring to the southward continuation of the N.N.E.-S.S.W. Pozzale fault on the west of Rodella (*antea*, p. 40), my view of the structural relationship of Rodella to Fassa Valley is already so far evident. The central and western fault-blocks of Rodella Mountain represent to my mind the structural continuation, along the N.N.E.-S.S.W. cross-strike, of the sedimentary rocks in the Fassa Valley slopes below Campitello. These Rodella-Fassa fault-blocks represent a cross-arch or cross-upthrow relatively to downthrown areas on the west and east. *Augite porphyrite has been abundantly intruded* into both of the cross-troughs or cross-downthrows, and now forms the imposing crags of Bufaure Massive and Mt. Donna on the opposite sides of the Fassa Valley, as well as the slighter occurrences of porphyrite in the Pozzale area and the Gries-Canazei area on the opposite sides of the Rodella Summit fault-blocks. It was from similar evidences in my study of the Buchenstein and Gröden areas that I previously arrived at the same conclusion regarding the age of the augite porphyrite intrusions and showed that the augite porphyrite sills and dykes in these areas were not intruded until an advanced epoch of cross-compression, an epoch after overthrusting had taken place towards the south, after local strike-curvature of the thrust-masses from W.N.W.-E.S.E. to E.N.E. and N.N.E. directions had been effected, and the leading N.N.E.-S.S.W. faults had developed parallel with strongly-marked flexures of the thrust-masses towards east and west directions (Q.J.G.S. 1899, pp. 610, 628, 631, etc.).

In the eastern part of the central fault-block there is more satisfactory evidence of the history of thrust-mass II. than in the portions farther west. Only a small irregular streak of Werfen strata is here exposed in the actual shear-plane between thrust-mass I. and thrust-mass II. The shear-plane strata are very much fractured and contorted and cut by cleavage-planes with striated and fluted surfaces, and lenticles of calcite; strike N. 10° W., inclination 70°-80° E. The Mendola Dolomite that succeeds the sheared Werfen strata is itself only a sheared and fragmentary streak of quite irregular thickness, and is succeeded by a much more uniform series of Upper Werfen strata continuous with the series below the summit crags of Mendola Dolomite. The explanation seems to be that the main thrust-plane has passed through a trough between overcast arches, but the under-lay or trough portion of the higher overcast fold being next the shear-plane has itself been thrown into subordinate puckers, and cut by subordinate fault-planes. On the other hand, the main body of the overcast fold has been so far protected from deformational changes owing to the presence of the underlay "buffer" of rock between it and the actual plane of differential movements, and has been pushed as a coherent mass southward above the sheared rocks of the covered trough. Thus while the whole knee-bent fold[1] moved southward, there was a tendency for the less retarded upper portion to slide over the infolded portion next the original plane, and consequently for subsidiary planes of thrust and downslip to arise. The sheared underlay of thrust-mass II. is that which occupies the middle levels of Rodella in the central fault-block, and in this and other similar cases I shall refer to the infolded portion as the "Crush-Zone."

I showed above (p. 31) that the thrust-plane I. had also originated in reference to an overcast fold or "Knie-Biegung"; it is thus proved that the Rodella thrust-masses originated in virtue of a prolonged history of crust-movements, bending of the rocks, overcasting of the arches towards the S.S.W., faulting, and overthrusting.

The Eastern Fault-Block.

Two systems of divisional planes are developed in the eastern part of the central fault-block, viz.: E.N.E.-W.S.W. system with steep dip S.S.E., and a N. 10° W. system with steep eastward inclination. The E.N.E.-W.S.W. is also very pronounced in the Werfen strata of the eastern fault-block, where they lean against the transverse fault-plane. One can see in following the fault that these Werfen strata belong to thrust-mass II., and have been primarily bent eastward along with the Mendola dolomite of thrust-mass I. beneath them, and finally sliced away along a normal fault-plane. The Werfen strata on the east or downthrow side have been bent eastward and let down from the higher horizon of level which they occupied upon thrust-plane I. The evidence of this fault being normal in Rodella is important in view of my opinion that it is one of those upon which farther south the intrusive augite porphyrite ascended in Bufaure (p. 44). The facts are in harmony with what I have always found, that the augite porphyrite ascended most copiously into *planes of downslip, i.e. in normal fault-planes.*

A number of instructive exposures are presented in the channel of the stream that descends from the high pasture east of Rodella to the village of Gries. The bedding-planes of the Werfen strata lie almost horizontally in the stream exposures close to Gries, or with a very slight dip eastward. Farther up the bedding-planes are plicated along N.-S. axes, and the porphyritic rock on the east sends extensions into interstices in the bent bedding-planes. Divisional planes are present, directed

[1] In reference to the horizontal thrust the actual knee-bend of an overcast fold becomes the front-portion of a moving thrust-mass, and the liability of the front of the thrust-mass to extreme fracture and deformation has been admirably delineated by Professor Rothpletz in his recent works on the Glarus and Rhaetikon district.

N.N.W.-S.S.E. and inclined here steeply towards the E.N.E. This system is dominant throughout the exposures in Gries stream, and is parallel with one of the latest faults in Rodella, a N.N.W.-S.S.E. fault, which I shall distinguish as the "Gries fault." Another persistent cleavage-system is directed N. 10° E. to N. 25° E., and the cleavage-slabs incline to the E.S.E. at varying angles from 40° to vertical. Some distance up the stream near the Gries Alpe Huts, the rocks are seen to be bent parallel with the N.N.W.-S.S.E. axis of strike, the side of the curvature facing the west being steeper and shorter than that facing the east. A local transverse horizontal thrust has therefore acted from E.N.E. to W.S.W. The same strata also show bending and fractures in W.N.W. direction of strike, the fractures inclining northward. As this W.N.W. plication has affected the old thrust-masses, it shows that horizontal thrusts acted again from north to south long after the action of those which were associated with the overthrusting of the Rodella thrust-masses; in short they prove *intermittent action of thrusts in the same direction in the same locality*. The Werfen strata have here been rendered slaty, and the fossils are squeezed and distorted.

The Werfen and calcareo-dolomitic rock belonging to the eastern fault-block of Rodella have been cut by a number of shear-planes following the same strike-curve as those in the Pozzale area, viz., from W.S.W.-E.N.E. to S.S.W.-N.N.E. Crush-breccias occupy the N.N.E. and E.N.E. fault-planes, and have been interpenetrated with porphyrite. The intrusive character of the augite porphyrite here will be best demonstrated by means of a few note-book sketches taken on the right and left of the tributary stream that flows through Canazei to Fassa Valley.

The first prominent peak (fig. 5) in the rocks on the right or west bank of the Canazei stream occurs about the 1500 mèt. contour. It is composed of Mendola dolomite cut by vertical cleavage-planes (str. N. 20°-25° W.). Below it is a shear-plane with E.N.E strike and dip N.N.W.; the rock above the shear-plane is altered and schistose, the rock below the shear-plane is a crush-breccia where fragments of the Mendola rock are embedded in porphyrite, and below the breccia is another slice of Mendola dolomite. The outcrop of the shear-plane turns northward and the crush-breccia becomes more and more filled with porphyrite and at quite a short distance passes into a massive dyke of porphyrite which runs practically north and south. Precisely the same is found to be the case in respect of the crush-breccia that succeeds this outcrop of Mendola dolomite; it becomes continuous with a N.S. porphyrite dyke, and its upper limit is a schistose band representing the sheared floor of another slice of Mendola dolomite and Upper Werfen rocks.

In this eastern fault-block of Rodella, we have an example of differently inclined faults. For the western fault-plane is inclined eastward at a high angle, but these shear-planes against the east fault incline north-west. The N.N.W.-S.S.E. Gries fault passes through the area between the differently inclined faults.

The porphyritic dykes continuous with these breccias are characterised by their block-structure, in fact the term "Block-

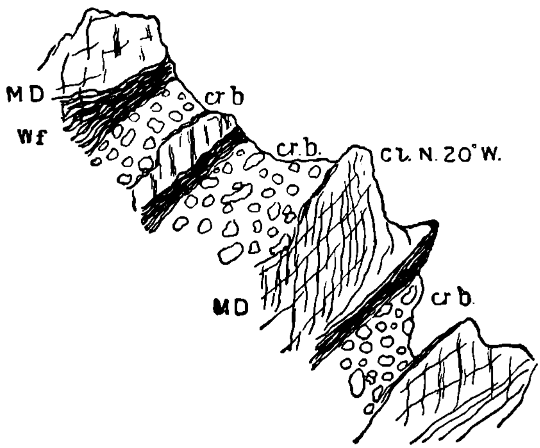


FIG. 5.—Cr.b.=crush-breccias in E.N.E. fault-planes in Eastern fault-block of Rodella; porphyrite threads impregnate the breccias, and dykes occur in the northward continuation of the strike.

Porphyr" was used by Mojsisovics in describing these and other examples in the neighbourhood. As no very suitable explanation has been given of these, I may suggest one which occurs to me from their structural position in planes of inclined shearing. May they not represent intrusions made in a crush-zone undergoing at the time the strains of differential movement? So that, while the magma was consolidating it was being dragged and rolled in the crush-zone and acquiring shear-structure, some portions of it segregating and consolidating, others remaining mobile, but consolidating later as veins of a certain schistose structure (*cf.* p. 56); with the result that a crushed tufaceous-looking or serpentinous ground-mass surrounds irregularly-dispersed segregation nodules of coarse or fine-grained porphyrite. The problem is of course one for the mineralogist, yet the field-relations suggest that any special investigation of this problem must take into account the effects produced by intermittent shearing upon a slowly-consolidating magma.

Fig. 6 is a diagrammatic rendering of the three N.N.E.-S.S.W. step-faults in Rodella with downthrow on the east. The dotted lines " rev." show how the old thrust-planes have been sheared and displaced. The N.E.-S.W. and E.N.E.-W.S.W. branch-faults from the Roja fault show how in consequence of the downslipping towards the east there was a tendency for the strata of the piled-up thrust-slices to be thrown into short

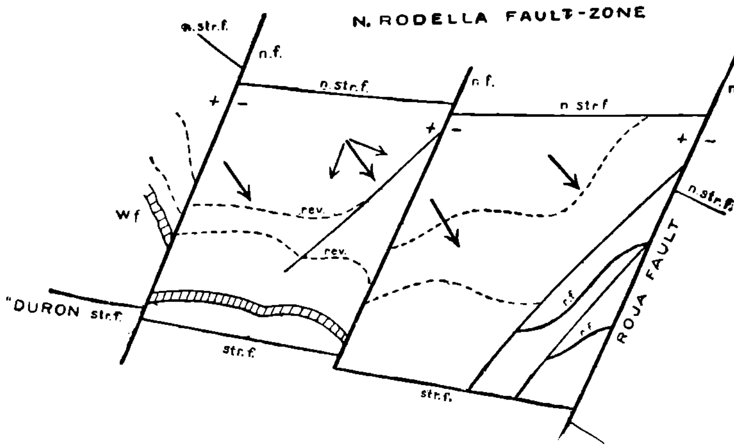


FIG. 6.—Diagrammatic sketch-map of the downthrown Central and Eastern parts of Rodella with arrows to show the direction of the local horizontal thrust during the cross-faulting in N.N.E.-S.S.W. direction. Wf.=the outcrop of the Passage-Beds belonging to Thrust-Mass. I. n.f.=normal. r.f.=reverse faults.

distorted folds with some oblique strike, and for local reverse faults with E.N.E.-W.S.W. strike and N.N.W. inclination to originate. The chief overthrusting which took place at this period from some north-westerly direction may be referred partially to cross-compression, partially to resistance offered on the south by the thrust-masses and the strike-faults.

The next sketch (fig. 7) shows an exposure at the level of ca. 1750 mèt. in the rocks immediately surmounting those in the foregoing sketch. The crush and porphyrite breccias occupy the inclined shear-planes in Mendola dolomite and Upper Werfen strata which have just been described. Here the whole mass including the breccias has been cross-crumpled and faulted. Werfen breccias and Mendola dolomite have been knuckled up along N.N.W.-S.S.E axes and the tendency has then been for the

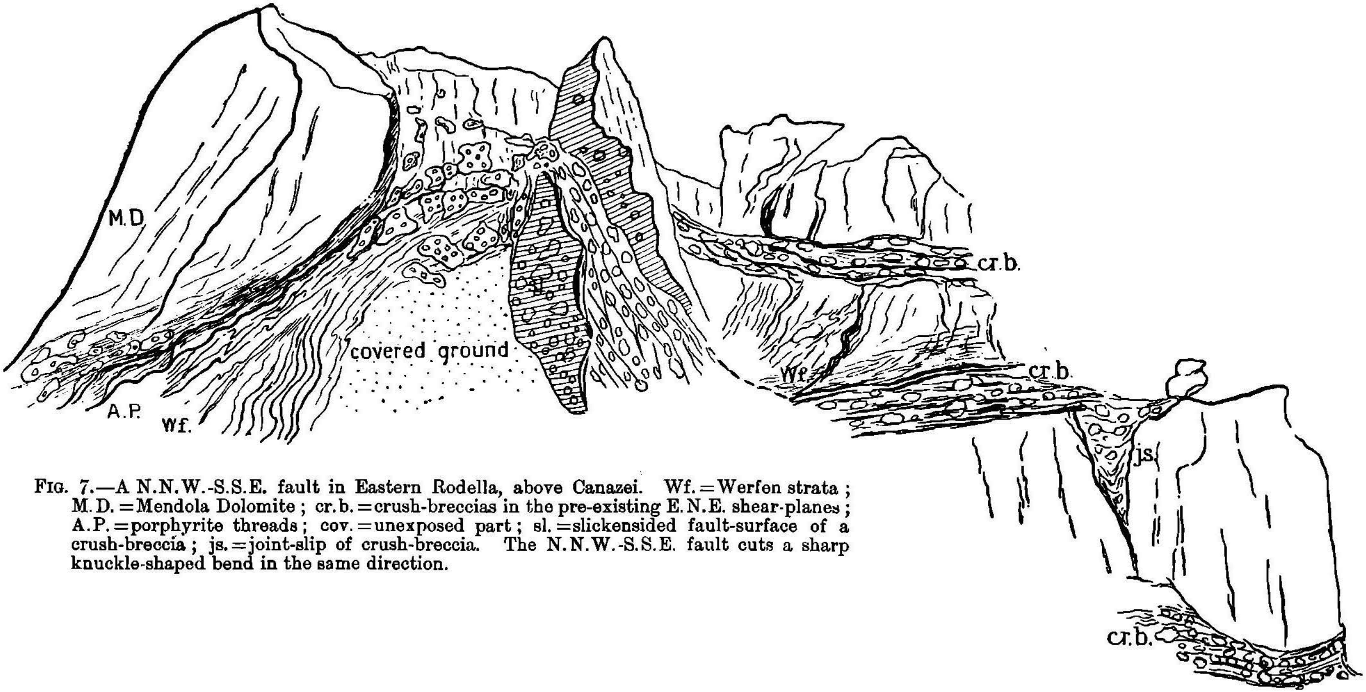


FIG. 7.—A N.N.W.-S.S.E. fault in Eastern Rodella, above Canazei. Wf. = Werfen strata; M.D. = Mendola Dolomite; cr.b. = crush-breccias in the pre-existing E.N.E. shear-planes; A.P. = porphyrite threads; cov. = unexposed part; sl. = slickensided fault-surface of a crush-breccia; js. = joint-slip of crush-breccia. The N.N.W.-S.S.E. fault cuts a sharp knuckle-shaped bend in the same direction.

Mendola dolomite to slide down to the cross-troughs, and faults and joint-slips to occur.

The Gries and Canazei series of N.N.W.-S.S.E. faults may be said to have caused a distortion of the former N.N.E.-S.S.W. to E.N.E.-W.S.W. strike by means of a number of small lateral shifts, the distorted strike being necessarily oblique to the N.N.W.-S.S.E. faults (fig. 8). If the lateral displacement be

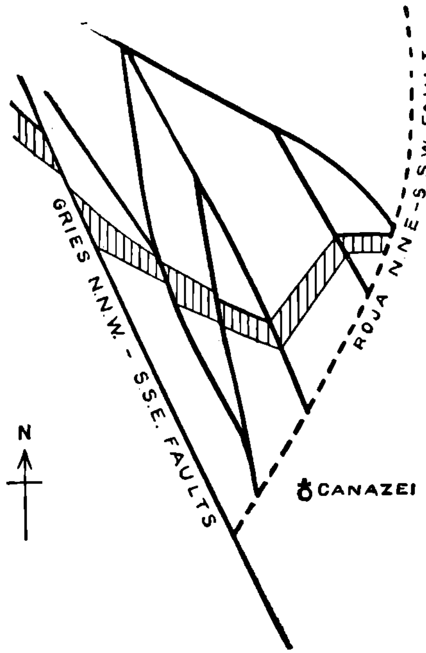


FIG. 8.—Sketch-map showing the displacements of outcrop effected by a series of N.N.W.-S.S.E. faults with downthrow on the east. (The earlier E.N.E.-W.S.W. fault-curves, to which the N.N.W. faults were rectangular, branched from the N.N.E.-S.S.W. Roja Fault: they are here omitted for the sake of clearness.)

small, the distorted strike will be W.N.W.-E.S.E.; if greater, it will be N.W.-S.E.; if still greater, it will approximate to the N.N.W.-S.S.E. direction of the displacement faults. In virtue of the lateral displacements above Gries, patches of the Werfen strata that were in the shear-zone between thrust-mass I. and thrust-mass II. of Rodella appear again and again in the eastern slope, always a little lower and a little more to the south—the Werfen strata in fig. 7 appearing at the 1700 mèt. contour-line above Gries, whereas in the central fault-block they are exposed at the 1900 mèt. contour-line. The N.N.W.-S.S.E. and W.N.W.-E.S.E. faults are rectangular to the W.S.W.-E.N.E. and S.S.W.-N.N.E. fault curves in which the shear-breccias and dykes of the east part of Rodella are situated.

Canazei.[1]

The area of Canazei which is immediately east of the "Roja fault" shows great distortion of the strata. The Roja fault is the structural limit of the Rodella mountain on the east (fig. 9). The Pordoi fault-block east of the Roja fault is part of the Sella Massive area of subsidence. The Roja fault is parallel with the fault between the central and eastern fault-blocks of Rodella, being north-south in direction in its course through Rodella, but swerving to E.N.E.-W.S.W. direction at the Fassa Valley. The eastern part of Rodella is therefore enclosed within a hook-shaped arrangement of faults. Whereas this hook-shaped fault curve is open towards the west, the hook-shaped fault-curve which encloses the part of Sella Massive on the north of Rodella or the part of Bufaure Massive south of Rodella is open towards the east. These structural forms are the result of the superposition of one movement upon another, and the consequent definite limitation of local areas of subsidence. The important feature is the cross-crumpling and faulting of a series of thrust-planes, with the strata composing the sequence of underlays and thrust-masses.

The exposures of sedimentary strata east of Canazei are limited to the bed and banks of the stream that passes through the village of Canazei to the Avisio. The bedding-planes of the Werfen strata dip northward; they are cut by slickensided planes directed N. 80° E. with high dip south like those so well developed in the Werfen strata of thrust-mass I. in the Piav fault-block. Another system of divisional planes has N. 10°-20° E. strike and the dip is gently eastward. The contact-plane between the augite porphyrite and the Werfen strata runs across these N.N.E. planes; the strata in the zone of contact are altered and present a compact, grey-green tuffoid appearance. The porphyrite is jointed along N. 35° E. direction and the joint-slabs are inclined about 40°-50° towards E.S.E.

The Werfen strata bend steeply to the north, and are cut by a series of shear-planes. The relation of these to crumpling of

[1] I visited Canazei in 1900, before the quarrying of the eastern slopes had been done in connection with the new road from Fassa over Pordoi Pass to Arabba in Buchenstein Valley. Doubtless fuller information regarding the geological structure could now be obtained. Knowing the road-making was impending, I did not attempt to map the Pordoi slopes, and have only entered in my map the general outcrops for the sake of showing that the Pordoi area is a downthrow relatively to Rodella.

the strata is fairly clear, the crumpling having followed E.N.E.-W.S.W. strike, and the folds have been gently overcast against one another with knee-bends southward.

The first E.N.E.-W.S.W. shear-plane is exposed a couple of

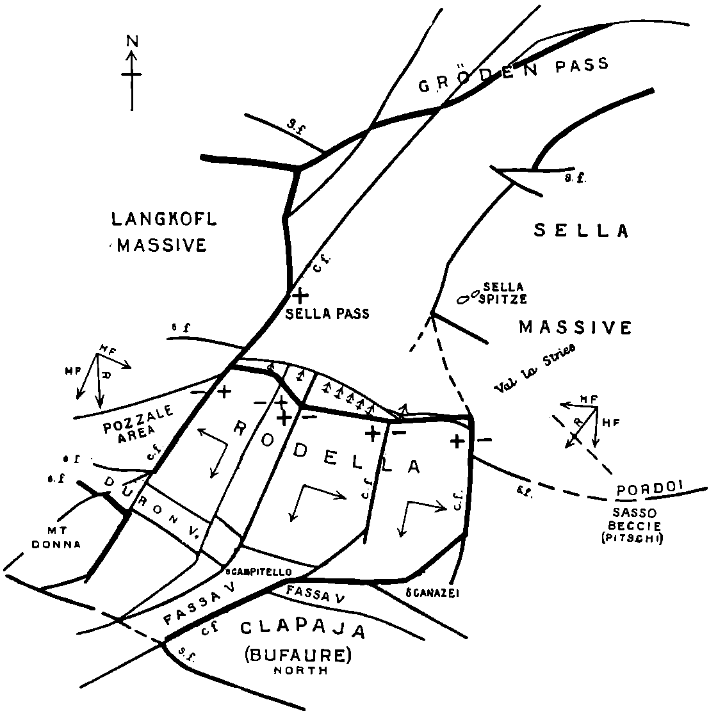


FIG. 9.—Sketch-plan (diagrammatic) of the leading strike-faults (s.f.) and cross-faults (c.f.) in relation to which the hook-shaped fault-limits of Rodella round the East, and of Sella Massive or Bufaure round the West have been determined.

+ – relative upthrow or downthrow at cross-faults. H.F. = Local horizontal Forces compressing the rocks against the strike and cross-faults. R. = Resultant local horizontal Force in the subsiding areas. ↑ = normal downslip fault-zone north of Rodella.

minutes' walk up stream from Canazei village. Downslip has taken place on the north of the fault. The fault is inclined north about 50°, but in the downslipped strata there is a shear-plane with not more than 25° inclination. It is almost in the bed of the stream. Crumpled, schistose Werfen marls form the floor of the shear-plane; the fossils are elongated and distorted and the layers are streaked with calcite. The roof of the shear-plane is schistose or brecciose. It is waved and striated, the direction of the broad wave-lines and the fine fluting being N.N.W.-S.S.E. Above the shear-plane there is a thick fault-breccia full of slickensided shear-planes. And, so far as the steep wooded crags and few exposures allowed me to examine, the augite porphyrite has covered and invaded the breccias; that is to say, the fracture, downslip, and brecciation of the rock mass preceded the irruption of the igneous material.

Types of Porphyrite.

The porphyrite appears to have welled up in the downthrow east of the Roja fault, and to have sent fingers westward into the fractures and shear-planes of the adjacent downbent masses of Rodella. The mineralogical character of the augite porphyrite is the same on both sides of the Roja fault. A typical specimen from the porphyrite above the Werfen strata east of Canazei shows microscopically—

"a coarsely crystalline character, very numerous phenocrysts of Plagioclase Felspar and Augite, and a structure approximating to intersertal. The ground-mass, which shows no glass, is a mixture of Felspar, Augite, and Magnetite. The dominant mineral is the Plagioclase, which forms prismatic crystals of various sizes crowded with zonally arranged inclusions, and somewhat decomposed. There are some well-formed and fresh crystals of a pale-green Augite, but the coloured silicates are mostly replaced by a pale-green fibro-radiate serpentinous product whose abundance gives a general greenish tint to the whole slide."

The typical specimens I took from the augite porphyrite above Gries show microscopically the same coarsely-crystalline structure, but as a rule are less fresh. The felspars and ground-mass are for the most part stained reddish by the decomposition of the ferro-magnesians. In one specimen the augite is entirely replaced either by serpentine or by serpentine and calcite. The serpentine has throughout a microsphærulitic arrangement; secondary quartz is not noticeable. Another specimen presents a large number of circular and irregularly-shaped vesicles filled with serpentinous matter, but is in essential structure precisely like the Canazei specimen.

A great many later intercalations of finer-grained character are present in the augite porphyrite, and similar intercalations occur as dykes amid the sedimentary strata or in the group of N.N.W. fractures which have dislocated the eastern portion of Rodella. Two or three of these are present on the right bank of the Canazei stream, at the 1600 mèt. contour near a fault which cuts the block-porphyrite and throws down Werfen strata on the north. The dykes lie almost east-west in the

Werfen strata. Other dykes occur in the north-south fracture near Roja; one is present in the bed of the stream and sends east-west or W.N.W.-E.S.E. apophyses into the neighbouring strike fractures.

A specimen which was taken from a dyke intercalation in the porphyrite east of Canazei, shows under the microscope—

"a very fine-grained pilotaxitic ground-mass of minute Felspar rods, pale Ferro-magnesians and much Magnetite. There are very numerous crystals of a striped and zoned Plagioclase which is decomposed and full of inclusions. The Augite is entirely replaced by chloritic matter; there is secondary Magnetite and a general faint-red stain over the whole section."

A specimen from the dykes in the stream and near Roja is a rock

"with a phanero-crystalline ground-mass of lath-shaped twinned Felspars, magnetite and chloritic matter, showing distinct flow-structure, the general appearance lying between the trachytic and the pilotaxitic; there are numerous large phenocrysts representing Plagioclase, Augite and apparently Olivine, but the phenocrysts are almost without exception replaced by Calcite and Serpentine; there are some cavities filled with Quartz. Many of the Felspar crystals show sections circular in outline, and as usual, strongly zoned."

These olivine-bearing "melaphyre" dykes penetrate all other intrusions in this neighbourhood and intercalate older contact breccias of sedimentary and igneous material.

A hand-specimen that looked in the field like a calcareous conglomerate but was taken from the Roja dykes shows—

"a ground-mass of abundant well-formed Plagioclase laths, the magnetite and ferro-magnesian material being somewhat shrunk relatively to the Felspar crystals; there is also Chlorite, etc., in the ground-mass. There are big phenocrysts of Plagioclase largely replaced by Calcite, large Augite phenocrysts also replaced by Calcite and Chlorite, but retaining in places residual fragments of the original mineral, pseudomorphs in Calcite after Olivine, and numerous large vesicular cavities filled with Calcite and radiate Serpentine."

This specimen is a type of the intrusive rock associated *in the field* with various kinds of "Kalk Breccie," "Breccienlava," "Agglomeratlava," "Tuff-Breccie," or "Kalk-Tuff Breccie"—all of which terms are in use for describing certain of the typical rocks in Fassa. In this particular case the "Breccie," in question is merely an altered igneous rock, where secondary mineralogical and disintegrating changes have practically reformed the rock. Many of the thin threads of igneous material that have extended into the Upper Werfen, Mendola and Buchenstein rocks are thoroughly altered; their origin as igneous rocks is only discoverable in the field by tracing the veins to the bigger intrusions. The cracks in a calcareous rock impregnated with the thin threads are filled with coarse-grained crystalline calcite.

In examining the Canazei block-porphyrite I found that the coarser-grained nodular masses of different varieties of porphyrite were embedded in a compact tuffoid-looking rock. But there could be no possibility of regarding it as a *sedimentary tuff.* It travels through and through the block-porphyrite, enwraps and impregnates the fragments of coarser-grained porphyrite, having the character of true contemporaneous veins injected into the joints and tears of already consolidated portions of the porphyrite. Microscopically examined, a typical specimen has all the appearance of "volcanic ash"; it contains—

"fragments of rocks mostly of the nature of Porphyrites and Andesites (?) with bits of Felspar, Calcite, and much interstitial chloritic material."

Threads of this vein-material pass into the brecciated sedimentary and igneous rock at the contact zone, and ramify amidst the calcareous fragments just as in the porphyrite. The following two specimens are taken from an impregnated contact zone in Canazei:—

"A Volcanic tuff, consisting of fragments of Porphyrite and kindred rocks, with bits of Augite, abundant Chlorite, etc. The section shows one peculiar feature in that quite a large number of the rock fragments with their porphyritic crystals are quite isotropic, so that the tuffs as a whole must have undergone some form of decomposition or alteration."

"An unusual tuff, quite unlike the other tuffs or porphyrites; it contains large crystals or fragments of a grass-green Augite, some bits of colourless Pyroxene, a few crystals of striped Felspar, and a great amount of vermicular Chlorite. There is also a quantity of stringy pumice-like glass. The texture is coarse-grained."

The intrusive rock on the north slope of Rodella in the fault-zone is remarkable for the very large size of the Felspar crystals. In the field the most common type is a blackish rock with large white crystals. Microscopically examined it shows—

"a comparatively fine-grained ground-mass and fewer phenocrysts than the majority of the above-described varieties. The Felspar phenocrysts are, however, of large size, elongated parallel to the prism and twinned on the Carlsbad and Albite Laws, and stand out boldly from the general mass. The Augite is generally replaced by Calcite and Serpentine, (Epidote ?)."

Another type in the N. Rodella fault-zone is as seen in the field a dark grey porphyrite with augite and felspar crystals. Examined microscopically, it shows—

"a holocrystalline ground-mass of small twinned Felspars, abundant magnetite and chloritic material and Augite granules: the structure is pilotaxitic. The phenocrysts are large crystals of Plagioclase Felspar, large Augite crystals, serpentinous pseudomorphs after Augite, and

Magnetite. The Felspars are tolerably fresh, but full of inclusions from the matrix. The proportion of the ground-mass is large relatively to the phenocrysts."

The North Fault-Zone of Rodella.

The chief types of augite porphyrite that occur in this fault-zone have just been described. The same types characterise the intrusive rocks in the fault-zone north of Buchenstein Valley, and as I showed in my previous paper, one has to regard the original intrusive mass at Rodella, Canazei, and Buchenstein[1] as a continuous subterranean flow with countless small ramifications. ("Torsion Structure," *aut.* Q.J.G.S. 1899: Map, p. 614, and Fig. 13, p. 588.)

The north fault-zone of Rodella separates the Rodella fault-block from that of Sella Pass. The exposures are unsatisfactory, only occasional lines of crag cropping out. At the inthrown eastern end near Roja, the rocks have been exposed by reason of frequent landslips, but the original relations can be best judged on the north slopes of the Rodella summit, by working eastward to them from the Pozzale section.

The Mendola dolomite is succeeded by concretionary limestones, and the northward dip suddenly steepens on the north slope of the summit to as much as 60°. The bedding surfaces are strongly moulded by pressure and the patches of Wengen strata are kneaded and bent into the pressure-hollows; in other places the calcareous rocks are coarsely brecciated. A grassy ridge runs parallel with the crags, and in the surface depression between them the rocks that show are chiefly porphyrite and Wengen shales. Threads from the porphyrite run southward into the Rodella crags and a fine calcareous and porphyritic breccia is locally formed.

There are also outcrops of Buchenstein limestone, and it is difficult to say under the poor conditions of the exposures whether the Buchenstein outcrops are really rock in position or only remains of old screes. If they are in position, then this ridge represents the remains of the eastward continuation of the

[1] Since the present paper was written and presented at the Royal Society, I have received a leaflet by Professor Doelter which was read at a meeting of the science section of the Royal Academy in Vienna on the 23rd October 1902. In it he writes: "At Pordoi Pass a new road is being constructed, and I had a look at it, under the guidance of Herr Delago, engineer. I found here below the limestones a mass of melaphyre, which up to the present time has been regarded as *older* than the limestones. In this melaphyre I found at a distance of one mèt. from the limit of the limestone a fairly well-preserved ammonite; as this had alearly been torn away by the eruptive rock, the latter would therefore be *younger* than the Triassic limestone at that place." The translation and the italics are mine. I need only refer to my Q.J.G.S. paper published in 1899, to point out that I had already at that time mapped and described this Pordoi melaphyre as *intrusive* and *younger*.

small third overcast fold, west of the Pozzale stream. In favour of this view, there is the fact that at the Roja end of the ridge, there are streaks of Buchenstein limestone in true position and thoroughly impregnated with intrusive porphyrite. In any case the ridge marks an important east-west fault-line with downslip to the north. On the south of it the old thrust-masses are present, but have been cut by the fault; on the north of it the Sella Pass fault-block and successively younger horizons of Wengen-Cassian strata are cut off against the east-west fault as it is followed eastward to Roja.

The age when the intrusive porphyrite entered the downslip zone can be determined as later than the cross-bending and the initiation of the N.N.E.-S.S.W. cross-faults of the Rodella thrust-masses, from the fact that the intrusive rock in the fault-zone sends dykes into the three cross-fissures. Therefore on

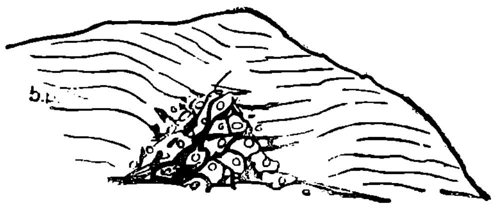


FIG. 10A.—A N.N.E. dyke intercalated into Mendola dolomite on the north slope of Rodella, ascending from the North Fault-zone. The bedding-planes dip about 40° N.

the grounds of geological structure as well as of resemblance of the rocks, this fault-porphyrite was originally a continuation of the intrusions in the Canazei, Gries and Pozzale fault-blocks.

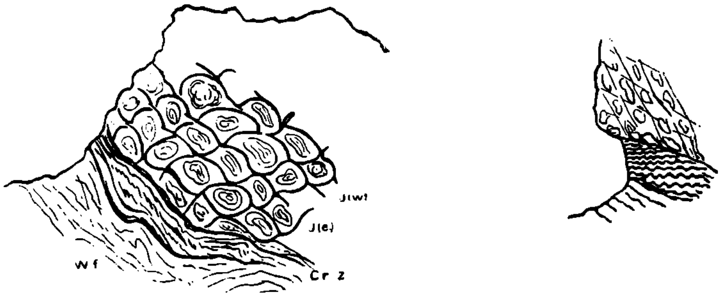
In the eastern part nearer Roja the east-west fault-zone has suffered along with the eastern fault-block from the effects of intense strains in E.N.E.-W.S.W. direction and the local overthrowing to the west or south-west (*cf.* fig. 9). It has been jointed and torn along N.N.W. and S.S.E. lines and small dykes have been injected at this late period of segmentation of the fault-zone.

The appearances at this eastern end are at first confusing, as the sedimentary tuffs and interbedded lavas of Wengen-Cassian age have been brought against the intrusive porphyrite of the fault-dyke. The fault-breccias in consequence contain numerous fragments of the Triassic igneous rocks, and next them is the intrusive rock-material.

A typical exposure of the fault-zone may be seen about half-way between Rodella summit and Roja Alpe (fig. 10). The crush-breccia includes angular fragments of Upper Werfen and Mendola rocks, as well as pieces of the Buchenstein and Wengen strata. Below the shear-plane are small lenticles of Mendola rock, but the main portion of the floor here is com-

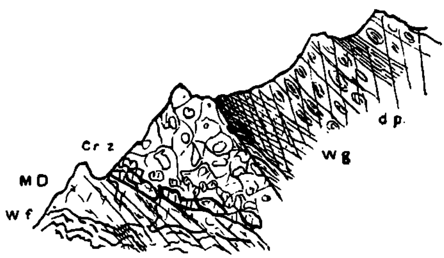
FIG. 10.—The Fault Zone N. of Rodella.

B. = Downslip plane viewed from the front. C. = Viewed from the side.



B. = "Block structure" within the divisional planes. Wf. = Altered Werfen strata. Cr. z. = Crush zone strata N. 50° W. J(w). = N. 40° W. joint-system dip N.E. J(e). = N. 25° E. joint-system dip 70° E.S.E.

C. Fault-pl. seen from the side.



D. = Section through the fault-zone farther east than section C. d.p. = Divisional planes.

posed of Werfen schistose rock, the bedding-planes of which have a remarkably small northward dip as compared with the steeply-tilted and disturbed dip displayed in the Wengen horizons *above* the crush-breccias of the fault-zone. The floor and roof of the shear-plane are both waved and fluted, but the roof has a finely polished surface showing a wonderful mosaic of rock-fragments. The fault-plane dips 40° N.E. and there is parallel with it, but more steeply inclined, a rough joint-system, more especially developed in the overlying rocks. These have served as companion planes of movement, or as I called such planes in my former paper, "*subordinate shear-planes.*" The Werfen strata below the shear-plane have during the differential movements been squeezed up between large blocks of the overlying calcareous rock, and then nipped off and incorporated in the crush-breccia.[1]

The schistose crush-zone of the Werfen strata is about three or four feet thick; in it the rocks are altered to hornstone or pale greenish schists, and layers of pyrites crystals (iron sulphide) are developed. The compact greenish beds have quite the tuffoid appearance and coloration of the "Pietra Verde" rock of this district that used to be regarded as contemporaneous "Buchenstein Tuffs." In this case, the conversion of ordinary sedimentary shales to banded and tuffoid schists can be readily traced. As the crush-breccia above has been freely intercalated with augite porphyrite, the altered rocks may be held to represent a shear and contact zone.

The crush-breccia contains many bedded fragments from the concretionary tufaceous grits and breccias of Wengen age as well as occasional blocks of the scoriaceous felsitic type of interbedded lava. Such included fragments are cut by the intersecting divisional planes that penetrate the crush-breccia as a whole. This shows that the spheroidal structure in the Wengen sedimentary tuffs had been developed in them *before* the breaking up of these strata in the neighbourhood of the fault-zone. The superinduced joint-planes in the crush-breccia are slickensided and they curve much in the same way as one sees curved joints in igneous rocks. Near the shear-planes these joints are directed N. 20°-25° E., high dip 70° to E.S.E., and N. 40°-50° W., steep dip N.E. As the latter direction is parallel with the local strike of the fault-zone, I concluded that these divisional planes developed as a result of the shearing and were in a manner subordinate shear-planes accompanying the main shear-plane. Next these joints the rock-material has been strongly squeezed and powdered, whereas a nodular mass of harder rock occupies the central area between intersecting joint-planes. In this case the "block-structure" is clearly a pressure effect.[2]

[1] The nipping-up and away of the softer rocks has taken place in a joint-plane vertical to that of the inclined fault-plane and shows how the rocks may become slickensided along vertical fissures in the same direction as the deep fluting or fine striation presented on the bedding-surfaces at inclined fault-planes. It is a process that has taken place extensively in the Dolomites, both on large and small scale, and to it I trace the *initiation* of N.N.W. and N.N.E. vertical joints and cleavages, along many of which at subsequent more advanced stages differential movements caused displacements of outcrop (*cf.* fig. 8) in definite transverse direction to all parts of the previous strike-curves round the S.E. or round the S.W.

[2] *Block-porphyrite* conf. the present writer's paper in Geol. Mag., July 1902, where she points out that this term used descriptively may be, and has been applied, in Fassa to rocks with a quite different geological history. The present writer distinguished at least four types of block-structure:—(a) *Joint block or spheroidal structure*, due to decomposition of the porphyrite along intersecting

The strata above the shear-zone are Halobia and plant shales of Wengen age and the concretionary sedimentary tuffs (pp. 24, 25, figs. 10D and 11). Near Roja the relations of the shear-plane are a little different. The bedding-planes of Werfen strata below are almost horizontal, and a row of large blocks is above the shear-plane; it apparently represents a calcareous layer in

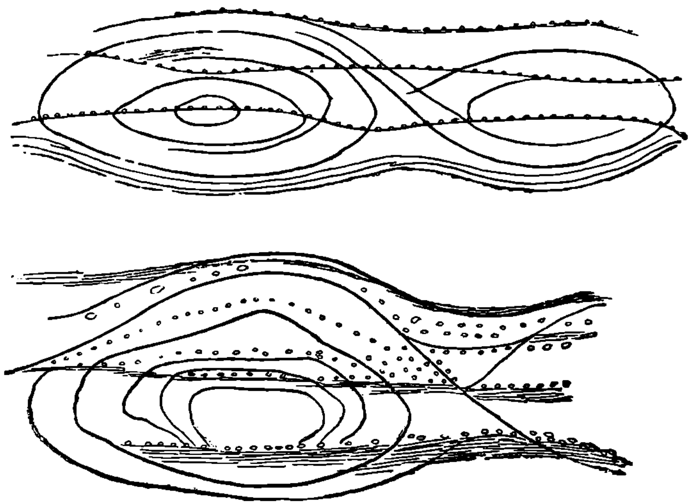


FIG. 11.—Concretionary Structure in the Wengen Sedimentary Tuffs. The coarser grits can be traced through adjacent joint-blocks.

the passage-beds which has been cut up *in situ.* Above it is a coarse crush-breccia mostly composed of material from the passage-beds.

The shear-plane and the crush-breccias are slipped and broken in the intervening portion.

Comparison of the Rodella and Buchenstein Areas.

On reference to my Geological Map of Sella Massive and Buchenstein, a glance will show that I then recognised—(*a*) the structural identity of the normal fault-zone south of the Prelongia Meadows and Cherz Hill with that between Sella

joints, and shown either by sills or by true surface flows in Fassa; (b) *Original segregation or shear-structure,* where richly felspathic or richly augitic masses, lenticles, or bands have segregated out during the consolidation of intrusive masses under varying pressure conditions; (c) *Superinduced agglomeratic or brecciose structure,* where either an intrusive sill or a surface lava has been broken up subsequently to consolidation, and jointed, brecciated, or crushed to tuffoid condition at planes of differential movement; (d) *Combination-sill structure,* where older injections have been broken up, and impregnated by later injections.

Pass and Rodella ; (*b*) the intrusive character of the porphyrite within this fault-zone; (*c*) the dismemberment of the fault-zone by E.N.E.-W.S.W. faults ; (*d*) the occurrence of dykes in association with the lateral shifts undergone by the fault-zone. From my former paper I quote the following description of the Cherz fault-zone:—"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" (Q.J.G.S., 1899, p. 585).

The kind of transverse fault here referred to is quite similar to the N.S. transverse fault at Roja, on the east side of which the N. Rodella fault-zone is displaced to the south, and the Wengen strata above it are thus brought alongside the Werfen strata belonging to the upper thrust-mass of Rodella Mountain.

The transverse section through Cherz Hill (*l.c.* fig. 10, p. 587) shows that the thrust-masses exposed at Rodella Mountain are present on the N. slopes of Buchenstein Valley, and are cut by the normal fault with downthrow on the north into which, as well as the N.N.E.-S.S.W. Campolungo fault, the porphyrite has penetrated.

Having now fully investigated the Rodella area on the west of Pordoi Pass, as well as the Buchenstein area on the east of it, I have found confirmation of my explanation of strike-torsion as due to the cross-movements that have occurred in this district. As I then showed, the basis of the torsional movements was the determination, in a region which had already been folded and dislocated in an almost east-west direction, of a series of incipient cross-arches and troughs and cross-faults, parallel with a N.N.E.-S.S.W. direction. The intersecting fault-systems formed a network of limiting-planes within the crust, against which the subsequently developed undulations in the rocks were closely pressed. A good example is given in fig. 6, where the "Duron" strike-fracture separating the piled-up thrust-masses of Rodella from the bent Fassa thrust-slice on the south of it represents a leading limiting-fault of the Rodella area. The "Roja" N.N.E.-S.S.W. fault with downthrow on the east represents a leading limiting-fault in the strike direction of the later cross-movement. During subsidence the insinking segments in the transverse fault-blocks of Rodella exert horizontal pressure rectangularly to the Roja fault, and at the same time parallel with it, inasmuch as they push southward against the strike fault. The resultant local horizontal strains act along N.N.W.-S.S.E. or N.W.-S.E. lines and give rise to shear-planes in E.N.E.-W.S.W. or N.E.-S.W. directions that branch from the leading N.N.E.-S.S.W. faults. Hence the strata are torn, brecciated and displaced along the N.N.E.-S.S.W. faults, and have been freely intercalated with porphyrite intrusions. The general effect of the tearing and twisting strains in East Rodella has been to displace the outcrops according to a curve round the south-east. Precisely similar effects of curved outcrops and shear-planes round the south-east are displayed in this district where-ever in subsiding areas local horizontal strains acting from the N.N.W. have driven the rocks obliquely against any two such intersecting faults as the Roja and the Duron faults (*cf.* fig. 46).

Sella Pass.

The strata that have slipped down at the normal fault-zone north of Rodella are the Wengen-Cassian series exposed on Sella Pass (fig. 12). The palæontological features of this series are described above (p. 23 ff.). With regard to their structural aspect I have purposely laid the section east-west to show the cross-crumpling of the series. A comparison of this section with the drawing of the cross-bent thrust-masses (fig. 3) will at once prove that the cross-compression has affected all the crust-horizons and is not limited to any particular horizon. Some subordinate features due to the cross-compression are apt to confuse the study of the palæontology. Patches belonging to higher horizons of the Cassian strata have frequently fallen into wedge-shaped hollows during or after cross-compression, and as the joint fractures are inclined similarly to the strata the position of the higher horizon in the trough is very deceptive. Fig. 13 gives an example of a group of slips that I observed in the slopes east of Sella House. Where the slopes are fairly grass-grown such scraps of the harder limestone might easily be taken for blocks of Cipit Limestone thinning out in tufaceous strata, but the relations in this particular case are as shown in the figure.

