

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 super-induced 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

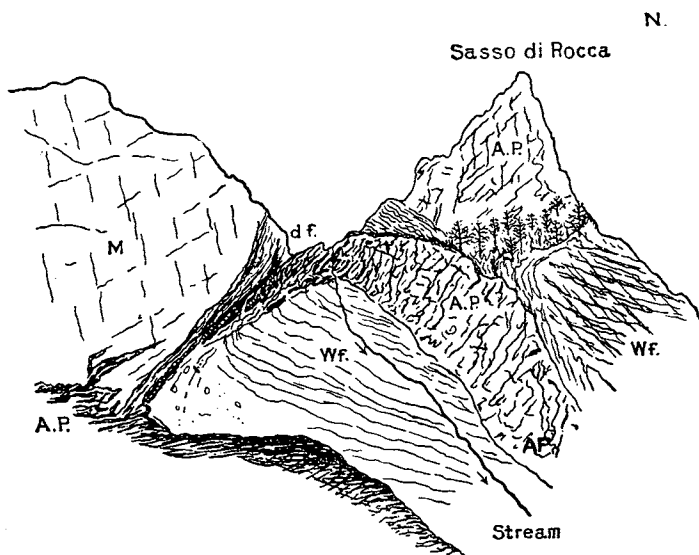


FIG. 17.—A stream-cutting between Col Laz and Varos; the stream flows east from Sasso di Rocca to join the Contrin Stream. d.f.=a downslip fault-plane at a "knee-bend" of the rocks; the fault-plane strikes N. 45° E. and dips 30° south-east, it is occupied by a fault and contact breccia of Wf. (Werfen),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

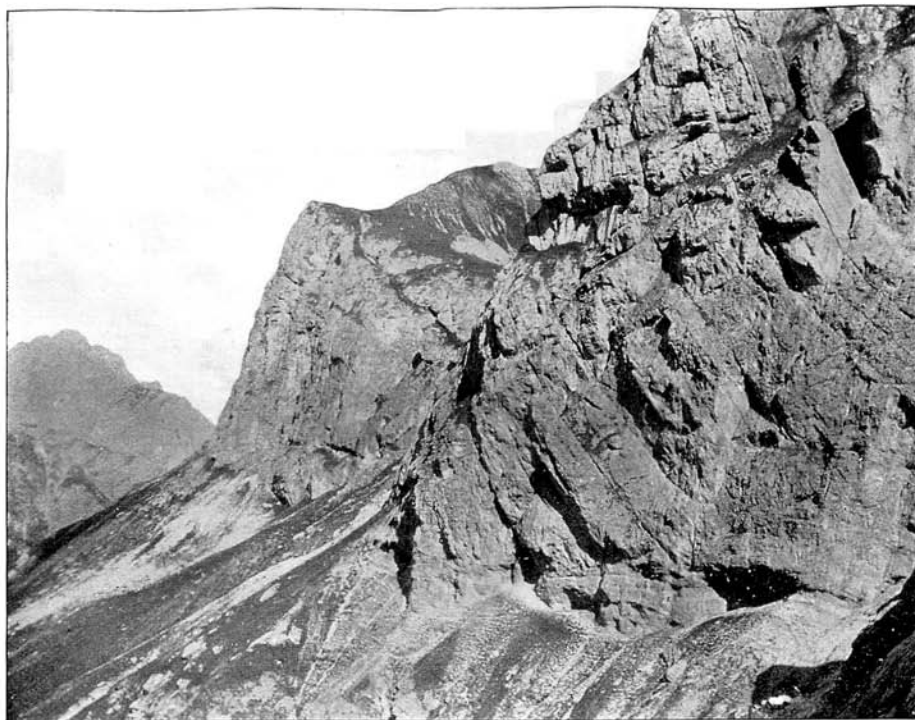
The rocks of Contrin Alpe, Col Ombert and Forca Alpe formed the underlay slice of the Varos thrust-mass, and the over-thrust slice in relation to the Costabella and Cirelle limestone.

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 mètr. 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 Verde" 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:—

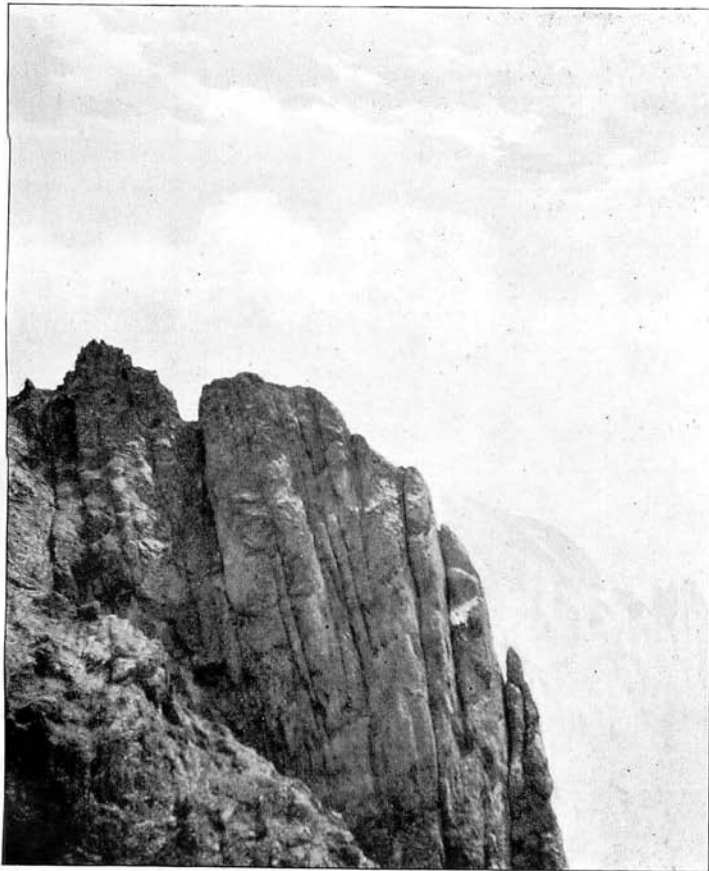
- (1.) A thrust-plane inclined northward is present.
- (2.) The thrust-mass above it has been dislocated, and twisted towards an E.N.E.-W.S.W. direction of strike, local crumpling and faulting taking place.

