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MONZONI AND UPPER FASSA.

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THE following pages present some results obtained by me from the geological survey of the Fassa district in the Dolomites comprising the Bufaure and Monzoni mountain groups, where the porphyritic and monzonitic rocks are widely exposed. In selecting this district I had two objects in view—(1) to study in detail the tectonic relations between the igneous and stratified rocks; (2) to test the results which I had previously obtained from my survey of Sella Massive, etc.

THE TERTIARY AGE OF MONZONI.

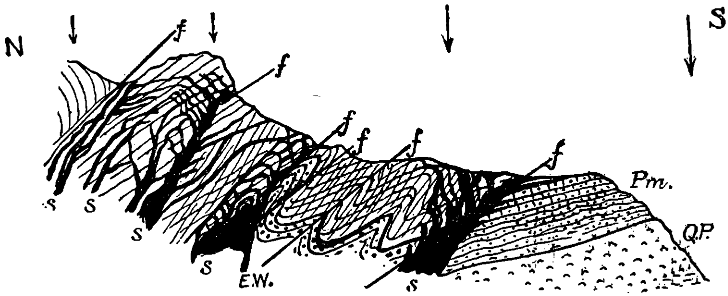
The Campagnazza Meadowland stretches east of Monzoni as undulating slopes descending southward from the Costabella range of limestone to the Pellegrino Valley. The meadowland is composed of Permian and Werfen strata, and I discovered in it a number of intrusive sills of porphyrite associated with two faults. The more northerly of the faults runs east-west at the southern base of the Costabella range, and it continues westward as the northern fault-limit of the Allochet ridge and Monzoni. This fault is steeply inclined to the north, and the differential movements have effected the relative downthrow of the Costabella fault-block on the north. The other fault follows a curved strike, its course being E.S.E.–W.N.W. in the Campagnazza, but curving to E.N.E.–W.S.W., where it is continued as the southern fault-limit of the Allochet ridge and the monzonite rocks of Monzoni. The curvature is convex towards the north, and the fault-plane is inclined northward. In the Campagnazza there is north of the fault a crumpled sheared slice of Werfen strata; but this block is represented at Monzoni by the intruded igneous rocks. The tectonic relation of the monzonite intrusion is therefore that of a fault-sill, representing in the strike the Campagnazza crust-slice between the two faults, and injected at an angle of strike-curvature.

The fault-block south of the curved fault may be conveniently termed the Pellegrino fault-block. It comprises quartz porphyry, Permian strata, and fault-fragments of Werfen strata, and has been driven southward, representing one of a series of overthrust slices which occur south of the Pellegrino Valley (Fig. 1).[1] Still farther south the Cima d'Asta overthrusts are present, and as there are occurrences of Jurassic and Cretaceous strata in the shear-zones of the overthrust faults, it is clear that the slicing took place in connection with Tertiary movements in the Alps. The Campagnazza fault-curves were certainly not earlier than the overthrusts; thus, my geological mapping, which proves the replacement of the Campagnazza sheared slice by the monzonite intrusion, proves at the same time that the intrusion was of Tertiary age. I find further that I can offer an interpretation of the sequence of injections

[1] I have made no personal examination of the district south of the Pellegrino Valley.

in the Monzoni mountain based upon the details of strike-cleavage in the Campagnazza Meadowland and Monzoni.

The Costabella downslip slice strikes N. 75°–80° W., the Campagnazza shear-slice strikes N. 65° E., the Pellegrino thrust-slice strikes N. 65°–80° W. These facts indicate that the proximal crust-slices have adjusted themselves in the Campagnazza along different strikes, the one being the differential correlative of the other. But at Allochet the strike both of the Costabella and Campagnazza crust-slices curves to the E.N.E.–W.S.W. direction, and the monzonite rocks of Monzoni have this as their fundamental strike, the dip-cleavages being towards the north-west at an angle of ca. 50°, and towards the south-east at an angle of ca. 40°. The E.N.E. and W.N.W. strikes may both be suitably termed 'Asta' strikes, from the famous Cima d'Asta Massive in the Dolomites, where Professor Suess first determined overthrust movement towards the S.S.E.