A rather bare grassy ridge that runs close up to the rocks of Sella Spitze presents good exposures of the fossiliferous Upper Cassian tuffs which comprise the typical blocks and banks of Cipit reef-limestones. The general strike is N. 30° W. and dip slightly to N.E., but immediately below Sella Spitze the bedding planes twist towards a N.E. strike with E.S.E. dip. The highest reddish crags of Cipit limestones and ferruginous tuffs full of nodules occur at the 2400-mètre contour; the Cipit limestones

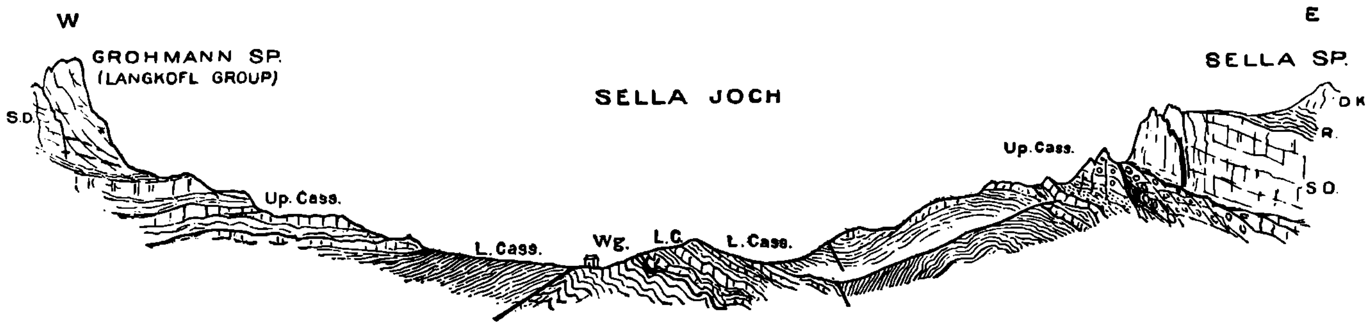


Fig. 12.—Section through Sella Pass on the north slopes of Rodella mountain proving the cross-deformation of the rocks. Wg. = Wengen tuffs; L.Cass. = "Pachycardia rugosa" tuffs; Up. Cass. = same with more "Cipit Limestone" interbedded, and a greater admixture of Raibl species with the typical Cassian species; S.D. = Schlern Dolomite; R. = Raibl marls and sandy Limestones; D.K. = Dachstein Dolomite.

dovetail eastward with stratified dolomitic limestone instead of with tuffs, but a thickness of 300 mètres of Schlern Dolomite at Sella Spitze intervenes between the Cipit rock and the brownish or reddish marly, sandy limestones of the Raibl series situated on the high terrace of Sella.

As the Sella Pass section shows, the plane between the Cipit limestone horizon and the Dolomitic limestone above it has been especially marked as a *zone of shearing-strains.* The tuffs and Cipit limestone are steeply bent towards the N.E. and have been cut by inclined sliding planes in this direction upon which the overlying rock apparently slipped downwards (*cf.* Q.J.G.S., 1899, p. 609, fig. 20, fault between 3*b* and 4*a*). A north-south fault passes through the dolomitic rock and throws down the eastern side, but it is impossible to determine definitely the

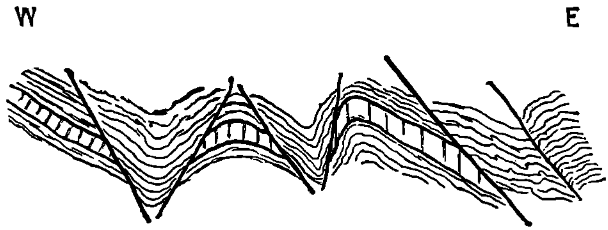


FIG. 13.—Slips of overlying tuffs into deeper horizons of Cassian strata (Sella Pass, east slopes).

course of these faults, as any continuation southward is obscured from view by extensive screes. All that can be said is that nearer Roja a N.S. disturbance in the Wengen-Cassian strata can be determined on the basis of a general twisting southward of the whole series from a N. 20° W. to a N. 60° W. direction of strike and relative subsidence on the east of the Roja fault. The sections of Rodella and Sella Pass show that there has been at all stages of deformation a decided tendency for the curvatures and fractures to be developed, as it were, *independently in the horizons below the Wengen-Cassian group and the horizons above that group.* The position of this softer group of strata between the calcareous masses above and below determined it as a shelf of differential slip and shear relative to the horizons above and below it. The thrust-slices of Rodella are almost wholly composed of the Werfen and Mendola rock-material; very little of the Wengen shales have been caught in with them. Rather, *the Wengen rock has presented a horizontal plane of limitation in the crust which was as effectual a stop-gap to continuity of deformational structures as the steep strike and cross-faults presented in a vertical direction.*

In the earlier stages of the crust-movements the different petrographical constitution of rock horizons seems to have been the chief factor in determining the localisation of groups of overthrust faults within the calcareous masses, and correlatively of downslip normal faults affecting the Wengen-Cassian group. When cross-flexures and cross-faults formed, differential movements between the Wengen-Cassian and the calcareous rocks took place parallel with the new axis of strike, with the result that the Wengen-Cassian group got twined and crumpled, and therefore *locally thickened* in the course of curved zones of deformation between piled-up thrust-masses of calcareous rock.

It was only after the cross-movements had been in progress that the augite porphyrite ascended, and there had thus been prepared for it, as well as the steep fractures, a number of horizontal and gently inclined shelves of crust-weakness and differential shearing in the crust; where (as on the north of Rodella) the Wengen and Cassian strata had been retarded and slipped down relatively to the southward drive of the Werfen and Mendola dolomite thrust-slices. Such shelves were not continuous for any great distance in the crust, but bent northward and either eastward or westward or N.E. or N.W. according to the particular local flexures of the rocks towards the intersecting strike, oblique, and cross-fractures. As it rose the intrusive magma sought out these shelving planes of differential movement for itself, and becoming embodied in them, inevitably participated in the shearing and displacement that occurred pre-eminently at those critical zones in the crust (*antea*, p. 29).

The term "Asta-Judicarian."

In the course of the foregoing description of the geological map of Rodella, evidences have been given to show that the augite porphyrite was intruded subsequently to the cross-bending and dislocation of the thrust-masses, that it found ingress chiefly in the faults limiting the cross-troughs or down-thrown bands east and west of Rodella and in the group of normal faults north of Rodella; and that igneous material was intermittently irrupted throughout prolonged epochs of the cross-strains, younger dykes having been intercepted in the older, more extensive porphyrite sills and dykes, and into, or in the proximity of, later fractures dislocating older fault-zones, *e.g.* at Roja.

In my previous papers I termed the tectonic complications that arose from the cross-movements "Judicarian,"[1] in contra-

[1] From the important Judicarian N.N.E.-S.S.W. fault west of the Dolomite region.

distinction from the earlier movements of overthrusting to the south to which I have applied the general term "Asta"[1] movements. The Judicarian cross-movements bear transverse relation to the Asta movements and I have therefore often referred to them together as the "Asta-Judicarian" system, and have already shown that the deformational results of the protracted sequence of Tertiary movements created a curious piece-work of fault-segments to which and *not* to original "reef" accumulations the striking aspects of geological structure in the Dolomites are due. Limiting faults and the interruptive effect of rock-bars, composed either of piled thrust-masses or of the crumpled down-slipped Wengen-Cassian tuffs and marls, defined the several local areas of inthrow in the neighbourhood of Rodella; and the horizontal thrusts gradually generated within these local areas modified the more widely-acting Judicarian cross-strains that affected the larger area. In my first contributions to this subject I identified the more widely-acting cross-pressures with the subsidence of the Peri-Adriatic region, and have since demonstrated in lectures and papers that the Peri-Adriatic subsidence was itself local in relation to regional Alpine cross-movements. So that the correlation borne between any individual area of inthrow in the Dolomites and the system of cross-folds in the whole Peri-Adriatic region is similar in character to the correlation of any basin of subsidence within the Alps to the regional Alpine movements. And by devoting very close attention to detail, I have hoped to elicit general principles helpful to our understanding of the distorsional effects produced by the superposition of local and regional forces of compression acting simultaneously or intermittently on the same area (ref. author's papers from 1894 to 1900).

The Crush-Conglomerates of Rodella.

In my paper of 1899 I established the fact that the so-called volcanic conglomerates of Mid-Triassic Buchenstein Age were in reality subsequent structures associated with Tertiary crust-movements. I can now say the same with regard to a horizon that has hitherto been termed an *Upper Werfen Conglomerate* in this part of the Dolomites. In Rodella, in the case of any normal succession, such as that presented immediately below Rodella summit, there is no such conglomerate, but the succession from Werfen and Mendola dolomite is as I show in my table of strata (p. 19). But at the shear-zone that runs through the middle of the south slopes of Rodella, the Werfen

[1] From the Cima d'Asta Mountain Massive in the south of the "Dolomites" where Prof. Suess first proved the presence of overthrusts to the south.

strata of the infolded rock-masses between the two thrust-masses have been much brecciated. The same is true of the Upper Werfen strata in the Pozzale area where the sharp knee-bend of the lower thrust-mass has been cut by shear-planes passing between the softer Werfen marly limestones and the Mendola horizon. These breccias are true crush-conglomerates and had been formed during the overthrusting to the south, *i.e.* long before the inrush of igneous rock. But the crush-breccias of the middle shear-zone of Rodella have been subsequently thrown down along with the thrust-masses in the east wing of the mountain, and have there been cross-sliced by the E.N.E.-W.S.W. faults. Along this direction the older crush-zone and the rock-slices above and below it were broken up into a number of fault-blocks which then underwent differential movements of the nature of thrusts and downslips, oblique in direction to the older series. New shear-breccias were thus formed, much more complex than the older; and it was into this complex network of faults and crush-breccias that the porphyrite magma found ingress. Thus the *second system of crush-conglomerates*, which were strongly developed near the important Judicarian cross-faults, and at the inclined shelving zones of Wengen-Cassian downslip and twining, were those chiefly impregnated with augite porphyrite.

Crush-conglomerates in the calcareo-dolomitic rocks or *crush-schist* in the Werfen marly shales and limestones accompany *almost all* the N.N.E.-S.S.W. and E.N.E.-W.S.W. faults that are entered in my map of Rodella, and many of them have been subsequently displaced along N.N.W.-S.S.E. or N.-S. fractures with the formation of slickensided bands of crushed and torn rock. During these subsequent deformation movements in N.N.W.-S.S.E. direction differential movements frequently took place along the older N.N.E. or E.N.E. fault-planes, or along the W.N.W. strike-faults, and still farther crushed the fault and contact material; and as there were still occasional intercalations of igneous material, the ultimate stages of many of the crush-breccias were mylonitic, tuffoid, or brecciose altered rocks. The history is one of rock-metamorphism accomplished at definite crush-zones and fault-lines in the crust, where metamorphism due in the first instance to dynamic causes has been complicated locally by the contact effects associated with intrusive magma.

A crush-breccia of the type of so-called "Buchenstein conglomerates" is exemplified in any of the breccias between the slices of calcareo-dolomitic rock in the east wing of Rodella or in the precipitous part of the Pozzale ravine, the essential structure of these breccias being calcareous fragments surrounded by igneous material. Another type is exemplified in the downslip fault-zone north of Rodella, where fragments of the Wengen concretionary tuffs and lavas, as well as fragments of banded limestone, of the Buchenstein cherty limestone and the Mendola dolomite, have been rolled into the form of a massive breccia, and it has been locally intercalated with the intrusive porphyritic magma. The extreme fissuring of the fragments, and generally the alteration of the rock along fine crevices, points to the emission of vaporous exhalations from the magma. As a general rule, it may be stated that where soft strata such as Werfen or Wengen shales and marls have been subjected to crush and intercalated with igneous threads they have been discoloured, baked, powdered, and rendered "tuffoid" in appearance. Where the harder calcareous rocks have been similarly treated they have been rendered brecciose and look quite like a "volcanic" neck agglomerate. But there is one essential distinction in the mode of origin of a neck agglomerate and these breccias, since the breccias originated in fault-fissures and their brecciation was associated with dynamic causes as well as with explosive subterranean agencies. It seems to me from field evidences and examination of rock-specimens (*cf.* pp. 55, 56) that the *crystalline-granular* condition of the intercalated calcareous rocks in the north Rodella fault-zone, and the dolomitisation of the homogeneous calcareous masses in this area, are explained upon the basis of concomitant or intermittent action of the dynamic and explosive agencies. I have emphasised in the foregoing pages the continuation or recurrent action of the shearing strains at many of the fault-fissures after the intrusion of the igneous material, so that during these *advanced* stages in the Tertiary movements, subterranean heat, pressure, volcanic activity in the form either of irruptions or vapours conjoined to produce various forms of rock-metamorphism of which the dolomitisation of the calcareous masses is only one. The pseudo-tuffs, for example, are dynamo-metamorphic products of marls and shales.

Additional Evidences of the Epoch of Porphyrite Intrusions.

The recognition of these crush-breccias and the differentiation of their relationship to the successive fault-systems denote two important additional clues to the solution of problems connected with the porphyrites. The evidences regarding the Tertiary age of certain porphyrites which I gave in former papers had relation to: (1) their occurrence as fault-dykes or as fault-sills, sending ramifying threads into contact zones; (2) their intrusion in "Judicarian" cross-faults; (3) the enclosure within them of fragments and patches of fossiliferous Wengen or Cassian horizons, that lay above them or at their side.

From Rodella, there is further evidence that the crush-breccias between the "Asta" or W.N.W.-E.S.E. thrust-masses had been formed before the intrusion of porphyrite: that the deformation of these thrust-masses and crush-breccias by cross-plication was followed by the development of new cross-faults and curved faults in the sense of the cross-movements and the resultant local movements, and that only then was augite porphyrite intruded. It is also a significant fact that certain faults are lost sight of when they are traced to an intrusive porphyrite mass. The natural explanation is that the igneous rocks concealed the faults through which they passed. For example, in the neighbourhood of Canazei the strike-fault in W.N.W.-E.S.E. direction which separates the overthrust-masses of Rodella from the rocks on the south (*cf.* fig. 6) would, if continued eastward, pass *into* the augite porphyrite sheet south of Canazei. The disturbance of the Werfen strata in this area is very great, but although the porphyrite rests upon them, *it has not shared in this disturbance.* This seems to me to give witness that the sill was intruded into a prepared line and horizon of weakness in the crust *after* the epoch of acute differential movements. Again north of Canazei the N.N.E.-S.S.W. fault of Roja with downthrow on the east side was locally obliterated by the porphyrite that spread westward into the east wing and north fault-zone of Rodella.

Alba.

Following southward, towards Alba, the contact plane between Werfen strata and augite porphyrite as exposed near Canazei, the Werfen strata are seen to be often crumpled, and fragmentary patches of Mendola rock sometimes crop out.

Opposite Alba, on the east bank of the Avisio river, the Upper Werfen and passage-beds are well exposed, with typical fossils, but the strike of the bedding planes is N. 35° W. and the dip south-west; and the southward dip continues as characteristic of the Alba-Penia area.

It will be remembered that the strike-faults on the north and south of the Duron Valley separate the Rodella fault-block on the north with northward dip, from the Mount Donna fault-block on the south, with southward dip as exposed in the neighbourhood of Campitello. If one or both of the W.N.W.-E.S.E. faults be assumed to have continued eastward through Fassa Valley to the disturbed exposures east of Canazei, the southward dip in the Alba-Penia area would exactly correspond to the similar dip in the Mount Donna fault-block, south of the Duron Valley (*cf.* fig. 1, also pp. 30, 31, 78).

The Upper Werfen strata, forming the differential plane or shelf below the block-porphyrite of the Alba area, show considerable shear and contact alteration. The fossils are crushed and distorted and covered with seladonite, and the strata are much creviced, and impregnated with porphyrite streaks and greenish contact veins. Between Alba and Penia streaks of limestone rock are often present, and at the calcareous contact-planes there are local contact-breccias, composed of crystalline rock-fragments and strings of porphyrite ; numerous dykes run southward from the main sheet of porphyrite, and divisional planes directed N. 10° E. and inclined gently eastward are well-marked. The augite porphyrite in the dykes has a more vesicular aspect than that of the main sheet, and is richly veined with heulandite.

A coarse contact-breccia of calcareous rock and porphyrite, or a massive development of block-porphyrite, is exposed on the north bank of the Avisio, where the river bends northward from the "Fedaja Valley" to the "Fassa Valley." The breccia is jointed along E.N.E. direction, the slabs incline ca. 20° N.N.W. These breccias strike N.E. through the Penia slopes, and above them there crop out patches of Upper Werfen strata and passage-beds, more breccias and irregular bands of Mendola dolomite, succeeded by the porphyrite sheet that extends to the Canazei area and Buchenstein rocks.

The whole succession of sheared sedimentary rocks, contact-breccias, and porphyrite is cut off along a N.N.E.-S.S.W. fault east of Penia Church.

The porphyrite rock which is exposed farther east, near the Cernadoi houses, rests upon a sheared floor of the Buchenstein siliceous and banded limestones and Lower Wengen plant shales.

This area is very complicated in the field, and knowing that Professor Salomon had treated it (*l.c.* Profil G, pp. 57-60), I did not examine it with my customary detail. My chief aim was to arrive at the correspondence between it and the part of the Bufaure Massive, which occupies the opposite west bank of the Avisio Valley.

As Professor Salomon determined, the Mendola dolomite of the Penia slopes has been overthrust along an east-west fault in relation to the Marmolata limestone, on the south slopes of the Fedaja. I also agree with Professor Salomon in his interpretation, that at least two well-marked faults run east-west in the Fedaja Valley. I have determined the continuation of both these shear-planes in the remnants of sedimentary rock at Campaz in the Bufaure Massive, and of the more northerly shear-plane still farther east, on the slopes of Mount Donna (*cf.* figs. 1 and 15).

But there is an important point of difference between Professor Salomon's survey work and mine here, inasmuch as he treats the porphyrites at Penia and on the Belvedere slopes as Wengen lavas, accumulated contemporaneously with the sedimentation of the Marmolata limestone on the south of the Fedaja slopes. Now, I certainly found isolated patches of Wengen strata in the midst of the porphyrite, between Penia and Cernadoi, at about the 1700 and 1800 contour-line—*i.e.*, 200 mètres above the Fedaja Valley level, but they were baked,

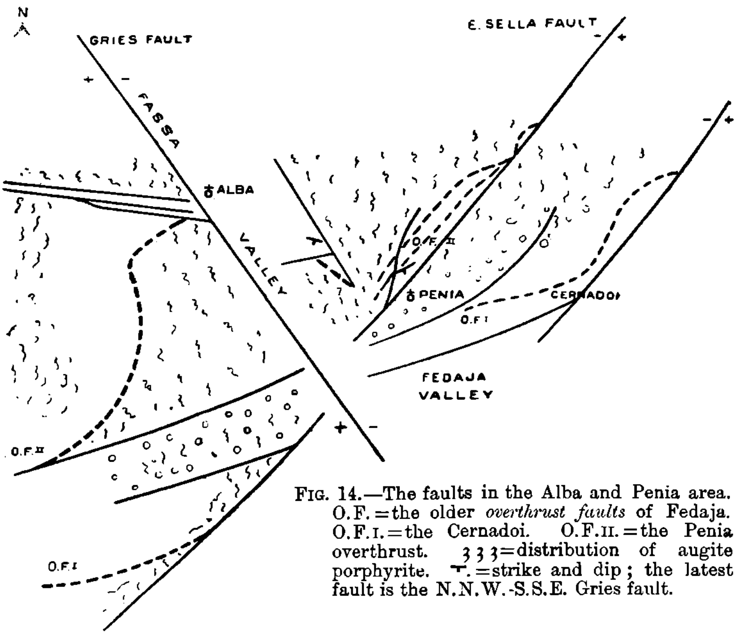


FIG. 14.—The faults in the Alba and Penia area. O.F. = the older *overthrust faults* of Fedaja. O.F.I. = the Cernadoi. O.F.II. = the Penia overthrust. ȝ ȝ ȝ = distribution of augite porphyrite. ┬. = strike and dip; the latest fault is the N.N.W.-S.S.E. Gries fault.

crushed, and altered patches, clearly material from the sedimentary roof of the intrusive sheet, carried along with the magma. Again, the porphyrite in the valley-level at Penia is, according to my interpretation, one of several dykes that entered the fractures associated with the overthrusting of the Lower Trias above the Marmolata limestone.

The Werfen strata, to the north of Penia Church, which repose upon a limestone breccia or the porphyrite, strike N. 50° E., and are either vertical or dip steeply southward. They are crushed into a narrower strip northward, parallel with the cross-fault which runs N. 35° E. The Werfen bedding-surfaces are polished, slickensided, and altered. The shear-breccia, above and west of the Werfen strata, is chiefly porphyrite, containing fragments of Werfen strata; nearer the Mendola rocks it is practically a fault-breccia of the calcareous rocks. The Mendola dolomite, west of the breccia, is jointed both N.N.W.-S.S.E. and N.N.E.-S.S.W., but has indications of original bedding-planes with strike N. 80° W. and high dip south.

Tracing the fault-line northward, the Werfen strata are seen to have been dragged along the fault-line and the oolitic marls and limestones of the passage-beds have been crumpled to schists or sheared into lenticles. The porphyrite, breccia, and dolomite have all been dragged and slickensided at this fault, and there is a group of faults furcating from the main N.N.E.-S.S.W. fault, all of which have been planes of differential movement subsequently to the intercalation of the porphyrite (see fig. 14).

The N.N.E.-S.S.W. fault-line is the direct continuation southward of the fault I described in the east wing of Sella Massive, where Dachstein dolomite has been thrown down on the west of the fault. I also showed that as the fault-block slipped down on the west the successive horizons—viz., Cassian strata, Schlern dolomite and Raibl strata had been crumpled, dragged, and attenuated in the N.N.E.-S.S.W. direction of lateral displacement. This N.N.E.-S.S.W. fault displaced to the south the older Pordoi fault-plane and fault-slices, and on the south of the Cima di Rossi, it similarly displaced the older Fedaja overthrusts. The original position of the most northerly of the Fedaja planes I take to have been *as far north of Penia* as the streak of Werfen strata reaches; owing to its tremendous shearing and distortion along the cross-fault, the old thrust-plane strikes from its original position through a curve N.N.E.-S.S.W., N.E.-S.W., E.N.E.-W.S.W., and is again clearly exposed fully 1½ kilomètres south of its original position.

The Cernadoi exposures of Buchenstein and lower Wengen strata are separated by another old thrust-plane from the Marmolata limestone on the south of the Fedaja Valley. The Cernadoi thrust has likewise been sheared and displaced southward along a parallel N.N.E.-S.S.W. cross-fault, the thrust-plane having now a curved strike from Cernadoi to the Campaz like its fellow the Penia thrust-plane.

The dips in the Penia exposures show that the thrust-planes passed through an overcast fold with steep "knee-bend" arch to the south, and intucked trough. Thus all the "Asta" thrust-masses, that have been described above, show the same essential features of origin and structure. And within a horizontal distance of 3¾ kilomètres from the fault-zone north of Rodella to the Penia fault-zone, the lower Trias and Mendola and Buchenstein horizons have been broken up by four thrust-planes and each fault-block on the north driven forward some distance to the south upon its neighbour. The original strike of the thrust-masses was W.N.W.-E.S.E., nearly east-west.

The Intrusions in the neighbourhood of Penia.

It is very easy to define precisely the position which the augite porphyrite occupies in reference to these fault-slices or "leaves" ("Blätter," see Suess) in the crust. The augite porphyrite on the lower slopes of the mountains on the west side of the Avisio Stream between Penia and Alba, and on the east side of the stream at the Penia corner occupies the shear-planes below the Fedaja thrust-mass and above the Marmolata limestone. The augite porphyrite on both sides of the Avisio Stream between Alba and Canazei, and above the breccias at Penia, occupies the cross-sliced crush-zone *above* the Fedaja overthrust.

At very many places it is apparent that the Fedaja thrust-mass had been fractured by strike-faults and the porphyrite had found a passage from the lower to the higher zone of crust-weakness. It must, however, be borne in mind that on my principle that the augite porphyrite was intruded during the epoch of cross-faulting, planes of weakness at quite different horizons of the crust were open to any magma ascending either the cross-fractures and vertical strike-fractures or the furcating oblique-fractures simultaneously developed. Thus the term "dyke-and-sill network" is that which I have always used to describe the tectonic relations of the intrusive rocks where I have examined them in the Dolomites. The lateral displacement of a crust-slice by 1½ kilomètre demands a very considerable geological epoch; ample enough to permit of the development of the dominant systems of divisional planes in the earlier intrusions, metamorphic alteration and brecciation at lines or planes of movement, and the intermittent intercalation of veins and dykes.

One of the chief faults that have affected the earlier massive intrusions of the porphyrite besides the N.N.E.-S.S.W. faults, is the N.N.W.-S.S.E. Gries fault (see p. 47), that continues in S.S.E. direction through the Fassa Valley between Gries and Penia, downthrow being on the east. The fault runs west of Alba, where it has intersected and displaced an east-west bundle of faults. These strike faults fracture the porphyrite in the Bufaure Massive, downthrow being on the north of the fault-bundle. Thus the porphyrite on the Clapaja or north slopes has been let down relatively to the porphyrite in the Greppa and Col Bel portions of the Bufaure Massive along the E.-W. fault-group, and afterwards, the porphyrite of the Canazei fault-block has been thrown down relatively to the Clapaja porphyrite along the N.N.W.-S.S.E. Gries fault.

The E.W. fault-group is present again on the east slopes of Alba, having been there slightly displaced to the south on the downthrow side of the N.N.W.-S.S.E. Gries fault. The E.W. fault-bundle is thus traced into the brecciated porphyrite above Penia, but I did not follow it further east.

The complex geological structure of this part of Fassa indicates therefore that the porphyritic magma was introduced *after* the overthrusting to the south and the dislocation of the thrust masses along N.N.E.-S.S.W. lines, and that there ensued an epoch of local readjustments complicated by the altered position of the magma within the crust, and its slow consolidation. Subsidences took place along any previous fractures, and more especially in the immediate proximity of inthrows, there was a tendency towards the development of fault-groups inclined to the area of inthrow, such as those at Penia.

The East-West fault through the Clapaja porphyrite may have followed an old line of crust-weakness and fracture, for it occurs in direct continuation of the Fedaja fault which together with the Buchenstein-Rodella parallel fault seems to have been a leading fault throughout the geological history of the Dolomites.

This suggests that no matter from what particular direction the successive systems of crust-strain were acting, differential movements still took place at any important older lines of crust-weakness, so that the newer fault-blocks were limited by faults whose initiation dated from many different epochs of crust-movement—in a word, they were limited by *heterogenetic faults.* During any horizontal crush of rocks against a fault, a local fold-system may develop, and it may be possible to explain in this way the occasional marked exhibition of very narrow east-west or nearly east-west folds in the rocks of Fassa. The only other likely explanation is that true north-south pressures acted intermittently with those obliquely directed pressures which produced the dominating diagonal faults in later epochs of crust-movement.

The geological structure at Penia seems to show that the older strike-faults in the Fedaja Region acted as local bars against which, as the cross-movement proceeded, the twisted slices with N.N.E.-S.S.W., N.E.-S.W. or E.N.E.-W.S.W. strike on the downthrow side of the Sella-Penia N.N.E.-S.S.W. fault were driven; so that the rock masses were piled up in the neighbourhood of the Fedaja strike-faults, an area of attenuation being thus developed on the north of them. Afterwards the same area was still further lowered on the west of the Gries N.N.W.-S.S.E. fault, but the effect produced was that of localised inthrow limited on the south against these Fedaja strike-faults, and on the east by the N.N.E.-S.S.W. faults.

Mount Donna.

The name of Mount Donna is given to the precipitous crags and summits of porphyrite above the Fassa-Valley pastures on the west of Campitello. On the north, the slopes of Mount Donna descend steeply to the Duron Valley. The strike-fault in W.N.W.-E.S.E. direction which cuts the northern slopes has already been mentioned (p. 31).

Immediately west of Campitello, the passage beds and possibly the lowest horizons of Mendola Dolomite are in the line of the fault; they stand erect and in their midst is a porphyrite dyke, flanked by a shear and contact breccia of highly altered rocks. Ramifications run from the dyke in south and S.E. directions, and may be traced through the Werfen strata (with numerous *Pleuromya fassœnsis* fossils) that descend to the fields next the valley. A thick porphyrite dyke is present there directed nearly north-south. The intercalations of dykes close to Campitello occur in or near the N.-S. (slightly N.N.E.) line of fault which I determined on the west face of Rodella summit and through that mountain (pp. 40-43). This fault has intersected the strike-fault at Campitello, and the strata beside it have been pulled to a variable shear-strike N.N.E.-S.S.W., and dip eastward.

Following the strike fault through the higher contour-lines west of Campitello, the uppermost horizons of Werfen strata and a streak of Mendola dolomite on the north are cut off obliquely by the strike-fault. Fault-breccias occupy the line of fault and are intercalated with intrusive material. The rocks south of the fault are Werfen strata belonging to the "Clarai" zone, lower horizons than those north of the strike-fault. The Duron Valley segment represents therefore a downthrown segment relatively to the Mount Donna segment.

In Duron Valley, west of the Pozzale fault, there is in the fault-zone a much thicker development of fault and contact breccia and the massive augite porphyrite of Mount Donna is present on the south. The massive intrusion of the porphyrite thus occurs at Mount Donna as at Pozzale on the west or downthrow side of the Pozzale cross-fault. The strike-faults north and south of the Duron Valley have both thrown down the north fault-segment; they are therefore comparable to the group of strike-faults with down-throw on the north, which occurs on the north slope of Rodella Mountain (*cf.* pp. 57, 58). In that case it was shown that the porphyrite passed continuously into the Pozzale cross-fault and into the strike fault-zone, and the same is true of Mount Donna. Still another strike-fault with downthrow on the north is present in Mount Donna. It may be traced from the village of Fontanazza westward through the sedimentary strata, marked by occasional dykes and very disturbed stratigraphical relations. Round the south crags of Mount Donna, an over-thrust fault is exposed; the thrust-plane (described below) is exposed below Werfen strata of various horizons and above Mendola Dolomite and the Passage-Beds. Thus the series of downthrows towards Duron Valley have occurred on the north or down-slip zone of an overcast fold whose arch had been over-thrust towards the south. The augite porphyrite of Mount Donna therefore gained entry into an attenuated and weakened crust-horizon, and did so after the subsidences had been going on relatively to both strike and cross-faults (*cf.* fig. 15).

The terms "strike-fault" is used above in reference to the original strike of the thrust-masses which seems to have been W.N.W.-E.S.E. In point of age the W.N.W.-E.S.E. faults of Duron Valley and Mount Donna are younger than the thrust-masses, since the latter have been dislocated by these faults. In so far the W.N.W.-E.S.E. strike-faults resemble the E.N.E.-W.S.W. faults which occur on the Pozzale slopes north of the Duron Valley, but in point of their relations to the N.N.E.-S.S.W. faults there is some difference, since only the E.N.E.-W.S.W. faults can really be demonstrated to have developed as a result of the cross-plication, being fault-branches from the main cross-fault. The strike-faults, the E.N.E. furcating faults and the N.N.E. cross-faults of Mount Donna, were all invaded by the porphyrite, but the porphyrite of Mount Donna has been greatly broken up by a series of N.N.W.-S.S.E. faults. The age-relations in the initiation of the flexure-faults that have affected the thrust-masses would accordingly be:—

(1.) Gentle folding of the thrust-masses in strike direction; the initiation of W.N.W.-E.S.E. or strike-faults parallel with the plicated thrust-masses; these are either vertical faults or steeply inclined to synclinal hollows.

(2.) Cross-plication of the thrust-masses and subsequent determination of local crust-basins; initiation of certain steep N.N.E.-S.S.W. flexure-faults parallel with the cross-plication, and also of N.E.-S.W. and E.N.E.-W.S.W. fault-branches and curves due to local horizontal pressures. The chief thrusts then took place towards E. or S.E., downslips to W. or N.W. (*cf.* Rodella, fig. 9); differential movements also occurred at older fault-lines.

(3.) Later system of N.N.W.-S.S.E. faults and fault branches, associated with foldings, flexures, and with horizontal thrusts; the chief thrusts then took place towards W. and N.W., downslips towards the east. At this period differential movements continued along many of the previous fractures.

The Rocks of the Mount Donna Thrust-Mass.

(*Cf.* Fig. 1.)

Ascending the mountain westward from Campitello, the lower levels, ca. 1500 and 1600 contours, are occupied by the thick-bedded limestones, sometimes full of *Pleuromya fassaensis* and *Myophoria ovata,* in which numerous threads of porphyrite ramify. At about 1650 mètres there is a line of marked disturbance of dip and contact alteration of the rocks, and from the frequent outcrops of porphyrite, along a north and south line, it seems as if a small fault-dyke were present in this direction. Above this level a succession of rather crumpled, reddish marls of the typical "Campil" group is obtained (fossils:—*Pseudomonotis aurita* and *inæquicostata, Pleuromya fassaensis, Myophoria ovata.* It is followed successively by bluish marly limestone, with *Pseudomonotis aurita,* sandy granular limestone, and grey thick-bedded limestone, with *Naticella costata* and *Turbo rectecostatus.* At the *Naticella* horizon another N.S. dyke of porphyrite is present, ca. 1740 mètres. The strike of the bedding-planes is changeable, but the general reading is E.W. and dip S., about 20°-30°. But the strata also show a cross-flexure, certain readings giving N.S.; the correlated dip below the disturbance at the 1740-mètre contour is eastward; to the west of that it is westward. There is fairly good evidence, therefore, that the cross-flexures along a direction nearly N.S., which are present in Rodella mountain (*cf.* p. 46), are continued through the Mount Donna slopes, and that the frequent small dykes on these slopes have been intercalated subsequently to the cross-bending.

The group of strata with westerly dip comprises sandy limestones, with layers full of tiny gastropods (Holopella, etc.), and marly limestones with some large species of bivalves, which Dr Broili has not been able to identify more closely than that they are indefinite species of *Avicula, Macrodon,* and other genera. The succession of the passage-beds is completely present, but all higher horizons are brecciated and occur only as a sedimentary patch-work between the augite porphyrite of the high precipices and the other Werfen strata of the slopes. The rock-breccias are essentially fault-breccias parallel with the continuation of the N.N.E.-S.S.W. Pozzale cross-fault. An irregular streak of Mendola Dolomite is succeeded by a calcareous and porphyritic breccia, that by Buchenstein limestone with siliceous concretions and by banded limestones, Wengen shales and a bed of porphyrite; then there is again Buchenstein siliceous and banded limestone, succeeded by Wengen concretionary tuffs, a contact breccia, and the augite porphyrite of the high precipices. As the strike of the sheared and altered rocks is E.N.E.-W.S.W. and the dip N.N.W., these appeared to me to represent a furcating system of obliquely placed shear-slices, branching from the main N.N.E.-S.S.W. fault with downthrow on the west.

In the central part of Mount Donna, above Fontanazza, the Mendola Dolomite rocks attain their greatest thickness. They are cut by cleavage-planes, with E.W. strike and inclined 80° towards the south. A shear and contact breccia is present in the midst of the calcareo-dolomitic precipices, and parallel with the strike. I attribute this breccia to a sill of the same coarse-grained porphyrite as forms the main Mount Donna intrusion. The sill has been intruded at a fault-plane, with strike N. 50° E. and low inclination to N.N.W., upon which Mendola Dolomite has been driven eastward above Buchenstein horizons. The larger sill intrusion of the high precipices was probably intruded at the normal fault-plane coupled with this thrust-plane, and allowing downslip towards the west.

The South Aspect of Mount Donna.

(*Cf.* Fig. 15.)

Both the thrust-mass and the underlay crust-slice of Mount Donna are exposed on the South slopes. The thrust-plane has been several times displaced southward and lowered by branches of the Pozzale fault. It is exposed at the 1900-mètre contour in the Werfen strata in the immediate proximity of the N.N.W. fault between Fontanazza and Campestrin. At Col del Orso, above Campestrin, a little Mendola Dolomite is present below the shear-plane.

A N.N.E.-S.S.W. fault, the chief continuation of the Pozzale fault, throws down the thrust-plane to contour 1800-mètre on the west of the fault. Examined on these slopes the thrust-plane strikes N. 70° W. and is inclined at 20° North.

The strata reposing upon the thrust-plane in the slopes above Campestrin are the red marly horizons of the "Campil" series; they strike E.N.E. and dip N.N.W., and are crumpled and slickensided along N.N.W.-S.S.E. axis. Below the thrust-plane Mendola Dolomite is present, at this area only as thin streaks between horizons of the Passage-Beds, but farther west it is much thicker. The complete succession of Werfen strata below the Mendola Dolomite was carefully worked out through several sections and may be given as a type :—

Mendola Dolomite.

Werfen Strata: Unfossiliferous limestone, with uneven bedding surfaces;
grey marly limestone with bivalve remains;
interbedded reddish *Crinoid* limestone and calcareous shales with bivalve remains;

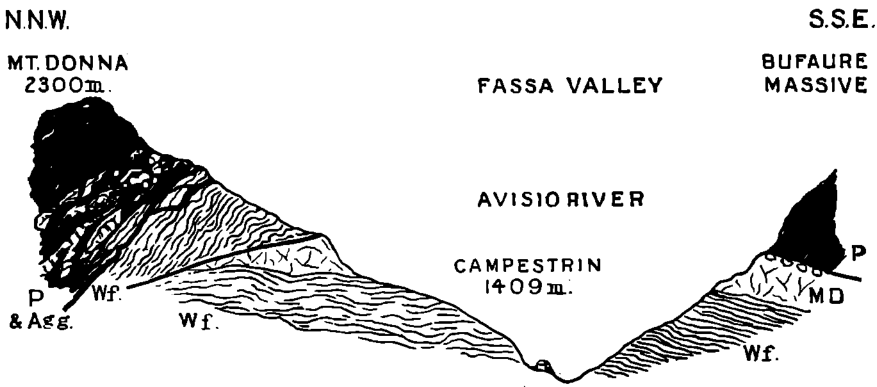


FIG. 15.—Section through Fassa Valley (between Fontanazza and Campestrin). Wf. = Werfen marls and marly limestones; MD. = Mendola Dolomite; P. = Augite Porphyrite; P. & Agg. = Porphyrite and Contact Breccia, the enclosed fragments are mostly Mendola Dolomite (Scale 1 : 25,000).

grey-blue marly limestones;
thick-bedded limestones with *Naticella costata;*
granular limestone;
red and brightly-coloured marls and marly limestones with *Pleuromya fassaensis*, etc.;
dark-grey shales and marls with *Pseudomonotis Clarai*, etc.;
arenaceous limestones with beds of hornstone;
variegated marls and shales, and dark shales with *Lingula tenuissima.*

The sandy limestones, with layers of hornstone, are exposed in the lower horizons (ca. 1450 mèt.—1500 mèt. contour) of the slopes in the neighbourhood of Campestrin. They strike

W.N.W. and dip 30° S.S.W. and are cleaved N. 10° E., showing, therefore, the influence of the same cross-compression as affected the rocks of Rodella. The strata are strongly slickensided in this direction, parallel with the N.N.E.-S.S.W. line of disturbance which can be traced from the summits of Mount Donna through the rocks of Col del' Orso to the Valley.

Deformation of the old Thrust-slices of Mount Donna.

As appears in section 1, the sedimentary rocks of Mount Donna compose the original crust-slice between the lowest thrust-mass of Rodella and the next crust-slice on the south. The strata exposed in the thrust-mass of Mount Donna are the Werfen strata (not the lowest horizons), Mendola dolomite, Buchenstein, and Wengen. The rocks of the thrust-mass are themselves undulated; they dip northward on the south side and southward on the north side of the summit, and the central portion of the thrust-mass is synclinal in form. The augite porphyrite has passed quite obliquely over the bedding-planes of the series. On the south side facing Udai Valley, the Augite Porphyrite reposes on the north-dipping Werfen strata; on the south-east side facing Fontanazza, the porphyrite rests on Mendola dolomite, Buchenstein, or patches of Wengen strata; on the east side facing Campitello, the porphyrite rests on the lowest horizons of Mendola dolomite or shear-breccias of higher horizons. The synclinal form parallel with the strike of the thrust-mass must, therefore, have been given to it before the inrush of igneous rock-material, since the calcareous rocks had already been chiefly heaped up in the central or trough area. Again, if the underlay of the porphyrite be examined from east to west—*i.e.*, from the main Fassa Valley up the lateral valleys either of the Udai or Duron rivers, it will be found to *rest on younger rocks of the thrust-mass towards the west.* The limit of the porphyrite on the east side is the southward continuation of the Pozzale N.N.E.-S.S.W. fault, the porphyrite having gained ingress into the west or downthrown fault-block. The rocks of the thrust-mass on this side strike E.N.E. and dip N.N.W., and are cut by several curving fault-branches that diverge from the N.N.E.-S.S.W. fault (*cf.* p. 79). These more oblique slices have been driven eastward over one another against the Pozzale fault, and afterwards intercalated with augite porphyrite. The most westerly of the Pozzale fault-branches continues through the east face of Mount Donna to Udai Valley, which it crosses at about the 1600-mètre contour and continues its same direction to the Vajolett Valley. Thus the opposite slopes of Fassa Valley together represent the southward continuation of the western and central fault-blocks of Rodella, from which there has been downthrow to cross-troughs both on the west and on the east sides (fig. 15, pp. 44, 45).

The N.N.W.-S.S.E. Faults.

The augite porphyrite, the breccias accompanying the N.N.E.-S.S.W. fault-band, and the Werfen strata below them on the east face of Mount Donna above Fontanazza, are cut and thrown down by a group of N.N.W.-S.S.E. and N.W.-S.E. faults, which intersect the older W.N.W.-E.S.E. strike-fault, and the Pozzale N.N.E.-E.N.E. fault-system. The strip of mountain through which this fault-group passes is exceedingly involved in its structure, as my map indicates.

The older strike-fault in this strip passes through the central hollow of the synclinal form into which the thrust-mass had been thrown, and from its position relative to the extent of the porphyrite, it may be concluded that this strike-fault, together with the N.N.E.-S.S.W. Pozzale fault, was the chief vent through which the rock-magma had gained ingress into the area of inthrow.

The leading N.N.W.-S.S.E. fault continues from the Duron Valley into the Bufaure Massive. It is occupied by dyke intercalations from place to place. Microscopically examined, the dyke-rock above Fontanazza is tolerably coarse-grained,

"with phenocrysts of a green augite and striped felspar, the latter is strongly zoned. The ground-mass is abundant, and has in general a greenish colour, owing to the augite and alteration products; there is much magnetite. The rock is amygdaloidal, being generally filled with vermicular chlorite."

The extreme resemblance of this rock to the nearly N.S. dykes west of Campitello, makes it likely that the latter also represent very late intercalations. But more important is the resemblance of the Fontanazza dyke to the intercalations in the similar N.W.-S.E. group of faults above Canazei, as these faults have also segmented the older Block-Porphyrite in that area.

The N.N.W.-S.S.E. fault at Fontanazza is parallel with the "Gries Fault" (pp. 51, 74), the horizontal distance between them being about 3 kilomètres. At other 3 kilomètres farther west, there is the N.N.W.-S.S.E. fault-line, which is a limit between Mount Donna and the Dolomite Mountain-Massive on the west. The western fault-block has been downthrown, and although I have not examined this in detail, the exposures which I saw from Duron Valley and the Udai Valley led me to think the porphyrite had been thrust westward above the dolomite. In the Duron Valley, the Schlern dolomite of the Molignon group lies below the augite porphyrite of Mount Donna, along a plane which strikes N. 20° W., and dips ca. 30°-35° E. between the Schlern dolomite and the igneous rock. The relations on this western side of Mount Donna have a general resemblance to those which obtain at Costella, on the western side of Monzoni (*cf.* p. 163). The N.N.W.-S.S.E. fault-line west of Mount Donna crosses the Udai Valley obliquely, and enters Bufaure at the very evident fault-dyke in that direction, close to the village of Mazzin. The fault-block on the west side of the N.N.W.-S.S.E. Mazzin fault-dyke is likewise thrown down relatively to the fault-block on the east side. The N.N.W.-S.S.E. Udai fault meets the N.N.E.-S.S.W. fault, limiting the Col Pedoi downthrow on the east; the Udai and Col Pedoi rocks are, therefore, enclosed within a triangularly-shaped inthrow.

The Fontanazza N.N.W.-S.S.E. fault and the Gries N.N.W.-S.S.E. fault both throw down the fault-block on the east side relatively to that on the west. There are one or two cases where actual shear-planes are exposed in the Fontanazza and Gries groups; they appear vertical, but the numerous companion slickensided divisional planes show eastward inclination. There has been a thrust from E.N.E. to W.S.W., but this thrust was subsequent to that which caused the leading N.N.E. and associated shear-planes.