(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 super-induced. 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

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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.

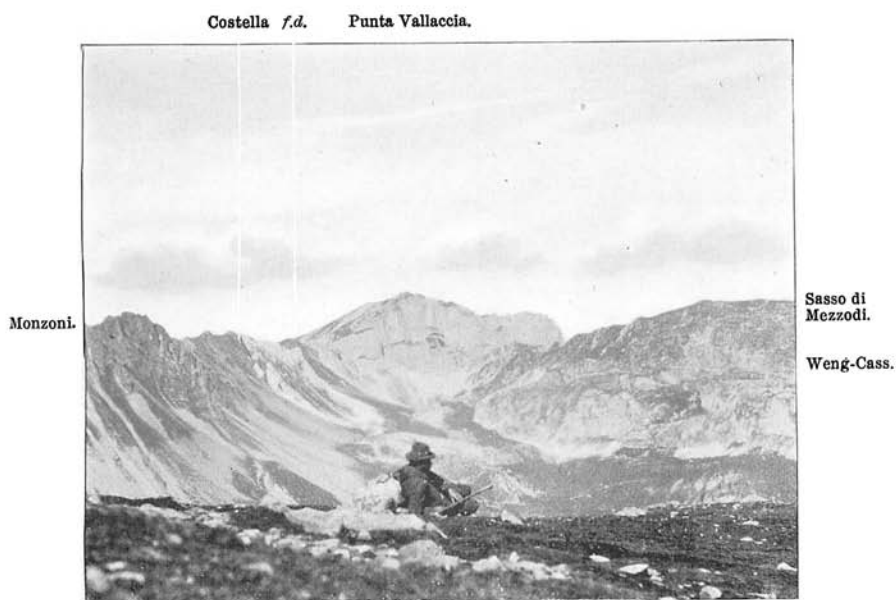
The calcareous rocks of Col Ombert are represented by the fault-block of calcareous rocks immediately surmounting Monzoni Alpe on the south, and divided from the deeply-sunk Cima di Selle fault-block by a N.N.E.-S.S.W. fault or fault-dyke. The Cima di Selle and the north face of the Costabella range 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

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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

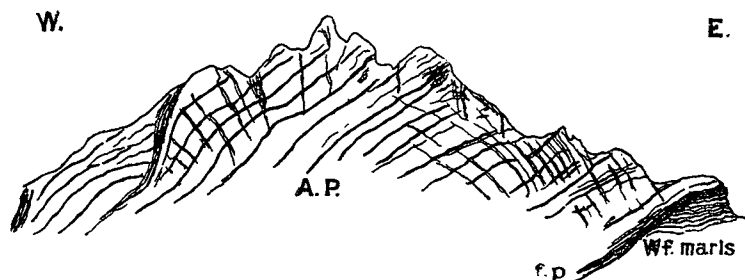


FIG. 18. South aspect of the Col Guschel sill (augite porphyrite), showing the intersecting systems of curved cleavage-planes inclined to the north-west and to the south-east. f.p.=fault-injection plane. Wf.=Werfen strata.

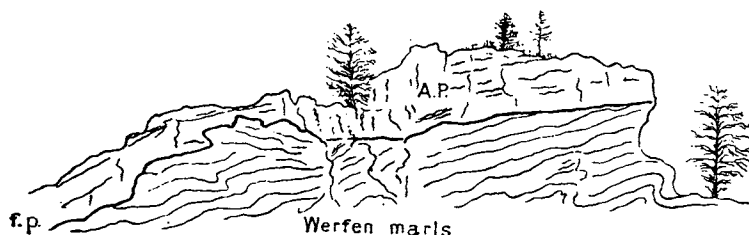


FIG. 19. A portion of the fault-injection plane (f.p.) exposed on the south escarpment of Col Guschel. The Werfen marls strike N. 35° E. dip north; the fault-plane strikes N. 50° E., dips 20° towards N.N.W. The Werfen marls are slickensided, waved, and altered, the contact zone of the sill is porous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

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 scree 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

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“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 ferromagnesian, 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-porphyrity" 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 Verde" 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 overthrust 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