Transverse section through the Costabella range (Middle Triassic limestone); the Campagnazza Meadowland (Lower Triassic mixed deposits and fault-fragments of Permian strata); the slopes of Pellegrino Valley (Permian strata (*Pm.*) and Quartz Porphyry (*Q.P.*)); *f f*, 'Asta' faults; *E.W.*, old east-west fault; *s s*, porphyrite sill and dyke system ascending faults, cleavage-planes, and bedding-planes.

In my previous papers I have demonstrated that these correlative strikes developed in consequence of the superposition of the Peri-Adriatic movements upon the regional East Alpine movement, and this explanation is fully borne out in the Campagnazza. The east-west fault north of Monzoni and the Campagnazza is, according to my researches, an old synclinal fault between two fundamental East Alpine anticlines, that of the original Pellegrino anticline on the south of the fault, and on the north of it the anticline which I shall term the Contrin anticline, from its favourable exposure on the Contrin Alpe north of the Costabella range.

The north fault-limit of Monzoni with east-west direction has in previous literature gone by the name of the 'eruptive fissure,' and probably the direction of this fault gave the erroneous impression that the monzonite had a parallel strike. But the monzonite rock both here and in the Predazzo area, a little to the south-west of Monzoni, strikes E.N.E.–W.S.W., and as will appear from what follows, the original intrusion of monzonitic magma was a continuous

'Asta' fault-sill—the western or Predazzo portion having been *subsequently* displaced southward, and downthrown relatively to the Monzoni portion. Again, the 'eruptive fissure' has been described as "probably" continuing through a porphyrite fault-dyke east of Lago di Selle and passing E.N.E. through the Costabella range. This is, however, not the case. The east-west fault holds its own direction, passing due east into the Campagnazza. I regard it as one of the leading Alpine faults in this district, comparable with the Gröden and Buchenstein faults which I have described in my former papers. Its age *may* be far greater than the injection of the monzonite, seeing that the injection was synchronous with the superposed 'Asta' movement. Moreover, the term 'eruptive' was applied under the conception that Monzoni was a volcanic centre in Triassic time, the monzonite being the deep-seated facies of Triassic surface flows of porphyritic lava and tuff. This I hold to be a mistaken conception, as I have carefully examined all the supposed surface flows of porphyrite in the vicinity of Monzoni and in Upper Fassa, and have found them to be intrusive sills and dykes, injected subsequently to the main intrusion of monzonite, at that epoch in fact when the monzonite fault-sill was cross-sliced, and its western portion laterally displaced as far as Predazzo. According to my mapping of this district there are no igneous *contemporaneous* rocks later than the quartz porphyry except the tuffs in the Wengen-Cassian beds.

Having now pointed out how some of the older misconceptions regarding Monzoni may have arisen, I shall proceed to indicate briefly a few of the leading observations I have made throughout the district.

The Miocene Age of Porphyrite Sills.

Fig. 1 is a generalized transverse section through the Campagnazza Meadowland and the Costabella range. It shows how the two crust-slices, the Campagnazza and the Costabella slices, are themselves cut by subordinate fractures. These are 'Asta' fractures, striking either E.N.E. or W.N.W.; the inclination of all shear-planes is northward, but the angle of inclination varies very considerably. The chief tectonic complications occur in the immediate proximity of the older east-west fault. In the *eastern* or Fuchiade part of the Campagnazza, a small segment of older strata is at this fracture overthrust above Upper Werfen strata. In the *middle* part of the Campagnazza, several porphyrite fault-sills ascend at this shear-zone. The *western* or Allochet portion near Monzoni, like the middle area, shows several shear-planes and porphyrite fault-sills, but the strata dip more steeply. The porphyrite sills run continuously from the 'Asta' faults into virgating cross-faults directed N.N.W.–S.S.E. and N.N.E.–S.S.W. Two virgating groups of faults and fault-dykes divide the Campagnazza into the three segments which I have indicated—the Allochet segment on the west, the middle or main cross-segment, and the Fuchiade segment on the east. The middle segment is an upthrow relatively to the segments east and west of it; the cross-fault limiting it against the Allochet ridge is directed N.N.W. - S.S.E., but the cross-fault limiting it against the Fuchiade segment on the east is directed N.N.E.–S.S.W. Hence the leading strike-curve of the Campagnazza is convex to the north.