The general effect of these N.N.W.-S.S.E. Udai faults subsequent to the porphyritic sill of Mount Donna and to the Bufaure intrusions beside it has been to allow subsidence of the Dolomite Massives on the west of the intrusive masses; the N.N.W.-S.S.E. fault group of Fontanazza continues northward across Duron Valley and appears in its further continuation to form the western limit of the downthrown Plattkofl and Langkofl Massive. Thus the tendency has been for subsidence of the rocks in front of and behind the Mount Donna porphyrite during the subsequent thrust from east to west. All the N.N.W.-S.S.E. faults continue southward to Bufaure, and have there effected similar relative displacements within the porphyrite mass itself. But it must be remembered that previous to the N.N.W.-S.S.E. faulting the Bufaure area had been downthrown, and the porphyrite had entered there on the east of the N.N.E.-S.S.W. Rodella and Bufaure fault (*cf.* p. 52). While it is quite easy to show that the N.N.W.-S.S.E. faults cross Fassa Valley and enter Bufaure, as these have occurred after the main porphyrite intrusions, it is very difficult and indeed impossible to demonstrate the original continuation of the strike faults from Mount Donna to Bufaure, as these have been concealed by the intruded porphyrite. But if a line be drawn from the nearly E.W. group of faults at Alba through the Clapaja to Fontanazza, such a line would indicate the limit of the Clapaja downthrow, and may possibly represent the shifted continuation of the Fontanazza strike-fault.

A comparison of the Mount Donna sedimentary strata and the exposures on the Alba and Penia slopes shows that the old thrust-plane exposed on the south slopes of Mount Donna is the westward continuation of the Fedaja thrust-plane exposed on the Penia slopes (p. 73); and the sill *above* the Fedaja overthrust has apparently entered the same strike-fault as the Mount Donna sill. The part of the Fassa Valley between Campitello and Canazei is in the strike continuation of the Duron exposures and therefore also of the strike faults that were demonstrated on the north and south of Duron Valley. The continuation of the strike fault on the north of the Duron Valley is indicated in the disturbed Werfen strata east of Canazei.

Summary.

Summarising the results of my survey of Mount Donna—There is on the south aspect of Mount Donna an old thrust-plane inclined northward which I regard as the westward continuation of the Fedaja Thrust-Plane exposed at Penia. It passes between Werfen strata in the Thrust-mass and Mendola Dolomite in the underlay. The thrust-mass and underlay as well as the intervening shear-zone have been deformed, and dislocated—(*a*) by a fold-system and by vertical or very steep faults parallel with the W.N.W.-E.S.E. strike. Undulation of the thrust-masses parallel with their strike was also pointed out in Rodella (p. 47). The leading strike-fault in Mount Donna passes through the middle of the Mount Donna area, and crosses the Fassa Valley at Fontanazza, downthrow was on the north; the other is on the south side of the Duron Valley and downthrow was again on the north. Two other well-marked strike-faults occurred between Duron Valley and the Langkofl Dolomite group—viz., the fault immediately north of Duron Valley, and the Rodella fault (p. 57), which continued westward to Fassa Pass, both having downthrow on the north; therefore there was a strike system of step-faults throwing down the Langkofl Dolomite group developed subsequently to the epoch of overthrusting to the south.

(*b*) By a fold-system and by faults across the W.N.W.-E.S.E. strike. The faults show great variation in their angle of inclination, the main N.N.E.-S.S.W. fault is vertical, but associated with it there are numerous fault-planes inclined to the north-west, and following a curved strike from N.E.-S.W. to

E.N.E.-W.S.W. The inclined faults branch from the main fault. The leading N.N.E.-S.S.W. fault in Mount Donna is the continuation of the Pozzale fault between the Sella Pass on the east and the downthrown Langkofl fault-block on the west (*cf.* p. 38). It continues through the east of Mount Donna and crosses the Udai Valley; on its east are the slopes of Fassa Valley, on the west of it at Udai Valley is the downthrown dolomite mountain-massive with the Antermoje, Mantello, Cima di Lausa, Crampie, and other summits. I have followed this fault from beyond Plon in the Gröden Pass area to Udai Valley, a distance of eleven kilomètres and have found it to be here and there occupied with intrusive rocks in the form of dykes irregular in thickness. Moreover at all places where the cross-fault intersects old strike-faults, the intrusive porphyrite runs continuously from the cross-fault into the strike-faults, as also into the companion branch-faults on the downthrow side, which curve away from the cross-fault to more oblique directions.

Therefore I conclude that the augite porphyrite of Mount Donna is only a copious intrusion into part of the downthrown strip on the west of this fault. The augite porphyrite has spread in the Wengen rock-horizons, *above* the old thrust-masses, the Wengen rocks having been, as in the case of the fault-zone north of Rodella, faulted and downthrown both parallel with and across the W.N.W.-E.S.E. strike.

(*c*) By a system of N.N.W.-S.S.E. faults showing great variation in the angle of inclination of their planes; these have dislocated the augite porphyrite of Mount Donna. There is a suspicion of undulation of the porphyrite in this direction, but N.N.W. folding is not so apparent in Mount Donna as in the east wing of Rodella. Small dykes and veins of porphyrite and melaphyre are associated with this epoch of dislocation. The chief fault-group occurs on the east face of Mount Donna, crossing the Fassa Valley at Fontanazza and Campestrin. The east side comprising the Fassa slopes near Campitello is downthrown relatively to the west side comprising the Campestrin slopes, but the strip within the fault-group is itself more downthrown than either. This group continues north of Duron Valley and appears to converge and form the *West fault-limit* of the Langkofl and Plattkofl downthrown massive. The other group has not been examined by me in detail; but it forms the western limit of Mount Donna, the west side in this case being downthrown; it continues northward from Udai Valley between the augite porphyrite of Mount Donna and Schlern-Dolomite rocks towards "Auf der Schneid" and the Mahlknecht region. In respect to the cross-compression *after* the inrush of porphyrite, the igneous rocks of Mount Donna have been driven both eastward and westward over subsiding sedimentary strata; the chief thrust has been from east to west.

The Clapaja Slopes between Mazzin and Campitello.

The northern portion of the Bufaure Massive is bounded on the west, north, and east by the part of the Avisio river, which goes under the name of "Fassa Thal." This portion of Bufaure is generally termed the Clapaja by the village people. The Clapaja slopes are precipitous, and even near the valley base are rendered almost impassable by the thick natural wood that grows upon the steep terraces or along the stream courses. These were the slopes which I examined; I did not attempt the precipitous porphyrite above them.

The small occurrences of Upper Werfen shales and limestone above Fontanazza di Sotto show the cross-folding very well. In one place the rocks are gently arched along a N. 30° W. strike, *i.e.*, in the direction parallel with the N.N.W. cross faults. In the exposure nearer Campitello the strata strike N. 30° E., and have a very slight dip south-east. This slight inclination to the south-east (not exceeding 20°), may be traced throughout all the outcrops of Triassic strata on these slopes, although it is locally masked by the N.N.W. strike and shear-planes. The strata in the outcrop opposite Campestrin strike N.E.-S.W., and dip 15° S.E., and are cut by vertical joints in N.W.-S.E. direction.

The porphyrite resting upon the Fontanazza di Sotto outcrops of Trias is typical "Block-Porphyrite," entirely composed of segregated masses of igneous material. The floor upon which it rests shows contact alteration, and is slightly brecciated, but there is no thick development of a shear and contact-breccia above the strata of the Fontanazza outcrop. On the other hand, a well-marked breccia of igneous and sedimentary rock occurs in the vertical fault-planes directed N.N.W. and S.S.E., and ample evidence is given that the contact-breccia was formed in position in the faults, since the inclusions are mostly of Werfen rock material next these strata, and mostly limestone material next the Mendola limestone. The slickensiding of the N.N.W.-S.S.E. cleavage-planes in the sedimentary rocks is very strongly developed in the immediate vicinity of these faults with igneous intercalations. The whole of the rocks are cut by vertical cleavage-planes, frequently with polished surfaces, directed north-south or a few degrees east or west of that direction.

Near Mazzin, the Triassic strata are again cut by N.N.W.-S.S.E. fault-dykes. The thicker dyke is limited on the north by a N.N.W.-S.S.E. fault-plane, on the south by an east-west line of contact. On the south side of the thick Mazzin fault-dyke the strata are downthrown, and have a quite different strike and dip from the exposures at Campestrin and Fontanazza.

Comparing the eastern with the western slopes of Fassa Valley (fig. 15), it is clear that the strata on the opposite sides are continuous portions of the underlay of that thrust-slice into which on the west side the porphyrite sill of Mount Donna gained ingress. In respect to the N.N.E.-S.S.W. cross deformation, the Fassa Valley slopes of the Bufaure Massive represent the eastward wing of the Rodella arch in its continuation southward (*cf.* p. 45). Near Fontanazza, downthrows have subsequently taken place in association with the group of N.N.W.-S.S.E. faults that cross Fassa Valley, and are locally occupied by intrusive threads.

The Clapaja Slopes opposite Canazei and Alba.

Opposite Canazei, the limestone at the base of the Clapaja slopes is succeeded by a thin zone of contact-breccia and then by the porphyrite sill. Two fault-segments of Upper Werfen strata and Mendola limestone have been carried along N.N.E.-S.S.W. shear-planes, and very greatly distorted, crushed, and brecciated. Shear-contact breccias of the "agglomerate" type occur at all their limits against the porphyrite. These planes of cross-shearing and injection of magma denote the continuation southward of the same N.N.E.-S.S.W. faults which I demonstrated in the east wing of Rodella, with downthrow on the east (*cf.* p. 49, fig. 6).

The outcrops of Triassic strata, west of Alba, have a general N.N.W. strike, and the dip bends from E.N.E. to W.S.W. The complications upon these slopes are due to the intercrossing strikes, the N.N.W. strike and its associated dips having crossed the N.N.E.-S.S.W. or N.E.-S.W. strike, and dip-planes inclined to the S.E.

Professor Salomon refers to one of the Alba outcrops in his work on the Marmolata district, and gives a "Schematic section," but the strata do not lie so regularly as are depicted in this section (Palaeontographica, 1895, p. 14, section II.).

Professor Salomon describes conformable succession of Mendola Dolomite upon Werfen marls filled with *Pseudomonotis ovata*, and attributes the absence of the dark-coloured or red and yellow beds of limestone and dolomite sometimes present between the marls and Dolomite to their local development as a facies not distinguishable from the Mendola Dolomite. I see no reason to assume a local facies here. The relations, as they appeared to me, are shown in the accompanying sketch (fig. 16). The missing horizons are those which I have termed "Passage-Beds" (pp. 20, 29), and their absence here is due to the occurrence of an inclined shear-plane upon which the Mendola horizon and the underlying strata have slipped down relatively to the Werfen marls.

The shear-plane is well exposed in a waterfall cutting through the cliffs, where it strikes N.E.-S.W., and is inclined about 20° to the south-east; a higher plane of fracture in the limestone cliffs has the appearance of being similarly inclined.

The dolomite roof of the lower shear-plane is white and brecciose, and the Werfen horizons are slickensided and schistose, with alternating green and white foliar bands.

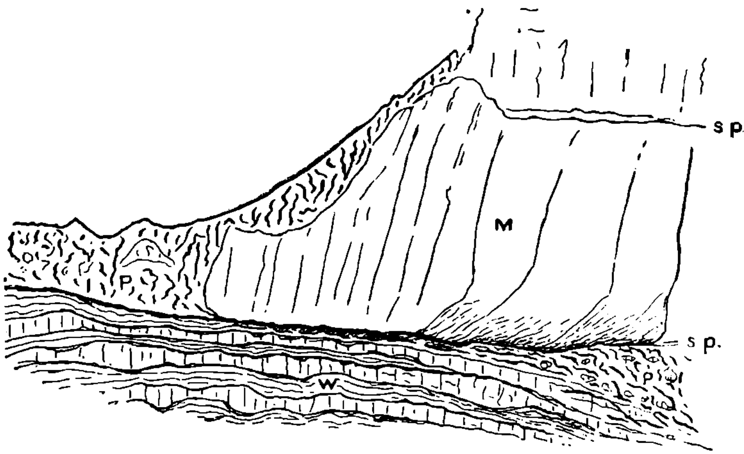


FIG. 16.—In the Bufaure massive west of Alba. S.p. = Shear-plane viewed along the strike. W. = Upper Werfen limestone and marl, note shear-lenticles. M. = Mendola Dolomite sliced by two shear-planes. P. = Augite porphyrite as injected sill-and-dyke-system. The strata next the shear-plane are waved and slickensided. The shear-plane at the base of the Dolomite strikes N. 45° E. and is inclined 20° to the south-east.

Following the strike of the shear-plane northward, it passes more and more *through the calcareous and dolomitic passage-beds* between the Werfen marls and the Mendola Dolomite, and these calcareous beds have been roughly brecciated and freely intercalated with porphyrite.

This plane of shear-slip has occurred in a twisted segment of the same thrust-slice that was described in the exposures north of Penia, *i.e.*, in a remnant of the thrust-slice above the Fedaja and Mount Donna thrust-plane (pp. 72, 84). The Werfen strata forming the floor of this slice are highly tilted, much altered and distorted. The presentation in my geological map of streaks of the Werfen strata, patches of Mendola rock, and intrusive threads of porphyrite, is diagrammatic, the details being far too complex to reproduce faithfully.

The intrusive rocks in this area are varied in character, sometimes of the melaphyre type, sometimes of the coarse-grained and highly segregated types. The fine-grained, richly amygdaloidal and veined basic varieties are those which chiefly appear in the small sill and dyke outrunners from larger masses. For example, the sill in the plane of shear-slip (fig. 16), has vesicles elongated in the direction of the shearing movement; streaks of included calcareous fragments are arranged in the same direction, so that the sill intrusion presents a fluxion-structure comparable with the slickensliding and foliation of the Werfen strata. This fact speaks for my interpretation that the magma rose and began to consolidate during crust-movement. Similar igneous material has ascended vertical or steeply inclined joint and cleavage fissures in the dolomite, more especially those with N.N.E. strike and inclination towards south-east. The observations on this side would therefore indicate that the Bufaure Massive is made up of several sills, is a *composite* body of igneous or brecciose material, and not *one* massive volcanic accumulation.

The intrusion of augite porphyrite occupying the lower Alba slopes becomes continuous, at the leading N.N.E.-S.S.W. fault between Campaz and Col Laz, with the porphyrite that forms the prominent summit of La Greppa. It has locally followed one of the Fedaja strike-faults that has been a plane of subsequent differential movements, and the fault-line is occupied by a massive fault-breccia of mixed igneous and sedimentary fragments intercalated with threads of later fine-grained porphyrite or melaphyre.

The Campaz and S. Bufaure Thrust-Mass.

South of this Fedaja fault, on the Campaz slopes, the lower and more important of the Fedaja thrust-slices, corresponding to the underlay of the Mount Donna thrust-slice, is exposed, partially resting upon the Marmolata limestone of the Col Laz mountain, partially faulted against it.

The strike of the limestone strata of Col Laz is N. 50° E.; the dip is about 30° N.W. on the south aspect of the mountain, but bends more and more steeply on the north face, where the strata are cut by the N.N.E.-S.S.W. Judicarian fault with downthrow on the west side of the fault. In this case the downthrown rock consists of Werfen strata and Mendola Dolomite but that is because these formed part of the lower

Fedaja thrust-mass of which the Marmolata limestone of the Col Laz had been the underlay (*cf.* plate xv., fig. 1).

In the Campaz pasture the Upper Werfen strata and Mendola Dolomite repose sometimes upon the limestone of Col Laz, sometimes upon porphyrite, which has been intruded in the Judicarian N.N.E.-S.S.W. fault-zone.

The Upper Werfen strata, including the Passage-Beds, are here richly fossiliferous ; they strike at various angles between N. 55° E. and N. 70° E., and the dip ranges from 55°-70° northward. The Mendola Dolomite is at some parts a large crag, at others a brecciated mass; and large and small blocks of the Mendola Dolomite and the Upper Werfen strata have been engulfed in the porphyritic rock-magma.

The porphyrite has ascended as sills into dip-planes and planes of differential movements (*cf.* section). The finer threads of igneous rock that ramify through the sheared sedimentary rocks have not well-defined porphyritic structures, but are fine-grained, vesicular, and often greenish pseudo-tuffs. At the same time they can be traced to thicker flows with good porphyritic structure.

The augite crystals of the main sill, west of the N.N.E.-S.S.W. fault, are especially large and well-developed. This sill is part of the broad expanse of porphyrite in southern Bufaure.

The limestone rocks of Mairin Wand and Toal Longo are in their higher horizons like those of Col Laz, and occur in the continuation of the strike. Above them are thick bands of the shear and contact conglomerate, wherein frequently fragments of Werfen rock material are found, as well as the brecciated limestone material. The same kind of conglomerate is present on the west of Mairin Wand, where the *porphyrite runs as a diagonal fault-dyke;* I have therefore concluded that the thrust-plane above Col Laz originally continued westward through Bufaure towards Pozza in Fassa Valley, but was broken up when the Judicarian cross-movement in N.N.E.-S.S.W. direction passed over this area.

On the west of the diagonal fault-dyke contorted and highly disturbed strata are exposed, and are succeeded by Mendola Dolomite and calcareous rocks of the character of Cipit limestone. These are fragmented by intrusive dykes, most of which are directed N.N.E.-S.S.W., and are surmounted by the augite porphyrite of the Toal Longo area.

My determination of the thrust-mass at the Campaz, and of its dislocation there by strike and cross faults, gives an indication of the way in which the Toal Longo area may probably be solved. In my opinion the fragmented Triassic strata below the porphyrite of Toal Longo, represent the westward continuation of the disturbed rocks at the Campaz, which formed part of the lower Fedaja thrust-slice, but was displaced southward at the N.N.E.-S.S.W. faults.

Accordingly, the copious inflows composing the Bufaure Massive were Judicarian intrusions in the two Fedaja thrust-slices, and these thrust-slices are exposed on the slopes of the Fassa Valley and Mount Donna.

The Mairin Wand.

The general strike reading for the calcareous rocks of the Mairin Wand *below* the thrust-plane is W.N.W.-E.S.E. (str. N. 70° W., dip 40° N.N.E., cleavage N. 20° E.). But the torsional effects are very pronounced in the limestone of the Mairin Wand, more so than in the Col Laz rocks. The shear-cleavage planes, with strike N. 45° E., and dip S.E., intersect the planes associated with the W.N.W. strike, and the joints seem to be curved from the one direction to the other. At Col Laz and Campaz the strike is E.N.E. or N.E., at Toal Longo and Mairin Wand it is W.N.W. or N.W., and these readings represent the leading strike-curve of Bufaure convex towards the south. This strike-curve is clearly the result of a later N.N.E.-S.S.W. strike, having been superinduced upon thrust-masses which had a W.N.W.-E.S.E. strike, and whose fragments were twisted into positions with characteristic variations of strike from the W.N.W.-E.S.E. direction through E.N.E., W.S.W. and N.E.-S.W. directions to the N.N.E.-S.S.W. leading cross-strikes. The chief Judicarian faults in Bufaure are the N.N.E.-S.S.W. fault which divides Toal Longo from the Mairin Wand, and the N.N.E.-S.S.W., fault which divides Mairin Wand from Col Laz. Both are occupied by thick fault-dykes continuous with the porphyrite of the Bufaure sill. Thus it is quite clear that the sill and dyke system was intruded during the Judicarian epoch.

The Peripheral Shear and Contact Zone of Bufaure.

The igneous rock of Bufaure has long been famed for its well-formed augite crystals. The more compact facies of porphyrite occurs in the body of the sills or dykes, the vesicular facies occurs at the peripheral contact zones of the injections as well as in threads passing from this zone into the shear brercias of the stratified envelope. At the Campaz, where this differentiation is well seen, it is especially at the contact zones that the large crystals of augite are porphyritically disseminated. The amygdaloidal replacements are plentifully developed all round the outcrop of the Campaz thrust-plane. The plagioclase crystals are small and much decomposed in the porphyrite of the Campaz area; but the segregation veins and cavities containing secondary minerals are numerous—heulaudite, quartz with ruthile enclosures, chalcedony, analcime occur very commonly.

In all the parts of the Bufaure intrusive rock which I was able to examine closely, there has been a strong tendency for the felspathic constituents to segregate in nodular concretions within the basic facies. Examining the concretions, I found usually a close-grained basic variety in the inner core, *large* plagioclase crystals disseminated in the middle zone, and the outer layers porous, slaggy, and rich in *small* plagioclase crystals. I sometimes found large, well-formed crystals of plagioclase confined to one half of a nodular concretion, and the other half composed of coarse or close-grained basic porphyrite. This original segregation within the mass is quite distinct from the mixed shear and contact breccia which is displayed on the floor of the porphyritic intrusions at Bufaure (*cf.* pp. 86, 87, and footnote p. 179).

General Interpretation regarding the Bufaure Porphyrite.

The Roja-Canazei N.N.E.-S.S.W. fault, was shown above (pp. 62, 63) to have been the leading fault between the Rodella cross-arch and the Pordoi cross-trough or downthrow, and the seat of intermittent igneous injections. That is the fault which I have continued in my reference map through the igneous Bufaure Massive, there being good evidence both at the north and south extremities of this line in Bufaure, that the magma ascended here through the strata, and spread both westward and eastward. The westward extension took place on a gently-inclined floor of calcareous rock, much like the floor of the Mount Donna sill, so that the form of this portion of the sill tended to be saucer-shaped. But in its eastward extension the magma became confluent with other sill and dyke inflows in Bufaure, and apparently with those in the Canazei and Belvedere area.

More especially in the east of Bufaure one can see that the older east-west fractures were also lines of ascent for the magma. For the purpose of affording a general idea of my interpretation, I have carried these lines through Bufaure in my reference map, but it will be understood that except where subsequent movements have occurred, these older fault-lines would naturally be obliterated at the sill extensions of the magma, above the actual orifices.

From a perfectly general aspect, the importance of the foregoing observations is that they offer a new interpretation for the accumulation of porphyrite rock in the Bufaure Massive. Hitherto all observers have referred to it as an accumulation of igneous material around one of the chief *Triassic* volcanoes, whose activity was contemporaneous with the formation of coral or algal calcareous reef-like accumulations in the neighbourhood. The agglomeratic or tuffoid material in Bufaure was said to represent volcanic ejecta, the bombs, ashes, &c., usually associated with an eruption at the surface.

In my interpretation, the whole process of accumulation at Bufaure, so far as there is evidence, has been subterranean; and there is absolutely no field evidence to show that the subterranean intrusions were connected with volcanic explosions at the surface. The igneous material has ascended through a network of fault-lines; in such lines one finds, as might be expected, the same agglomeratic mixture of rock, and even tumultuous character, as is typical of volcanic necks. The definite limitation of the igneous material is explained in my interpretation as the result of previous definite fractures and forms of plication in the crust: and the ascent of the magma into these pre-existing fractures and crust-planes, shows that the intrusions did not take place until Middle Tertiary time.

PART III.

The Contrin Slopes and Monzoni Alpe.

The Local Judicarian Arch—The Col Laz Thrust-Mass—The Varos Thrust-Mass—The Varos Inthrow—The Contrin, Col Ombert, and Forca Alpe Thrust-Mass—The Limestone Rocks of Cirelle and Campodella—Comparison of the Contrin and Monzoni Alpe Sections—The Vallaccia Slopes—The Guschel Fault Sill—Col del Guschel—The Pocal Fault—Monzoni Alpe—The Pocal and Forca Virgating Fault-Groups—Lago Usel.

The Local Judicarian Arch.

In my examination of Contrin Alpe, I found the continuation westward of the two thrust-planes which were determined by Professor Salomon in the Marmolata group. For the sake of showing the relations of the opposite sides of Contrin Valley, I have entered roughly the position of the thrust-planes on the east or Marmolata side, for the description of which I refer the reader to Professor Salomon's work (*cf. Introductory*, p. 7).

Professor Salomon expresses his opinion that the two sides of the valley bear undisturbed relation to one another, but I am inclined to think the N.N.W.-S.S.E. fault from Gries in the Rodella district passes through the Contrin Valley and has slightly lowered the outcrops on the Marmolata side. The disturbance is indicated by turning and dragging of all the strata occupying the lower contours of the Contrin Alpe, by the difference of strike upon the two sides, and by the lateral displacement of the older faults of overthrust and downslip. The steep flexure to the south-south-east which can be traced throughout the Contrin anticline is exposed on the east side in the Werfen strata which have been eroded by the tributary stream of the Val di Rosalia, but on the west side, the arch of the anticline is farther north, its position being indicated by the exposures of Permian strata which run westward from Contrin Valley to Pozza Alpe.

The leading faults are the series of N.N.E.-S.S.W. faults which have produced lateral displacements of the older thrust-masses in the sense of downthrow of the western fault-block and horizontal displacement southward. These faults are the continuation of the N.N.E.-S.S.W. faults which I described in 1893 and 1899 on the east side of Sella Massive, with downthrow to Sella Massive.

The geology of Contrin Alpe at first seems very complex, owing largely to the fact that the N.N.E.-S.S.W. faults have N.E.-S.W., E.N.E.-W.S.W. branch-faults connected with them, and very often a branch-fault gives place to a dip-flexure in the same direction of strike as the branch-fault. This fact, together with the predominance of the N.N.E. strike, shows that the wide outcrop of the Permian and Werfen strata, with general E.N.E.-W.S.W. trend, stretching from the Contrin stream across the Contrin, Pozza, Pocol, and Monzoni Alpes, represents part of a N.N.E.-S.S.W. Judicarian arch, in relation to parallel N.N.E.-S.S.W. Judicarian troughs on the east and west.

The trough-form on the east contains the subsided calcareous rocks of Col Laz, Mairin Wand, Vallaccia, and Pesmeda. The area of subsidence has been largely invaded by porphyritic dykes and sills; the massive intrusions build up the Bufaure mountain-massive and Col del Larisch (Larca). The superinduced dips, connected with the Judicarian arch, are towards W.N.W. or N.W., and towards E.S.E. or S.E. The position of the superinduced arch-summit can be accurately defined on the evidence of these oppositely-inclined dip-readings. It may be traced from Contrin Alpe, where it keeps close to the fragments of calcareous rock at the base of Sasso di Rocca and Varos, through Pozza Alpe to the Pocol and Monzoni Alpes, where the arch-summit keeps close to the calcareous rocks on the south of it. The older piled-up thrust-masses have been deformed by the superposition of the later strike and dip. They have been cut on the north wing of this superinduced arch by a N.E.-S.W. fault, with downthrow north towards Varos, Sasso di Rocca, and Col del Larca. Similarly the south wing of this superinduced arch has been cut by a steep fault with curved strike E.N.E.-W.S.W. in Contrin Alpe, N.E.-S.W. at Pocol and Costabella, on the south of which the strata are downthrown.

The Col Laz Thrust-Mass.

The Reference Fault-Map will show how the older thrust-masses of the Contrin area have been dislocated by the Judicarian N.N.E.-S.S.W. cross-faults. The old thrust-planes can be detected on the north and south of the rugged cliffs of Varos, and the outcrops are exposed in the fragments left below Sasso di Rocca and at Col del Larca. For convenience, I shall distinguish the higher (geographically, the more northerly) thrust-slice, as the Col Laz Thrust-Mass, the lower, as the Varos Thrust-Mass. The Werfen strata, that crop out in the Nicolo Valley between Col del Larca and the Mairin Wand, have been displaced southward from the Col Laz Thrust-Mass at the N.N.E.-S.S.W. cross-fault that runs between the Campaz and Col Laz, and continues southward as the east limit of Col del Larca. Together with the limestone of the Mairin Wand, they have been very greatly twisted during their subsidence into the Judicarian cross-trough. The Sasso di Rocca sill-and-dyke system, continuous with the Bufaure intrusive magma has run along the thrust-planes and the N.N.E.-S.S.W. faults, and has locally obscured the original course of the thrust-plane between the Col Laz and Varos thrust-masses. Branches of the Sasso di Rocca sill-system have run eastward from Sasso di Rocca into the Varos fault area, and the corresponding area east of Contrin Valley.

The Upper Werfen strata below the calcareo-dolomitic rocks of Col Laz are full of fossils. They strike E.N.E. and dip N.N.W., but are crumpled across the strike by a series of small waves, with axes directed N. 25° W. Hence at Col Laz, as at Rodella, the folding in N.N.W.-S.S.E. direction was subsequent to the superposition of the E.N.E. or N.N.E. strike.

The thrust-mass of Col Laz is cut off against that of Varos by a N.N.E.-S.S.W. fault, parallel with the fault on the north of the Col Laz mountain. The rocks here are very much sheared and slashed. Frequently a strike N. 70° W. to N. 80° W. is obtained, and a steep dip to the south, this strike being the same as in the adjacent fault-block on Contrin Alpe. But the predominant strike is the superinduced Judicarian strike N. 50° E., and dip 20° N.W. The whole series is cut by N.N.W. and W.N.W. cleavage-planes, almost vertical.

The Varos Thrust-Mass.

The outcrop of the Varos thrust-mass curves round the western slopes of the steep escarpment of Upper Werfen and Mendola strata opposite Sasso di Rocca. The outcrop of the thrust-plane is in Werfen strata, but can easily be followed owing to the shear-breccias and slickensided surfaces. The Werfen strata of the thrust-mass lie in an erosion hollow; they are much bent and disturbed, but have a general strike N. 80° W. and variable dip north. The ridge on the south of this hollow is composed of Upper Werfen strata surmounted by erosion remnants of Mendola calcareo-dolomitic rock. This series represents the underlay of the Varos thrust-plane, while the patches of sedimentary strata in the Varos cliffs belong to the thrust-mass. The latter have been brecciated and intercalated with porphyrite.

The thrust-plane is intersected on the east slopes of the Varos escarpment by an almost N.E.-S.W. Judicarian fault; and along it the 'Varos' thrust-mass and underlay have been thrown down relatively to the Permian and Lower Werfen strata on Contrin Alpe. The two Judicarian faults that limit Varos unite in their continuation westward through Pozza Alpe. The strata within the fault-wedge are very much crumpled, brecciated and distorted, more especially on the Pozza slopes. West of the N.N.E.-S.S.W. fault, the Varos thrust-plane is exposed between Werfen strata and Mendola Dolomite, upon which patches of Buchenstein and Wengen strata have been preserved. The irruptive rock in the shear-plane is finely laminated, locally schistose; the Werfen strata above are baked and conglomeratic, the calcareous material below shows contact alteration, is crystalline or serpentinous, and often conglomeratic.

The Varos Inthrow.

The precipitous crags of porphyrite and calcareous rock between Sasso di Rocca and Contrin Valley represent a local subsided wedge limited and penetrated by faults. The limiting fault round its southern aspect is well exposed in the ridge that separates the Contrin Alpe from the basin-shaped depression with Werfen strata at the base of Sasso di Rocca. Mendola Dolomite and augite porphyrite have glided down upon a brecciated floor of Upper Werfen strata; the inclined fault-plane where it is exposed on the ridge strikes N. 80° E. and dips 35° north, but the slickensides are directed N. 25°-30° E. The fault curves westward with strike N. 65° W., and meets a parallel fault passing through the Varos rocks, then joins the main N.N.E.-S.S.W. fault limiting Varos on the north.

At this fault the Werfen strata are well exposed in a stream-cutting. The bedding-planes strike N. 50° E. and dip 40° N.W. The porphyrite of the Sasso di Rocca sill has ascended these bedding-planes obliquely from the west (see sketch, fig. 17). The bedding-planes bend sharply southward, and are cut off by the N.N.E.-S.S.W. fault. Augite porphyrite has also entered this fault, and is interleaved between a Varos fragment of calcareous rock, and disturbed Werfen strata of the Col Laz thrust-mass. The Varos crags therefore belong to the same

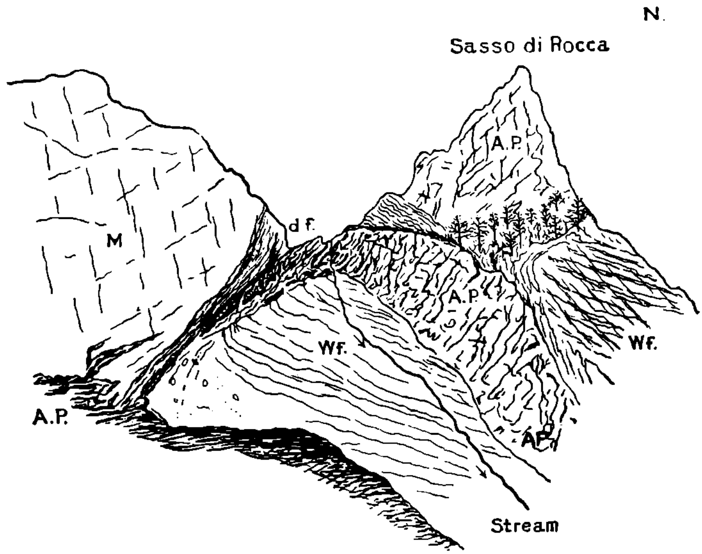


Fig. 17.—A stream-cutting between Col Laz and Varos; the stream flows east from Sasso di Rocca to join the Contrin Stream. d.f.=a downslip fault-plane at a "knee-bend" of the rocks; the fault-plane strikes N. 45° E. and dips 30° south-east, it is occupied by a fault and contact breccia of Wf. (Werfen), M. (Mendola) strata, and AP. (Augite porphyrite) forming part of the Sasso di Rocca intrusion.

thrust-mass as the Werfen strata in the basin-shaped depression above, but are cut off from it by the curved branch-fault between the Werfen strata and the subsided calcareous and porphyrite rock.

The Contrin, Col Ombert, and Forca Alpe Thrust-Mass.

(See pl. xv., fig. 1.)

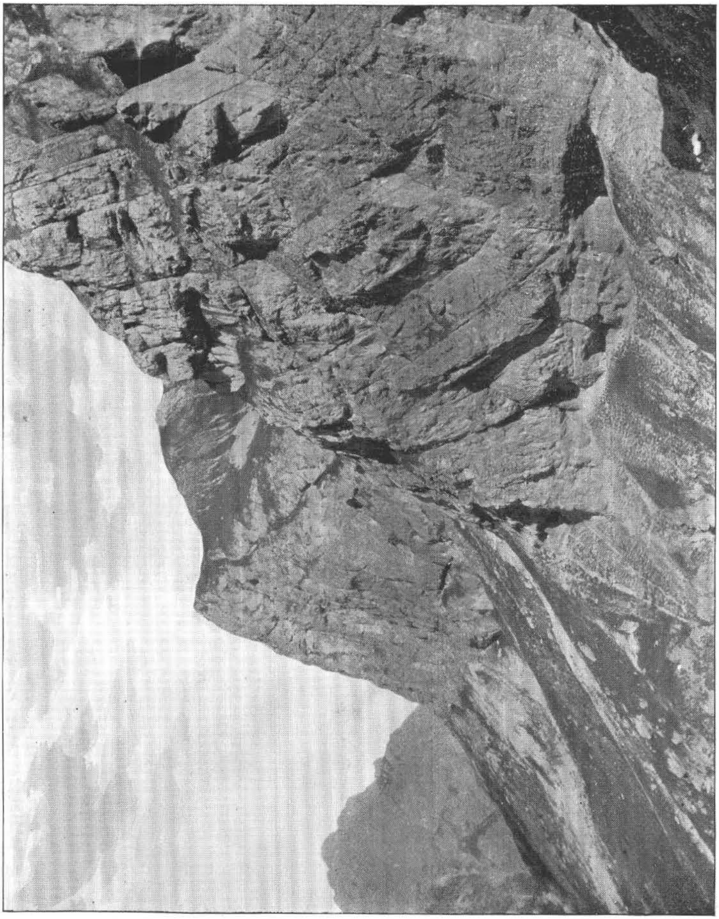
The rocks of Contrin Alpe, Col Ombert and Forca Alpe formed the underlay slice of the Varos thrust-mass, and the over-thrust slice in relation to the Costabella and Cirelle limestone.

But the thrust-mass has been very much bent and faulted. The chief fault occurs in Upper Werfen strata, and keeps near the calcareous rocks of Col Ombert and Costabella. The calcareous rocks of the thrust-mass subsided at Col Ombert and the Upper Werfen strata at their northern base are cut by shear-planes, contorted and much brecciated all along the plane of downslip. The downslip plane has cut a steep knee-bend flexure facing the S.S.E., as shown in the section through Col Ombert. The front of the original thrust-mass is undoubtedly represented by the Werfen rocks of Forca Alpe which dip northward, hence the inthrow of the calcareous rocks of Col Ombert has taken place behind the front of the thrust-mass. The inthrown limestone has probably been locally thickened by transverse pressure, as the thrust-mass has been crumpled into synclinal form, and dislocated by shear-planes and small faults. The fault-breccias are best exposed below the calcareous rocks that run east from Col Ombert: at Col Ombert itself the Upper Werfen strata are closely contorted, waved, slickensided, and cleaved, with distinct evidence of local thickening due to pressure.

The thrust-mass has been segmented by the leading faults and their branches developed during the N.N.E.-S.S.W. Judicarian movements. One of these faults crosses the Contrin valley near the Contrin Club-Hut, and enters the Campodelle calcareous rocks east of Col Ombert at the 2160 mèt. contour. The Werfen strata of the Alpe have here the W.N.W.-E.S.E. strike, but various strike-disturbances are shown in the proximity of the cross-fault, the local strike being ca. N. 35° E. —the dip southward and very steep. Nearer Col Ombert, there are dip-flexures connected with the superinduced Judicarian strike, the strike being ca. N. 40° E., and dip ca. 30° S.E. suddenly bending to a high dip to the N.W. Divisional planes highly inclined to the S.E. are those which are chiefly displayed by the calcareous rocks, and they are cut by a system of vertical cleavage-planes directed N.N.W.-S.S.E. On the other hand the softer mixed series of Werfen strata in the middle horizons give the best evidence of an older W.N.W.-E.S.E. strike and its torsion to E.N.E.-W.S.W., N.E.-S.W., and N.N.E.-S.S.W. directions. An example of intersecting systems of bedding and cleavage-planes is given in the photograph of the Vernel crags (pl. ii.).

The entrance of the porphyrite has taken place into the N.N.E.-S.S.W. cross-faults, into the crush-breccias and into various lines of strain. Small appearances of dykes are present in the Permian and Lower Werfen strata at contour 2100 mètres on the east slopes as well as in the bent Werfen strata exposed

Col Laz. Vernel.



The Vernel Crags east of Contrin Valley.

At the base the bedding-planes of the Passage-Beds strike E.N.E.-W.S.W., dip ca. 30° N.N.W.; the limestone crags above show a steep curved system of divisional planes with N. 80° W. strike.

on the Pass ridge. In surveying the slopes of Contrin Alpe, I followed the Werfen succession zone for zone, and was enabled to collect on this Alpe the data which form the main basis of the sequence given in the "Table" above (p. 19).

The west slope of Col Ombert offers good exposures of the Upper Werfen porous and granular limestone, the orange-coloured calcareous marly limestones with Naticella costata and the red crinoid limestones. Near the Col the bedding-planes strike N. 50°-60° E. and dip steeply southward; these are cut by two sets of cleavage-planes, the one set being N. 80° W. and the other N. 30° W. The same group of Upper Werfen strata is present on the south of Col Ombert where they repose as a thrust-mass upon the Marmolata Limestone of the Campodelle part of the Cirelle range.

The thrust-mass is thinner on the east side of Col Ombert than on the western face. The rocks of the thrust-mass are mainly Upper Werfen strata including the Passage-Beds and there are fragments of Mendola Dolomite and Buchenstein rock not entered on my geological map.

On the top of the ridge between Forca Alpe and Campodelle, the rocks composing the thrust-mass strike E.N.E.-W.S.W. and have varying dip. At the extreme southern end of the thrust-mass the bedding-planes are almost horizontal, nearer the central portion of the thrust-mass they dip as much as 50° northward, and towards the northern end they are thrown into a series of small folds then tilted up steeply with high dip S.S.E. The south-dipping portion of the thrust-mass rests upon the calcareous rocks of Col Ombert, and has probably been driven there during the Judicarian movements. Divisional planes in almost North-South direction, or slightly east or west of due north, split up the rocks of the thrust-mass on the western face, and these planes dip high to the east. Thus there has clearly been a cross-compression of the thrust-mass that has produced a certain elongation of the mass in north-south direction and over-faulting and over-thrusting from east to west. The push northward or rather N.W. of the thrust-mass rocks above Col Ombert was clearly subsequent to the epoch of the thrusting southward, as it is the thrust-mass itself which has been cut by a reverse fault and the one portion overthrust above another.

Several N.E.-S.W. fractures penetrate the thrust-mass and into them dykes have passed, running continuously through the thrust-mass and its underlay, therefore younger than the epoch of thrusting. My geological map shows the position of the chief porphyrite dykes. Innumerable ramifying threads of igneous material have entered the rocks of the thrust-mass. These threads make a fine network within which the sedimentary rocks have been so greatly altered that they are locally converted into calcareous or serpentinous schists, or into a rough conglomeratic pile where altered limestone blocks are enveloped by igneous intercalations. The greenish colour of the igneous intercalations and their common distribution as bands and thin threads, might give the impression that they represent "Pietra Verte" tuffs belonging to the Buchenstein horizon, but examination of the relations in the field prove these greenish bands to be out-runners from dark porphyrite dykes, and as the latter have entered the N.N.E.-S.S.W. and E.N.E.-W.S.W. fractures they are undoubtedly intrusions subsequent to the deformation of the thrust-mass along these lines; the disjointed rocks of the thrust-mass clearly afforded easy access to igneous invasions (*cf.* pp. 39, 40, 42, 81).

To recapitulate the chief tectonic features of the Forca Alpe and Cirelle area:—

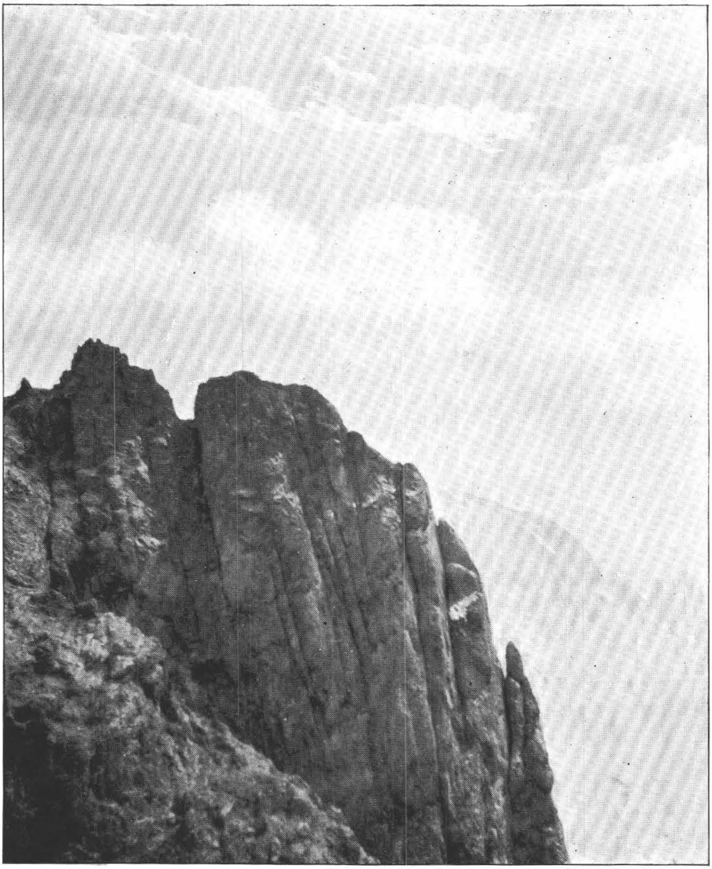
(1.) A thrust-plane inclined northward is present.

(2.) The thrust-mass above it has been dislocated, and twisted towards an E.N.E.-W.S.W. direction of strike, local crumpling and faulting taking place.

(3.) In these earlier Judicarian stages, the calcareo-dolomitic rocks of the thrust-mass subsided at Col Ombert, and during the still farther stages of deformation, the Upper Werfen strata of the thrust-mass were back-folded and driven towards N.N.W. and N.W. above them, so that isolated wedges, or elliptical masses of rock, which rested upon an older shear-plane inclined northward, were driven north-westward upon younger shear-planes. Such masses have the appearance of a "double fold," but the differently-inclined shear-planes took origin during folding-movements along different axes of strike—a W.N.W.-E.S.E. strike having been crossed by a N.N.E.-S.S.W. Judicarian strike, and various resultant strikes in E.N.E.-W.S.W. and N.E.-S.W. direction having then been produced, still later, a N.N.W.-S.S.E., locally almost N.-S., strike having been superinduced. During the earlier stages, the horizontal push acted southward and S.S.E.; during the later stages, the chief push was westward, but as the thrust-mass, or slices of it, *turned about on the old plane*, the appearance is that of a continuous "double-fold."

The Limestone Rocks of Cirelle and Campodelle.

The limestone plateau known as Campodelle is separated from the Forca Alpe exposures by a N.N.E.-S.S.W. fault, the Forca Alpe or west side being downthrown. The plateau bears several sheared remnants of the rocks belonging to the thrust-mass, but as these could not be entered with full detail on the



Punta Cigole.
"Marmolata Limestone" cut by vertical cleavage-planes in N.N.W.-S.S.E. direction.

map, I have omitted them. In the field, they show that the limestone of the plateau represents the continuation eastward of the under-lay of the thrust-mass. Sills of porphyrite can be followed in W.S.W.-E.N.E. direction, which is the general direction of the strike in the rocks of Campodelle. The dip is about 30° N.N.W. On the east side of the N.N.W.-S.S.E. Gries and Contrin Valley fault, the porphyrite is injected into Judicarian cleavage-planes, with N.E.-S.W. strike, and very steep dip towards the north-west.

The high rampart of Marmolata limestone south of the Campodelle and Cirelle group is separated from it tectonically by a zone of very disturbed strata. A steep knee-bend to the south is locally exposed in the rocks that run westward from Cirelle Pass to Forca Alpe, whereas a steep dip to the north is characteristic of the calcareous rocks composing the Cadin and Uomo groups farther south. The south limit of the Cirelle fault-block against the Cima di Cadin range is formed by a shear-plane with steep northward inclination, which was probably the original continuation of the Forca Alpe thrust-plane. In the rocks of the Cirelle Pass, the divisional planes have strikes that veer round from N.N.E. to E.N.E., the corresponding dip is always westward, and the whole massive of calcareous rocks shows a well-marked vertical cleavage in N.N.W.-S.S.E. direction. The photo (pl. iii.) is an example of this cleavage in Punta della Cigole above Fuchiade. The dykes that penetrate the Cirelle and Cadin Massive run chiefly in N.N.E.-S.S.W. direction, and are connected with sills that ascend the bedding-planes.

Comparison of the Contrin and Monzoni Alpe Sections.

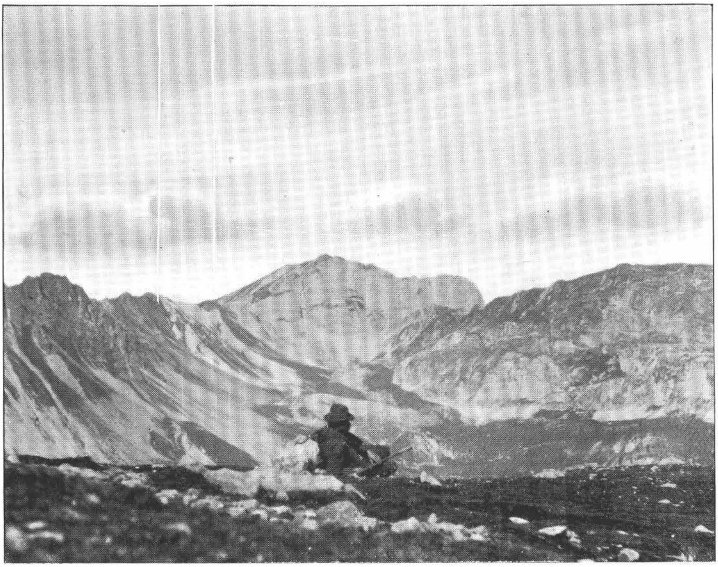
Comparing the geological section through the Contrin Alpe with that through Monzoni Alpe (pl. xv., figs. 1, 2), there will not be much difficulty in recognising the same essential features of structure. The older thrust-planes that are exposed north and south of the Varos crags in the Contrin section are exposed north and south of the Col del Larisch (Larca) crags in the other section; the Judicarian fault, with downthrow to the N.N.W., which cuts off the Permian and Lower Werfen strata of Contrin Alpe on the north, is exposed north of Monzoni Alpe at Col Guschel and Lago Usel, and is occupied by crush-breccias and by a fault-sill; the long northern dip-slope and short, steep knee-bend to the south, which is the chief feature of the Werfen strata and Permian rocks exposed on Contrin Alpe, is repeated at Monzoni Alpe, and the fault, with downthrow to the south, which penetrates the knee-bend of the Werfen strata at the base of Col Ombert, is well exposed at Pocol and Monzoni Alpe.

The calcareous rocks of Col Ombert are represented by the fault-block of calcareous rocks immediately surmounting Monzoni Alpe on the south, and divided from the deeply-sunk Cima di Selle fault-block by a N.N.E.-S.S.W. fault or fault-dyke. The Cima di Selle and the north face of the Costabella range represent the calcareous rocks of the Forca Alpe thrust-mass, whereas the Lago di Selle rocks, the Camorzao and Punta di Costabella range, represent the Lastei and Cadin range below the Forca thrust-mass, this underlay being downthrown to the north and west from the Werfen strata of Allochet, Campagnazza, and Uomo. (See Geol. Sections, pl. xv.)

The Vallaccia Slopes.

The name of Monzoni Alpe is applied more particularly to the undulating slopes east of the Monzoni stream. The strata exposed on Monzoni Alpe and at the base of the Vallaccia mountain are the continuation along the strike of the crumpled and torn Werfen strata exposed on the Contrin and Pocol Alpes. The predominating strikes, faults, and dykes are directed in accordance with the N.N.E.-S.S.W. strike of the Judicarian cross-movement, the chief N.N.E.-S.S.W. fault continues from the Col Guschel sill to the Costella intrusion of porphyrite. A later N.N.W.-S.S.E. fault crosses the main Judicarian fault and divides the strata of Monzoni Alpe from those of the Sasso di Mezzodi slopes on the west side of the Monzoni stream. The western or Mezzodi side is the downthrown fault-block and the outcrops of the strata are here displaced a little to the south of those on Monzoni Alpe. On the Mezzodi slopes the strata strike N., 55° E., and dip 35° N., representing a part of the gently-inclined long north dip-slope of the Contrin arch. The Werfen strata are there conformably succeeded by the "Mendola Dolomite" horizon with a thickness of ca. 30-40 mètres; above it is the Buchenstein series ca. 60 mètres, comprising flaggy, banded, and concretionary limestones; then follow conformably the Wengen calcareous and tufaceous grits and breccias with interbedded thin lavas; and above them the thin-bedded hard limestone like the "Cipit limestone" of the *Cidaris dorsata* zone, containing remains of echinoderms and corals, and typical Cassian bivalves. This zone is succeeded by the "Marmolata limestone" which builds up the cliffs and upper terraces of Sasso di Mezzodi.

Although the fossils of the *Cidaris* zone do not weather out favourably for collecting purposes, they can be quite well seen and recognised on the weathered surfaces. The thickness of strata from the uppermost Werfen horizons to the base of the Marmolata limestone is not more than 150-180 mètres. The



View towards Punta Vallaccia (from the east).

The Wengen-Cassian strata are exposed at the horizon indicated; the Costella fault-dyke forms a dark streak in the photo between the limestone rocks of Vallaccia and Costella, the igneous rocks of Monzoni being next Costella on the left.

succession shows that the "Marmolata limestone" is at Vallaccia a stratigraphical representative of the horizon termed "Schlern dolomite" in the district north of Fassa.

A thin dyke of Augite porphyrite has penetrated the Wengen-Cassian strata and sends numerous fine threads into them; a few small sills are also apparent in the gentle dip-planes of the Marmolata limestone and have there the reddish weathered surface so general in the intrusions at high horizons of the limestone. These dykes and also certain small intrusions in the Werfen strata follow the N.N.E.-S.S.W. strike and some of them have a curved strike to E.N.E.-W.S.W.

The importance of this conformable succession of Trias at Sasso di Mezzodi is very great. For my geological map shows that the upper horizons in the succession have been preserved in the Vallaccia mountain-massive chiefly in virtue of the fact that that area was lowered on the west of a leading N.N.E.-S.S.W. Judicarian fault—the same fault which farther north lowered the area of Col del Larisch and Bufaure, and still farther north that of Pordoi and Sella Massive. Whereas the upper horizons in the succession at Vallaccia are absent on the relatively upraised Usel, Pocol and Contrin Alpes, either because they have been eroded away or have subsided along inclined planes of downslip and have in consequence been locally attenuated or thickened. Hence the Marmolata limestone of the Vallaccia mountain-massive does not represent an original isolated reef-like occurrence, but is emphatically a weathered remnant of a calcareous sheet of deposit that originally spread continuously from the Marmolata group to Vallaccia, and belonged tectonically to the Contrin thrust-mass. The calcareous rocks of Col Ombert is another such remnant preserved in a local downthrow area, and there are others at Usel, as my map shows. The breaking up of the calcareous sheet of deposit took place chiefly as a result of the Judicarian cross-compression and fractures; and the apparent isolation of different wedges followed as a natural consequence of local sagging, and the changes of form due to surface erosion.

The photograph (pl. iv.) was taken looking due west to the Vallaccia summit, the succession described above is present in the Mezzodi cliffs on the right in the photo; on the left is the Monzonite of Monzoni, and in the corner between Vallaccia and Monzoni is the Costella strip of limestone and the porphyrite dyke in the N.N.E. fault. The photo shows the general relations at the Monzoni corner, and shows the steep southern dip of the rocks of the Vallaccia mountain. The flexure is really to the south-east and is a flexure associated with the superinduced N.N.E. or N.E.-S.W. strike. It is also shown by the Buchenstein strata near a spring between the Costella and Mezzodi rocks, and is present throughout *the whole length* of the Monzoni Alpe, Pocol, and Contrin thrust-mass; I have described it at Col Ombert, and the downthrown fragment of limestone at Costella has structurally much in common with the downthrow of the calcareous rocks at Col Ombert. It follows that the Monzonite rocks next the Costella and Mezzodi limestone occur in the strike of the "front" of the Forca Alpe thrust-mass and its underlay. The strike runs westward through the Cima di Lastei and Cima di Selle range where the calcareous rocks of the thrust-mass and underlay have been downthrown, and continues into Monzoni. These structural relations are quite readily followed on the geological and reference maps; while the geological sections show the steep knee-bend flexure to the south-east which I have traced from Contrin Valley to Pesmeda, on the Contrin Alpe, Pocol Alpe, Monzoni Alpe, and at Sasso di Mezzodi and Vallaccia.

The Guschel Fault Sill.

(*Cf.* Section, pl. xv., fig. 2.)

The eastern or Monzoni Alpe fault-block shows much greater stratigraphical disturbances than the subsided calcareous rocks of the Sasso di Mezzodi fault-block. The oblique shearing which the lower horizons of the thrust-mass have undergone is accentuated by the presence of the porphyritic fault-sill of Guschel and several porphyritic dykes directed N.N.E.-S.S.W.

The Guschel fault-sill (fig. 18) occurs where a steepening of the dip has taken place, associated with downthrow of the Werfen strata and Mendola dolomite to the north-west. The relations of the fault-sill to its floor of Werfen strata are shown in the sketch made at the Col del Guschel, the name of the pass from the Monzoni Alpe to Lago Usel and the Pocol Alpe. The plane of downslip strikes N. 50° E., and dips 20° N.N.W. The strata below strike N. 30° E., and dip circa 35° W. From this reading the sill will be recognised as an injection into a shear-plane associated with the superposition of the Judicarian system. The porphyrite in contact with the floor of upper Werfen strata is vesicular and slaggy, but above this selvage-zone the sill is a compact augite porphyrite. Studied on the Lago Usel side of the pass it is seen to pass obliquely across the tilted bedding-planes of the Werfen strata. The latter are sliced by companion shear-planes in the same direction as, but steeper than, the main plane. They are altered to banded hornstone through a contact-zone several feet thick, and have slickensided and rippled surfaces.

The sill is segmented by a horizontal joint-cleavage in which the slabs are inclined north-west, with a curving dip, and by an intersecting system of curved joints facing steeply to the south-east. On the Lago Usel side one can study the joint-blocks (photo, pl. v.), see their concentric laminar structure, note the greater decomposition next the joints where laminæ weather with brown surface and crumbly, tufaceous appearance, and the more highly crystalline character of the

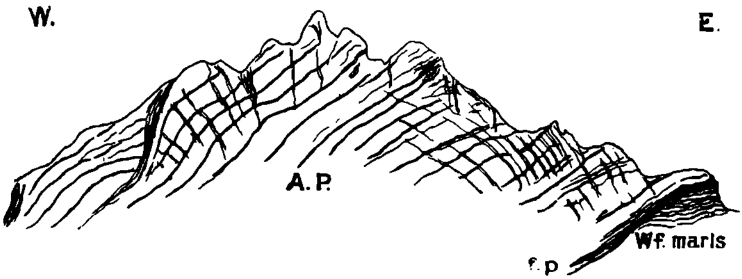


FIG. 18. South aspect of the Col Guschel sill (augite porphyrite), showing the intersecting systems of curved cleavage-planes inclined to the north-west and to the south-east. f.p. = fault-injection plane. Wf. = Werfen strata.

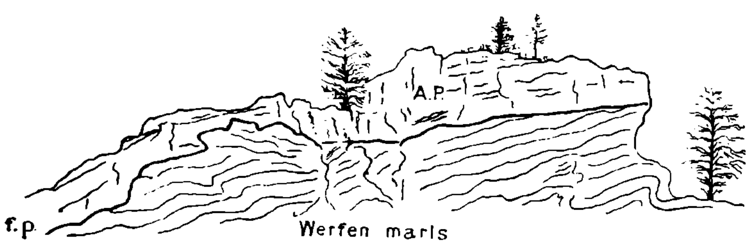


FIG. 19. A portion of the fault-injection plane (f.p.) exposed on the south escarpment of Col Guschel. The Werfen marls strike N. 35° E. dip north; the fault-plane strikes N. 50° E., dips 20° towards N.N.W. The Werfen marls are slickensided, waved, and altered, the contact zone of the sill is porous and slaggy.

rock towards the centre. The impression I got was that the rock consolidated under the influence of the Judicarian cross-pressures and cross-shearing, and owed its block-like structure next the shear-planes to the localised stronger effects of the pressures acting during consolidation. The roof of the sill is exposed west of Lago Usel, the broad selvage zone between it and the upper Werfen strata being a typical shear-and-contact breccia, wherein angular, sheared, or hollowed pebbles of the upper Werfen strata are imbedded in a tuffoid matrix, representing crushed streaks of igneous material. The strata above the sill strike N. 50° E., and dip 50° north-west. As the strata below the sill have an average dip of 30° or less, it is evident that local steepening of the angle of dip has taken place in the direction of downthrow. This is another case of so-called "Werfen conglomerate," which is not of sedimentary but of geotectonic origin (*cf.* p. 20).

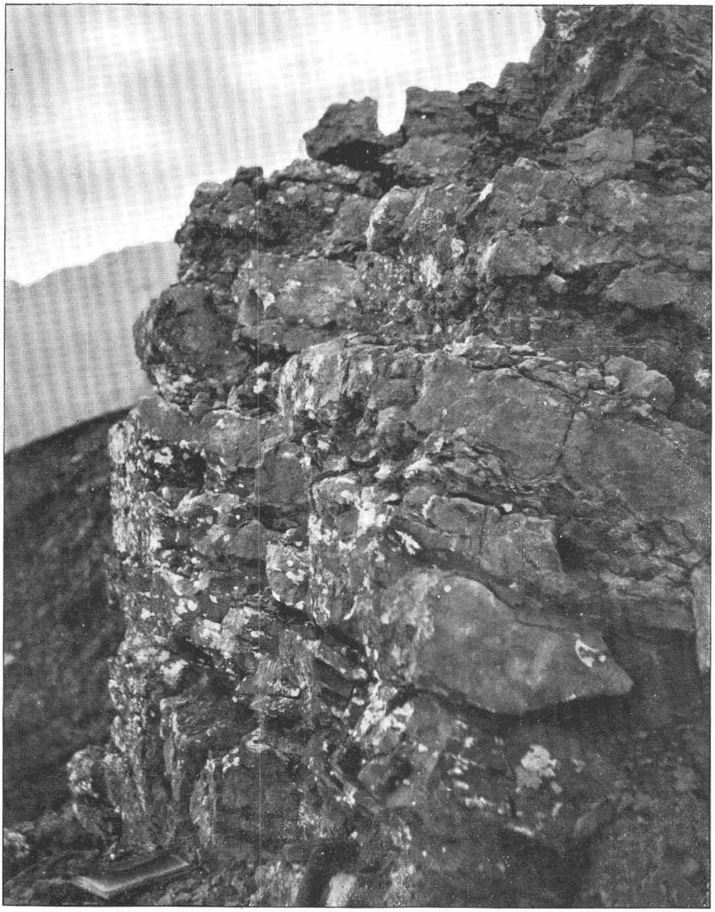
Col del Guschel. (See section, pl. xv., f. 2.)

The anticlinal curvature of the upper Werfen marls from a north-west to a south-east dip may be seen on the Col del Guschel, several paces south of the path to Pocol. This curvature corresponds to the N.N.E.-S.S.W. Judicarian arch; being the same arch-curvature which is apparent in the photograph of Punta Vallaccia. The alternating calcareous and marly strata of the Upper Werfen horizons have been strongly compressed at the arch-curvature; the individual beds show alternately lenticular swellings and attenuated portions. The strike also varies, and a thin sill of porphyrite is present, having the same structural position as the Costella dyke and sill threads. Above this sill the bedding planes are more regular; they strike N. 55° E., and dip 35° S.E. The strata are cleaved in E.N.E. direction, and the cleavage-planes are steeply inclined to the north. This cleavage is crossed by intersecting vertical cleavages, with N.N.E. and N.N.W. strikes. The Upper Werfen Naticella Costata beds of impure, dull-grey limestones, are succeeded by the creamy and pinkish rocks which represent the passage-beds. Small faults penetrate them, and the Mendola dolomite and Buchenstein concretionary rocks are present only as fragments, best seen on the Col ridge.

Many weathered stones in the screes that descend from the calcareous precipices show that the "Cidaris dorsata" horizon occurs in the limestone cliffs, but I saw no good specimens of Wengen rock. There are brown, flaggy limestones in the position of the Wengen horizon, but they are unfossiliferous so far as I could find.

The thin fault-sills in the south-dipping Werfen strata on the Col are more widely exposed on the Pocol Alpe, north of Col Guschel. They are there polished and slickensided at many of the cleavage-planes, and curve from N.E. to an easterly direction.

Close to the base of the cliffs, the Upper Werfen strata strike E.N.E. and are strongly crumpled and sheared. The strike of the calcareous rocks in the mountain massive is also E.N.E. and the dip S.S.E. whereas the strike of the Werfen



" Block-Structure " in Augite Porphyrite (Col Guschel).

strata on the north slope of Col Guschel is north-north-east. It follows that the sills were distributed in shear-planes produced during the torsion of the thrust-mass towards the N.E.-S.W. strike.

The Pocol Fault.

On Pocol Alpe a N.E.-S.W. fault emerges from the limestone mountain (section, pl. xvi., fig. 1). The east wing of this cross-fault has been thrown down. The fault-plane is steeply inclined to the south-east and is occupied by a porphyrite dyke with ramifications. The limestone strata on the west of the fault strike N. 60° E. and dip 55° or more S.E. They are finely fissile and slickensided, and show strongly the effects of dynamo-metamorphism. Rough cleavage planes are developed parallel with the fault and steeply inclined (50°-80°) to the south-east, these planes curve more and more steeply as they ascend the rocks. The limestone strata on the downthrow side of the fault-dyke are blackened and polished, numerous interstices are present in the horizontal bedding-planes, and in some of these the intrusive rocks swell out. The igneous rocks in the joint and fault-cleavage fissures nearly always have polished contact surfaces. The torsion of the strike in virtue of the cross-movement can be very well determined in the Upper Werfen and Mendola strata beside this fault.

Monzoni Alpe.

(Photo, pl. vi.; Section, pl. xv., fig. 2.)

The sheared and crumpled flexure to the south-east is easily traced on the southern or Monzoni Alpe slopes of Col Guschel. The strike of the disturbed Werfen strata bends more and more to a N.N.E.-S.S.W. direction so that these strata cross the 2100-mètre contour obliquely and descend to the 2000 contour at the corner of Monzoni Alpe, where the Monzonite rocks are in contact with the limestone of Cima di Sella. Hence the Werfen strata which are present at the base of the calcareous rocks on the Pocol Alpe have been twisted and dragged southward for more than a kilomètre owing to the superposition of the N.N.E.-S.S.W. Judicarian strike. And the virgating faults diverging through the Alpes of Monzoni and Pocol are torsion-faults developed during the period of superposition. Farther, the porphyrite dykes occupying these faults cannot be older than the same Judicarian period of superposition.

The Monzoni Alpe dykes run parallel with the strike of the sheared flexure. The first is not more than two or three feet thick and ramifies in north-dipping and south-dipping planes of the bent Werfen rocks; the second is a thick sill in south-dipping planes. The igneous rock is a close-grained, olivine-bearing porphyrite. Under the microscope, a typical specimen from these dykes is seen to contain

"abundant plagioclase phenocrysts strongly-zoned, full of inclusions and decomposed crystals of a pale augite; many pseudomorphs in calcite and serpentine (with epidote); a ground-mass pale, consisting of small plagioclases, some iron ore, abundant serpentinous products after ferromagnesians, traces of brown mica—no quartz and no appreciable glass."

The third dyke and sill system is that which occurs where the Werfen strata have been most steeply bent to the S.S.E. It shows in the field segregation bands, nests, and veins of plagioclase in a basic fine-grained ground-mass.

The large dyke that passes through the limestone cliffs was previously observed by Professor Doelter and its microscopic structure examined. I have now been able to determine that it is a FAULT-DYKE in the direct south-west continuation of the Pocol fault-dyke, with downthrow on the east side of the fault. Large patches and nodular balls of red and brown weathering porphyrite with abundant crystals of plagioclase and augite are embedded in a finer-grained "melaphyre" type, with fewer large crystals and a dark ground-mass, often vesicular. The block-structure in this dyke is quite like the "block-porphyrite" of the E. Rodella dykes (p. 48). And it is important to observe that here also the block-structure has been assumed by magna which consolidated in a leading fault-plane *where recurrences of differential shearing must have been frequent.*

The limestone in the shear-and-contact zone between the third and fourth dykes strikes N. 50° E. and dips 45° S.E.; the cleavages are N. 40° W. and N. 50° E. The rock has been rendered highly crystalline; it is impossible to distinguish successive horizons, but the Mendola and Buchenstein horizons of limestone are those which are involved in the third fault-dyke at the higher contours.

Regarding the Monzoni Alpe intrusions as one group, it may be said to comprise every variety from a fine-grained basaltic type to a true augite porphyrite, and to a porphyrite with the plagioclase crystals predominating over the augite. Moreover, the structure likewise shows all varieties, from a fluidal and a vesicular, to typical porphyritic structure, and to concretionary block-structure. They form the tectonic representative of the porphyrite fault-dyke between Vallaccia and Costella.

The Pocol and Forca Virgating Fault-Groups.

The downthrow part of the mountain east of the Pocol cross-fault includes the Cima di Selle and Costabella, and is interleaved with a close meshwork of sills and dykes, intruded into superinduced Judicarian divisional planes inclined to the south-east, as well as into the original south-dipping bedding-planes next Pocol.

Wide screes descend from the mountain to the Nicolo Valley, but mapping as I did from Contrin Alpe, I was enabled to trace to this area several branch shear-planes in the Permian and Werfen strata. The Pocol group of faults virgating to N.N.E. and N.E. indicates the oblique slicing and torsion suffered by the thrust-mass in connection with the superposition of the N.N.E.-S.S.W. Judicarian strike.

A similar group of minor shear-planes branches towards Col Ombert and the Forca Alpe from the next N.N.E.-S.S.W. cross-fault. These diverging faults are occupied by dykes of close-grained augite porphyrite, exactly the same as the intrusive rocks in the Costabella fault-block (see pp. 118, 120). Veins of heulandite, reddish ferruginous weathering, and the presence of decomposed green augites give the porphyrite a characteristic appearance. I traced two of the chief dykes to certain greenish bands and threads of the "Pietra Verte" interlayered with altered limestone south of Col Ombert.

Lago Usel.

(Section, pl. xvi., fig. 1.)

On the ridge of Mount Pocol north of the east-west strike-fault, the dip of the Werfen strata is quite slight (str. N. 40° E., dip 20° N.W.), but it steepens towards the fragment of Mendola rock which is present near Lago Usel. This fragment is part of the downslip series reposing upon the normal fault-plane of Col Guschel, with inclination to the north-north-west. On the Pocol ridge, a shear-breccia of Werfen and limestone fragments is present in the continuation of the strike of the Col Guschel fault-sill. The Upper Werfen and Mendola dolomite above the downslip plane strike N. 50° E. and dip 50° north-west, but are penetrated by cleavage-planes inclined ca. 40° south-east.

A small stream runs north-north-east from the Lago Usel plateau to the Nicolo Valley. It flows at the base of a cliff of limestone which is surmounted by the augite porphyrite rocks of Col del Larisch. The Werfen rocks below the limestone have a general N.E.-S.W. strike and steep dip towards Col del Larisch; they are much crumpled and show the most marked effects of crush, being rippled or sharply ridged, striated or polished, and frequently associated with intrusive rocks. About the 2000-mètre contour, at a narrow gorge, a polished and striated surface of crinoid limestone is exposed. The Upper

Werfen strata here have a general strike N. 75°-80° E. and a very steep dip south, but the striated shear-plane dips 35° north. This polished surface is probably an exposure of the thrust-plane that underlies the Varos thrust-mass and continues round the south of Col del Larisch; but the Werfen strata with nearly east-west strike belong to the crumpled and twisted Werfen rocks that crop out at intervals below the calcareous and igneous shear-breccias and porphyrite rocks of Col del Larca, and are *above* the thrust-plane.

The calcareous and igneous agglomerate and the sheared occurrences of Werfen strata round the west, south, and east limits of Col del Larisch demonstrate that the porphyrite sill spread in a group of strongly sheared and twisted strata occupying the crush-zone below the thrust-mass of Col Laz and Mairin Wand. The torsional effects were associated with steep dip flexure and downthrow to the west of the leading N.N.E.-S.S.W. Judicarian fault. The intrusions at Col del Larisch and Col Guschel mark the "middle limit" or septum between the N.N.E.-S.S.W. Judicarian arch or upthrow zone and the reciprocal trough or downthrow zone on the west. They are occurrences along the same N.N.E.-S.S.W. fault in which the magma of Sasso di Dam and Sasso di Rocca ascended.

Although not quite so much thrown down, the strata west of Lago Usel bear the same general relation to Monzoni Alpe as the strata of Sasso Morin and Sasso di Mezzodi. The occurrences of porphyrite on the east slopes of Mezzodi, as well as the Costella fault-dyke, farther denote the intrusions in the proximity of the N.N.E.-S.S.W. line of downthrow. The north-dipping plant shales, Buchenstein limestone, and Mendola dolomitic limestone that occupy the Piarazza slopes north of Sasso Morin are the original continuation along the strike of the calcareous remnants east and west of Lago Usel below the over-thrust Werfen strata of Col del Larisch.

PART IV.

The Campagnazza Meadowland.

Its Tectonic Importance—Differential Shearing at Chergore—The Porphyrite Intrusions at Col Uomo—The Campagnazza Fault-Block—The Costabella Fault-Block—The Costabella Fault-Sill—The Camorzao Fault—Summary.

Its Tectonic Importance.

In order to determine the tectonic relations between the intrusive rocks of Monzoni and the stratified rocks in the district east of Monzoni, I mapped generally the Campagnazza

The Selle-Monzoni Contact Zone and Monzoni Alpe.

PLATE VI

meadowland which descends to the Pellegrino Valley. The only part of the meadowland which offered no exposure was that below the Uomo ridge, but as the highest and the lowest contours were exposed, there is not much of the geology missing.

The Permian rocks repose upon Quartz Porphyry, and extend through the lower contours of the Campagnazza slopes. The general strike is W.N.W. and dips northward at a very slight angle, averaging 10-20°. This strike is present at Col Lifon, south of the Allochet ridge, but is crossed by the superinduced N.N.E.-S.S.W. strike, the strata undergoing an actual local curvature from W.S.W. round the south towards the S.W.-N.E. direction. In the middle and east portion of the Campagnazza there is a local strike-curvature to a N.W.-S.E. direction. Thus the outcrops of the Permian strata in the Campagnazza follow a curved strike, convex round the north. At Fuchiade, on the east of the Campagnazza, an E.N.E. strike predominates.

The W.N.W.-E.S.E. strike is the fundamental strike in the Campagnazza. All the diagonal strikes represent local strikes due to the torsion of the strata in the several fault slices determined during the cross-movements.

The curved strike in the Campagnazza, inasmuch as it was produced in successive folding movements, may be termed heterogenetic, as I have already termed the fault-systems associated with successive epochs of crust-folding (p. 75).

In addition to the determination of cross-strikes and dips in the Campagnazza, my observations show the presence of a porphyrite and sill system hitherto undetected in the Werfen strata, and prove conclusively that these are injected continuously in the fault and cleavage fissures parallel with the fundamental strike and the Judicarian strike. Having obtained the same result in the case of the Costabella and Cirelle injections (pp. 101, 117), the inevitable conclusion is that the porphyrite dykes and sills were injected not earlier than the Judicarian movement.

Before describing some of the observations, I wish to point out in what their interest lies. If my observations are correct, then my conclusion is also correct, and the porphyrite sills and dykes were intercalated during the Oligocene-Miocene movements in the Alps. The special mineralogical works upon Monzoni have treated the porphyrite of the sills and dykes in the Costabella limestone range as radiating threads representing either a contemporaneous facies of the monzonite rocks in Monzoni, or intrusions older than the monzonite.

In either case, according to my determination of the age of intrusion of porphyrite, the age of the monzonite intrusion would be definitely fixed as not earlier than the age of the N.N.E.-S.S.W. Judicarian cross-movement. My own opinion is that the first sills of monzonite were rather earlier than the porphyrite network.

Differential Shearing at Chergore.

Pl. xvii., fig. 1, represents a section through Col Sallei, a hill north of the Chergore huts, and separated from the Campagnazza Meadowland by the intervening depression called Campa Cigole. The Cigole depression is strewn with blocks from the limestone cliffs of Punta del Uomo. The strata strike N. 60°-65° E., and dip north at an angle of 25° in the lower horizon, increasing to 35° and 50° near the crest of the hill. Vertical cleavage-planes, parallel with the E.N.E. strike, penetrate the whole succession. The lower horizons are composed of the "Seis" fossiliferous limestones, and are succeeded by the reddish "Campil" marls, above which the fossiliferous limestones of the Upper Werfen series are exposed along the crest. The upper limestones dip more steeply, and are thrown into a group of narrow, oblique folds, the bedding-planes being sheared and slickensided, and traversed by calcitic veins. The fault shown in the section is well exposed opposite the Fuchiade hamlet, where the fault-zone is occupied by vertical strata striking N. 40° E. The fault cuts a steep knee flexure with N.N.E.-S.S.W. Judicarian strike, and divisional planes of steep cleavage can be observed along the crest of the hill; these superinduced planes at Col Sallei incline westward at 55°-60° W., but on the Fuchiade side of the fault, they are inclined steeply eastward.

The north slope of the Col Sallei Hill descends to one of the sources of the Fuchiade stream. Upon this slope an excellent exposure is afforded of the core of a rock-fold, following a strike that curves from N.N.E. to E.N.E. direction. One may observe how the layers of softer rock have been squeezed and mylonitised into quite irregular thicknesses between layers of harder rock. The bent strata are broken up into mere pellicles at one part, and at another, massed into lumps or wedges; in section, these are seen as thin threads and lenticular eyes of the mylonitic rock. The harder layers are polished and slickensided. I especially notice these features, because they show, in miniature, precisely what I have seen in the case of the Wengen-Cassian series of softer strata, between the limestone groups above and below them, and also in the case of the Werfen Marls, between the horizon of Mendola dolomite and either the Seis or the Bellerophon limestones below.

These Judicarian disturbances in E.N.E., N.E., and N.N.E. direction, are due to the cross-faulting and folding, and the Col Sallei fault has dislocated an older thrust-plane exposed on the Chergore slopes.

On the other side of the stream-hollow, opposite the Col Sallei, there is a thick bed of porous rauhwacke, passing upward into limestone, in which I could find no fossils to guide me regarding its age. As Director *v.* Mojsisovies enters a Permian overthrust in the Sallei area, this rock was probably regarded as Bellerophon limestone, and may be so. The other possibility is, that it belongs to the passage-beds and lower horizons of Mendola dolomite. As I could see no evidence of a disturbance between the north-dipping Upper Werfen strata with Naticella costata on Col Sallei and the rauhwacke in question, I have mapped the rauhwacke as passage-beds, this interpretation seeming to me to have most in its favour.

There is an inclined shear-plane between the limestone and the Werfen marls above it. The limestone strikes N. 60° E., and dips 30° N.N.W. at its base; but the upper horizons against the shear-plane are tilted as much as 55°, and this may be taken as the angle of inclination of the shear-plane. The Werfen rocks above dip 45° N.N.E., the strike being N. 80° W. They belong to the Punta del Uomo succession, and therefore are a portion of the thrust-slice that formed the underlay of the Forca Alpe thrust-mass. If the limestone below the shear-plane belong to passage-beds or Mendola horizons, then the Chergore succession of Upper Werfen strata has been driven above it; and if the unfossiliferous limestone be Bellerophon limestone, then it has been overthrust above the Upper Werfen strata exposed on the Col Sallei ridge and its northern slope. The important structural fact remains the same—namely, that the Upper Werfen series are repeated at Col Sallei and at Chergore, in consequence of an overthrust-fault.

Different horizons of Werfen strata rest upon the shear-plane above the limestone band. In the line of section, the shear-plane is cut at the 2140-mètre contour, and the Werfen strata continue upward for 300 mètres. The group of marly limestones containing Naticella costata, is succeeded by 10 mètres of marls and flaggy limestones rich in very small bivalves and gastropods, and these by 12 mètres of brightly-coloured, poorly fossiliferous, oolitic limestones. A few mètres of fossiliferous marly limestones follow, and then a thick series of red crinoid limestones interbedded with oolitic yellowish, pink, and creamy limestones, in some places packed with sections of Molluscan shells. The red crinoid beds and the poikilitic limestones form a cliff 30 mètres high, succeeded by 40 mètres of well-stratified limestones, richly fossiliferous in the lower horizons, poorly fossiliferous in the upper. Above them are concretionary limestones, of the kind usually recognised as "Buchenstein" limestone. In my map, I have included the crinoid and the poikilitic series with Upper Werfen strata; the stratified and concretionary limestones above are coloured as the Mendola-Buchenstein horizon (*cf.* pp. 20, 21). The marly and flaggy limestones contain the following characteristic Werfen fossils:—Naticella costata, Mstr.; Turbo rectecostatus, Hauer; Myophoria ovata, Bronn; the Passage-beds above contain species a little different from known Werfen forms. Dr. Broili tabulates them as Myophoria sp.; Myophoria sp.; (?) Modiola sp.; Pseudomonotis aff. Telleri, Bittner; Pseudomonotis aff. inaequicostata, Ben.; Dinarites cf. dalmatinus, Hauer.[1]

A porphyrite sill occurs in the Buchenstein limestone, and continues with the strike to the cliffs east of the Cirelle Pass. There the sill is seen to ascend vertically through the strata below the Buchenstein horizon. In addition to the main sill which enters the north-dipping bedding-planes, several fine ramifications pass into the Judicarian cleavage-planes in the limestone above the Buchenstein horizon. These planes are inclined to the south-east, and are crossed by vertical cleavage-planes directed N.N.W.-S.S.E. Another porphyrite dyke occurs farther up the Cirelle Pass on the Cigole side. It ascends through a vertical E.N.E.-W.S.W. fissure, and sends a ramification into one of the Judicarian cleavage-planes, dipping 30° to the south-east.

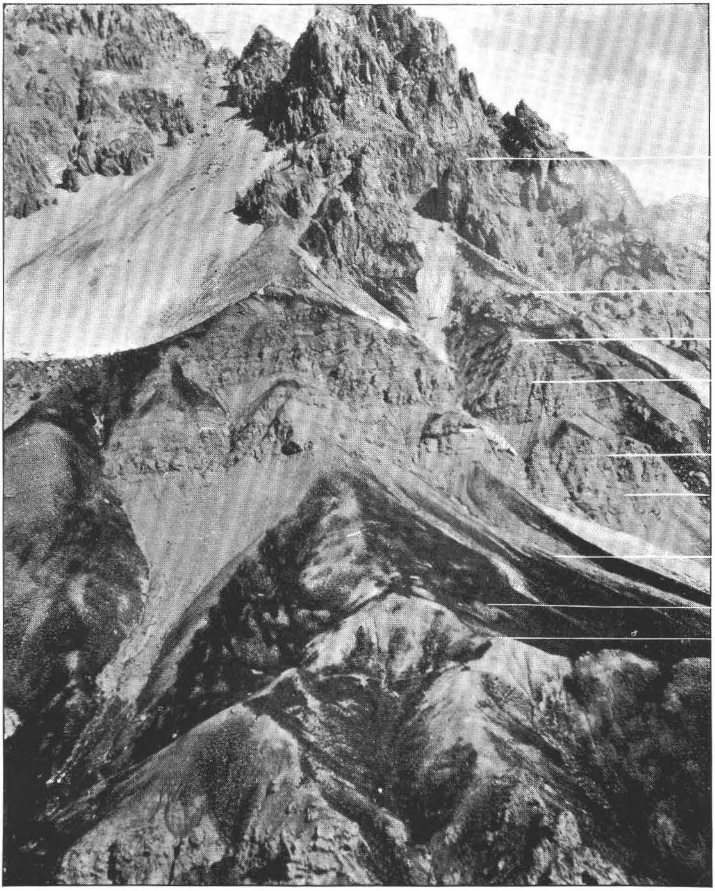
The Porphyrite Intrusions at Col Uomo.

There are several intrusions of porphyrite in the strata at Col Uomo. Two dykes close to a spring on the east slope of Col Uomo run north and south across the strata, and are finely polished and slickensided. The chief intrusions occur at the westward continuation of the inclined shear-plane. At Col Uomo, there is no doubt that the shear-plane passes entirely through Werfen strata. Below the shear-plane the strata have 15° dip to N.N.W.; above the shear-plane, they dip 50° to N.N.E. The dyke and sill system ramifies in the dip-planes of the underlay inclined to N.N.W., which are true bedding-planes, and also in superinduced planes of dip-cleavage penetrating the same rocks, but inclined steeply to the south-east.

The red marls show contact alteration to the characteristic

[1] The Chergore exposure of this new fossiliferous horizon is extremely favourable for fossil-collecting. When I visited it, a severe thunderstorm came on, and I only spent a couple of hours collecting, but several of the specimens were undoubtedly unknown forms.

Punta di Fuchiade.



Marmolata Limestone.

Buchenstein Limestone.

Mendola Dolomite.

Creamy dolomite and red crinoid-limestone (Passage-beds).

"Myophoria ovata" flaggy limestone.

"Naticella costata" marly limestone and marls.

Purple, flecked oolite.

Micaceous marls.

Marly limestone with "Holopella gracilior."

The Passage-Beds at Chergore.

"hornstone" of the neighbourhood. The porphyrite contains both plagioclase and augite crystals, and there are well-marked segregation bands of richly plagioclastic, and richly augitic rock at some of the contact zones. Continuous with these dykes are several that ascend the mountain in vertical cleavage fissures directed N.N.E.-S.S.W. and N.N.W.-S.S.E., and some of these ramifications become continuous with the porphyrite sill in the Buchenstein limestone horizon. This sill is much branched at the Punta del Uomo; a lower branch has been intruded in the middle of the Mendola rock, and the thick sill occurs fully 80 mètres higher. The Mendola rock is a dolomitic limestone. The superinduced planes of dip-cleavage inclined south-east are very well developed in the calcareous rocks between the two intrusive sills branches, but are not occupied by intrusive rock.

The inclined shear-plane at Col Uomo has been thrown down on the east or Chergore side of a N.N.W.-S.S.E. fault, which branches from the N.N.E.-S.S.W. fault that divides the Forca Alpe fault-block from the Cirelle Pass fault-block. The continuation of the N.N.E.-S.S.W. fault southward cuts off the Col Uomo block from the Campagnazza fault-block on the west of it.

The Campagnazza Fault-block.

(Section, pl. xvii., fig. 2.)

Plate xvii. shows a section through the Campagnazza meadowland, and the Costabella part of the limestone range. The Permian and Werfen rocks of the lower fault-block (which I shall for convenience term the Campagnazza fault-block) lie almost undisturbed, with W.N.W. strike, and 10° to 15° dip N.N.E. The Upper Werfen and calcareo-dolomitic strata of the higher fault-block (which I shall term the Uomo fault-block) have a more variable strike and dip, but form the continuation westward of the steep-dipping Upper Werfen series, exposed in the thrust-mass of Col Uomo and Chergore.

The sill and dyke intercalations in the shear-zone are continuous with the Costabella intercalations. Connecting dykes occupy vertical cleavage-fissures directed N.N.E. to S.S.W. and N.N.W.-S.S.E. In several cases these Judicarian cleavage-fissures have been planes of differential movements; slight local displacements and shearing effects are apparent. The Permian strata are well exposed in a stream cutting due north of the Pellegrino Valley Pilgrimage Chapel, beginning about the 1900-mètre contour. They strike N.W.-S.E. and dip 20° N.E. The horizon of Gröden sandstone is here represented by a series of unfossiliferous quartzites and quartziferous grits. I examined the succession in detail, but it may be described in general terms as a succession of brightly-coloured, mostly coarse-grained grey, grey-white, green-specked, or streaky reddish and orange grits and quartzites—the individual beds varying in thickness from a centimètre to half a mètre. Bands of nodular quartz frequently occur in the lower horizons. The total thickness of the quartziferous grits is not more than 50 mètres. They are succeeded by 20 mètres of grey and creamy porous rauhwackes, and these by about 5 mètres hard blue-black bituminous limestones with small indeterminate fossils; these are succeeded by 4 mètres of rauhwacke and fine sandstone, and then follow the typical marls and marly limestones and the lower Werfen series.

The creamy rauchwackes of the Upper Permian horizons are interbedded with the more typical bituminous facies of Bellerophon kalk; they have a very wide outcrop on the hill of San Pellegrino, and as they strongly resemble the crystalline-granular dolomite in Upper Werfen Passage-Beds it is very difficult to distinguish whether it is the one horizon or the other that is present in the Chergore section immediately east of the San Pellegrino hill (*cf.* p. 113).

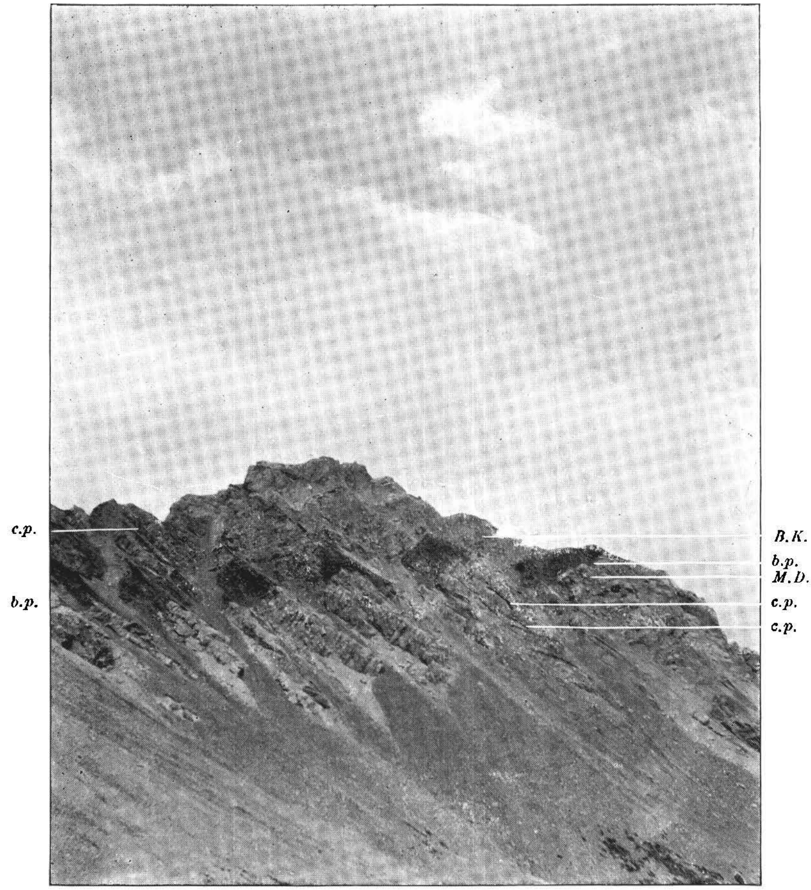
The Lower Permian quartzites here rest not upon the characteristic Quartz Porphyry, but upon the red facies in which comparatively little Quartz is present, and both plagioclase and orthoclase are porphyritically scattered. I made no attempt to follow this porphyrite, my object being only to obtain the leading structural features of the Werfen strata in the Campagnazza.

The Costabella Fault-block.

While the fault-system of sills and dykes of the Campagnazza meadows has, so far as I am aware, hitherto escaped notice, the intrusive system in the limestone of the Camorzao and Costabella range is well known. Mojsisovics has given an excellent photograph of Camorzao, the part of the range west of Punta di Costabella, and has described and figured the ascent of the dykes into fissures inclined to the south-east, naming these fissures "Gangspalten," to distinguish them from the bedding dip-planes inclined north.[1] I examined the "dyke fissures" both at Camorzao and Costabella, and found their mode of occurrence quite similar to that of the dyke-system in the Werfen strata of the Uomo ridge.

The accompanying photograph (pl. viii.) shows the main sill of the Costabella range resting upon a bedding-plane in the Mendola dolomitic limestone.

[1] *V.* Mojsisovics, "Die Dolomit Riffe von Süd Tyrol u. Venetien" (Wien, 1879, p. 370).



The Main Costabella Sill.

The sill occupies bedding-planes (*b.p.*) dipping north, but threads ramify in the "Judicarian" cleavage-planes (*c.p.*) inclined south-east. *M.D.* altered contact zone of "Mendola-Dolomite"; *B.K.* altered contact zone of green, banded, schistose rock "Buchenstein" horizon.