The diagonal fault-dykes continue their course northward and cut the Costabella range into similar cross-slices. In the Costabella range the fault-dykes are again continuous with sills which follow the strike, penetrating the strata at various horizons. Two leading sills are fault-sills,—the lower is injected at the horizon of Mendola limestone, the higher is included in a complex shear-zone of Cassian and Schlern limestone horizons. The latter has previously been regarded as the direct continuation of the east-west fault, but it is only one of several branches from the east-west fault, diverging E.N.E. from the Lago di Selle plateau.

The whole rock succession in the Campagnazza and Costabella has undergone vertical cross-cleavage according to a north-east and south-west (N. 40° E.) strike, and inclined cross-cleavage along a N.W.-S.E. direction with the dip-cleavage planes inclined south-east at an average angle of 35°–40°. The intrusions of porphyrite ascend chiefly in the planes of strike-cleavage, and the sills occupy irrespectively the north-dipping bedding-planes and the inclined cleavage-planes with south-east dip. I have incontestible proofs (1) that injections run continuously into the Asta planes and the planes of cross-cleavage; (2) that the cross-cleavage strike and dip system has disjointed and deformed the Asta strike and dip system; and I therefore conclude that the leading porphyrite sills and dykes in this area were coeval with the superposition of the cross-cleavage system. In previous papers I have called the cross-cleavage system the 'Judicarian' system, and referred it to the Miocene geological epoch, treating it as a more advanced phase in the protracted history of superposed movements than that which gave origin to the E.N.E. and W.N.W. strikes. The 'Judicarian' and 'Asta' systems of strike have orthogonal correlation with one another, the N.N.E. 'Judicarian' strike being rectangular to the W.N.W. 'Asta' strike, and the N.N.W. 'Judicarian' strike being rectangular to the E.N.E. 'Asta' strike. Thus cross-cleavage was superinduced upon the 'Asta' strike-system, but the differences in the detailed stratigraphy of the cross-segments in the Campagnazza show that both systems were acting simultaneously, the orthogonal stresses being associated with the superposition of the N.N.E.–S.S.W. or 'Judicarian' strike upon the fundamental east-west 'Alpine' strike.

The Cross-Cleavage of Monzoni.

The 'Asta' injection of monzonite apparently engulfed the stratified rocks of the Permian and Werfen horizons, and as it consolidated did so in conformity with the actual strike and dip of the bedding-planes above, around, and amidst them. The rock-magma, owing to the action of the local pressure-strains, consolidated as a series of gneissose zones, and these original segregation zones have the

E.N.E. strike and northward dip of the whole mass. In succession from south to north the zones are: (*a*) the lowest zone, a light coarse-grained monzonite specially rich in mica; (*b*) a finer-grained differentiation of the micaceous type of monzonite; (*c*) a coarse-grained, pyroxenic, or gabbro-like monzonite; (*d*) a finer-grained dark type, highly augitic; this uppermost zone sends short apophyses into the limestone of the peripheral zone.

Differential movements subsequent to the 'Asta' injection of monzonite have concentrated themselves at the zone between the finer-grained micaceous type and the coarse gabbro-like monzonite. The dip-joints curve steeply northward at this horizon, and the augitic segregation zones have been downthrown to the north and west and sliced by several shear-planes both in strike and cross directions. *The chief fault-zone runs entirely through the Monzoni mountain,* following a curved strike, which, like the Judicarian-Asta fault-system round Allochet and Campagnazza, is convex to the north. The fault-zone through Monzoni is parallel with the peripheral fault-system, limiting Monzoni on the west, north, and east. In the fault-zone the monzonite rock is sheared and slickensided in the very highest degree, having been converted into a monzonite fault-schist, or in some places into a coarser fault-breccia. Moreover, *the fault-zone is the seat of later injections,* in contact with which the earlier gneissose bands of monzonite have endured extreme contact alteration. The later injections have two very important tectonic features in common with the porphyrite sill and dyke system of the Campagnazza. They extend continuously in the strike fault-curve through Monzoni, and in numerous cross-faults (N.N.W., N.S., and N.N.E.) which cut Monzoni into a series of cross-segments comparable with those of the Campagnazza. This feature in itself gives a safe indication that the later injections in Monzoni were, like the porphyrite sills in the Campagnazza, associated with the 'Judicarian' movement. But there is still stronger evidence. The whole of Monzoni has been cross-cleaved, the strike-cleavage being north-east to south-west, and the slabs of dip-cleavage being inclined to the south-east. The cross-cleavage planes of Monzoni are in fact a repetition of those displayed in the stratified rocks of the Campagnazza, and the differential correlative planes are similarly developed. The later injections in Monzoni ascend pre-eminently the vertical cross-cleavage planes or the inclined planes dipping south-east. Thus it may be safely concluded that the later irruptions in Monzoni took place in the Miocene epoch when the Asta-Judicarian movements had reached their most intense phase in the Alps.