Dyke threads from this sill enter the Judicarian cross-faults and the planes of cleavage inclined south-east. By following almost any of the cross-dykes, the observer can establish the continuity of the Costabella sill with the Campagnazza sill and dyke system. Hence the whole system can be dated with accuracy as having been injected *after* Judicarian cross-ruptures in N.N.E.-S.S.W. direction had taken place.

The sketch (fig. 20) shows that as a result of the intrusion of rock-magma into a bedding-plane inclined north, and a dip-cleavage plane inclined south-east, the Mendola limestone fits wedge-like into a curved shell of porphyrite rock, concave towards the south. From this sketch it will be clear that a simultaneous system of intrusions at different horizons in the crust, and passing into intercrossing systems of planes, may thoroughly riddle and break up a mass of strata, rendering it partially or wholly agglomeratic, reconstituting it as a schist, or largely absorbing and replacing it under given conditions of heat and pressure. I have given examples of all these stages in the foregoing pages; and have shown the essential structural feature to be that of intercrossing planes of fissure due to superposed strike-systems.

On the east side of the crescent-shaped mountain hollow below the Punta di Costabella, the fissures which strike N. 45° to 50° E., and dip at an angle of 30° to the south-east, are developed as regularly in the rock as any series of dip-planes (*cf.* photo, pl. ix.); in fact, they almost conceal here the original bedding-planes that dip to the north. Only a few of these northward fissures are occupied by the dykes, and the dykes, in many cases, enter them for quite short distances. The dykes ascend in vertical planes of strike-cleavage parallel with the north-east strike, and send "V"-shaped ramifications into the oppositely directed inclined-planes. Such a regular system of north-east strike and south-east dip is not sufficiently explained by regarding them merely as "dyke-fissures." They lack none of the essential features of an independent system of strike and dip-cleavage in the rocks, and represent a later shear-cleavage system, superposed upon the older strike and dip-system of the Costabella range, during the period of intense action of the Judicarian cross-pressures. This dyke-and-sill system has been injected immediately east of the N.E.-S.W. fault with downthrow on the west which, crossing Costabella here, continues through Col Ombert. There it separates the downthrown limestone on its west from that part of the Forca Alpe thrust-mass which was gently driven from S.E. to N.W. above the limestone.

I examined a typical dyke, about 3 mètres thick, for evidences of contact alteration. The limestone rocks at the contact are altered to a creamy, veined marble, and the porphyrite is itself veined with calcite. Decomposition products and secondary minerals are well developed in fine clefts. In the unaltered Marmolata limestone I found a few remains of coral stems, but in far greater abundance, the spheroidal masses which have been regarded in palæontological literature as Evinospongia.[1]

The Costabella Fault-Sill.

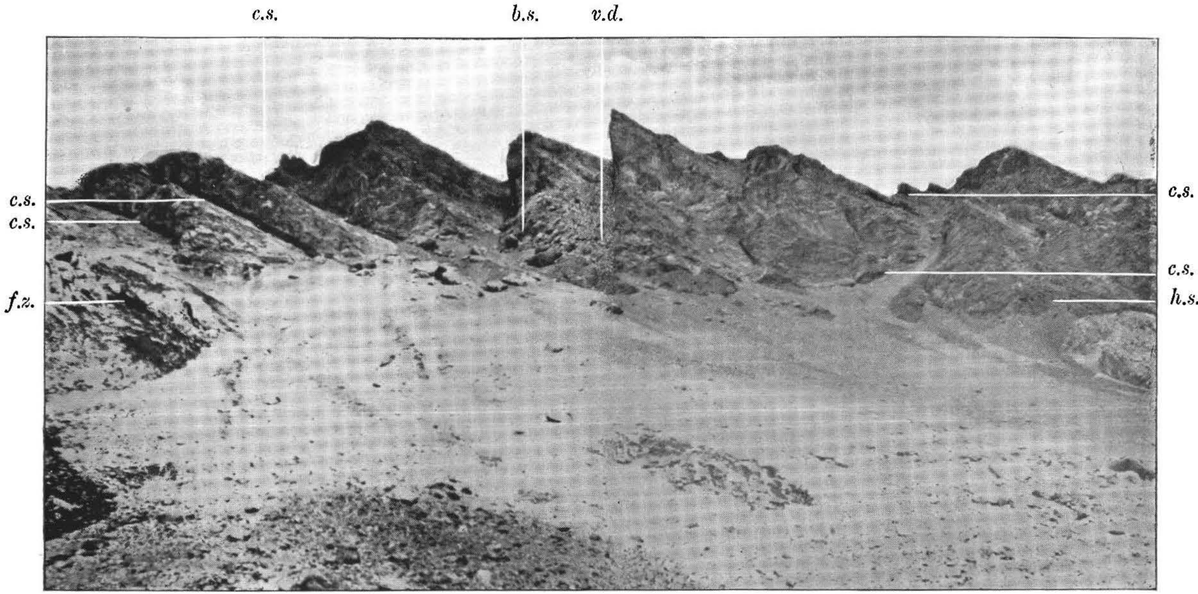
A massive intrusion of porphyrite ascends from the sill of the mountain-hollow, well up towards the "Punta di Costabella" summit, having a thickness here of 80 mètres (*cf.* photo, pl. x.).

Microscopically examined, the rock shows large phenocrysts of plagioclase and augite, but the phenocrysts are almost all replaced by calcite and serpentine. The joint-fissures are often lined with iron oxides. There are many veins of heulandite and the amygdales are stilbite and other zeolites, calcite, quartz, &c. The weathered blocks are reddish or greenish in colour, and show ferruginous decomposition products. A specimen of weathered rock, that looks in the hand a red rock with green crystals, shows microscopically "phenocrysts of plagioclase, and serpentinous replacements of some ferromagnesian, with much calcite and other decomposition products." Olivine can occasionally be detected in fresh specimens.

This is the typical rock of the Costabella and Campagnazza, its texture varies, being either coarser or finer grained; its resemblance to the dark types of porphyrite or olivine-bearing "melaphyres" with large amygdaloids in the Fassa Valley, will be seen on comparison with p. 55.

The limestone *below* the sill is conglomeratic for a thickness of 1½ to 2 feet, then it is altered for a couple of feet into a white rock, very like the "Predazzite" near Selle Lago, and below that has the rough, irregular surface and siliceous concretions usually regarded as characteristic of the Buchenstein horizon. *Above* the sill, the limestone is also lumpy and concretionary, and is then succeeded by 30 mètres of highly fissile calcareous flagstones, finely intercalated with the greenish threads of igneous or contact rock, familiar in the district as "Pietra Verte." The igneous threads run irregularly through all the fine cleavage-planes in the schistose rock, and here and there surround and isolate masses of the strata (fig. 20).

[1] Evinospongia Remains,—*conf.* Salomon "Entstehung der Lommeli-Kalke und Dolomite" (Palæontographica, 1895, p. 24). My specimens were examined by Dr. Hinde, F.R.S.



Cleavage-Sills East of the Costabella Cross-Fault.

f.z. disturbed rock next the fault; *c.s.* sills in "Judicarian" cleavage-planes inclined S.E.; *b.s.* sills in north-dipping bedding-planes; *v.d.* vertical dyke; *h.s.* horizontal sill curving with wide "V" form from the cleavage-sills to the main Costabella sill in north-dipping bedding-planes.

Punta di Costabella.

Fault-Sill occupying a Wengen-Cassian Crush-zone between the "Mendola-Buchenstein" and "Marmolata-Limestone" horizons; *b.p.* = bedding planes.

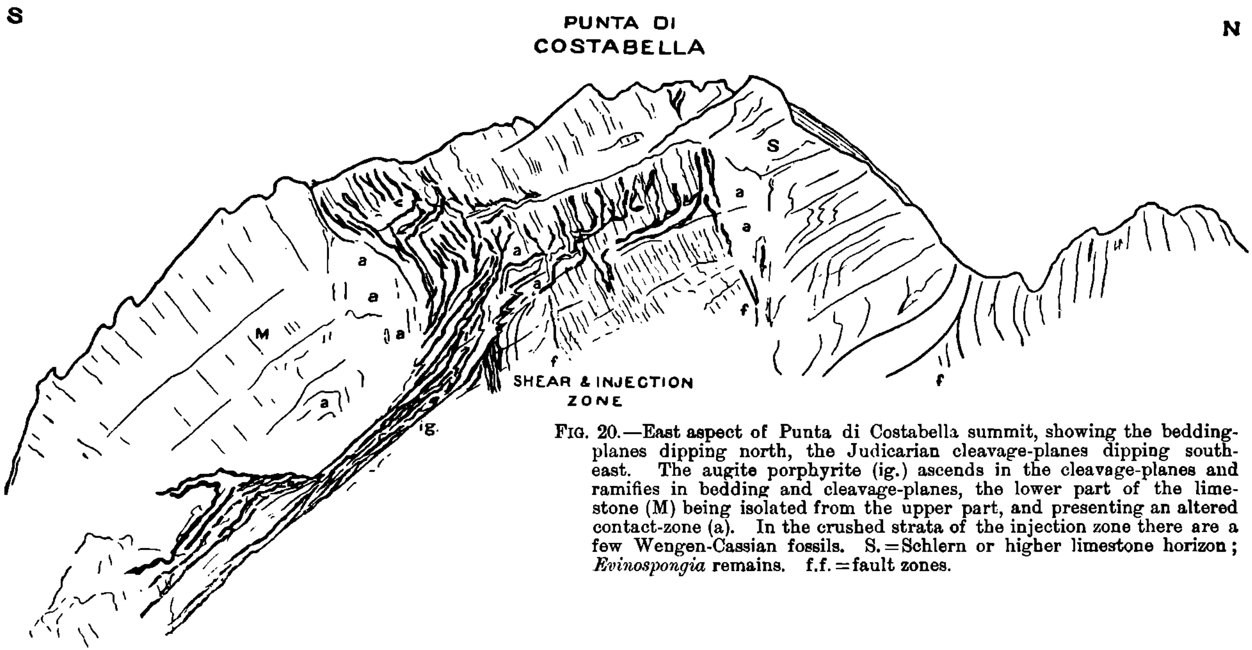


FIG. 20.—East aspect of Punta di Costabella summit, showing the bedding-planes dipping north, the Judicarian cleavage-planes dipping south-east. The augite porphyrite (ig.) ascends in the cleavage-planes and ramifies in bedding and cleavage-planes, the lower part of the limestone (M) being isolated from the upper part, and presenting an altered contact-zone (a). In the crushed strata of the injection zone there are a few Wengen-Cassian fossils. S. = Schlern or higher limestone horizon; *Evinospongia* remains. f.f. = fault zones.

Above the band of schistose calcareous rock and "Pietra Verte" there is a series of thin-bedded limestone, about 50 mètres thick. The weathered fragments of this series show remains of Cidaris dorsata, Posidonomya Wengensis, and several other Wengen-Cassian species. Therefore, the augite porphyrite sill and "Pietra Verte" intercalations *are intrusive in the Wengen-Cassian series.* It has been usual to treat the "Pietra Verte" of the district as contemporaneous tuffs in the Buchenstein or Wengen horizon; but this interpretation is quite impossible at Punta di Costabella.

After careful examination I concluded that the varying grades of brecciation, schistosity, and serpentinous alteration displayed in the Wengen-Cassian strata, and giving them a "rotten" appearance were not wholly due to the contact effects with the igneous material, but that the injections had taken place in association with differential movements causing relative downthrow on the north of the fault-sill. The original strike of the strata in the shear-zone is N. 75° W., the dip is 35° N.N.E., the Judicarian cross-cleavage dip-planes to S.E. are strongly developed, and also vertical cleavage planes in N.N.W. and N.N.E. strike directions. The "Pietra Verte" intercalations ascend *all* these cleavages.

Descending the scree west of the Punta, I observed a dyke of almost black compact porphyrite with several lateral offshoots intruded through the coarser-grained augite porphyrite of the sill, and in the limestones above and below the sill. This dyke represents a later injection into the main sill-and-dyke system of Costabella. The fine ramifications from this dyke in the limestone are green, or greenish white; in fact, they so strongly resemble in colour, texture and mode of distribution the "Pietra Verte" intercalations above, that I thought it possible these might have been derived from similar fine-grained, highly pyritiferous dykes (*cf.*, the hornblendic and pyritiferous dykes of Selle Plateau and Passo, p. 137).

The Costabella fault-sill branches as it continues westward, but has the same essential features of distribution into two sets of inclined planes striking N. 75°-80° W., and N. 45°-55° E., and into the vertical cleavage-planes. The Costabella shear-plane is the westward continuation of the inclined shear-plane between the Punta di Fuchiade, and the Cima di Cadin and Cigole, with downthrow on the north (Ref. Map). The fault-zone on the north of the Punta di Costabella peak runs at this part W.S.W.-E.N.E., but continues westward to Camorzao. It passes through Marmolata Limestone, and therefore it is impossible to tell from direct evidence whether it is one of downslip to the north or overthrust. The calcareous rocks are

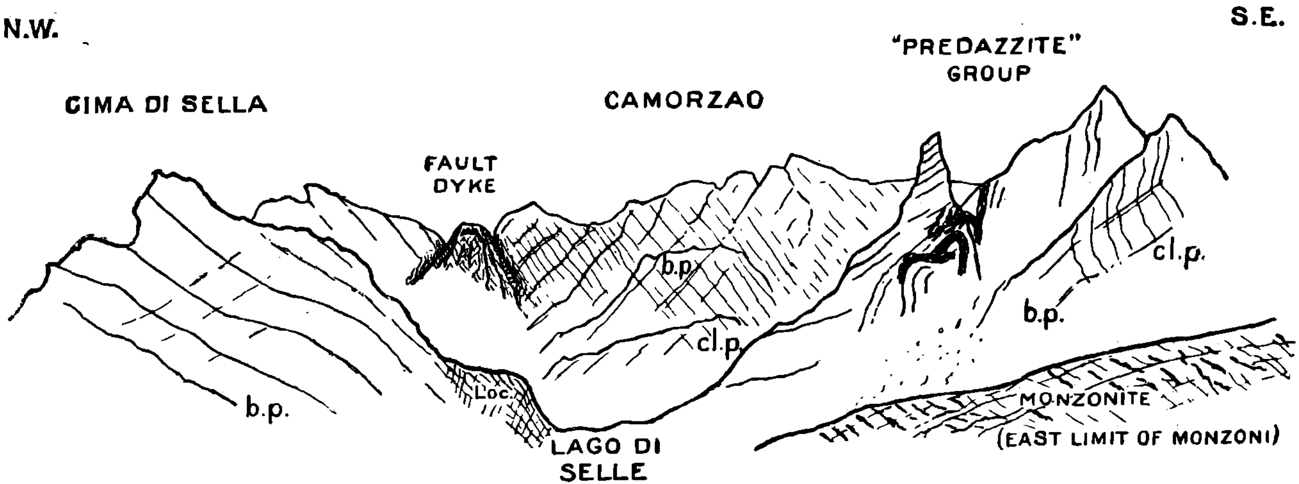


FIG. 21.—General view eastward from Lago di Selle to Camorzao to show the position of the Camorzao-Selle fault-dyke, and of the famous locality (Loc) for contact minerals at Lago di Selle. b.p. = Bedding-planes. cl.p. = Cleavage-planes.

strongly sheared in the proximity of the Costabella cross-fault that separates the Costabella from the Uomo part of the range. As the western part is downthrown, I am inclined to regard the fault-zone north of Punta di Costabella as the displaced continuation of the reverse fault, limiting Cirelle and Forca Alpe on the south.

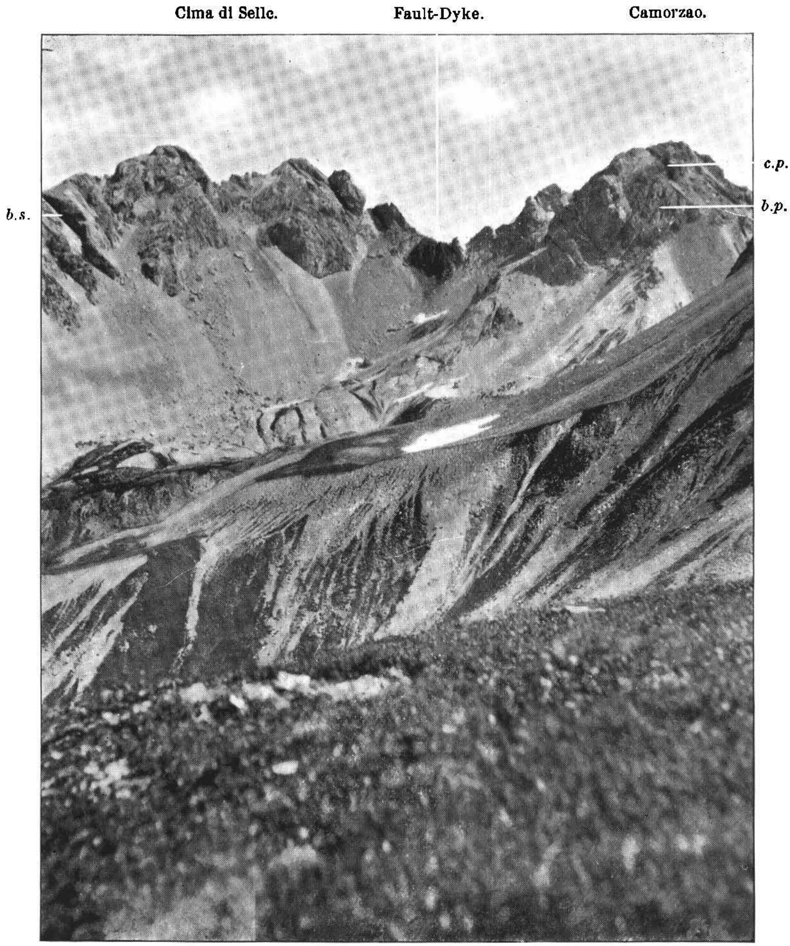
The Camorzao Fault.

The Camorzao mountain at the western extremity of the Costabella range, as seen from Lago di Selle, shuts in the view towards the east. To a geologist the most noticeable feature is the presence of a thick dyke known in the literature as a "Melaphyre" dyke in the notch between Camorzao and the Cima di Selle limestone mass to the north (photo, pl. xi.). This has long been recognised as a fault-dyke, but I submit a few tectonic details. The mineralogical description of this dyke-rock is given below. The fault in which it occurs is the continuation of the fault on the north of Punta di Costabella, *i.e.*, of the Forca Alpe fault. The presence of numerous larger and smaller sills and dykes all along this fault has already been made clear. And it will be remembered that in the Forca Alpe thrust-mass, the fine ramifications of igneous rock in the calcareous rocks have the greenish close-grained and often serpentinous appearance of "Pietra Verte," the same as the ramifications of the sill-and-dyke system at Punta di Costabella, and as those at Selle Plateau (*cf.* pp. 100, 118, 137).

The dyke is really a group of dykes comprising compact augitic and plagioclastic porphyrite, amygdaloidal porphyrite, and "agglomerate." The agglomerate is quite clearly a shear-and-contact fault breccia. The thicker dykes are continuous with sheared and serpentinised ramifications in the limestone strata of the Camorzao mountain. The limestone of Camorzao has been crumpled, slabbed, sheared and brecciated, and slickensides have been developed in the system of cleavage planes inclined south-east. The sills and dykes enter the bedding-planes with dip N.N.E., and the Judicarian planes of dip-cleavage inclined towards the south-east (fig. 21), and have endured along with the limestone the effects of crush from S.E. to N.W. direction.

On the Cima di Selle side of the fault-dyke, an old shear-plane is exposed passing through the limestone rocks. The limestone roof of the shear-plane is slickensided, polished, and rounded, the underlay of the shear-plane shows a broader shear-zone of strongly crumpled and broken rock (fig. 22).

The dykes of this Camorzao fault are part of the general system of Judicarian intrusions which have ascended the inter-



The Camorzao Fault-Dyke.

"X" and "V" shaped intersection of bedding-planes (*b.p.*) and cleavage-planes (*c.p.*) in Camorzao ; *b.s.* sills in the bedding-planes of Cima di Selle.

crossing planes of original and superinduced dip-cleavage in Camorzao and Costabella. The pressure-surfaces of the porphyrite in contact with the limestones are always serpentinous, and the limestone contact zone shows the typical contact and shear-breccia which I have throughout my papers treated as essentially a fault-injection breccia. As there can be no doubt that the tuffoid and brecciose rocks are here present in a fault-plane at a high horizon of the upper limestone series, it is impossible to claim them as a definite "Buchenstein" formation of Mid-Triassic "sedimentary tuffs" above the Mendola horizon. They are *pseudo-tuffs*, the products of differential shearing between the limestone and the basic magma.

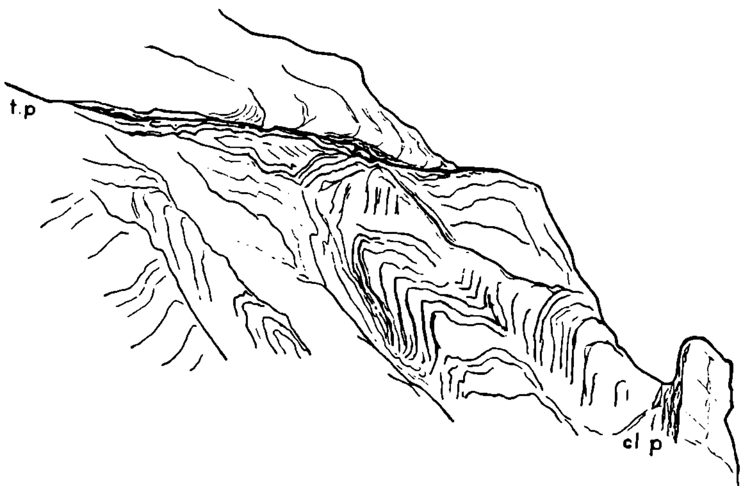


FIG. 22.—Crush-zone in the limestone below the thrust-plane (t.p.) of Cima di Selle; sketch taken on the east slope, on the other side of the fault-dyke. The thrust-plane strikes N. 55° W., dips N.N.E. but is bent, the cleavage planes in the limestone strike north-east and dip south-east.

The so-called "Melaphyre" dyke-rock shows flow-structure; a typical specimen shows under the microscope

"abundant plagioclase phenocrysts, and pseudomorphs after a ferro-magnesian consisting mostly of Calcite and Serpentine. The ground-mass shows a mixture of Plagioclase microliths with abundant needles of a greenish mineral which, from its colour, average high extinction angle, absence of pleochroism and double refraction is evidently an Augite; there is much Magnetite, and the whole ground-mass is stained with Haematite (?) and a greenish chlorite material."

From my observations in the field, I would take the fluxion-structure to be essentially a shear-structure assumed before complete consolidation in virtue of the differential pressures in the fault-zone. The seams of serpentinized contact material can be directly traced to such dykes, and may be regarded as porphyritic and calcareous contact-rock. The close mineralogical resemblance of these Melaphyre, or generally *basic* types with the *later* intercalations at Canazei and other parts of Fassa is at once apparent (*cf.* p. 82).

Summary.

The parallel north-south sections (pl. xvi., xvii.) display the essential continuity of the porphyritic dyke and sill system in the Campagnazza, Uomo, and Costabella fault-blocks. They also demonstrate the presence of three main shear-zones inclined northward. The Punta di Costabella, Uomo, and Chergore series of strata are dislocated portions of an old thrust-mass that had been driven southward over the Campagnazza group of strata; another old thrust-plane runs through the calcareous rocks of the Cirelle, Forca, and Costabella ranges. The sills of porphyrite have been chiefly injected in the zone of downslip south of the Punta di Costabella summit, in the Judicarian planes of dip-cleavage to the south-east and in the N.N.E.-S.S.W. and N.N.W.-S.S.E. faults that have dislocated the older thrust-masses. The differential movements throughout the mass of strata have left stronger or feebler traces on all cleavage-planes, upon the vertical strike cleavages as well as the inclined dip-cleavages.

The whole mass has been rendered schistose. It possesses schistosity primarily in virtue of the crust-pressures. At the same time, the igneous intercalations are so numerous that the presence of partially consolidated magma throughout epochs of pressure must have been an additional factor in inducing fissility and metamorphism of the rocks. The contact zones of alteration are clearly traceable in each case, and exhibit extreme secondary alteration of minerals. The intrusive rocks have themselves been locally rendered fissile, have been locally slickensided, polished, and squeezed to a porphyritic schist. This condition shows that the movements of cross-shearing and deformation continued throughout long geological periods after the leading Judicarian fault-planes and dip-cleavage had been developed. The porphyritic magma at the first ascended into previously-established bedding-planes and the superinduced cleavage-planes, and while it consolidated under the superincumbent pressures from the overlying rock-masses was all the time undergoing intense pressure on account of the strains of crust deformation. As younger injections can be traced in the midst of older sills and dykes, it is clear that the intercalations of igneous material occurred intermittently. The maximum degree of schistosity and alteration of the sedimentary rocks is met with at fault and contact-planes, and at slickensided cleavage-planes which practically represent minor fault-planes, and may be directly traced to intense torsional strains during the superposition of the Judicarian cleavage systems upon the already crushed and folded strata composing the thrust-masses.

PART V.

Passo le Selle and Allochet.

General Structure—Allochet Ridge—The Curved Strike of Outcrops—Punta d'Allochet—The Judicarian Shear-Zone east of Monzoni—The Predazzite Rocks—Domal and "Laccolithic" Sills on Selle Lago Plateau—The "Wernerite" Locality—Lago di Selle.

General Structure.

(Section, pl. xvi., fig. 2.)

The whole ridge-line of Allochet is over 2500 mètres in height; the highest peak is 2594 mètres high and is near the Passo; the summit called Punta d'Allochet is nearer Monzoni. The path from Lago di Selle to the Campagnazza crosses the ridge at a depression between the Punta d'Allochet and Camorzao Mountain known as Passo le Selle. The limestone plateau which descends from the Passo to the Selle Lake will be referred to below as the Selle Plateau.

The general geological structure in the Allochet area may be first stated in brief outline, by comparison with the structure of the Campagnazza area.

The Werfen strata of Allochet ridge (see photo, pl. xii.), are the continuation of those in the Uomo fault-block. The strike of the strata which is W.N.W.-E.S.E. at Col Uomo is in Allochet E.N.E.-W.S.W. The strata composing the Uomo thrust-mass therefore follow a strike-curve round the north parallel with the strike-curve of the Campagnazza strata.

The altered limestone associated with the Costabella sill also curves towards the south-west, and is represented by the still more altered "Predazzite" rocks between the Werfen strata of Allochet and the Lago di Selle. The downslip fault which at Punta di Costabella is occupied by the Costabella sill, is at Selle Plateau also occupied by porphyritic sills, and continues westward as the limiting fault between the Werfen strata of Allochet and the calcareous rocks of the "Predazzite" group.

The tectonic position of the Monzonite rocks is accordingly in an area of inthrow subsequently determined within an old thrust-mass whose original strike was that of the Uomo rocks—viz., W.N.W.-E.S.E. but which has been distorted. The sedimentary rocks have been wrenched towards the N.N.E.-S.S.W. superinduced Judicarian strike and the igneous rocks have ascended in consequence of the torsional strains within the crust, and the development of wrench-fractures.

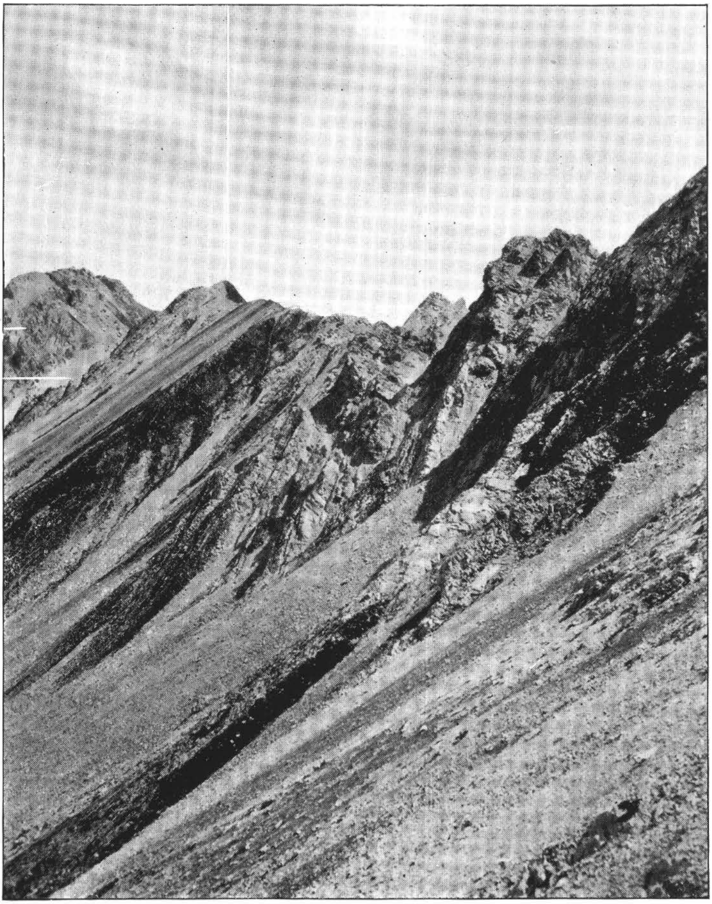
The Cima di Selle is the direct continuation of the northern half of the Costabella range and formed part of the overthrust-mass already described at Forca Alpe. But in the neighbourhood of the monzonite intrusion subsidences have afterwards taken place along the contact zone, with downthrow on the north.

The essential features in unravelling the tectonic structure of this area are—(1) to keep clearly in view the presence of the Punta di Costabella downthrown fault-block between the Uomo-Allochet thrust-mass and the Forca Alpe—Cima di Selle thrust-mass; (3) to allow for the crust-torsion that has taken place in consequence of the Judicarian cross-compression—all the fault-blocks having now a resultant strike-curve, convex round the north.

Allochet Ridge.

Examining the ridge from Passo le Selle to the Monzoni mountain, I mapped the numerous dykes of porphyrite. The rock is rich in augite and plagioclase, and is continuous with the Costabella and Campagnazza sill and dyke system. The stratified rocks have been altered at contact zones into banded layers and concretionary hornstones. On the south slope of the ridge I found plenty of Werfen fossils and could trace the passage of the fossiliferous zones into the altered contact rock. Near the Passo, the strata have a general strike N. 75°-80 E., dip 55° N., vertical cleavage N. 10° W.; but the outcrops of the dykes are directed as follows, in the order of their occurrence—(1) N. 40° E.; (2) N. 50° E.; (3) N. 50° E. curving to N. 80° W.; (4) a dyke and sill group; (5) N. 70° W. bent to N. 85° E., dip N. 50°. There are no intrusions in the next part of the slope, between dyke "five" and the summit entered as 2594 mètres high. The strata strike N. 80° W. and dip north at an angle of 50°, but are throughout their entire mass cross-cleaved by steep planes dipping south-east.

Assuming that the W.N.W. strike is at Allochet as at Col Uomo the original strike, the E.N.E. and N.E. strike and the planes of dip-cleavage inclined to the south-east may be taken



Allochet Ridge.

The altered Werfen strata of the Passo le Selle and Allochet ridge, showing the steep northward dip.

to represent the local resultant cleavage superinduced in virtue of the Judicarian cross-strains.

The porphyrite dykes occur both in the bedding-planes dipping northward and in the superinduced Judicarian cleavage-planes that incline S.E., and they run in several cases continuously into these previously established fissures. The dykes at Passo le Selle frequently show marked fluidal structure; microscopically, a typical specimen shows "phenocrysts of plagioclase and fresh augite (?); also some serpentinous pseudomorphs after augite (?), a ground-mass of granular augite and plagioclase laths with iron ore, little or no glass." In some of the specimens olivine is indicated, but is not so common as augite.

A very dark pyritiferous rock that occurs by itself, or as finer intrusive threads in the plagioclastic rock, shows under the microscope, "large, plagioclase phenocrysts, dusky and zoned, some fresh augites, and abundant green pseudomorphs after augite; ground-mass holocrystalline, consisting of small plagioclases, augite granules, small fragments of a brown pleochroic mineral (Hornblende?), abundance of iron pyrites, and some magnetite." This specimen may be compared with the Camorzao and Sella Plateau fault-dyke (p. 123).

The Curved Strike of Outcrops.

The most instructive part of the ridge follows between this summit and the somewhat lower point called Punta d'Allochet. The latter has often been mentioned in geological literature, on account of a dyke of gabbro porphyrite. The strata immediately beyond the summit 2594-mètre strike N. 80° E., dip 55° N., and are crossed obliquely by dykes directed N. 70° W. These may be traced a little distance down the north slope, where they are seen to occupy Judicarian cleavage-planes. Evidences of differential movement *at all planes* throughout the mass of strata are very convincing. Schistose structure associated with serpentinization, rippling and slickensiding are very strongly developed in the vicinity of series of N.N.W.-S.S.E. faults. In every case, displacement has been effected in the same sense, the west side of each fault being the downthrown side. The north-dipping planes of bedding have thus been displaced more and more southward, and the actual outcrop of any particular horizon follows a curve round the north.[1]

[1] The N.N.W.-S.S.E. faults (average N. 30° W.) are of the nature of "Sprünge," transverse or oblique to the local torsion-strike which is E.N.E.-W.S.W., and represent wrench-fractures developed in consequence of the local counterclockwise torsion of the strata. For an explanation of the general strike-curve round the north, reference may be made to the "quarter D" in my diagram illustrating the torsion-movements at the Gröden Pass (Q. J. G. S., 1899, p. 581, fig. 8); notice that in the descriptive text, p. 580, there is a misprint,—the text should read, "A and C to be moved *clockwise*, B and D *counterclockwise*."

Strictly speaking, the curve is made up of a series of zig-zags, but in the field, the general effect is a curved outcrop (*cf.* fig. 8, as an example of this principle).

Take, for example, the brightly-coloured series of creamy pink, brick-red, and violet marls and limestones which succeed the Naticella costata strata, and form the passage-beds to the Mendola horizon. In accordance with the steep dip to the N.N.W., these are exposed at the base of the Passo portion of the ridge, but curve south-westward, crossing the ridge immediately west of the main N.N.W.-S.S.E. cross-fault. I have indicated their outcrop by a dotted line in my map. The strata have been thinly cleaved by vertical planes parallel with the N.N.W.-S.S.E. faults, and the entire mass rendered

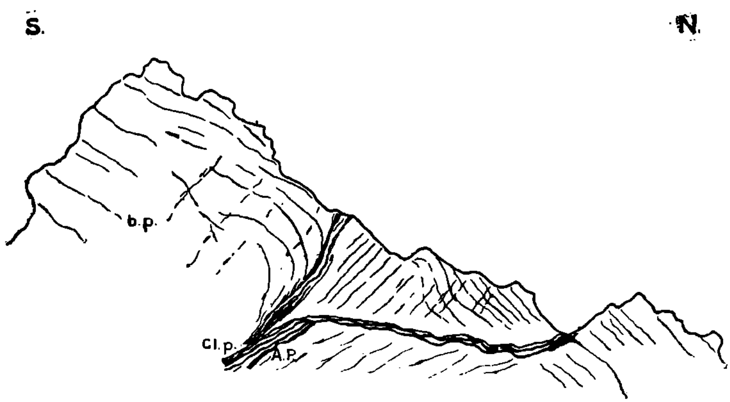


FIG. 23.—Dyke-fissures in the ridge between Passo le Selle and Punta d'Allochet. b.p. = Bedding-planes, dip north. cl.p. = Judicarian cleavage-planes inclined south-east. A.P. = Ascent of porphyrite in a cleavage plane with slickensided surfaces, and an almost horizontal fissure.

schistose. The alteration of the Werfen strata at contact zones, and their conversion into banded hornstones, varies very much at different parts of the ridge; the presence of the igneous intrusions in planes belonging to a regular cleavage system shows that the development of crush-planes preceded the effects of contact metamorphism.

Punta d'Allochet.

The part of the ridge between the N.N.W.-S.S.E. fault and the Punta is cut by two minor wrench-faults, N. 70° W. A little distance down the north slope, a Judicarian dip-plane cuts the strata obliquely through the older W.N.W.-E.S.E. strike. It has been a plane of differential shearing, and of igneous injection. In consequence of subaerial erosion, the loosened strata below the gash become more steeply tilted to the north, and tend to slip down. The accompanying sketch (fig. 23) shows a Judicarian strike-fissure, the faces of which are polished, and in some parts slickensided.

Towards the Punta, the Judicarian divisional planes strike N.N.E.-S.S.W., and are crossed by N.N.W.-S.S.E. cleavage planes inclined steeply E.N.E. Nearer Monzoni, the W.N.W.-

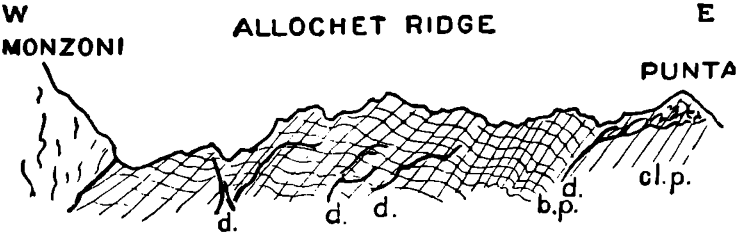


FIG. 24.—Cross-plication and cleavage of the bedding-planes (b.p.) in Upper Werfen and Mendola limestone strata next Monzoni. South aspect to show the relationship of the larger "Punta" injection of porphyritic gabbro to several smaller threads of aplitic monzonite and lamprophyre (d).

FIG. 25.—*West aspect of the* injection ; W=Werfen strata.

E.S.E. strike of the bedding-planes is still apparent, and the superinduced N.N.E. and N.N.W. cross-cleavage intersect at a smaller and smaller angle, the readings near the contact with the Monzonite being N. 15° W. and N. 5° E. At the same time, the shearing-effects are much increased in intensity, and a cross-roll *from W.N.W. and E.S.E.* has billowed the strata into a series of small wave-forms (strike N. 15° E.), *after* the development of the Judicarian planes of dip-cleavage (fig. 40).

This later compression is doubtless associated with the sagging of the peripheral zone west of Monzoni.

Fig. 25 is a sketch of the south-west aspect of the dyke of porphyritic gabbro at the Punta; it indicates the intersecting dip-planes. Fig. 26 is a sketch of the north aspect. The Punta dyke has been intruded in a N.W.-S.E. Judicarian fissure and spread eastward, partly ascending the Judicarian dip-planes, partly crossing them obliquely. Large and small fragments of the stratified rocks are contained within the dyke. The microscopic examination of my specimens shows that the rock-structure is practically schistose. Thus, while this richly augitic dyke cannot have been injected before the development of the Judicarian cleavage-system, it has subsequently endured shearing and secondary alteration.

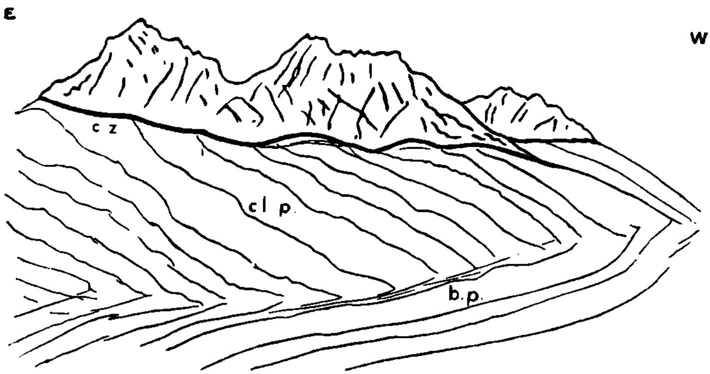


FIG. 26.—North aspect of the injection of orthoclase gabbro (porphyritic) at the Punta d'Allochet in Upper Werfen strata: c.z. contact plane; cl.p. cleavage-planes str. N. 15°-20° E., dip. 45° west to Monzoni; b.p. bedding-planes, dip north. Probable age of this injection—contemporaneous with the cross-movement from east to west in Monzoni, being an injection into the inthrow of strata *behind* the resistant monzonite.

Werfen strata continue for about 200 mètres west of the Punta, and several fine sills of porphyrite are present. A wedge of limestone intervenes between the Werfen rocks and the monzonite mountain. Fragments of limestone occur in the narrow fault-zone which forms the western limit of Allochet ridge. The main outcrop of limestone is in the group of summits near the Lago, which have been quarried for the sake of the altered rock termed "Predazzite."

In addition to a dark, fine-grained peridotite dyke, there are three small occurrences of monzonite aplite threads in the limestone between Punta d'Allochet and Monzoni, in each case striation of the limestone and the local development of contact minerals is associated with the occurrence of the intrusive threads. Locally, the rock looks like a mixture of two rocks, an aplitic and a lamprophyric type; it effervesces in places; augite, hornblende, and occasionally nepheline, occur in some specimens. An aplitic form shows "a holocrystalline mixture of orthoclase, plagioclase, quartz, and much brown mica, with iron ore. The arrangement of the mica is markedly linear and it shows strongly-marked crush effects." The original intrusion has clearly been very much altered by the pressure-effects in the vicinity of the N.N.W.-S.S.E. fault-limit of Monzoni.

The Allochet ridge has hitherto been treated in a general way as an inthrow in the proximity of Monzoni associated with shrinkage of the igneous mass and sagging of the strata around. While this is quite true, it is clear from the above details that the Allochet ridge displays all the structural features which are exhibited in other areas, remote from Monzoni. The schistosity of many of the dykes as well as the differential shearing along N.N.W.-S.S.E. vertical planes shows that strains were experienced parallel with this direction *subsequently* to the chief Judicarian epoch of folding and faulting in the N.N.E.-S.S.W. direction and the associated directions of the resultant N.E. and E.N.E. strikes. Further evidence of later crush effects is the set of small crust-waves or folds directed almost north-south, into which both the bedding-planes and the Judicarian cleavage-planes have been thrown at Punta d'Allochet. Such later transverse folds and cleavage with localised characters have been pointed out in numerous other places—*e.g.*, Col Laz, Forca Alpe, and indicate compression transversely to the earlier established torsion strikes.

The Judicarian Shear-Zone east of Monzoni.

The fault-zone limiting Monzoni on the east has a zig-zag course as shown in my geological map, the limestone is characterised by the occurrence of many dykes of aplite, diorite-gabbro or gabbro, and pyroxenite, in the immediate vicinity of the fault-zone, and these have all undergone a high degree of metamorphic change. On the south slope of Allochet Ridge a group of such injections occurs in the contact fault, and at the horizon between the Mendola limestone and the Werfen strata, occupying, therefore, planes of easy fission between different kinds of rock. The dykes send threads obliquely eastward into the midst of the Werfen strata. These have been examined by Dr Weber (*l.c.* pp. 43-45), they embrace a granite aplite, 5 or 6 mètres thick, associated with an altered fault and contact monzonite breccia and small threads of basic, hornblendic monzonite, rich in magnetic iron. Fine serpentinous threads ramify from the latter into both the bedding and cleavage-planes in the limestone, and slickensides are developed in the inclined and vertical cleavages; contact minerals are well developed. All the intrusions here have undergone secondary changes, associated with the intense local pressure-strains.

Dr Weber mentions a "broad apophyses 30 mètres wide, which extends for some distance towards the Campagnazza. He describes it as a "fine-grained, dark monzonite, rich in biotite . . . a piece about 2 mètres distant from the contact shows the predominance of the uralite-form of pyroxene." I followed this pyroxenite dyke and found that from an almost easterly course it curves rapidly into a north-easterly, and at the curve sends out a number of fine threads all of which curve northward round the south limit of the Allochet ridge. The Bellerophon limestone into which it passes has the very slightest dip north. A rich development of barites marks the contact of limestone and dyke, an occurrence which I believe has not been previously observed. This pyroxenite dyke occupies a north-north-east Judicarian fault between the gently-inclined Bellerophon limestone of the Campagnazza and the steeply-inclined downthrown Werfen strata of the Allochet and Passo ridge.

The continuation of the fault is occupied by porphyrite with abundant crystals of augite and plagioclase and grains of magnetite, and this fault-dyke may be traced to the sill-and-dyke network in the Campagnazza, where diagonal faults from Costabella and Passo le Selle cross the main east-west fault. Owing to occasional disappearances under grass, I could not determine any actual connection between the portions of biotitic monzonite and porphyritic character, but there is no doubt that both have been injected into the same Judicarian fault.

There is a precisely similar occurrence on the north slope of the Allochet ridge. There a porphyritic gabbro or monzonite type occurs upon a scree plateau half way down towards the Predazzite rock, and runs eastward in the shear-zone between the altered limestone and the Werfen strata. The dyke has enclosed larger and smaller fragments of the Werfen hornstones; small threads of reddish syenite (" orthoclase porphyry ") are present in it as in the neighbouring rocks of Monzoni. The pyroxene dyke extends in the N.N.E.-S.S.W. direction of the Judicarian shear-zone, crossing the strike of the bedding-planes obliquely, but sending extensions into them. In the continuation eastward of the same line of fault are dykes and sills of typical plagioclase and augite porphyrite, and these are continuous with the dyke and sill system of Costabella and the Campagnazza.

Therefore the Allochet ridge is limited north and south by typical plagioclase porphyrite fault-dykes continuous with the fault-sills and dykes throughout the Campagnazza, and in the same fault-lines as porphyritic and aplitic monzonite injections and serpentinized threads ramifying in the altered limestone. On the other hand *altered* Werfen strata are included in the porphyritic gabbro or monzonite dykes, a fact indicating that certain pressure and contact alteration effects had preceded the injection of the dykes.

Westward from the porphyritic gabbro on the north slope, the plateau leads to a curious islet of limestone in the midst of basic gabbroid rock; it resembles the fragmentary occurrences of sedimentary rocks in the Pesmeda localities. Small dykes of plagioclastic monzonite and of syenite occur in the gabbro. The N.N.W.-S.S.E. cross-fault, west of the Predazzite group is marked by the occurrence of dykes which ramify eastward through Judicarian dip-planes in the altered limestone. Some threads are dioritic or gabbroid, others porphyritic in character, but they are locally crushed and altered to serpentine. The narrow fault-zone between the limestone and the monzonite is particularly rich in contact minerals, idocrase, fassaite (monticellite), being the most plentiful, traversellite is present in many of the joints of olivine gabbro.

The Predazzite Rocks.

(Section, pl. xvi., fig. 2.)

The Predazzite rocks occur in the shear-zone east of Monzoni, and are limited on the south by the E.N.E.-W.S.W. fault which is the direct continuation westward of the Costabella fault-sill with shear-slip to the north, on the north by the E.N.E.-W.S.W. Camorzao-Selle fault. Viewed from the Lago di Selle, three summits are seen, one more northerly is divided by screes from a turret-shaped peak, and a higher, broader bastion of rock behind (fig. 21). In the turret-shaped peak the Judicarian strike N. 35° E. predominates, and the corresponding planes of dip-planes incline 60° towards the west. In the summit behind, the leading strike-cleavage is N. 45° W., the inclination of planes south-west, but the fundamental strike and dip (N. 80° W., dip 55° N.) is also apparent.

The cross-shearing within this small area has been very intense. In the narrow Col between the turret peak and in the strata composing the turret, fine injections are threaded in the Judicarian dip-planes. The main thread is a monzonite aplite, and thin, schistose and serpentinized seams of pyroxenite are banded with, and ramify into the altered limestone chiefly in the south-west dip-planes of the superinduced system. Prehnite occurs in this Col at contact zones.

Domal and "Laccolitic" Sills on Selle Lago Plateau.

The Selle Lago plateau (*cf.* p. 122) is the western continuation of the higher limestone strata at Camorzao and Punta di Costabella, and is similarly threaded by a sill and dyke system of porphyrite intrusions. The strata show the N. 80° W. strike and northward dip; and are cut up by cross-systems of shear-cleavage, here almost rectangular to one another (N. 25° E., dip 60° S.E.; N. 50° W., dip 60° to 70° S.W.).

I have entered the chief injections in the map, but such indication can only be schematic. The injections ascend the

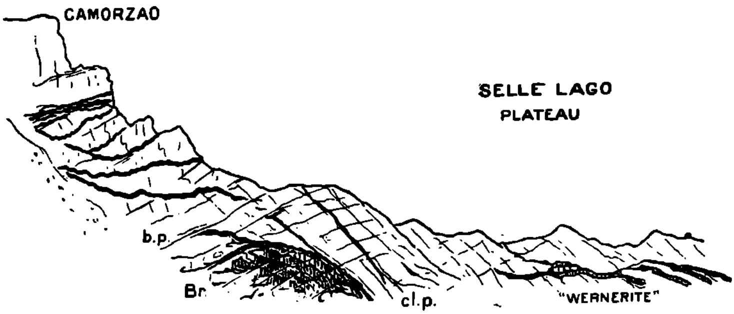


FIG. 27.—Camorzao escarpment and plateau. Intercalated system of porphyrite dykes. Contact minerals well developed, the "Wernerite" locality being rich in ores. Br. is a contact breccia of dyke and limestone, the threads of the magma have ascended both cleavage and bedding-planes, and the appearance is that of a lenticular meshwork surmounted by an "arch" of stratified rock, the *apparent* domal shape is here the result of injection along planes intersecting almost rectangularly.

vertical planes of cross-cleavage, and follow the steep dip-planes belonging to these intersecting systems, or spread obliquely across them. The rocks of the plateau have also been gently cross-rolled like those of Allochet ridge, *after* the igneous rocks had been embodied in the strata. Here, where the cross-cleavages are almost rectangular in position, the igneous intrusions have the shape of small domes or ellipsoidal "laccolites." For, if a series of joint or cleavage-planes be inclined towards one direction, and be either contemporaneously, intermittently, or subsequently cleaved at some considerable angle by a system of inclined planes dipping towards another direction; and if a thick body of irruptive material then makes its way into both systems of inclined planes, the domal form may be assumed at any number of different horizons in the crust (fig. 27). In the case of Selle plateau, the gentle cross-roll that has happened after the intrusions still farther accentuates this feature. The tendency also of connecting sill-layers to run along almost horizontal fissures from which ramifications pass upward into either bedding or cleavage-planes, is a feature very often presented in the Selle and Costabella area. The steeper the dip-planes, the more conical will be the shape of the sills in these intersecting cleavage-systems; the more gentle the dip-planes, the more "laccolitic" or ellipsoidal will be the form of intrusion.

Again, there may be every gradation in the quantity of irruptive material, whether it is only sufficient to interleave the strata, or whether it is more massive, and engulfs and alters the strata, afterwards consolidating in accordance with the pre-existing dip-planes of the roof and floor, and sharing in any subsequent cleavage. At Selle plateau many gradations are seen. The exposures in the plateau have a mode of distribution intermediate between a finely-interleaved sill and dyke system like that of Campagnazza and Costabella, and a massive cup-shaped intrusion, such as that of Monzoni, Bufaure, and Mount Donna. By careful compass measurements, I have determined one important general feature in all the intrusions of this neighbourhood—namely, *that they are jointed parallel with the inclined planes of cleavage in the strata surrounding them.*

I cannot imagine a better field for demonstrating all the characteristic shapes and forms of intrusions. From my sections and drawings, it is evident that small sills and dykes may be distributed in cleavage-fissures meeting in a V or A-shape, and intersecting in X-shaped forms, and so produce lozenge-shaped figures; in the same way, more massive intrusions may have a cup-shaped or dome-shaped, spherical, or lenticular form, according to the angles of intersections of inclined planes in the roof and floor of their sedimentary envelope. In a word, the particular shape of an intrusive mass is determined by the crust-pressures that have previously acted upon the strata into which it is injected, and the particular planes of jointing or schistosity in the mass depend upon the pre-existing planes of the envelope and upon the pressures acting during, and subsequently to, consolidation.

With regard to the contact-alteration effects in the limestone of the plateau, two stages have to be clearly distinguished. In the first instance, the tilted mass of limestone strata formed part of a mass *above* a monzonitic sill, and as such was injected with monzonitic threads or charged with vapours. In the second instance, peripheral sagging during continued crust-movement took place round the sill, introducing *local* strains, which acted simultaneously with the stresses of the grander movements. The local strains acted from different directions relatively to the stresses affecting the whole area. Hence, while still under a heavy superincumbent mass of sedimentary strata, and in contact with partially unconsolidated magma, the Triassic limestone was involved in the differential shearing around Monzoni.

The limestone strata at the shear and contact zone are full of slickensided and serpentinised shear-cleavage planes, and the famous contact minerals of Lago di Selle are chiefly found in those planes (see fig. 28).

During the prolonged period of conflicting crust-strains, while internal deformation of the rock took place and new cleavage developed, dykes were injected from the original magma, but all such subsequent injections in the selvage zone appeared to have been more basic or more acid than the first consolidated monzonite. So far as my researches go they lead me to regard the plagioclastic and augitic porphyrite dykes in this area of Selle Passo and Selle Plateau as injections at an advanced stage in the whole history, as dykes injected *after* subsidence round the Monzonite mass had made considerable progress. My chief reason is that they occur in *all* the cleavage-systems, and in the curved faults at which the local subsidences have taken place.

The "Wernerite" Locality.

So many geologists and mineralogists have visited the Selle Lago plateau that little remains to be said respecting the various localities in which contact minerals are found. A porphyrite dyke immediately below the "Wernerite" locality (height 2325 mètres) is noteworthy for the very distinct streaks in it; bands full of plagioclase crystals alternate with bands full of augite crystals. Examining the relations more closely, I observed—(1) with respect to the alternating bands, that each displays fine segregation streaks of coarser-grained and more close-grained texture; (2) when a specimen including parts from the adjacent bands was hammered, it broke easily along all the selvages; (3) irregular veins of the plagioclastic porphyrite from 3-7 cm. thick occur next the limestone, and branch in the adjacent part of the dyke. The alternate bands are parallel with the N. 80° W. strike, and probably represent original schistose segregation. Another thin sill of plagioclastic and augitic porphyrite, with large crystals of augite and plagioclase, occurs parallel with the W.N.W.-E.S.E. strike, about fifteen paces to the north; beside it is a close-grained augite porphyrite with greenish, weathered surface, and full of calcitic amygdales and veins. The limestone associated with it is rendered crystalline; iron and copper ore, garnet and Wernerite occur in the contact zone, which is about 50 cm. thick.

This highly segregated group of dykes may be traced eastward through a ridge that leads towards the summit of Camorzao. The close-grained dyke continues N.N.E. in the direction of the fault between Camorzao and Cima di Selle.

Comparatively few dykes or sills are to be observed in the Cima di Selle Massive north of the plateau. Two that I examined in the cliffs above the Lago are fine-grained porphyrite, with irregularly dispersed plagioclastic and augite crystals. They are like the dark-green close-grained variety which crops out at intervals between Cima di Selle and the Lago. A slide prepared from a fresh specimen of this dyke next Cima di Selle shows under the microscope

"a fine-grained holocrystalline ground-mass of plagioclase, augite, and iron-ore, abundant well-formed crystals of augite and plagioclase, the latter strongly-zoned and full of inclusions."

Hornblende and olivine may be present, but are not typical. Two other occurrences are present in the neighbourhood of the Predazzite summits where they are *contiguous with the ramifying sills of monzonitic aplite.* The holocrystalline fine-grained variety present in this area is much like the dyke-rocks in the Monzoni Alpe in which olivine is present (see p. 108).

The microscopic examination of a number of porphyrite specimens shows them to be very much altered, secondary minerals almost obliterating the original components. This fact, together with their brecciose, gneissose, or schistose structure at all shear-zones suggests that the differences may, in many cases, be of secondary origin. Not all the facies at selvage zones are original facies, many are superinduced forms of structure, the partial melting-down and re-forming of the rock having been associated with the periodic recurrences of local crush and shearing.

In the Campagnazza, Passo le Selle, and Costabella area, there are two leading facies of porphyrite: a holocrystalline, coarse or fine-grained, less basic type, and a close-grained type, characterised by flow-structure; both are highly pyritiferous. The latter type corresponds to the kind of rock that has passed under the general term of "melaphyre." In the Selle area it occurs commonly as fine bands and threads extending from larger sills, or as the edge facies of sills. The porphyrite rocks show the same mineralogical constitution and characteristic decomposition in the several occurrences at Selle Plateau, Passo le Selle, and in their main occurrence, which is as a ramifying dyke and still system locally associated with the N.N.E.-S.S.W. Judicarian cross-faults at their intersection with the Camorzao-Forca Alpe fault in E.N.E.-W.S.W. direction. As the E.N.E.-W.S.W. fault is that in whose westward continuation the "normal monzonite" sill rose, and it has been locally displaced by the N.N.E.-S.S.W. faults in which the pyritiferous porphyrite and melaphyre types are distributed, the latter are most likely to have been younger injections than the original "monzonite" sill invasions in Monzoni.

Lago di Selle.

(Photo, pl. xiii., Section, pl. xvi., fig. 2.)

At the famous locality close to the Lago the rocks have been so cut up by collectors that the sheared surfaces are in a large measure destroyed; whole slabs having been gradually removed.

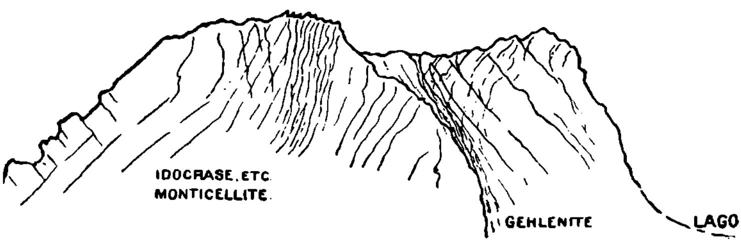
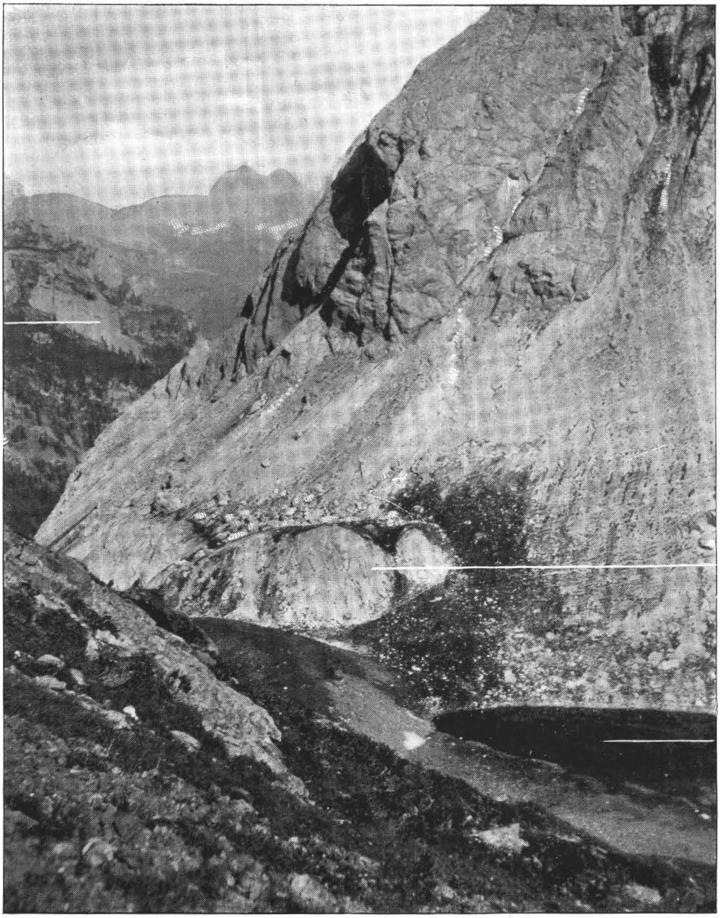


FIG. 28.—Shear-contact zone of altered limestone. Lago locality for contact minerals.

It may, however, still be seen that the contact minerals have developed on smoothed, polished, or slickensided surfaces. In their entirety, such planes may be seen to better advantage from place to place in the contact zone of the zig-zag cross-fault between the Monzoni and the Allochet ridge.

The leading contact-zone in the E.N.E.-W.S.W. fault-line descends the slope from Lago di Selle towards Monzoni Alpe. This zone of contact has also been one of downthrow to the north and it is during the period of downthrow that the various intrusions in the limestone north of the fault may be assigned. Two sets of inclined planes are present in the calcareous rocks of Cima di Selle; strike, N. 60° W., dip 50° S.W.; and strike N.E.-S.W., with planes inclined 60° and more towards the south-east. The W.N.W.-E.S.E. strike represents that of the bedding-planes, the N.E.-S.W. strike is the Judicarian dip-cleavage. Vertical cleavage planes are directed N.N.E.-S.S.W. and N.N.W.-S.S.E.



Lago di Selle.

c.m. the famous locality for contact minerals in the altered limestone.

Detailed descriptions of the strip of contact from the Lago to Monzoni Alpe have often been given.

The outflow from the lake passes at first underground below a ridge. On its appearance at the surface it keeps closely to the contact limit. Olivine gabbro or gabbro, locally with pyroxenite intercalations is present on the Monzoni side, and on the Selle side, dykes of different varieties of gabbro and monzonite aplite extend into the limestone. Two aplitic dykes occur where the path crosses the stream. They alternate in N.E.-S.W. direction with bands of altered limestone; idocrase, fuggerite, and other contact minerals are present. An olivine-gabbro dyke runs N.E. into the limestone, and sends out several ramifying threads of finer-grained structure. Where the path re-crosses the stream, there is a "Fuggerite" locality familiar to all. Herr Lehrer Trappmann showed me a place a few steps westward, where better specimens of Fuggerite are to be found. At the lowest part of the ridge, dykes of basic, olivine-bearing monzonite and gabbro are present, chiefly arranged in the intersecting dip-planes and in N. 10° E. and N. 20° E. vertical planes. Fragments of altered and brecciated limestone are thus enclosed within a system of dyke-fissures. The contact zone is intersected at the Monzoni Alpe by a N.N.W.-S.S.E. fault which passes through Monzoni Alpe and Monzoni, but it is again seen, displaced to the south, in the lower contours of the Riccoletta spurs (*cf.* pp. 154-155). It may be traced westward to the Costella limestone, at the western extremity of the Monzoni massive.

The injections at the Selle-Monzoni contact zone follow pre-eminently the north-east Judicarian strike and ramify in Judicarian planes as well as in the original bedding-planes. The same has been shown at the Allochet-Monzoni contact-zone. Therefore two general conclusions can be drawn: that the gabbro, pyroxenite, and diorite, and the syenitic, aplitic, and porphyritic intrusions in the limestone rocks at the periphery of Monzoni are not older than the Judicarian cross-compression of the thrust-masses, and that the peripheral contact-zone of the earlier intrusion of "normal monzonite" was a zone of subsequent injections and of strong differential shearing during more advanced periods in the protracted history of cross-compression and crust-torsion.

PART VI.

MONZONI.[1]

(See Frontispiece photograph.)

Leading Features in the Tectonic Relations of Monzoni—The Curved Median Fault-Zone in Monzoni—The East Side of Rizzoni Ravine—The West Side of Rizzoni Ravine—Cross-Fault in Rizzoni Ravine—The Riccoletta Slopes—Pegmatitic and Aplitic Fault-Dykes—The Cross-Fault in the Riccoletta Portion—Malinverno—The Rabbiosa Segment—The Toal Foie Localities—The Pesmeda Fault-Dyke—Summary—Original Gneissose Structure—The Porphyrite and Melaphyre Intrusions—The Evolute Form of the Monzoni Massive.

Leading Features in the Tectonic Relations of Monzoni.

IN the foregoing pages I have set forth the tectonic relations of the fault-blocks of sedimentary strata which are on the north and east of Monzoni mountain-massive. More especially reference may be made to pp. 101-104, 126, 136.

The strata of the Uomo, Punta di Costabella, and Allochet areas were on the south of an old thrust-plane, the strata of the Forca Alpe, Lastei, Monzoni Alpe, and Cima di Selle were in the thrust-mass above that shear-plane. Distorted arch-flexures formed with E.N.E.-W.S.W. or "Asta" strike obliquely across these thrust-masses and were faulted, inthrows taking place along an E.N.E.-W.S.W. line of trough-faults. An unsymmetrical arch-form affecting the "Contrin thrust-mass" has been demonstrated on the *north* of this line, from Contrin Valley to Punta Vallaccia; it has a steep flexure to the south, is locally knee-bent and overcast, or overthrust, and has been cut by later oblique and transverse faults. On the south of this line are short distorted arches with E.N.E.-W.S.W. strike affecting the Uomo-Costabella-Allochet group of strata, locally cut by series of inclined planes, some steep, others of very low inclination towards N.N.W. and N.W. At Forca Alpe, a part of the Contrin thrust-mass was obliquely rucked up into short folds, and turned round towards a N.E.-S.W. strike, partially upon the old thrust-plane, partially upon new obliquely-formed shear-planes. At Monzoni Alpe and Monzoni the same processes were passed through, and at the stage when the elasticity of the calcareous rocks could no longer bear the torsional strains, vertical and inclined "wrench" faults and joint-fissures formed,

[1] The map of Monzoni (scale 1 : 25,000) is carried out with all the details necessary in support of the conclusions I draw. But as I understand that Prof. Doelter has again been surveying the Monzoni district since my researches made in 1900-01, I have not thought it necessary to return to the country for the sake of following out the ramifications of the dykes at the peripheral zones, and completing the details in Monzoni.

into which the monzonite and gabbro magma gained access *up to a definite horizontal level in the crust.* The massive intrusions of monzonite and gabbro took place in the area where the E.N.E.-W.S.W. faults between Selle and Allochet with downthrow on the north intersected the east-west fault between the thrust-mass and underlay. The igneous rock-material occurs along the superinduced E.N.E.-W.S.W. strike of the strata composing the front of the Forca Alpe thrust-mass and the proximal part of the Uomo-Allochet thrust-mass, the latter, it will be remembered, forms the underlay in relation to the Forca Alpe slice, and the overthrust-mass in relation to the east-west Campagnazza fault.

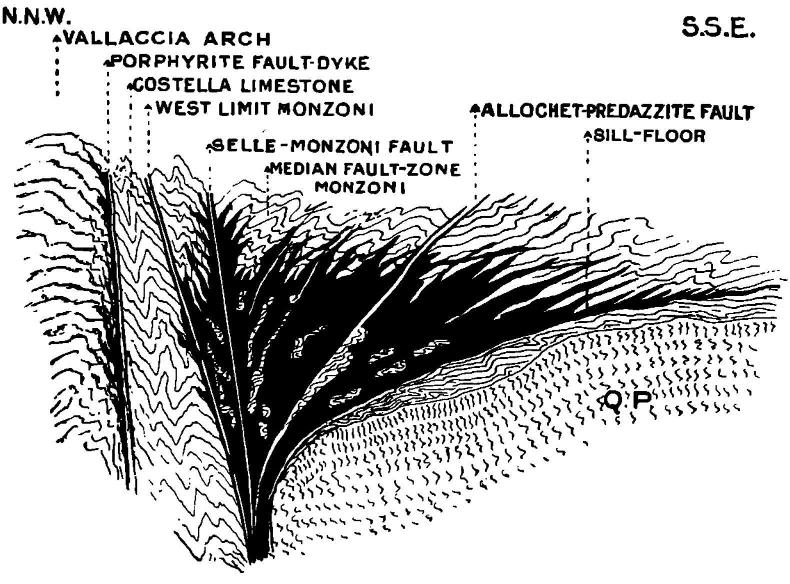


FIG. 29.—Generalised Form of the Monzoni intrusion, to show the essential dyke-and-sill relation to the strata.

In the Campagnazza fault-block the Werfen and Permian strata are present, reposing on Quartz Porphyry, and strongly altered and crushed patches of the series of Werfen and Permian strata are present on the south slopes of Monzoni.

The Upper Werfen, Mendola, and Buchenstein strata of the Uomo-Allochet thrust-mass are strongly crushed and attenuated, and are distorted along curved lines of shearing at the limiting fault between Monzoni on the west and the Allochet ridge and Predazzite summits on the east. The inthrow strip of

Marmolata limestone that runs westward from Punta di Costabella through Camorzao to the Selle Lago Plateau also belongs to the Uomo thrust-mass; it is preserved distinct on the Plateau, but is incorporated as fragments amidst the intrusive rocks of the Monzoni group.

Therefore the magma intruded itself parallel with the superinduced E.N.E.-W.S.W. strike in the Uomo-Allochet thrust-mass, entering higher and younger horizons in the western part than in the eastern. Tectonically, the intrusion is quite accurately described as a fault-sill, as it follows the E.N.E.-N.S.W. faults produced in virtue of torsional strains in the crust, and initiated by cross-compression over the region (fig. 29). The presence of a subsiding body of calcareous rocks with E.N.E.-W.S.W. strike in the hollow of the old Forca Alpe thrust-mass, and of an unequally thick calcareous thrust-fragment below the thrust-plane induced local differential strains and complications which gathered in intensity as the cross-compression continued.

The Werfen, Mendola, and Buchenstein strata of the "Uomo fault-block" have the N. or N.N.W. dip of the bedding-planes very much steeper in the ridge of Passo le Selle and Allochet than in the Uomo slopes.

The steepening of the dip is associated with the locally increased torsional strains in the strata at the area of the intersecting faults and local intrusions. Such is the effect of this steepening and twisting of the sedimentary series that the calcareous masses have been torn across the bedding-planes in different lines of direction during the crust strains—the chief tearing strains have been concentrated at the horizon above the Buchenstein siliceous limestone, the fragmented crust-slices tending to slip down and towards the N.N.W. When the igneous rock ascended, it spread obliquely across the steeply bent bedding-planes of the Werfen, Mendola, and Buchenstein strata. The strata, as it were, gave way, were crushed and dragged in relation to the newer strike, and, on the ascent of the hot vapours from the ascending igneous material, were converted into metamorphic schistose and serpentinous products. After the first intrusion of the monzonite magma, the continuation of the torsional strains caused faults in more and more diagonal directions; these faults intersected the first intrusion, and in addition to the earlier faults, afforded entry to later dyke injections.

Mention has often been made in geological literature of an east-west "Eruptive Fault" at Monzoni. This fault, or, more strictly, a *group* of parallel faults is present north of Monzoni; but, as I have just shown, a leading east-west fault existed previously and independently of the monzonitic intrusions. It was obliquely and transversely faulted over and over again during the Judicarian cross-movements. The intersection of this older fault-zone by the earliest E.N.E.-W.S.W. torsion-faults gave the signal for igneous invasions. The original east-west fault-zone was in the case of Monzoni just as in the case of Bufaure, Mount Donna, &c. (pp. 44, 84, 92), locally obliterated by the intrusive masses which rose through it, as well as by subsequent inthrows and fault-dykes.

As is apparent on my geological map, the east-west fault-zone north of Malinverno occurs in line with the old thrust-plane of the Campagnazza — the thrust-plane to which the duplication of the Werfen strata in the Uomo and Sallei section is owing (pp. 112-114). This old fault cannot be traced between the Monzoni Alpe corner and the Campagnazza because of its intersection by the E.N.E.-W.S.W. Selle-Monzoni fault, the local inrush of magma in the E.N.E. fault, the flow southward as a sill-intrusion, and the subsequent inthrows and sagging of the Allochet strata. On the east of the sill-intrusion, a series of N.W.-S.E. or N.N.W.-S.S.E. faults pass through the Allochet strata, one or two of them meet a leading N.N.E.-S.S.W. fault east of the Allochet ridge. These faults developed during the subsidence of the strata, and as it is in these N.N.E. and N.N.W. faults that the sills of pyritiferous plagioclase and augite porphyrite chiefly occur, the porphyrite here can be proved to have been intruded at a more advanced period in the sequence of the Judicarian cross-movements, and cannot possibly be older than the first intrusion of the monzonite at the E.N.E.-W.S.W. fault.

The local obliteration or distortion of the older thrust-planes is a constantly recurring feature in the Dolomites, and is not limited to cases of inthrow or of igneous invasions. Stated in general terms, it is accomplished in virtue of the common plication and dislocation of subjacent thrust-slices during the action of horizontal forces of compression in a direction different from that of previously-acting horizontal compressive stresses. For example, the old east-west reverse fault-plane of Forca and Pocol Alpe was, during the Asta stages of oblique compression, crossed by the superinduced E.N.E.-W.S.W. Contrin-Vallaccia arch-flexure at Guschel, and just there the Werfen strata of Pocol Alpe were deflected from west to S.W. strike and dislocated by several shear-planes inclined to N.N.W. and S.S.E., into which porphyrite has passed. The structural relations at Sella Plateau are quite similar. As shown in the accompanying sketch-plan (fig. 30), the same E.N.E.-W.S.W. flexure would, owing to the obliquity of the superinduced strike, affect the strata belonging to different thrust-masses on the north and south of the older

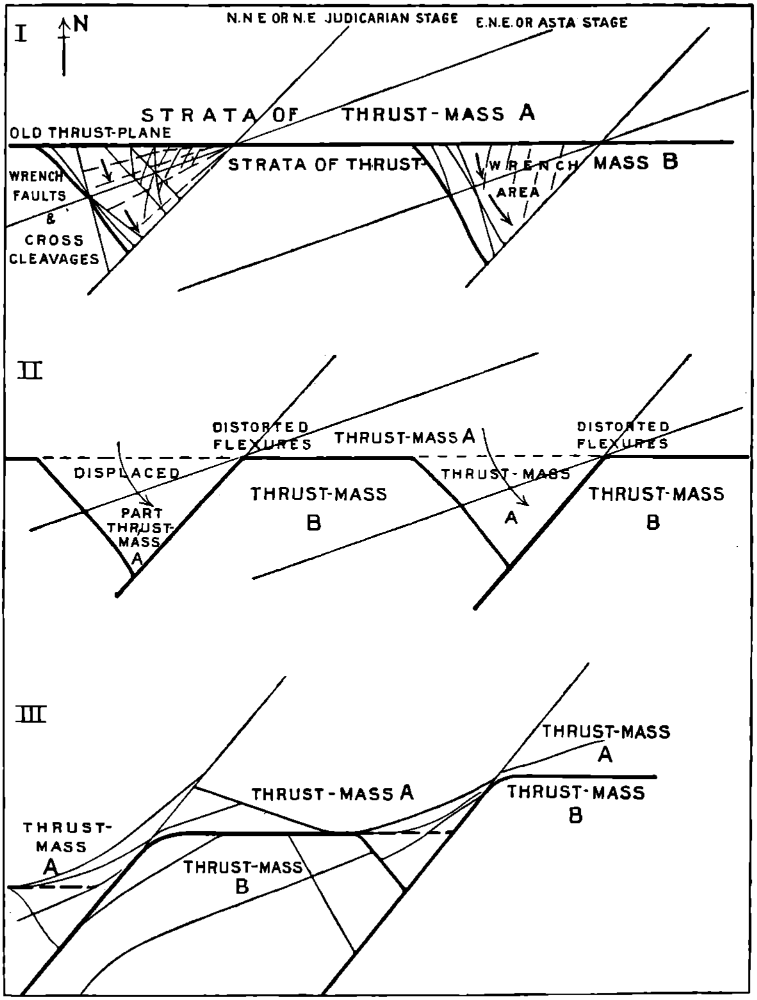


Fig. 30.—Diagram illustrating strike-curvature and distortional effects produced during cross-compression: I. Progressive stages of the superposed folds and faults. (1) "Asta" or E.N.E.-W.S.W. stage. (2) Judicarian or N.E.-S.W. stage affecting a series of thrust-slices with east-west (W.N.W.-E.S.E.) strike; wrench-faults in the direction of displacement. II. Same, showing the carriage of portions of one thrust-slice into line with the original strike of the thrust-slice below it. III. Same, showing some effects of horizontal displacements, and of plication or crush parallel with the cross-faults.

reverse faults. Where the old crush-plane of the reverse fault was caught in the later oblique flexure, it would, together with the strata above and below it, be bent and twined, and horizontally displaced through a certain angle from its original position to a new one. Or sometimes the rocks above the crush-plane, say, "Werfen marls," were obliquely rucked up into short folds upon a bent crush-plane in "Marmolata limestone," and carried independently to new positions upon it. As those distortional displacements took place at the definite localities of intersection of old fault-planes, there developed a fairly regular system of N.N.W.-S.S.E. and N.W.-S.E. wrench-faults transverse to the superinduced E.N.E.-W.S.W. and N.E.-S.W. oblique strikes; in a measure the wrench-faults developed simultaneously with the north-easterly faults, but they are lines along which differential movements have continued throughout late epochs of movement in this area.

Before proceeding with the details of the geology in Monzoni, or dealing with the question of the relative age of the plagioclase and augite porphyrite to the injections within Monzoni, I wish to emphasise two general structural features demonstrated in the foregoing pages; the presence of the older thrust-fault in the crust as a plane of crust-weakness certainly influenced the locality of intrusion of the igneous rocks, for the older fault formed the northern limit of the first intrusion of monzonite. But in the Monzoni Alpe, the throw associated with the east-west fault changed after its intersection by the E.N.E.-W.S.W. fault, the rocks on the north of this fault being inthrown relatively to those on the south.

One other general feature may at once be mentioned as a preliminary to the foregoing pages. I determined for the first time on the north slopes of Monzoni a fault-zone in the monzonite rocks, that extended continuously from the Monzoni-Allochet fault-limit westward to Malinverno, and was there joined by a N.E.-S.W. fault. This I termed the *Median Fault-zone* of Monzoni, and I showed that it as well as the peripheral and contact-fault between Selle and Monzoni was the chief seat of the later injections of gabbroid rocks. Its position is practically in line with the downslip fault between the Upper Werfen strata and the Predazzite rocks of the Selle-Allochet area, downslip having been towards the north, but any actual continuity has been broken by the N.N.W.-S.S.E. fault that limits Allochet on the west. In treating the Allochet area above, I have shown that the downslip fault was clearly a torsion strike-fault, inclined to N.N.W., parallel with the steeply-inclined and sheared bedding-planes. In it, in the Selle-Allochet area, are fault-dykes of typical plagioclastic and augitic porphyrite; in it, in Monzoni, are the main injections of gabbro types of monzonite, olivine gabbro, and pyroxenite.

The following pages will show that the main body of monzonite and gabbro in Monzoni was cross-cleaved in the direction parallel with the N.N.W.-S.S.E. faults which are such a well-marked feature in the geological map of the Uomo-Allochet thrust-mass east of Monzoni. And that the more highly segregated basic and acid types of rock, diabasic, syenitic, dioritic, and porphyritic, occur in connection with the N.N.W.-S.S.E. faults or the N.N.E.-S.S.W. faults that dislocated the gabbro and monzonite in Monzoni. Farther, pyroxenite rocks in Monzoni have invaded the gabbros, and the latter have veins and joint-linings of augite in the form of green traversellite; these are often grouped with veins of plagioclase, so that the differentiation of these minerals went on in the gabbro after its intrusion into the median fault-zone. This tendency in the gabbro magma, together with the considerations that relate to the age of the fault-injections of porphyrite in the Allochet strata, suggests that the porphyrite dykes in the Allochet area were likewise intruded after the gabbro. Of cellular structure, they ascended freely into the sedimentary strata, and consolidated there under conditions of environment, heat and pressure, differing from those experienced by injections into the monzonitic-gabbroid sill.

The Curved Median Fault-Zone in Monzoni.

Walking westward along the ridge from Punta d'Allochet towards Monzoni, about a hundred yards farther than the contact limit of limestone and monzonite, an inclined plane of differential movement is exposed in the monzonite rocks. The fault-plane strikes N. 70° E. and dips 30° N.W.; downthrow has been on the north of the fault-zone. A shear-zone a few inches in thickness is occupied by a schistose, serpentinized fault-breccia of monzonite. The cleavages in the monzonite rock below the fault-plane are rectangular; N. 40° E., dip N.W.; N. 50° W., dip N.E., and ramifying veins of red syenite are present here and there on the slope. The planes with north-east inclination dip very steeply towards the contact limit, but the planes with north-west inclination dip much less steeply.

The out-crop of the fault passes westward below the crags of Rizzoni.[1] It descends from the contour 2500 mètre on the ridge to contour 2300 mètre in the Rizzoni ravine. It continues at this height throughout the central part of the massive below

[1] The east wing of Monzoni, adjacent to Allochet, is regarded by the people of the district as part of the Punta d'Allochet crest, but in the survey map it is entitled Rizzoni.

Riccoletta Peak; there it meets the N.E.-S.W. fault from Monzoni Alpe which crosses the crest of Monzoni in a depression between Riccoletta and Malinverno. Thus, in virtue of the junction of an E.N.E.-W.S.W. fault and a N.E.-S.W. fault, a curved fault-zone was established in the monzonite rocks, and served as the chief zone of differential shearing and intermittent injection of igneous material throughout subsequent epochs of crust-strains.

The East Side of Rizzoni Ravine.

The greater part of the Rizzoni ravine represents the zone of shear and injection which runs through Monzoni, and the

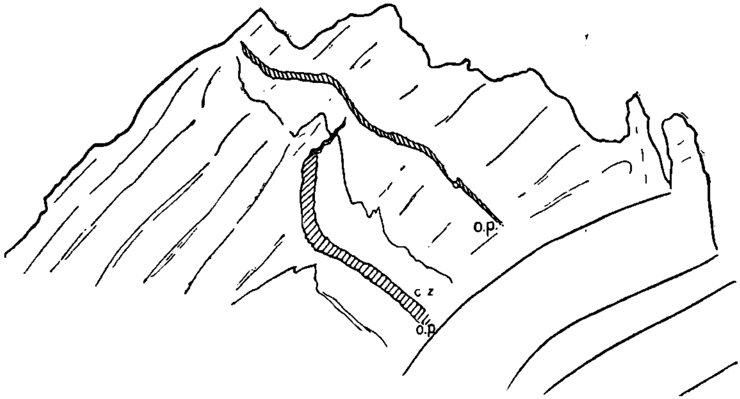


Fig. 31.—A high crag in Monzoni, east of the Rizzoni ravine, to show the injection of orthoclase porphyry into cleavage-planes with strike north-east, and dip south-east. The main joint-planes in the gabbroid monzonite dip north. c.z. = contact zone of sheared and altered rock. Traversellite occurs abundantly in the joint-planes.

relations of adjacent bands are best exposed on the right bank of the main ravine. Near a waterfall in the course of a side-stream at ca. 2140 mètre is a small dyke of fine-grained ultra-basic rock, some form of limburgite rich in olivine and augite, but with little felspar. The olivine-gabbro, and dark, coarse-grained gabbro type of monzonite are interrupted in the main ravine by a still more basic dyke of olivine gabbro with hornblende, and a light grey, fine-grained, highly felspathic monzonite belonging to the labradorite or plagioclastic aplite group. The latter is a later injection than the gabbro rocks, it looks fresh, and is not slickensided. The shear-zone both on the north and south of it contains bands of schistose and brecciated olivine gabbro rock. Above it the coarse-grained dark gabbro in the main fault shows every gradation of shear and foliation. It is puckered, and strongly cleaved and striated, with serpentinous or ferruginous weathering. Gabbroid and normal types of monzonite form the terrace below the highest cliffs; they are strongly cleaved, and veined with various mineral segregations.

As it was impossible to scale the cliff at the head of the ravine, I completed my section by ascending obliquely eastward, where the rocks of the summit strike through the east part of the Monzoni massive. At ca. 2400-mètre contour, a prominent crag of gabbroid monzonite juts forward. It is full of injection-veins of reddish syenite porphyry, rich in orthoclase and with some quartz. These have a wonderfully regular distribution in the shear-planes dipping south-east, and in vertical fissures directed almost N.S. The strike-cleavages here are N.50° E., dip S.E.; and east-west strike with dip north in curved planes steepening in the proximity of the fault-zone (*cf.* fig. 31).

Traversellite, chabasite, calcite, and other secondary minerals are present in the joints of the gabbroid monzonite rock, and large crystals of augite occur porphyritically. The gabbro surfaces in contact with the dykes of orthoclastic lamprophyre are decomposed, polished, and slickensided, and weather almost black. A vein of the orthoclastic rock over a mètre thick, contains fragments of almost unaltered gabbro within it as a breccia. This is only one of several breccias associated with injections of granitic, aplitic, or porphyritic veins in the east wing of Rizzoni, and they closely resemble the more altered breccia associated with the group of dykes on the south slope of Allochet underlying the limestone rock. It is important to observe that the gabbroid monzonite has undergone mechanical deformation and mineralogical changes along the superinduced planes of dip-cleavage, and in vertical planes in N.N.W.-S.S.E., N.S., or N.N.E.-S.S.W. directions. The changes were therefore accomplished after the gabbro injections. More especially striation and schistose alteration has taken place in the inclined planes, into which dyke and sill injections have passed.

The north-dipping planes are strongly curved and show pressure-effects in the proximity of the fault-zone. The steep curvature of the north-dipping planes (strike N. 65°-60° E.; dip-cleavage planes 70°-80° N.N.W.) is a feature presented throughout the northern slopes of Monzoni, and which is corroborative of my conception of the median fault-zone as one of downslip to the north (*cf.* p. 145). The monzonite at the highest contours is the finer-grained normal type, rich in biotite-mica, and is abundantly veined with syenitic threads.

The West Side of Rizzoni Ravine.

(Section, pl. xviii., fig. 1.)

A specimen of the dark-coloured olivine-gabbro rock from this side is seen under the microscope to be—

"a holocrystalline rock, containing a large amouut of closely-twinned plagioclase, a much smaller quantity of untwinned felspar (orthoclase), which is later than the plagioclase, abundance of pale augite, numerous crystals of olivine (partly serpentinised), some biotite, magnetite, and apatite."

A coarse-grained, very basic, augitic, and pyritiferous variety occurs strongly altered in the actual fault-zone, about the 2200 mètre contour. In it augite, often a diallage type, hornblende (uralite), hypersthene, rubellan, apatite, and other secondary minerals, together with nodular iron ore, attain their richest development. A specimen of the gabbroid monzonite in contact with this dark pyroxenitic fault-band in the Rizzoni ravine, as seen under the microscope is—

"a crystalline, even-grained rock, containing a large amount of felspar with plagioclase twinning, mostly not very basic, a considerable amount of untwinned felspar (orthoclase) to which the plagioclase is idiomorphic, a pale augite in large crystals, only sometimes showing characteristic outline, some brown mica, and magnetite."

Some other microscope slides show almost no orthoclase, and relatively more biotite and augite. The hand-specimens show roughly gneissose structure, and are black and yellow in appearance.

The olivine-gabbro and gabbroid monzonite rocks are crushed and folded, parallel with their strike (N. 50°-60° E.); and the rock flexures are cut by intersecting systems of steep joints facing N.N.W. and S.S.E., and by vertical joints directed N.N.W.-S.S.E. (N. 25° W.). The joint surfaces are often polished or striated, and lined with traversellite and anorthosite. At ca. 2100 mètre contour, the rocks acquire more marked schistosity of structure, the planes of foliation have a satiny greenish lustre. A fault runs across the ravine a little higher. On the west side, at ca. 2140 mètre, a reddish syenitic thread and a thread of labradorite rock (Anorthosite) run close together. They ascend an east-west gully in cleavage-planes that incline south-east, and then ramify irregularly north-westward. Similar occurrences of very thin threads are present in the neighbouring ravine on the west at a somewhat lower level. On the east side of the ravine, a plagioclastic lamprophyre (Kersantite) dyke is present, ca. 30° cm. thick; it ascends a plane inclined south-east. The presence of the plagioclastic variety associated with the orthoclastic is interesting, as these highly felspathic dykes are intrusive in the basic rocks of the injection-zone; the rocks beside these dykes are altered and fragmented in the contact bands. Calcitic veins are freely distributed at this horizon, and the joint-surfaces are strongly sheared and serpentinised.

Almost opposite the dykes of dark, coarse-grained, augitic gabbro on the west side, there is, on the east side, a line of fault-pressure and alteration in the olivine gabbro. The fault-zone cuts obliquely through the olivine gabbro, apparently in east-west direction. The gabbroid monzonite rocks associated with the olivine gabbro are fractured, and the fault-zone is occupied by a band of gabbro schists full of secondary alteration products. This black-weathering band of rock in the fault-zone is present at the 2200 mètre contour; it is the pyroxenic variety of olivine gabbro and represents the latest zone of crush and injection on the north slopes of Monzoni. The crush-facies may be described as a gabbro schist or gneiss. It can be easily traced through the mountain below the 2200-metre contour at the Rizzoni ravine but ascending a little towards the Riccoletta ravine. It has eroded and weathered much more readily than the rocks above and below it and forms a natural weathered notch in all the rocky spurs that run northward from the Riccoletta portion of Monzoni. The coarse-grained rock in the fault-zone is strongly sheared. The weathered surfaces are black or red-brown, the joints are often lined with hæmatite and nodules of iron ore are abundant. Between this fault-band and the gabbro type of monzonite above it there is in some places a thin greenish serpentinised contact zone with seladonite, and small diabasic dykes run southward from the fault-band. In the higher contours above the fault-zone the most instructive exposures occur in a small stream from the Riccoletta crags, not in the main ravine. A waterfall has eroded the gabbroid monzonite for a considerable distance back and on the steep slope above, in the stream-cutting, the gabbroid monzonite is seen as patches, blocks and lenticles embodied amidst a more normal monzonite that shows considerable evidence of secondary changes (see section).

Next the fault-zone the gabbroid monzonite is penetrated by steeply curved north-dipping planes; but above the waterfall the rock is seen to have been crushed into a fold-system, and each larger fold is itself crumpled along an almost east-west strike; the gabbroid monzonite here shows all the puckerings of a typical contorted schist or gneiss. From the exposures here I concluded that the yellow-black gabbroid type had intruded into the older normal monzonite; the latter undergoing certain mineralogical changes; that both rocks had been crushed to gneissose condition, rubbed together during differential movements, and closely folded. It is clear that the weathering of a slope made up of folded gneissose bands is sure to produce a patchwork appearance of the different facies.

I take the gneissose lenticles and bands of the gabbroid monzonite to represent a crust-breccia formed next the zone of fault and injection. The coarse gabbroid and gneissose monzonite sends streaks both in east-west and in cross directions into a more normal monzonite type rich in brown mica and poor in augite. Some of the gabbro threads are indicated in my map, and may serve as an example of the actual distribution in the field, but I did not carry my investigations into the precipitous summit crags.

The west side of Rizzoni ravine has one or two good exposures that bear upon the sequence of injections. Between

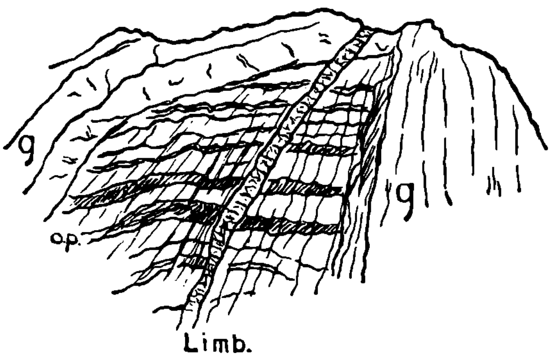


FIG. 32.—Rizzoni ravine; Limb=a dyke of limburgite injected into a north-south cleavage plane, and breaking through earlier injections of syenitic character. o.p.=orthoclase porphyry; g.=gabbroid monzonite.

the 2200-mètre and 2300-mètre contour-lines there is a series of well-marked dioritic and gabbroid bands, parallel with the ravine; all are obliquely cut by an aplitic dyke. Again, at the 2300 mètre contour, bands of crushed dark gabbro occur in N.N.W.-S.S.E. direction, and the whole system is intercalated with seams of pinkish orthoclase porphyrite distributed in E.N.E. cleavage fissures, and zig-zagging in the planes of cross-cleavage. A close-grained basic dyke (limburgite) ca. 50 cm. thick, has been injected north and south through all the other varieties (fig. 32). All the rocks are cleaved in north-south direction, and the cleavage-faces are steeply inclined to the east. This cleavage represents the later cross-roll, whose effects have been noted at Allochet, but at Allochet the cleavage-faces are inclined to the west (p. 129). Prehnite is abundant in the joints and fissures of this exposure. The limburgite seen under the microscope, is—

"a hemicrystalline porphyritic rock. The crystals of the first generation are *Olivine*, which occurs in well-defined forms, at times quite fresh, at times partly or wholly serpentinised; *Augite*, of exceedingly pale but faintly pleochroic variety, zoned, and frequently showing hour-glass structure. In the ground-mass there are abundant small crystals of the same two minerals, with very numerous small needle-like prisms of *Hornblende*, brown and strongly pleochroic, and abundant grains of magnetite, and a variable amount of brownish to whitish glass."

Basic veins, of a variety of camptonite with augite, are present in the higher precipices; the fallen blocks are fairly frequent, and certain threads can be quite well seen amid the normal and gabbroid monzonite. These belong to the series of camptonites and limburgites which are the latest injections in Monzoni.

Cross-Fault in Rizzoni Ravine.

Comparing the area of Monzoni near Allochet, with that on the west of Rizzoni ravine, an important difference is presented, both in the inclination of the fault and in the nature of the injections. The shear-plane, where it is exposed near Allochet, is inclined north, at a much smaller angle than the shear-plane as exposed in the neighbourhood of the Rizzoni ravine. Again, the black, augite and ore-bearing dyke-rock, in the fault-zone across Rizzoni ravine, does not continue eastward. The differential strains set up along any fault-zone, varying in the angle of inclination, would in themselves cause fracture across the fault-zone. In the Allochet ridge, and in the Uomo rocks, faults directed N.N.W.-S.S.E. have developed across the E.N.E.-W.S.W. fault, with downslip on the north, and appear to be practically confined to the thrust-mass, which has chiefly borne the torsion strains. A parallel fault was apparently directed along the Rizzoni ravine, probably on the east side of the ravine; the numerous crush streaks, parallel with the N.N.W.-S.S.E. direction, and the local injections, also indicate a cross-disturbance. In virtue of such faults, radial to the torsion-strike, the differential movements between any two adjacent fault-blocks were enabled to go on simultaneously with the movement of downslip to the north, common to both fault-blocks. The actual displacement, in horizontal and vertical sense, effected on the north of the downslip-zone, was, therefore, bound to be different in the neighbouring fault-blocks.[1]

[1] I have in this and previous papers frequently referred to the differences in the details of the deformation along one and the same fault-zone, and shown that this was only explicable on the assumption that the Judicarian cross-fractures were developing simultaneously with the downslips related to strike torsion-fractures in the thrust-masses.

The western part, which was in this case the more steeply inthrown, was subjected to stronger horizontal compression, and was more frequently invaded by fresh magma. The eastern part, which was not steeply inthrown, was afterwards, when the Judicarian cross-roll came, arched relatively to the Allochet limestone on the east, and to the monzonite in the inthrown fault-block on the west. The latest cleavage-planes incline towards it, westward in Allochet, and eastward on the west side of Rizzoni ravine. Although I have not examined the Rizzoni ravine on the south slopes in detail, there are several injections of augite-diorite at about 2200-2300 metres that occur in the continuation of the cross-fault. They are doubtless associated with the similar injections at about this level in the slopes of Monzoni (at the Malinverno cross-fault and other parts) and with the Col Lifon pyroxenite (p. 132).

The Riccoletta Slopes.

(Section, pl. xviii., fig. 2.)

The next spur that runs northward from Monzoni parallel with the spur of rock west of Rizzoni ravine, shows essentially the same structure, but has a more complicated system of later dykes. At the base of the ridge the rock is a typical monzonite, very rich in coloured constituents. Thin bands and small patches of limestone are numerously preserved in it at the lower contours; and at the upper contours, one or two aplitic dykes run obliquely across the gabbroid olivine-bearing rocks. The most important feature is the continuation of the median fault-zone at the same horizon of level. The very basic, black-weathering fault-dyke follows an E.N.E.-W.S.W. direction. It has the same sheared, crumpled, and schistose structure as in the Rizzoni spur, and is rich in ores and secondary minerals. This rock, together with the crush-facies of gabbroid monzonite, trends suddenly to the S.S.W. in ascending the contours to the west of the Riccoletta summit. The cleavage of all the crush-facies is here very pronounced in N. 45° E. direction, with an inclination of 80° to south-east. The curved joint-planes in the gabbroid monzonite south of the crush-zone strike N. 70° E. and dip 60° N., but are polished and slickensided, the striation being N.N.E.-S.S.W., oblique to the strike. The pyroxenic gabbro dyke that extends southward through the gabbroid monzonite here shows microscopically—

"a coarsely crystalline mixture of very pale Augite, a considerable amount of Biotite, a subordinate amount of basic Plagioclase showing albite and pericline twins, and large, irregular masses of magnetite."

A group of the younger, richly felspathic and aplitic dykes, and a dyke of olivine diabase, occur in the neighbourhood of the strike-curvature of the shear-zone; these send ramifying threads into the steep N.E.-S.W. cleavage-planes in the gabbro-rocks, and are accordingly injections into the shear-zone at a more advanced period in the history of cross-compression.

The exposures at this part are extremely instructive, in respect of the curvature of the planes of fissure through the rocks and the signs of folding. The rocks weather away along the curved planes, and show one inner core after another of the different facies, the gabbro or more normal types of monzonite. To me they suggested a superinduced gneissose structure throughout the mass, depending upon perfectly definite planes of schistosity, these having been determined by the repeated horizontal compression of the mass subsequently to the gabbro injections.

The Riccoletta summit is that which faces Monzoni Alpe. In the higher part of the mountain, the dominant cleavage-planes strike N. 35°-50° E., the horizontal joints incline north-west and south-east, but a closer examination of the rocks proves the additional presence of more oblique cleavages, N. 80°-85° W. curving to N. 70°-75° E., and the vertical cleavages are N. 10° E., and N. 20° W. The rocks of the Riccoletta ridge are largely the coarse-grained gabbroid monzonite and a finer-grained diabasic type, but I did not map in detail, and have, therefore, entered the general tint for monzonite in my map.

Whereas the two cross-spurs immediately west of the Rizzoni ravine show the limestone only in small fragments and threads, a thickness of 20 to 40 mètres of limestone has been preserved at the base of the next two cross-spurs on the west. These cross-spurs run almost in north-south line with the group of fault-dykes on the west of the highest part of the Riccoletta ridge. The limestone and gabbro meet here along a steep east-west fault exposed at the 2140-mètre contour. In the more easterly of these two cross-spurs, the olivine gabbro rock south of the fault shows sheared slabs with strike N. 80° W., and inclined steeply to the north; the altered limestone strata have almost vertical cleavage, but in some places the planes are steeply inclined to the north. The limestone is a crushed band between the olivine gabbro rock and the biotitic monzonite that is preserved at the base of the spur.

The gabbro south of the fault has also contact relations with certain thinner bands, layers, and patches of altered limestone not entered on the map, but occurring at high levels amidst the igneous rock. They are the source of the many excellent specimens of contact minerals to be found in the scree of the ravine between the two Riccoletta cross-spurs.

In the ravine, almost in line with the fault, specimens of iron-ore, chabasite, melanite, and pistazzite may be picked up in the scree. They occur in vertical joints directed N.N.W.-S.S.E., and also in horizontal joints. The fault at this lower contour (ca. 2140-2100) is the slightly displaced continuation of the Selle-Monzoni E.N.E.-W.S.W. contact and fault breccia; in the Riccoletta portion of its course, it is parallel with the median fault that runs between 2240-mètre and 2280-mètre contour. The zone between these faults is that in which the gabbro injections have pre-eminently occurred, and these injections, like the fault-planes, have been dislocated by the subsequent cross-faults that radiate through Monzoni.

Pegmatitic and Aplitic Fault-Dykes.

At the base of the other spur, immediately west of the Riccoletta ravine with contact minerals, a Pegmatite dyke ascends the fault-plane and sends fine threads into the serpentinized limestone. The dyke sends a short white vein eastward, and a longer and more aplitic branch into the crushed olivine-gabbro rocks in the middle fault-zone of Monzoni. The aplitic branch crops out at intervals along a N.N.W.-S.S.E. direction, continuing to the base of the summit ridge, where it joins other aplitic dykes. These denote a N.N.W.-S.S.E. cross-fault which separates the Riccoletta fault-block on the east from a downthrown western fault-block.

The weathered remnant of monzonite opposite the spur with the pegmatite vein, on the opposite or west side of the ravine shows a quite similar occurrence of sheared, altered limestone in the W.N.W.-E.S.E. fault strike. In it there is a dyke of orthoclase porphyry, ca. 1½ mètres thick.

The Cross-Fault in the Riccoletta Portion.

A close-grained pyroxenic rock runs as a dyke into a ravine or rather deep fissure which cuts southward through the ridge. This dyke sends threads irregularly into the gabbro of the cliffs. Close to it are the aplitic dykes, and upon the west side of the fault a massive injection of felspathic fine-grained monzonite similar to that in the Rizzoni cross-fault. These dykes represent later injections in the neighbourhood of a cross-fault directed almost north-south with downthrow on the west, repeating the effects at the cross-fault in the Rizzoni ravine. The evidence of strong shearing from east to west is apparent throughout the summit ridge between the fault fissure and the next ravine on the west. The latter is well-known in the neighbourhood as the easiest Pass through the Monzoni cliffs, and also well-known to mineralogists for the abundant occurrence of axenite in the joints of the monzonite.

The exenite occurs in the vertical fissues N. 25° W. and N. 15° E., and in the steep N.N.W. joint-planes corresponding to the E.N.E.-W.N.W. strike. There is also a system of inclined cleavage-planes dipping to the south-east. The gabbroid monzonite of the cliffs has been much altered, polished, and slickensided, and rendered roughly gneissose.

The main fault-zone comprising the gabbroid monzonite, the bands of magnetic iron ore, olivine-bearing and augitic schists, olivine gabbro and augite-diorite varieties, crosses the ridge at the ravine, and continues towards Malinverno; but a little east of the summit, it is interrupted by a N.N.E.-S.S.W. cross-fault. The N.N.E.-S.S.W. fault can be traced through the south slope of Malinverno as a line of strongly-crushed and brecciated rock-material on the west of the main exposure of Werfen and Permian rocks on the south slope. The fault-breccia contains fragments of normal monzonite as well as the altered gabbroid monzonite, and the olivine gabbro and schists. Therefore the materials of the main fault-zone have been broken up by later shearing movements in the N.N.E.-S.S.W. fault. Quartz monzonite occurs as dykes in the fault-line. The joints and shear planes in the breccia are directed N. 35°-45° E., and vertical cleavage N. 20° W. is also well developed. Therefore the breccia is essentially a Judicarian fault-breccia, and the gneissose bands and olivine gabbro and schists which were associated with the earlier stages of the Judicarian cross-compression were locally broken up and mixed during later stages.

Whereas the parallel strike-faults on the north slope of the Riccoletta ridge have been planes of downslip to the north, the subsequent horizontal pressure from the east has initiated a local reversal of the differential strains at the N.N.E.-S.S.W. cross-fault. The throw of the N.N.E.-S.S.W. fault is inclined eastward, but the east or Riccoletta wing is the upthrow side. Thus one may trace what appears to be a continuous curved fault-zone through Monzoni, but it is in reality limited by heterogenetic faults. The N.N.W.-S.S.E. fault and shear-planes between Allochet and Rizzoni are inclined steeply westward, the N.N.E.-S.S.W. fault between Riccoletta and Malinverno is inclined steeply eastward, these wrench-faults and the dykes associated with them are younger than the gabbro injections in the median fault-zone. The original downslip fault-zone probably continued westward in the Malinverno mountain, as gabbro occurrences are frequent in the southern crags, but it has also been intersected there by a cross-system of N.E.-S.W. shear-planes which are the continuation of the Monzoni Alpe group (*cf.* pp. 107, 108, and fig. 34).

The curved outcrops of a fault-zone in Monzoni is of scarcely less interest than the proof of the existence of the fault-zone itself, for the strike-curve has taken place in the sense of the Peri-Adriatic strike-curve from N.N.E. to E.N.E. round the north, which appears over and over again in the whole district as one of the characteristic tectonic curves. And such a fault-curve has been proved in all the cases examined by me to have taken origin during the progressive stages of the Judicarian cross-compression and strike-torsion.

It is here parallel with the curvature of the Pesmeda-fault which limits Monzoni on the west and north, and parallel with a number of the fault-curves shown in my reference map.

The fault-breccia south of the axenite ravine includes many fragments of hard, brittle, crystalline limestone in addition to the lenticles of igneous rock material. The banded hornstone and crystalline limestone strata which form the exposure are folded along a W.N.W.-E.S.E. strike and cleaved across the folds in N. 35° E. direction parallel with the fault. Similar but much smaller patches crop out amidst the monzonite rock on the south slopes of Malinverno, and I infer that they are part of the Allochet succession of Werfen strata possibly with some Mendola rock. At lower horizons of the exposure quartzites are exposed in the streams, so that these strata apparently are a part of the Permian and Werfen series, above which the magma periodically ascended.

Dykes of syenite porphyrite and melaphyre occur in the limestone in N.N.E.-S.S.W. direction; their intrusion is probably associated with the neighbouring cross-fault, at which, as well as at the east contact limit of the sedimentary rocks, quartz monzonite threads occur.

Malinverno.

(Photograph, pl. xiv.)

My investigations in the Malinverno and Rabbiosa area are only fragmentary; so far as they go, I have entered them in my map, but it was my original intention to have returned to map more fully. (Preface.)

I gave my attention chiefly to the direction of the dykes at Rabbiosa and the evidences of the relative age of the dykes. At Malinverno the crags were too precipitous to be scaled, and the south slope is grass-covered, therefore at the best, the geology cannot be completely obtained.

The leading general feature is the separation of the Malinverno by N.N.E.-S.S.W. cross-faults both from the Riccoletta area on the east and the Rabbiosa area on the west. The fault-breccia in this direction between Malinverno and Riccoletta has been described. With the exception of a well-marked schistose gabbro band a little below the summit, the monzonite of the Malinverno northern slopes belongs to a dark, coarse-grained variety of fairly normal type. Microscopically, it is a—

"coarsely crystalline rock, with a considerable amount of simply twinned or intertwinned felspar (Orthoclase), much Plagioclase which is idiomorphic towards the Orthoclase and frequently completely enclosed in it, augite more or less idiomorphic, some brown mica, magnetite and apatite; no appreciable quartz or Olivine."

It resembles certain fragments of monzonite at the lowest contours of the Riccoletta spurs. The relations of this normal

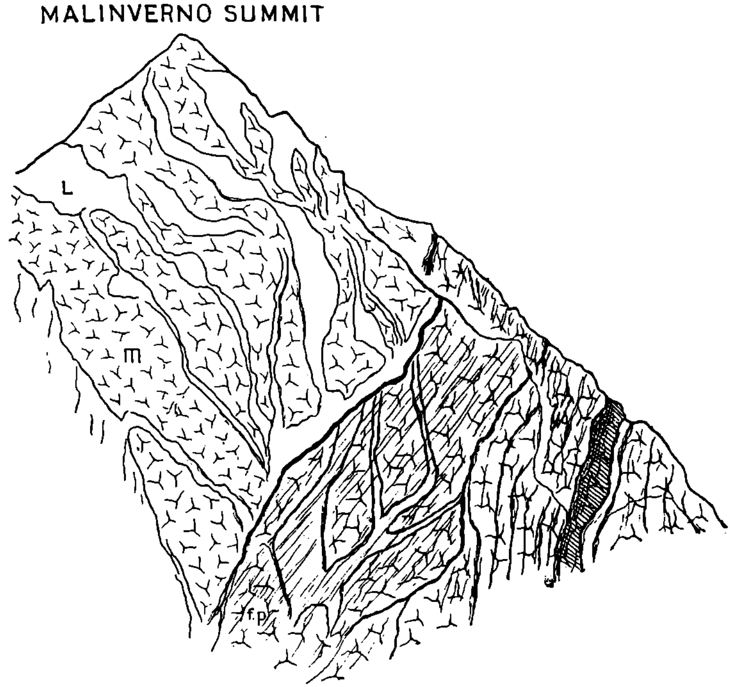
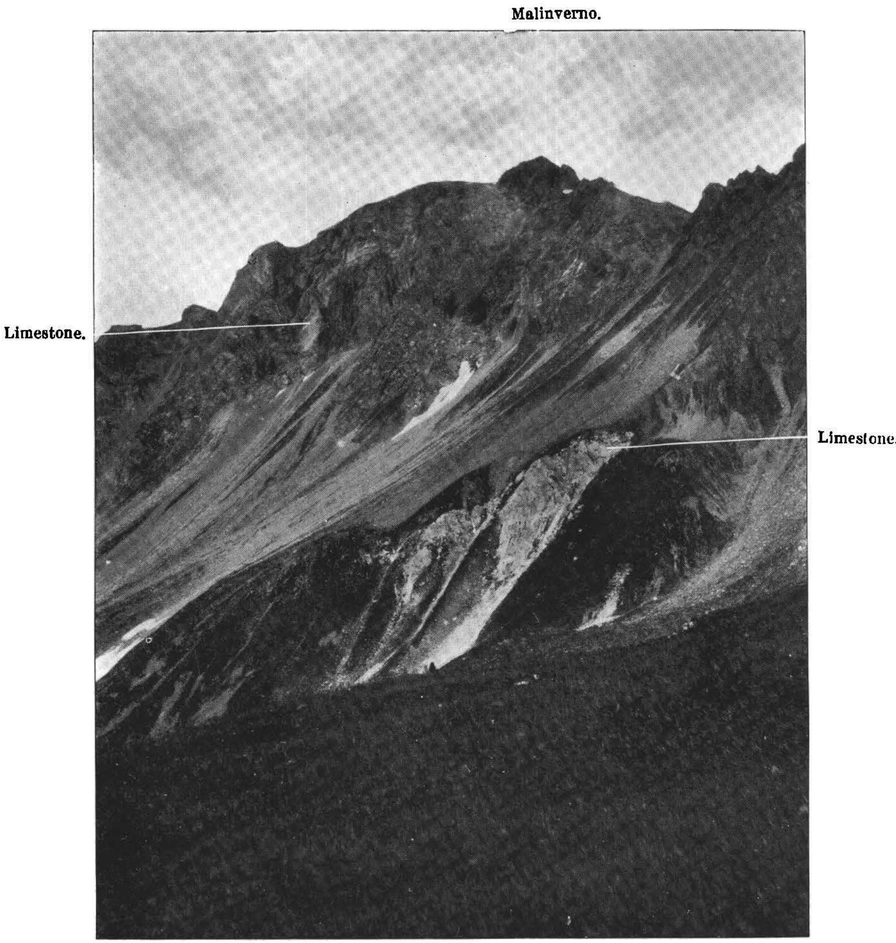


FIG. 33.—Relations of limestone and monzonite at Malinverno summit. the strings of limestone look like a broken-up series of bedding-planes with the north dip characteristic of the Costabella limestone range. The mode of intercalation of the monzonite suggests a sill-system. f.p. = fracture-plane inclined south-east (the cleavage-planes inclined northward are omitted for clearness).

monzonite to the limestone enfolded and absorbed in it, as well as its structural position as a downthrow relative to the



The Malinverno Summit.

Plications of the Earlier Sills and the bands and patches of altered limestone involved in them.

main fault-zone with the gabbro dykes, lead me to conclude that the Malinverno rocks, like those at the base of the Riccoletta spurs, represent part of the *original sill, and the original roof-rock*, as it were, of the subsequent intrusive masses. The gabbro rocks entered a fault-zone in the original fault-sill and locally penetrated through it to the sedimentary rock above the original sill, *e.g.*, in the Selle-Monzoni contact-zone.

The summit crags of Malinverno show a dark brown and reddish schistose band of gabbro between a higher and a lower crumpled mass of the contact-zone of monzonite and limestone. This band occupies a shear-plane inclined to the south-east; with this inclination the plane dips into the grass-covered slope on the south of the summit. The rocks below have a general high dip to the N.N.W.; they have been strongly crumpled and sliced by cleavage-planes inclined at a high angle to the south-east and, therefore, intersecting those of the north-dipping series.

The shear-plane in the Malinverno summit is probably a companion-fault to the more steeply-inclined N.N.E.-S.S.W. fault, occupied by fault-breccia lower down the slopes. At the highest pinnacle of Malinverno there seems to be another parallel plane of fault (fig. 33).

A noticeable feature in the summit is the evidence that the monzonite has been intruded as irregular sills into a broken-up, crumpled series of limestone strata with northward dip. After consolidation of the monzonite, the whole mass has been fractured by shear-planes dipping south-east, and bands of schistose, altered rock are present in these later shear-planes.

The Rabbiosa Segment.

The west wing of Monzoni Mountain is composed mainly of the dark, normal type of monzonite like that on the north slopes of Malinverno; there are small occurrences of gabbroid monzonite and olivine-bearing gabbro. The gabbro and monzonite are pierced by numerous dykes of monzonite aplite, syenite aplite, syenite porphyry, quartz syenite, anorthosite and augite diorite, and by later basic injections of camptonite or allied types.

The name of Cadinburt is applied more particularly to the basin-shaped hollow west of Malinverno. The hollow is surrounded on the north, east, and south by igneous rocks, and the west side is shut in by the calcareous rocks of Costella and Pesmeda. On the south side of the hollow there are two spurs of the igneous rock, the one nearer the Pesmeda limestone is called Palla Rabbiosa, the other is called Toal Masson. The lower slopes descending from these go by the name of Toal Foie, and are famous in mineralogical literature for the contact minerals found in several patches of limestone.

Although my specimens from this ridge have not yet been examined microscopically, I think it necessary to include in this paper the facts I observed in the field regarding their distribution. I ascended the summit ridge from the north side, crossing it through a niche about half-way between Malinverno and the Costella limestone summit (2539 mètres). The first monzonite rocks in position occur on the north slope at about 2350 mètres, and they have well-marked Judicarian cleavage; strike N. 35° E., dip 65° south-east. In no other part of the mountain has this superposed cleavage-system so much effaced the older. But the W.N.W.-E.S.E. strike and north dip is still apparent, owing to the fact that dykes of red orthoclase porphyrite and quartz syenite have been intercalated in the inclined joint-planes following this strike as well as in the intersecting planes of cross cleavage. One of the dykes occurs about the contour line 2500 mètres. The higher horizons of monzonite show good shear-planes, along which the monzonite has assumed schistose structure and been altered in appearance.

On the crest of the Monzoni ridge there is a thin dyke (30 cm.) of the fine-grained ultra-basic rock, with olivine and augite and specks of a felspar, probably nepheline, which I shall term provisionally a limburgite; its direction is N. 35° E., and threads ramify into the monzonite, which shows contact alteration. A few yards down the south face of the cliffs a quartz-bearing dyke occupies a north-dipping cleavage-plane. The monzonite rock is here much disturbed, showing bent joints and sheared surfaces. East of the rough track, the monzonite is of the very dark, sheared, gabbro-like variety. The bands, patches, and lenticles of gabbroid monzonite occur here in the same manner as in the Rizzoni ravine. The chief bands run N. 50°-55° E.; and in them are numerous veins of syenitic lamprophyre (orthoclase porphyry) and a few of plagioclastic lamprophyre. A typical olivine gabbro is rare, it occurs only as seams and small injections of comparatively fresh rock in N.N.W. cleavage planes of the normal monzonite. I am inclined to associate the gneissose banding of the gabbroid and normal monzonite here with the passage of a group of shear-planes in E.N.E.-W.S.W. direction, and the syenitic injections with the N.N.E.-S.S.W. cross-fault between Malinverno and Rabbiosa.

Rounding the crags that descend steeply from Malinverno, the most marked cleavage-planes strike nearly east-west and incline as steeply as 80° northward. A small dyke of true gabbro and three small dykes of the fine-grained, ultra-basic rock are present at the part where the ridge round the hollow turns westward. They occupy respectively fissures directed

N. 10° W., N. 10° E., N.S., fissures characteristic of "wrench" cleavage (fig. 30).

In the two southern spurs the gabbro injections are distinctly arranged as a series of curved bands convex round the south. The monzonite next the gabbro has been completely altered.

On Palla Rabbiosa, the normal monzonite is obliquely or rectangularly crossed by successive intrusive bands of monzonite and granite aplites, flesh-coloured syenitic rock, with tendency to porphyritic structure, and augite diorite and anorthosite varieties like the later dykes in the Rizzoni and Riccoletta cross-faults. A thick band of coarse-grained gabbro directed N. 35° W. forms the high point at the south end of the spur, and is intercalated by a north-south group of close-grained ultra-basic dykes. These appear to be transitional in character between a limburgite and a basalt type; they are dark, basic rocks with much olivine and augite, and little felspar. A slightly curved line drawn E.N.E.-W.S.W. through the ridge north of Cadinburt Basin and N.W.-S.E. through the southern spurs would connect this group with the basic dyke on the north ridge. This curved line is parallel with the N.N.E.-S.S.W. lines of fault and strain at the other localities of cross-cleavage and cross-compression.

In a cleft between Rabbiosa Peak and another near it which has the same name, there is a band of the flesh-coloured syenitic rock, directed N. 50° E. The other summit south of this cleft presents the continuation of the coarse-grained gabbro present in the opposite point, although here the strike has curved to W.N.W.-E.S.E. A finer-grained pyroxenite variety accompanies the coarser-grained and is crossed by dykes of syenite aplite and porphyrite. The aplitic dykes have the N.N.E. or N.E. direction characteristic of the Judicarian strike-cleavage, and have been injected transversely across the curved strike of outcrop of the gabbroid rocks.

The Toal Masson spur has several aplitic dykes, occurring banded with the pale, grey-green felspathic monzonite in W.N.W.-E.S.E. direction. A microscopic slide prepared from the aplite shows "an even-grained, holocrystalline mixture of orthoclase, plagioclase, and quartz, with a few fragments of a chloritic mineral (after Biotite)." While this is a normal aplite, it may be compared with the crushed aplite rock at Allochet (p. 131). Altogether, throughout Monzoni, the paired occurrence or segregated bands of orthoclastic and plagioclastic varieties of lamprophyre, and the intimate association of these with dykes and threads of anorthosite and allied labradorite types is the leading feature of the later injections in or near the cross-fault of the gabbro and monzonite masses.

The system of strain-curves as I have indicated them in the map are made up of the E.N.E.-W.S.W. strike (in the north ridge) bending to N.N.E.-S.S.W., then to N.N.W.-S.S.E. and then N.W.-S.E. strike. These curves are essentially torsional strike-curves due to the action of a cross-thrust from E.N.E.-W.S.W. direction.

On the western slopes of Palla Rabbiosa, the monzonite of the Rabbiosa segment is faulted against the altered limestone of the Costella segment. The fault-plane between them is a N.N.E.-S.S.W. fault (almost north-south), parallel with the Malinverno fault. The calcareous strata of Pesmeda and Costella, have subsided relatively to the igneous rocks, and the latter have been driven westward. The limestone is a much disturbed inthrown portion of the calcareous rocks in the Vallaccia Mountain (*cf.* pp. 103, 104).

The Toal Foie Localities.

The Toal Foie localities for contact minerals are situated above and below the 2300-mètre contour. They are most easily approached from the Pesmeda side; from Monzoni Alpe it is best to go over the Col at Costella. A rough track then leads southward from a spring at the outflow of the Cadinburt basin at about the height of 2300 mètres and gradually ascends eastward. Where the N.N.E.-S.S.W. Pesmeda fault is crossed, a reddish dyke of liebenerite porphyrite occurs in the monzonite. It is striated in the direction N. 50° E. The hornstone below the shear-plane is 5 or 6 mètres thick and is intercalated with close-grained or serpentinous bands and threads of porphyrite.

Two dykes of a camptonite variety, with augite and some nepheline, occur at some little distance from the Pesmeda fault in N. 25° W. direction. These occurrences probably follow the local direction of the lines of strain round the south of the Palla Rabbiosa.

The remnants of altered sedimentary rocks at Toal Foie are all coloured blue in my map to bring them out clearly in the map, but their age is quite indefinite. It is quite possible that they represent fragments in a shear-zone east-west through Rabbiosa on its southern declivity, representing a displaced part or branch of the median fault-zone on the north slopes of Monzoni. Such a shear-zone would inevitably have been cut by the Pesmeda N.N.E.-S.S.W. fault and the inthrow on the west of this fault.

The first Toal Foie locality occurs in a direct line south from the dyke of liebenerite porphyrite. It contains good specimens of fassaite and its pseudomorph monticellite, also olivine in joints of the monzonite. The second locality is a little eastward and rather lower; it has good specimens of spinel and brandisite. The third is immediately north of the spinel locality; serpentine and troctolite are found in it. The fourth is a few yards east of the third; it contains good fassaite and idocrase. The fifth is higher and close to the two camptonite dykes and the old shear-plane; it contains anorthite and spinels. The sixth, a little higher than the fifth, has fassaite and serpentine.

The fourth locality may be briefly described as an example. It is an exposure of thin-bedded limestone, about 14 mètres thick, and strongly crumpled, cleaved, and sheared. Bands of serpentine and hornstone are interlayered with the creamy altered limestone, and there is a definite inclination (15°-20°) to the south-east. The north-north-west and east-north-east cleavages are dominant. The fact that the serpentinous igneous threads are crumpled along with the limestone, shows that they had been intercalated at least before the latest stages of cross-compression in this locality.

On the other hand, the decomposed and serpentinous bands in the limestone of the Toal Foie localities seem, in some cases, to be connected with close-grained basic injections. And as diabasic dykes in other parts of Monzoni pass through the varieties of gabbroid rock, they must have been intercalated into the limestone quite late in the local sequence of eruptivity. They are very like the "Pietra Verte" aphanitic or serpentinous bands in the downslip fault-zone of Punta di Costabella, which are fine-grained intercalations associated with the plagioclastic augite porphyrite of the main sill.

The "Pesmeda" or "Costella" Fault-Dyke.

The limestone of Costella Peak, west of Monzoni, is a strongly-sheared portion between the calcareous rocks of Pesmeda and the Monzoni igneous rocks. The Pesmeda area has been downthrown relatively to the Monzoni rocks, and this downthrow cannot be explained as the result of a merely local inthrow at the western periphery of Monzoni. It is part of a downthrow that has occurred continuously across a long stretch of country. Reference to my fault-map will show that Costella is in the line of the leading Judicarian fault between a N.N.E.-S.S.W. direction of downthrow on the west, and upthrow on the east, a fault which I have now traced from the east side of Sella to Monzoni Alpe and Monzoni. The bedding-planes in the Costella limestone, immediately west of the Monzoni fault, strike N. 75° W., and dip 30° N.N.E., but are contorted and twisted, so that they turn to N. 75°-80° E., and dip N.N.W. The superinduced Judicarian strike, N. 25° E., with steep dip

S.S.E., is also developed as a cleavage-system. Accordingly, the rocks on the north face have been twisted from the W.N.W. strike round the north and west, and the cleavage planes incline to Monzoni. The whole strip of limestone is strongly cleaved by vertical planes directed N.N.W.-S.S.E., corresponding with the strike direction of the latest cleavage-strains in the adjacent Rabbiosa part of Monzoni (*cf.* fig. 30, III.).

The "melaphyre" west of Costella is a dyke-and-sill invasion in the Vallaccia limestone. At the Col it runs westward upon planes that strike N. 20°-30° E., and are inclined towards E.S.E. The dyke-rock is composed of nodular aggregates packed with plagioclase and augite crystals, and embedded in a more homogeneous ground-mass, in which large augite crystals are dispersed. It closely resembles the Pocol and Camorzao fault-dykes.

Nearer to Punta Vallaccia summit, the prevailing cleavage in the calcareous rocks is N. 50°-60° E.; now, both the E.N.E. and the N.N.E. cleavage are superinduced strikes, but the E.N.E.-W.S.W. Vallaccia strike is that which is common to the continuation of the strata westward in the Monzoni and Contrin Alpes, whereas the N.N.E. cleavage and steep dip towards S.S.E. is a cleavage-system strongly developed at those places where later faults have dislocated this earlier strike, *e.g.*, (1) at the fault between Monzoni Alpe and the Selle range; (2) at the Pocol fault; (3) at the fault-group west of Forca Alpe and Col Ombert. In all these places the N.N.E.-S.S.W. fault-lines have dislocated the Contrin Alpe and Monzoni Alpe thrust-mass, and displaced a leading E.N.E.-W.S.W. strike-fault with downthrow on the south.

The mineralogical resemblance of the Costella dyke with other fault-dykes in the Monzoni Alpe, Costabella and Campagnazza, is so strong, that there can be no hesitation in associating it with the virgating group of porphyrite dykes that run N.E.-S.W. or E.N.E.-W.S.W. through Monzoni Alpe. In direct E.N.E. line with it, there are the Pocol and Camorzao fault-dykes. The Costella dyke cannot be older than the virgating fault-system with which it is associated. But it has subsequently suffered torsional shearing along with the limestone in which it occurs; the torsion being towards a more and more diagonal direction of strike. The subsequent shearing may, therefore, be said to be due to the continuance of the differential movements in the same sense as before—namely, downthrow of the calcareous rocks west of Monzoni, but locally strongly accentuated in the proximity of a leading N.N.E.-S.S.W. fault.

The question comes to be, what is the age of the Costella and Monzoni Alpe virgating group of dykes relative to the age of the various intrusions in Monzoni Mountain? But the discussion of this question must be reserved until after a short review of the whole sequence of injections in Monzoni.

The monzonite rock east of Costella has shared the distortional effects at the cross-fault. The joint-slabs with northerly inclination strike N. 60° W. near the Costella limestone, but curve towards a N.N.W.-S.S.E. direction as they run eastward, so that they cross the ridge obliquely. Two occurrences of pink syenitic porphyry run along the N.E. joint-slabs that incline south-east. Two augite-diorite threads enter the Costella limestone at the contact-zone; the Costella rock is crystalline, but is not so highly metamorphic as the Predazzite rocks in the Selle Lago area, nor so metamorphic as the contorted fragment of altered limestone that occurs a little east of Costella, at ca. 2240-2280 mètre contour. It resembles rather the sheared limestone at the contact-zone between the Allochet ridge and Monzoni. The latter zone is a curved fault-limit N.N.E.-S.S.W., curving to N.N.W.-S.S.E., which was determined by differential movements *subsequent to the monzonite and olivine gabbro intrusions;* and the aplite and lamprophyre, augite-diorite and syenite types in the sedimentary strata of Allochet were later fault injections. The same conclusion seems applicable to the Monzoni-Costella fault-limit; farther south the liebenerite porphyrite dyke and the camptonite dykes are present close to the fault-zone, and the strain-curves with which the aplitic series of injections in the Rabbiosa area of Monzoni are associated, follow the same direction as the Allochet fault-curve.

The sickle-shaped strike-curve round the west is, therefore, characteristic of the later cleavages and injections, both in the Allochet peripheral limit and in the Costella peripheral limit. As the monzonite was *cleft by* these strain-curves, it must have consolidated before they developed. On the other hand, in Monzoni Alpe, the plagioclastic augite porphyrite and melaphyre types are *present in* these lines of strain.

The east-west fault-zone forming the original northern limit of the monzonite is locally obliterated by the downthrow at Vallaccia and Costella, it is ,in fact, cut off by the N.N.E.-S.S.W. Costella fault-zone. Taking all my observations into consideration, I would conclude that the Costella and Monzoni Alpe dykes were not present in the Werfen strata and limestone when the first monzonitic sill was intruded at the intersection of the leading E.N.E.-W.S.W. and E.-W. faults. But this opinion is based on partial knowledge in the case of the Costella fault-dyke, as I did not attempt to follow it farther south, or to determine the relations of the Monzoni and Predazzo areas of intrusion.[1]

Summary.

The relations of Monzoni Massive to the sedimentary strata were outlined in the preliminary pages of this chapter, where it was stated that the earliest intrusion at Monzoni was a monzonite dyke ascending a steep fault-fissure, initiated during torsional dislocation of old thrust-masses. The thrust-mass was the Uomo-Allochet thrust-mass, whose general strike was N. 80° W.; its limiting-fault on the south passes east-west through the Campagnazza as a reverse fault in the midst of Werfen strata, the Uomo-Allochet group of Werfen strata having been thrust towards the south above the Werfen strata in the lower levels of the Campagnazza. The Werfen marly strata of the Uomo-Allochet thrust-masses are succeeded by the calcareous succession; the Forca Alpe reverse fault passes through the calcareous rocks; the marly Werfen strata of the Forca Alpe thrust-mass have been thrust to the south above the calcareous rocks of the Uomo-Allochet thrust-mass. The Werfen strata present in Monzoni Alpe belong to the same thrust-mass as the "Forca Alpe" series.

These reverse faults had an almost east-west course, and were, therefore, obliquely intersected by the later E.N.E.-W.S.W. fault, at which the monzonitic magma was locally intruded. This E.N.E.-W.S.W. fault can be traced obliquely crossing the north-dipping bedding planes in the limestone strata of Punta di Costabella and Camorzao; it intersected the east-west Uomo-Allochet fault at the Allochet and Monzoni Alpe area, throwing down the strata on the south. The monzonitic magma rose copiously at the area of intersection and inthrow.

More especially the magma invaded the Uomo-Allochet thrust-mass, and swelled out in the horizons of the passage-beds and the succeeding calcareous rocks, engulfing and absorbing large masses of inthrown limestone. The floor of the original invasion of monzonite may be regarded as a steep downslip shelf inclined north in the Uomo-Allochet thrust-mass.

[1] I avoided the Predazzo district because I knew that Professor Romberg was investigating it. There can, however, be no great difficulty with regard to the general structural relationship between the areas. In treating Buffaure, Mount Donna, and the Canazei area, I have shown how magma derived apparently from one reservoir rose at different localities of fault-intersection into the Triassic horizons, and the earlier inflows might subsequently be farther distanced by horizontal shearing at later cross-faults. In the case of augite porphyrite, my geological map gives evidence of undoubted communication between adjacent localities of sill-intrusions by means of the steep cross-faults and strike-faults, *e.g.*, Buffaure, Col Larisch, Col Guschel.

The summit of Malinverno I regard as a fair sample of the original *roof* of the first monzonite intrusion; it shows how the calcareous strata were rent and the monzonitic magma distributed itself as a close network of sills and connecting threads.

The Cima di Selle strata on the north of the E.N.E.-W.S.W. Camorzao fault were being thrown down by a nearly parallel fault some distance farther north, viz., the fault with N.E.-S.W. strike, at the steep south flexure of the Werfen and calcareous rocks on Col Guschel and Monzoni Alpe. Therefore, a band of inthrow was present on the north of the monzonitic intrusion in virtue of these two oblique faults; and there was, going on west of the Monzoni Alpe, the protracted movement of inthrow to the west of the main cross-arch that tended to form in virtue of the Judicarian cross-compression. These movements of inthrow were *initiated* as part of regional movements, just like the movements of inthrow on the north and west of Rodella; the ascent of the monzonitic magma was a local circumstance that can only be regarded as one of the local consequences of the intense strains developed in the crust during differential torsional movements of the strata in contiguous fault-blocks.

Subsequently to the intrusion and partial consolidation of the monzonitic magma, the mass of igneous rock became a fault-block for itself. Differential movements were set up at the peripheral faults and the floor and roof contact-zones, and subordinate fault-fissures occurred within the fault-block, some of which did not continue into the neighbouring fault-blocks. But this isolated and independent history of a fault-block is not limited to the masses of *igneous* rock in the Dolomites. It is characteristic of all the main fault-blocks in the district—the Rodella fault-block, the Sella Massive fault-block, the Contrin Alpe fault-block, and numerous other examples demonstrate, that wherever the earlier faults in the deformational history happened to bring alongside of one another fairly big masses of rock with strongly contrasted physical characters, extreme localisation of thrust and fault effects ensued. Represented on the geological map, the localised effects are very puzzling; probably the chief features are the sudden stoppage of a fault, or group of faults, at an older fault; the occasional reappearance of one or more of them at a short distance, but generally with somewhat altered relations of throw; the convergence of numerous faults in one disturbed fault-zone; the prevalence of curved and sickle-shaped fault-figures. All these tectonic features are presented at Monzoni, but they are also presented in many fault-blocks composed of sedimentary strata, and are the *natural result of a long history of cross-*

deformation. In all cases, care is needful to arrive at a due appreciation of local effects and regional causes.

To the north of the original invasion of monzonitic magma, a broad band of sedimentary rocks was subsiding relatively to the Uomo-Allochet thrust-mass and its massive sill. The calcareous rocks belonging to the Forca Alpe thrust-mass were gradually lowered, and were brought alongside different horizons of the Uomo-Allochet thrust-mass. New faults were initiated as the cross-compression from time to time intensified, the tendency being for the faults at more advanced periods to be more diagonal in direction than the earlier. Thus, in the earlier stages, the intersections were chiefly E.N.E.-W.S.W. faults, with older strike-faults directed W.N.W.-E.S.E., or nearly east-west; but as torsional movements progressed, there were far more varied directions of intersection, as shown in the geological map. The cross-trough in N.N.E.-S.S.W. direction developed on the west of the Monzoni area, and with it are associated the virgating N.E.-S.W., E.N.E.-W.S.W. faults that run eastward through Monzoni Alpe. All of them converge in the old east-west limiting-fault north of Monzoni; they neither continue into the downthrow fault-block on the west, nor into the Monzoni fault-block. The bedding-planes in the segments of rock between these branching faults have been *turned* towards a N.E.-S.W. strike, but are very much torn and sheared; the porphyrite dykes in Monzoni Alpe run obliquely across bedding-planes, and the two chief dykes are fault-dykes north and south, or rather west and east, of the long triangular-shaped inthrown wedge of limestone between Monzoni Alpe and the Pocol fault. The twining of the various Werfen and calcareous horizons on Monzoni Alpe are associated primarily with the inthrowing of rocks on the west of the leading N.N.E.-S.S.W. fault; secondarily, with the development of subordinate torsion faults, and their stoppage at the old east-west fault-zone.

In the course of the continued movements, the monzonitic sill was consolidating *above* a crushed and attenuated floor of Werfen and Permian rocks, *below* an entirely calcareous roof, and bearing in its midst numerous calcareous fragments (fig. 29). The monzonitic sill was cut by two leading faults, limiting the fault-zone, which I have called the "median zone of injection" in Monzoni. From the supply-magma there differentiated out in succession—(1) a gabbro type of monzonite, which thoroughly impregnated the internal body of the earlier normal monzonite sill, and has a roughly gneissose structure; (2) variously constituted series of olivine gabbro types, copiously injected in the main fault-zone, and running out as dykes in the peripheral E.N.E.-W.S.W. fault, also with gneissose structure; (3) pyroxenite varieties of olivine gabbro, with tendency to highly schistose structure, and full of calcitic and serpentinous veins.

At the north limit of its intrusion, the olivine gabbro is in contact with schistose or serpentinised altered limestone thrown down from the original sill-roof; at the south limit, with crushed and gneissose gabbroid monzonite belonging to a previous injection into the fault-zone.

The whole complex of sill and dyke intrusions was *then strongly folded along a N. 50° E. strike, the steeper flexures being towards N.W. the less steep towards S.E.* The folded rocks were cleaved parallel with this strike, by intersecting sets of inclined cleavage-planes, inclined N.W. and S.E. These inclined towards N.W. are very strongly slickensided and have wavy pressure-surfaces. Up to this point in the history of deformation, the faults and cleavages in Monzoni had followed some E.W., E.N.E.-W.S.W., or N.E.-S.W. direction of strike. Subsequently, the crumpled mass was cut by cleavage-systems, directed N.N.W.-S.S.E. (N. 30° W.) and N. 10°-15° east. In the Riccoletta and Malinverno areas, the N.N.W.-S.S.E. cleavage-planes are highly inclined to the east, and show pressure surfaces indicating that the main cross-thrust acted from E.N.E. to W.S.W.; in the Rizzoni-Allochet area, the local thrust continued to act towards the east, pushing the igneous rocks eastward above the sedimentary rocks of Allochet.

The crumpling and thrusting at this epoch took place in directions transverse to the local torsion-strikes, and produced the hook-shaped fault-curves of the district. The transverse dislocations were acute torsional effects due to the wrench-strains in the rocks. These strains, as depicted in fig. 30, formed the basis of the characteristic intersection or convergence of N.N.E.-S.S.W., N.-S., and N.N.W.-S.S.E. faults. As I showed in the case of Rodella, the local inthrow areas were from this time forward well-defined.

The subsequent phases of movement are characterised by extreme localisation of the effects produced; such localisation being due doubtless to the development of the cross-fractures in N.E.-S.W. and N.W.-S.E. directions, which segmented the rocks into distinct fault-blocks of small size.

In the Riccoletta and Rizzoni fault blocks, the gabbro and monzonite rocks were cleaved and crumpled in east-west direction; the maximum effects were produced close to the east-west median fault-zone. The rocks of the olivine gabbro and pyroxenite are there converted into a narrow crush-band of gabbro schists full of secondary minerals, parallel with the east-west crumpling; the normal and gabbroid monzonite types on the south of the fault-zone were converted into a rough, banded gneiss with lenticles of both varieties, especially next the main fault. North-south crumpling and cleavage, or nearly north-south, is well developed in the vicinity of the leading cross-faults; more especially, the rocks show local cross-crumpling with reference to a strike N. 10°-15° E. Leading Judicarian faults in this direction having been initiated, there came to be associated with these leading faults, according to the local resistances, certain branch-faults in N.S., or slightly N.N.W.-S.S.E. direction,—similarly with the cleavages.

The resistance to the cross-compression was greater in the case of the igneous masses than in the sedimentary strata above these; accordingly round about the igneous masses the strati-

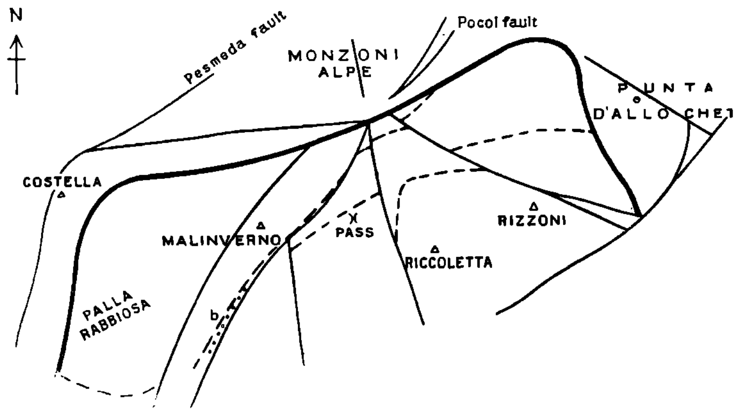


FIG. 34.—Sketch-map showing leading fault-curve of Monzoni, round west, north, and east.

— — — — older faults with gabbro injections. b=brecciated fault-rock.
———— later cross-faults N.N.W.-S.S.E., N.N.E.-S.S.W., or N.-S.

fied groups yielded and sagged inward; the igneous crust-slices creeping relatively in all directions above various horizons of sedimentary strata. The series of more advanced or later thrust effects are at Monzoni quite comparable with those described above for the Forca-Alpe thrust-mass (pp. 97-100). And we have in such cases the fundamental structural facts of any typical "Central Massive" in the Alps.

Thus the rocks of Cima di Selle, Vallaccia, Costella, after their subsidence on the north of the intrusive rocks have been subject to differential shearing round a torsion-curve convex towards the north. This torsion-curve, which is represented in diagrammatic form in fig. 34, is the leading strike-curve

("Leitlinie") of Monzoni; and is easily recognised as the leading strike-curve of many other localities that I have described, *e.g.*, the Campagnazza, Allochet itself, Bufaure, Rodella Mountain, Gröden Pass, &c. This curve is essentially presented in every part of my geological maps of the Dolomites by the forking N.E.-S.W. and N.W.-S.E. faults, or in general terms by the fan-like arrangements of faults which I have previously termed "fault radii" diverging towards S.W., S.S.W., S., S.S.E., and S.E. directions. In the case of Monzoni Alpe, this arrangement is clearly displayed in relation to a *local centre* in Monzoni Alpe where N.N.E.-S.S.W. and N.N.W.-S.S.E. fault intersected an *old fault-zone*. Similarly at Rodella Mountain this arrangement has relation to a local area where leading N.N.E.-S.S.W. and N.N.W.-S.S.E. faults, with down-throws on the west and east respectively, intersected an old fault-zone parallel with the W.N.W.-E.S.E. strike, and having downthrow on the north.

For the complete development of the leading fault-curve round the north the essential conditions have been shown above to be the Judicarian *wrenching-strains* that affected an area already sliced by thrust-planes and distorted by torsion-faults and folds. The previous deformational effects having brought about a very mixed patchwork of different kinds of rock at about the same crust-levels, pre-disposed the area for the production of extremely local effects with reference to innumerable separate centres of weakness. The point I wish to insist upon is that in the main structural features of Monzoni there is nothing particularly distinctive, although it happens to be an igneous massive; the characteristic Judicarian fault-curve and diverging local fault-radii have been developed quite as markedly in the mountain-massives in the Dolomites that are composed wholly of sedimentary strata. It is only necessary that previous crust-movements, or intrusions, or local conditions of sedimentation should have brought alongside one another at the same horizon in the crust rocks of very different physical characters.

The fault-curve round the north is that which I have distinguished as the "Judicarian" curve, it was not determined until an advanced stage in the Judicarian series of cross-movements parallel with the N.N.E.-S.S.W. strike. It will be recognised also as the Peri-Adriatic curve, the leading Alpine curve, the leading Mediterranean curve. In the Dolomites, there was a long preliminary period when the E.N.E.-W.S.W. which I have called the "Asta" strike was the leading torsion-strike produced in virtue of the Judicarian series of cross-movements.

The fault-radii in Monzoni were the seat of a third group of injections including certain more acid and more basic types of rock than any of the preceding. The basic types are dykes of specialised orthoclastic, porphyritic, or hornblendic varieties of gabbro and olivine gabbro, olivine monzonite, and diabasic rock, and dykes of biotitic or uralitic diorite. The acid types are exemplified in the Rizzoni, Riccoletta, Malinverno, and Rabbiosa faults and their immediate neighbourhood by normal aplites, syenite aplite, pegmatite, quartz syenite, and quartz monzonite; orthoclastic lamprophyre (syenite or monzonite porphyry) in association with plagioclastic lamprophyre (kersantite) types; anorthosite and highly felspathic (chiefly labradorite) varieties of monzonite. A dyke of liebenerite porphyrite occurs near the Pesmeda fault, and small dykes of ultra-basic character occur in groups or individually in fissures almost north-south in direction; these are the camptonite and limburgite types and are later than all the others.

Original Gneissose Structure.

A feature still more marked in the later or third group of injections in Monzoni than in the gabbro series, is what might be called their side-by-side occurrence as differentiated products; in other words, their original gneissose association. For example, the plagioclastic lamprophyre occurs either as an independent ramifying dyke in the vicinity of the orthoclastic complementary form, or in actual juxtaposition with it, or as nodular segregations within it. Thus there are, more especially in the later intercalations in Monzoni, the same variations of original gneissose segregation structure to be observed as in many of the occurrences of porphyrite in Fassa and elsewhere. I need only mention the banded richly-augitic and richly-plagioclastic porphyrite on the plateau east of Lago di Selle, and the nodular or block-structure so highly characteristic in the whole neighbourhood. But this gneissose structure cannot have been inherent in the magmas at their first injection as copious sills, since at Monzoni there is typical "normal monzonite," at Bufaure and other Fassa areas there is typical "augite porphyrite," of granitic and porphyritic structure respectively. The gneissose, schistose, aplitic, fluidal, amygdaloidal, and block-structures must, therefore, have been assumed locally, and, in relation to varying degrees of local crust-pressure and mobility, experienced by different parts of sill magmas during the processes of their differentiation and consolidation.

The "serpentinous schists" or "aphanitic tuffs" in the sedimentary strata at various places (Forca Alpe, Costabella, &c.), are examples of magma which invaded a fault-zone in calcareous rocks as an innumerable system of thin sill-threads, and consolidated there under extreme conditions of heat and pressure in planes of differential movement. Again, the fluxion-structure of "melaphyre" types is especially characteristic of basic contact zones of a larger sill (usually a plagioclastic type of augite porphyrite), where the magma has been *kept moving* as it consolidated. It is likewise presented by the thin sills in the systems of inclined cleavage-planes that developed in the Costabella limestone during torsional movements, and were subject to frequent differential movements. As showing the influence of environment, it may be noted that, although the porphyrite intrusions in the Werfen strata of the Uomo and Allochet slopes are continuous with those in the Costabella limestone, their mineralogical character is much richer in the plagioclastic relatively to the augite or olivine constituents.

In respect to the "cellular" character associated with the flow-structure, reference may be made to the cases observed on the east slopes of Bufaure and at Varos, where the vesicles are elongated parallel with the direction of the shearing-movements at the particular fault-planes.

These are only a few of the leading varieties of structure and composition shown by the subterranean flows of this district.

On the other hand, many of the so-called "tuffs" and "breccias" in Fassa owe their character to subsequent deformation and alteration of the porphyrite sills.

The Porphyrite and Melaphyre Intrusions.

The very numerous differences in the actual composition and structure of the porphyrites in this area have been called attention to in the course of the descriptive chapters, and it has been pointed out that within a quite small sill or dyke the original segregation effects have produced very different appearances (*cf.* pp. 91, 92). In very many cases localised shearing strains have caused a distinct block-facies or tuffoid facies of the porphyrite, in others fresh intercalations have impregnated the rock, inducing serpentinous changes at planes of contact, fissure and joint-cleavage. These variations in the porphyrite must be studied in reference to the particular locality and environment in each case, and I have mentioned above the more interesting particular cases in the area examined.

The question that remains to be treated in a more general way is the period of injection of the porphyrites as compared with the period of injection of the intrusive rocks at Monzoni. Throughout this paper I have shown—(1) that massive porphyrite sills and dykes were intruded at leading lines of fracture directed N.N.E.-S.S.W., and entered the previously existing E.N.E.-W.S.W. lines of oblique fracture in the older thrust-masses (2) that the earlier porphyrite sills and dykes were cut by later fractures and locally brecciated and sheared at such subsequent fault-planes, and intercalated with veins and dykes.

Professor Broegger cites a case in the Predazzo area where porphyrite rock has been altered at contact with monzonite. This case I had to leave unvisited, but before it can be regarded as a final general proof of the greater age of the copious porphyrite intrusions, one would require to make sure which variety of monzonite is concerned. If the altered rock be the coarsely-crystalline augite porphyrite, and the monzonite be the normal type, then this contact case is conclusive. But if there be any doubt about the monzonite, then farther proofs are required. Is the monzonite possibly one of the later types? Such as gabbroid monzonite, porphyritic monzonite, quartz monzonite, or highly felspathic monzonite—all of which are present at Monzoni and younger than the normal type, the last-named type being indeed one of the very latest intercalations in Monzoni.

Comparing the age of the porphyrite dykes in the immediate vicinity of Monzoni, with the monzonite and gabbro in Monzoni, fairly satisfactory results are obtained upon the tectonic grounds I have indicated. Take, for example, the highly segregated porphyrite dyke in the Pocol N.E.-S.W. fault-line, and the olivine-bearing dykes in the Monzoni Alpe. These dykes occur in fractures that dislocate the superinduced arch-form with E.N.E.-W.S.W. strike in the Contrin and Monzoni Alpes, and converge towards S.W. There they meet the E.N.E.-W.S.W. fault-contact zone between the calcareous rocks of Selle Massive and the Monzoni area. The Pocol fault was the one to the south-east of which the Selle limestone was thrown down, and it must have been after its downthrow that the olivine gabbro injections occurred in the Monzoni area, since they run across the fault-zone and enter the downthrown calcareous rocks. My conclusion would be that both the olivine gabbro injections and the porphyrite were intruded after the inthrow of the Selle limestone, and that the Pocol and Monzoni Alpe porphyrite and melaphyre were younger injections than the original monzonite, inasmuch as they ascended faults limiting an inthrow that occurred when the monzonite was present amidst the Triassic rocks.

It will be remembered, I showed that the monzonite magma ascended in a trough-shaped band of inthrow where a strip of the Uomo-Allochet thrust-mass was subsiding to the north, and a part of the Forca-Monzoni Alpe thrust-mass was being thrown down to the south. The inthrowing of the sedimentary strata along this band still continued after the ascent of the monzonite magma *except at the area of the sill itself;* that area became one of local uprise and differential shearing. Applying, therefore, the same tectonic evidences that I have just used for the Pocol and Monzoni Alpe fault-dykes, the porphyrite and melaphyre injections in the Camorzao and Allochet area can be similarly shown from my map to be younger than the original monzonite sill intrusion. For they not only occur in cleavage and fault-planes developed during the peripheral sagging of the sedimentary strata; but some of the fault-planes, or parallel faults, fractured the monzonite of Monzoni, and were there intercalated with the later injections into the original monzonite sill (*antea*, pp. 124, 136, 138, 146, 163-165, 168, &c.).

Within Monzoni, the injections that followed the earliest sills of normal and gabbroid monzonite types, namely, the olivine gabbro, diabasic and pyroxenite varieties, the augite diorites and plagioclastic lamprophyres, are those which, in their mineralogical character and mode of distribution, seem to have most in common with the intrusive porphyrites and melaphyres. These injections in Monzoni occur pre-eminently at the leading fault-intersection area on the north slopes of Riccolette or in the lines of the N.E., N.N.E., N.S., and N.N.W. cross-faults. And a glance at my geological map shows that many of the porphyrites and melaphyres in the immediate neighbourhood of Monzoni run continuously from older leading faults into the N.E., N.N.E., N.N.W., and N.W. cross-faults.

The Evolute Form of the Monzoni Massive.

The form of the Monzoni Massive represented in fig. 29 only professes to be a "generalised form," because to be really accurate one would have to visualise a series of stages. The "Monzoni" we now see was not formed by a *single* geological event but by a *history* of geological events, which was in progress when the igneous rocks of Monzoni were at a great depth within the crust, below heavy superincumbent masses of rock strata. In the first instance "Monzoni" was a simple wedge-shaped sill-mass with sill fingers intercalated in the strata, but during the progress of the Judicarian deformational movements that sill was added to, became a SILL-COMPLEX, which bulked more largely, pushed vertically and laterally, and *evoluted* itself as an intrusive mass thrusting itself within the crust. Space was provided for it by tears in the roof of strata, by partial absorption, lateral incrush, and involution of the sedimentary strata. Thus the "Central Massive" type of the present Monzoni group is a natural evolute, or overthrust, form assumed when molten rock-material intermittently ascends from a lower horizon to a higher at a locality of fault-intersection, and consequently of crust-weakness.

Compare the generalised form (fig. 29) with the actual transverse geological section of the Cima di Selle and Allochet series of strata (pl. xv., fig. 2). These represent strata close to the first monzonite sill, but which subsided fragmentarily after its entry. Neglecting the subsequent fragmentation, the flexures and flexure-faults coeval with the first inflow of monzonite are the steep flexure towards S.S.E. at Col Guschel and the steep flexure towards N.N.W. at Allochet. Between these oppositely-inclined flexures the strata had a definite trough-shaped arrangement, and the monzonite sill ascended a narrow E.N.E.-W.S.W. band of fault and steepest inthrow in the very heart of that trough-shaped arrangement of sedimentary strata. It ascended quite locally, only where the narrow band of inthrow obliquely intersected the older east-west Campagnazza fault; and it extended upward only as far as the equipoise of forces from above and below permitted it.

In many descriptions of wedge-shaped sills as well as of "laccolites" that have been given in geological literature, it is stated that their inflow arched the strata above them in domal form; I therefore strongly insist upon my observation in the case of Monzoni that the particular band of limestone strata entered by the sill was at the time of inflow *in process of sinking* steeply inward at the inthrow faults, and the Werfen strata south of the faults were being pushed and crumpled aside towards the south-east. While the ascending magma involved and engulfed fragmentary portions of the insinking calcareous rock, it clearly found easiest access amidst the multiplicity of fracture and shear-slip planes in the body of Werfen strata on the south. Thus, in *the first or inflow stage*, the magma tended at Monzoni as in many other places in this district, to follow the N., N.N.W. or N.W.-dipping planes of stratification in the Werfen series, and thus to assume a usual wedge-shaped sill-form, while immediately above the fault-intersection area it was absorbing insinking limestone into its midst.

The *second stage* is that of the *early consolidation processes and intermittent intercalations.* The peripheral zones cooled, escaping vapour passed into the strata of the roof and sides, and the contact strata were indurated and metamorphosed. As the crust-stresses still continued, the whole contact-zone became necessarily the seat of highly complex differential strains. So long as the strains were still supported by a torsional system of stresses twining the rocks from their former strike towards the N.E.-S.W. strike, new fractures and new invasions were bound to take place, each new set being oblique in direction to the previously developed set, and therefore intersecting them. Thus new areas of fault-intersections supervened, contiguous to the old, but contiguous *along a curve.* The original sill, while not yet wholly consolidated internally, was injected at the area of fault-intersection with gabbroid material that entered into the closest gneissose relationship with it, and passed along its whole length. Still later, at the time when many N.E.-S.W. fractures occurred in the district, a series formed across the combined sill, the most important being in line with the Pocol fault in Monzoni Alpe. Olivine gabbro ascended in the Riccoletta fault-intersection area, tailing off in the older contact faults, and consolidating there as finer-grained material than in its thick central body at the Riccoletta area of fault-intersection.

During this second, or consolidation and intercalation stage, shearing movements were going on at the peripheral contact zones, and the actual bulk of the sill-complex was from time to time being increased. As shearing movements proceeded, the tendency declared itself for the *sill-complex to assume an independent form* in relation to the band of insinking strata,—to pass from the "sill" phase to that of the "Central Massive." And the sedimentary "roof" of the sill-complex was, so far as its elasticity would permit, bound to share in any new form assumed by the sill-complex; if strongly attenuated and overstrained, it would be rent, and easily liable to fresh protrusions. The sill-complex drew its main feeders from that fault-intersection area within its interior, namely, the median fault-zone on the Riccoletta slopes. It therefore expanded upward and extended laterally with reference to the Riccoletta fault-intercalation area, and a certain unsymmetrical domal expansion of the intrusive masses began to take shape. *During the geological periods when the fault-vent continued intermittently active, the form of the sill-complex was capable of being re-moulded periodically in harmony with the localised crust-stresses.*

With regard to the lateral extension of the sill-complex, there is abundant evidence that it was driven towards the west and north-west on the *Malinverno* side of the fault-intersection area on the north slopes of Riccoletta, and towards the east and south-east on the *Rizzoni* side of that area (*cf.* Frontispiece photograph). The prevailing cleavage-planes of the monzonitic and gabbroid rocks of the complex accordingly incline towards N.W. and S.E. directions; the axis of elongation was parallel with the N.E.-S.W. or N.N.E.-S.S.W. Judicarian strike. Relatively to the sill-complex, the "Costella" limestone on the west, the "Cima di Selle" limestone on the north, the "Allochet" Werfen and limestone strata on the east, and the Permian and Werfen strata of the sill-floor on the south, all sagged inward; they were involuted in relation to the gradual evolute movement of the sill-complex. They twined round the resisting Igneous Massive, in relation to its long strike-axis in N.E.-S.W. direction, and its short transverse-axis in N.W.-S.E. direction.

In proportion as the evolute movements of the sill-complex towards Costella and towards Allochet proceeded, the wrench was greater in the Riccoletta area; the sill-complex found relief by the cross-fractures that diverge southward from that area, and a new series of magma intercalations passed into these fractures and old fault-limits. These intercalations were mainly the highly-differentiated pyroxenic bands and dykes, but plagioclastic patches and veins were also numerously distributed. The farther stages of injection need not be recapitulated here, as they are of the nature of incidental occurrences.

The outstanding structural feature in this outline of the evolution of an igneous mountain-massive is the existence of an *inthrow band or trough* in which a resisting mass of rock was locally accumulated, was then during farther crust-compression brought into differential relationship with more yielding rock-material, and driven outward from some local centre within itself. This centre was not its centre of mass, but its locality of greatest weakness, and was a gradually shifting centre. According to the precise position of this locality, the ultimate form of the mountain-massive was determined.

This result of *peripheral thrust* which I obtain for the igneous mountain-massive of Monzoni is a repetition of the result that I arrived at in 1893 for the "Dolomite" mountain-massive of Sella in Enneberg. But in the case of Monzoni, where the evolute rock-mass is composed of igneous material, the resemblance of its structural features to those of other igneous Central Massives in the Alps will appeal more directly to those geologists who may be personally unfamiliar with the "Dolomites."

But if a geologist will compare my geological map of Sella Massive (Q.J.G.S., 1899, p. 633) with that of Monzoni Massive or with the Monzoni fault-sketch (fig. 34, p. 170), he will at once see that the long axis in Sella, as in Monzoni, is the Judicarian strike-axis N.E.-S.W.; that the short axis in Sella is N.W.-S.E.; and that the bedding-planes of the rocks composing Sella Massive have been twisted towards this N.E.-S.W. strike, with dips N.W. or S.E. Farther, that the Mesules or west side of Sella Massive structurally represents the Malinverno or west side of Monzoni; the Pian de Sass and Pordoi side of Sella represents the Rizzoni and Riccoletta part of the Monzoni group; and the trough inthrow of Jurassic strata at the high central portion of Sella Massive, in the line of the N.N.E.-S.S.W. fault through the Massive, represents that fault-intersection and gabbro-injection area on the Riccoletta slopes in line with the branching N.E.-S.W. and E.N.E.-W.S.W. median fault-zone of Monzoni. To judge from the leading faults, there is precisely the same situation of long and short axes in the Bufaure porphyrite mountain-massive.

Thus the leading structural features are the same for a typical *igneous*, and a typical *calcareous*, massive in the Dolomites, and I have demonstrated in both cases that they are due to the twining-movements in the crust associated with any change in the direction of action of the prevailing horizontal compressive stresses. What the movements accomplish is the relative evolution and involution of rock-material belonging to different horizons of the crust, the differential displacements having reference to certain definite localities of fault-intersection and crust-weakness.

The general application of these results to Alpine areas is fairly evident on comparison of the geological maps of typical districts. As I wrote in 1899, "The principles thus demonstrated in Enneberg will be seen to involve the 'fan-shaped structure' of Central Massives. They could not fail to do so, since they have been deduced from the stratigraphy of Sella Massive in Enneberg, which presents a wonderfully symmetrical, although obliquely elongated, example of 'fan-structure.' . . . The problem resolves itself into involute and evolute movements of crust-slices with reference to central areas, the evolute slices tending ever to spread, the involute slices ever to narrow" (*Nature*, 7th September, 1899).

MAP NOTE.

The Bufaure Massive is coloured red in my geological map to show that it is mainly made up of intrusive porphyrite and melaphyre; but, as I expressly stated in the text, I only investigated the peripheral and contact relations of the igneous rocks to the sedimentary succession. There may be in the interior of the Massive other involved patches of the Wengen-Cassian bedded lavas and sedimentary tuffs such as I observed at Toal-longo and Sasso di Rocca. Where they occur, these remnants are like the lavas and fragmental tufaceous grits and fine breccias I described at Varda in Buchenstein Valley, at the N. Rodella fault-zone, and at Mount Donna. The tuffs show some remarkable alteration effects where they have been subsequently invaded by the intrusive sills, dykes, and vein-intercalations of porphyrite or melaphyre (*antea*, p. 56, microscopic slides of two specimens of the sedimentary tuffs taken from an impregnated contact zone in Canazei). I have mentioned in the text several occurrences of Wengen-Cassian strata which will not be found in my geological map; as it was impossible for me to undertake an exhaustive survey of the area, I purposely omitted to enter in my published Map small patches of strata whose precise continuation or occasional re-appearances along faults I had not time to trace out. The same holds good for many occurrences of limestone in the igneous rocks of the north slopes of Monzoni. The Monzoni portion of the map (see footnote, p. 140) and the transverse sections through Monzoni (pl. xviii., figs. 1, 2) have been treated upon general lines, merely to illustrate the leading features of the geological structure.

Scale 1:25,000

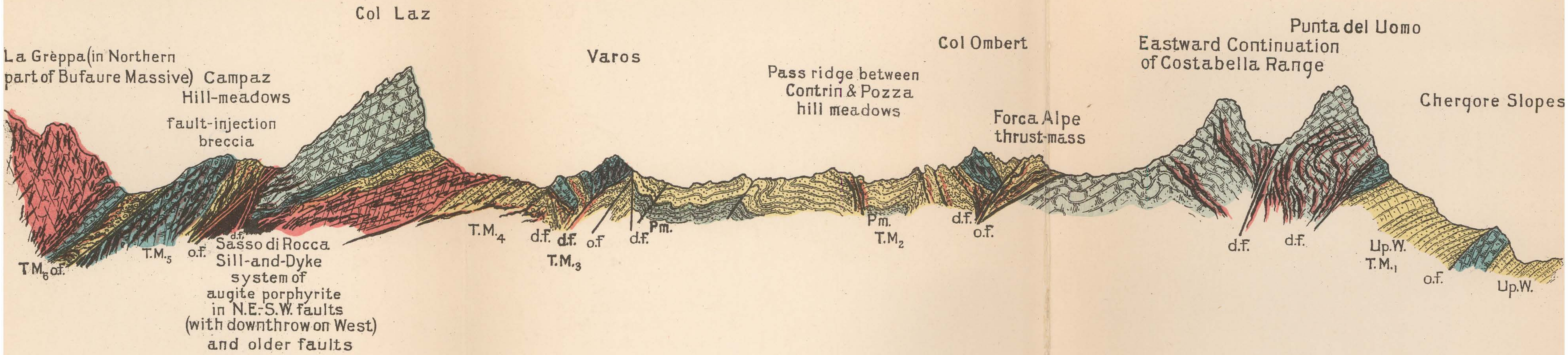


Fig. 1.—Transverse section from the middle of the Bufaure massive to the Fuchiade slopes or eastern part of the Campagnazza. Pm = Permian strata: Triassic as before; *o.f.* = overthrust faults; *d.f.* = downslip faults. TM_1 = Thrust-mass of Uomo and Allochet ridge. TM_2 = Thrust-mass of Forca Alpe, Col Ombert, and Contrin Alpe. TM_3 = Thrust-mass of Varos and Col del Larisch. TM_4 = Thrust-mass of Col Laz. TM_5 = Thrust-mass of Campaz. TM_6 = Thrust-mass of Upper Fassa.

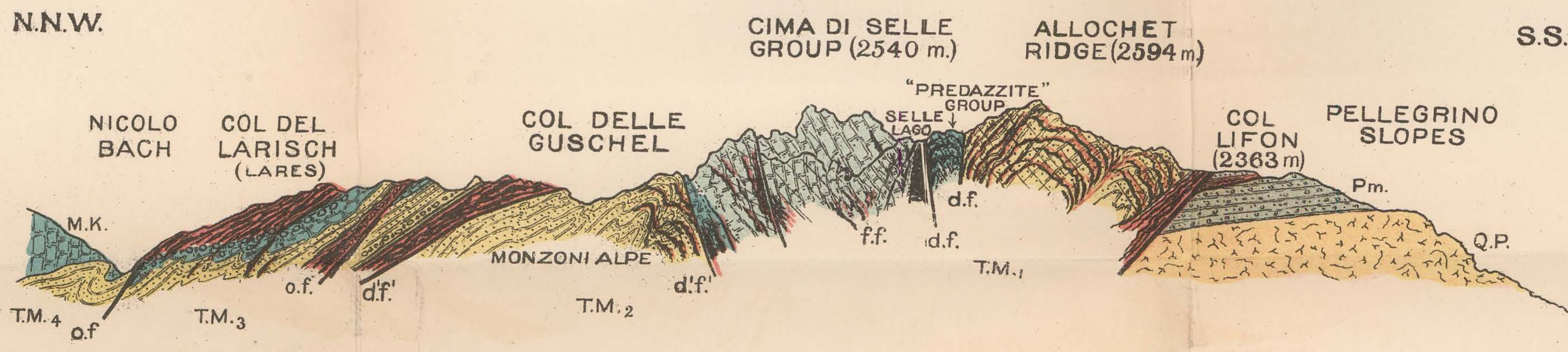


Fig. 2.—Strata as in Fig. 1. *o.f.* = overthrust faults; *d'f'*, *d'f'* = downslip zones north and south of Monzoni Alpe, with sills and dykes of augite porphyrite.
Strike of Monzoni Alpe arch E.N.E.–W.S.W.
ff = shear and injection zone into which the monzonitic rocks of Monzoni have been injected, strike E.N.E.–W.S.W.
Monzoni mountain being immediately west of this section.

Scale 1: 25,000

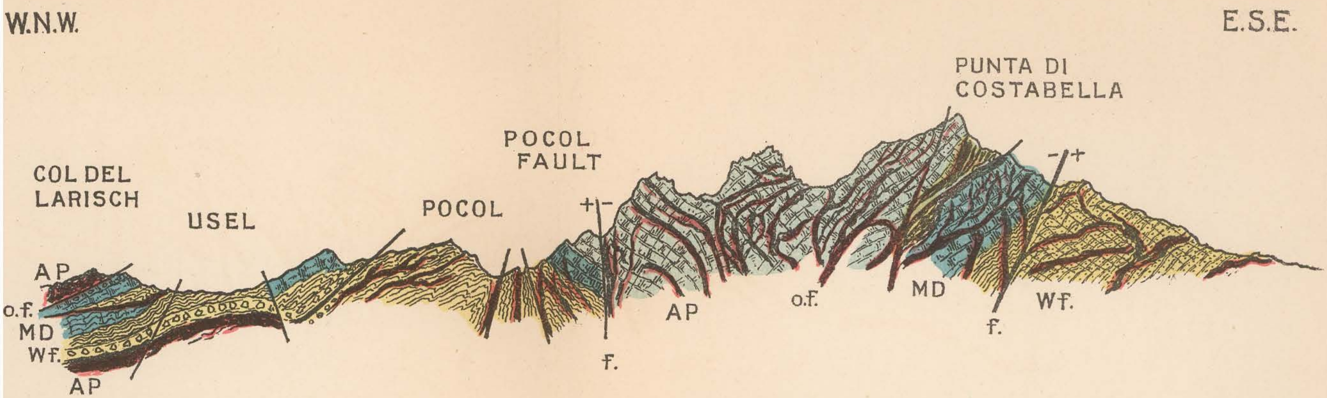


FIG. 1.—Section transverse to the Judicarian strike, from Col del Larisch to the Campagnazza, to show the two chief N.E.–S.W. faults which have thrown down the Costabella range (both have fault-dykes of augite porphyrite); the Col Guschel and Col del Larisch fault-sills and contact breccias of AP; and the sills in the Costabella range ascending bedding and cleavage-planes. *Wf* = Werfen strata. MD = Mendola horizon (succeeded by calcar. succession). *o.f.* = Older overthrust faults.

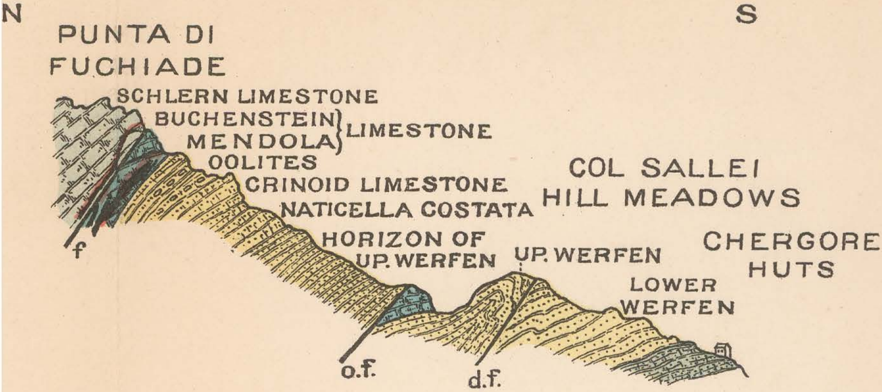
PART V. FIG. 2.—Parallel sections looking eastward across Lago di Selle Plateau to the Camorzao Mountain at the western extremity of the Costabella range. *f.s.* = Camorzao-Selle porphyrite fault-dykes. *c.z.* = Contact zone next Monzoni intrusions.

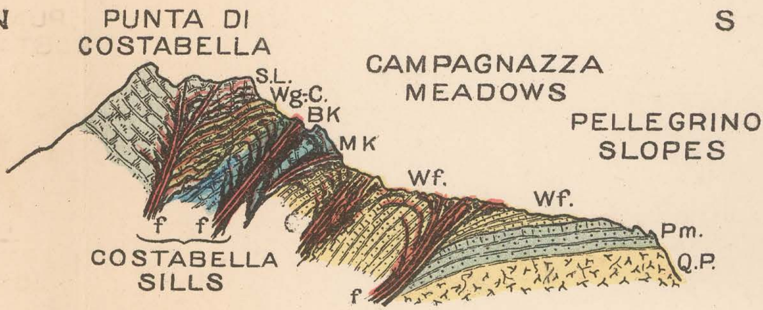
P = Predazzite, or altered limestone intercalated with threads of monzonite aplite and basic porphyrites (Mendola and Buchenstein horizons).

Lago.—The famous locality for contact minerals—occurrence on slickensided cleavages in the higher horizons of limestone.

Allochet ridge.—Composed of Werfen strata altered to hornstone on the northern slopes, which are intercalated with porphyrite. Immediately west, these strata are twisted towards a N.E.–S.W. strike, and crushed south-east, as the floor of the monzonitic sill.

Scale 1: 25,000





FIGS. 1, 2.—Parallel transverse sections through the Costabella range and Campagnazza, east of Monzoni.

Triassic Rocks.—

S. L. = Horizon of Schlern limestone; *Wg.-C.* = calcareous Wengen-Cassian horizon (these two horizons included in "Marmolata-kalk"); BK–MK = Buchenstein and Mendola horizons; *Wf.* = Werfen strata.

Permian Rocks.—

B = Bellerophon limestone horizon. G = Grey-white quartzites (Gröden Sdst. horizon). Q. P. = Permian sheet of Quartz Porphyry.

Tertiary injections of augitic and plagioclastic porphyrite, ascending bedding-planes dipping north, cleavage-planes inclined south-east, and faults (*f*).

Scale 1: 12,500

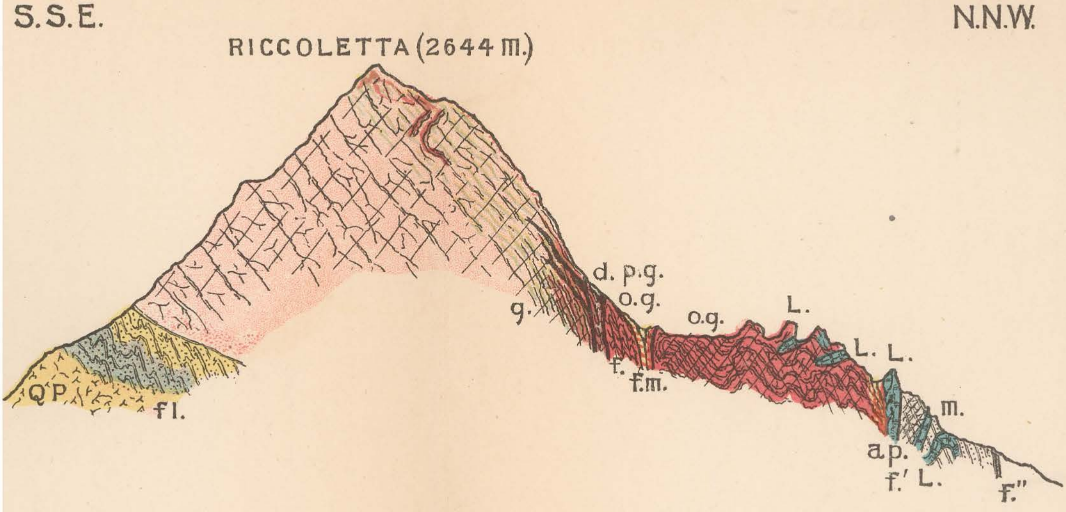


FIG. 1. —Transverse section through Monzoni, at the west side of Riccoletta summit, showing examples of Limestone inclusions ("L"). *m* = Monz. *g* = Gabbroid monzonite. *og* = Olivine gabbro. *p.g.* = Pyroxenite.
f' = North fault-limit of the zone of fault and injection. *f* = South fault-limit of same. *f''* = Monzoni Alpe fault-limit.
d = Diabasic dyke. *ap* = Aplite and pegmatite dykes next the chief occurrence of Limestone. *fm* = Felspathic monzonite (later dykes of labradorite rock).

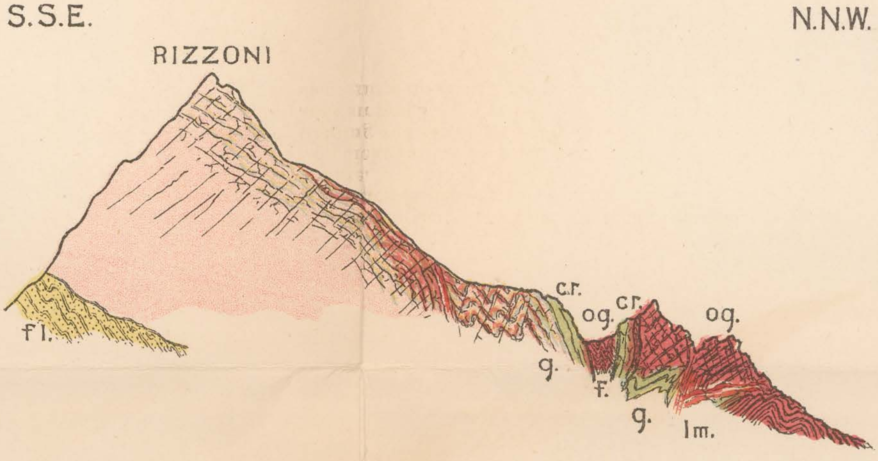
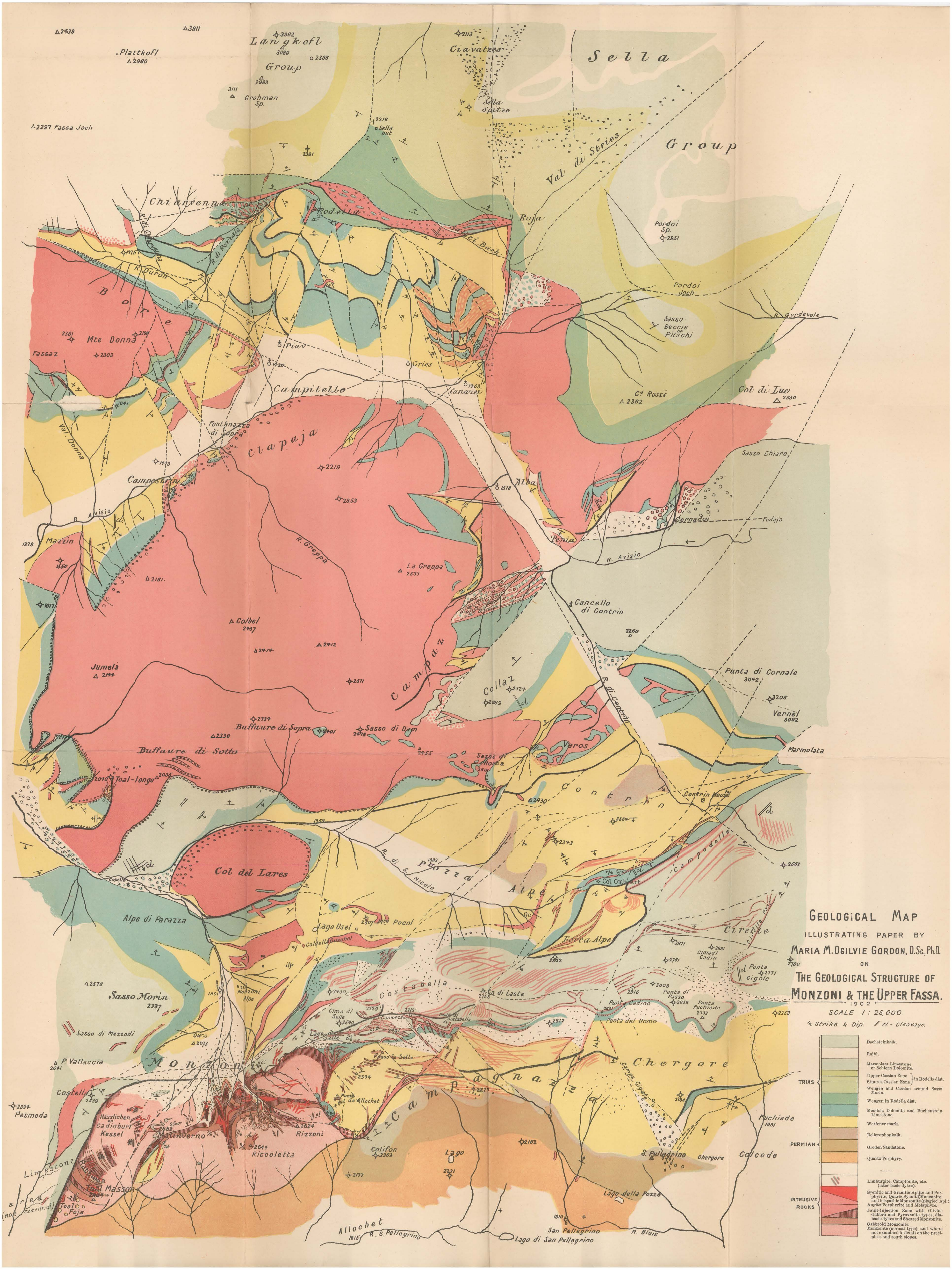


FIG. 2.—Transverse section through Monzoni, at the west side of the Rizzoni Ravine.
f = Chief zone of fault and injection (southern fault-limit).
g = Gabbroid types of monzonite.
cr = Crush-zone with sheared, slickensided gabbroid monzonite.
og = Olivine-gabbro types (folding and cleavages strike N. 50° E., incline N.W. and S.E.).
lm = Later dykes of aplite and lamprophyre.
fl = Sill floor (of original monzonitic invasion), comprising crushed Permian and Werfen strata.



GEOLOGICAL MAP
ILLUSTRATING PAPER BY
MARIA M. OGILVIE GORDON, D.Sc., Ph.D.
ON
THE GEOLOGICAL STRUCTURE OF
MONZONI & THE UPPER FASSA.
1902
SCALE 1 : 25,000
Strike & Dip. // cl = Cleavage.
TRIAS
Dachsteinkalk.
Raibl.
Marmolata Limestone or Schlern Dolomite.
Upper Cassian Zone
Stuores Cassian Zone
in Rodella dist.
Wengen and Cassian around Sasso Morin.
Wengen in Rodella dist.
Mendola Dolomite and Buchenstein Limestone.
Werfener marls.
PERMIAN
Bellerophonkalk.
Gröden Sandstone.
Quartz Porphyry.
INTRUSIVE ROCKS
Limburgite, Camptonite, etc. (later basic dykes).
Syenitic and Granitic Aplite and Porphyrite, Quartz Syenite, Monzonite, and felspathic Monzonite (plagiocl. apl.).
Augite Porphyrite and Melaphyre.
Fault-Injection Zone with Olivine Gabbro and Pyroxenite types, diabasic dykes and Sheared Monzonite.
Gabbroid Monzonite.
Monzonite (normal type), and where not examined in detail on the precipices and south slopes.
Langkofl Group
Plattkofl
Grohman Sp.
Fassa Joch
Sella Group
Ciavatzes
Sella Spitze
Sella Hut
Val di Stries
Pordoi Sp.
Pordoi Joch
Sasso Beccie or Pitschi
R. Cordevole
Chiavenna
Rodella
Roja
Duron
Bore
Mte Donna
Fassaz
Piav
Gries
Campitello
Canazei
Ca Rossi
Col di Luc
Val Donna
Fontanazza di Sopra
Clapaja
Camposarin
R. Avisio
Mazzin
Alba
Sasso Chiaro
Penia
Cernadoi
Fedaja
R. Greppa
La Greppa
Cancello di Contrin
Colbel
Jumela
Campaz
Collaz
Punta di Cornale
Vernel
Marmolata
R. di Contrin
Buffaure di Sopra
Sasso di Dam
Buffaure di Sotto
Toal-longo
Sass di Roca
Varos
Contrin
Contrin House
Col del Lares
Pozza
R. di S. Nicolo
Alpe
Col Ombert
Campodelle
Alpe di Parazza
Lago Usel
Pocol
Forca Alpe
Cirelle
Cimadi Cadin
Punta Cigole
Sasso Morin
Monzoni Alpe
Costabella
Sa di Laste
Punta Cadino
Punta del Uomo
Punta di Passo
Punta Fuchiade
Sasso di Mezzodi
Cima di Selle
Lago di Selle
Passo le Selle
P. Vallaccia
Monzoni
Campagnazza
Chergore
Costella
Pesmeda
Punta de Allochet
Hässlichen Cadinburt Kessel
Malinverno
Rizzoni
Riccoletta
Colifon
Lago
Fuchiade
S. Pellegrino
Col Code
Limestone area (not examined)
Toal Masson
Toal Foja
Lago della Pozze
Allochet
R. S. Pellegrino
San Pellegrino
Lago di San Pellegrino
R. Biois