The series of later injections includes a much greater mineralogical variety of igneous types than the earlier intrusion. The first injections of the later series include somewhat abnormal augitic and hornblendic types of monzonite and a still more basic olivine-gabbro type, coarsely crystalline for the most part, but passing into basaltic facies. This rock is readily recognized in the leading fault-zone by its characteristic ferruginous and serpentinous decomposition products. It also runs northward as cross-dykes in the rugged spurs that descend to the Monzoni Alpe. Certain peripheral dykes of very basic types of monzonite are also of this period.

The next set of injections show marked differentiation into granitic and augitic varieties. Usually the injections are found in group form, the more acid and more basic types occurring together or within a few yards of one another. Dyke-pairs of granite and porphyrite or of monzonite aplite and hornblendic monzonite are very common, and there are fault-dykes of aplite, pegmatite, or highly felspathic monzonite. Seams of orthoclastic rock are freely injected both in strike and cross directions. Those groups, pairs, or seams of smaller dykes occur across the olivine-gabbro and normal monzonite rocks in Monzoni, and also sporadically at the peripheral shear and contact-zone, where they are very often associated with a fine-grained basic porphyrite that weathers greenish, and answers in its thinner threads to the description of the igneous rock which has passed in the literature under the name of 'pietra verde.'

The last injections include liebenerite porphyry, plagioclastic porphyrite, and some ultrabasic limburgite types. Their occurrence in the field is in north-south direction or very few degrees east or west of this direction. They cross all other dykes; several excellent exposures that I found prove them to be the youngest type of injected rock in Monzoni. They mark certain 'focal areas' within the mountain where strike and cross faults intersect. At these areas local inthrows have occurred in relation to a cross-movement from east to west, whereby cross-slices of Monzoni were overthrust westward, and behind each thrust-slice there was a zone of downslip and inthrow.

The western thrust-slices present an arrangement of gneissose bands following strike-curves convex to the west. This strike-curve is orthogonal to the strike-curve convex to the south, which is characteristic of the front portions of the Pellegrino and other thrust-masses overthrust to the S.S.E. The focal areas around which these transverse or 'Judicarian' strike-curves are arranged occur within Monzoni, but the focal area corresponding to the general strike-curve of the monzonite rocks is immediately north of Monzoni, at an area in Monzoni Alpe where inthrow has taken place, and where the N.N.E., N.S., and N.N.W. cross-faults that radiate through Monzoni converge.

I regard the olivine-gabbro and contemporary basic types of monzonite in Monzoni as the deeper-seated facies of the massive porphyrite sills that spread through the Triassic horizons in the neighbouring districts; whereas the granites, aplites, and the more segregated types of porphyrite and monzonite in Monzoni were coeval with certain fine-grained basic injections into the porphyrite sills of the vicinity.

The occasional ultrabasic dykes in north-south cleavage-planes were still later. In Monzoni, in the neighbourhood of the chief shear-zone, the rocks have been rippled along an east-west strike; in the Allochet ridge east of Monzoni there is rippling in this direction, and cross-rippling due north and south. The wave-length of these ripples is quite short, but as the whole area shows north-south cleavage, I consider them confirmatory evidence that the East-Alpine pressure-system acted intermittently or synchronously with the Judicarian-Asta pressures, and that as these pressures temporarily waned after the epoch of crust-slicing and igneous intrusions, the effects of the East-Alpine movement became more pronounced. Whether this explanation be correct or not, the stratigraphy shows that horizontal compression acted along east-west and north-south directions after the epoch of the most intense Judicarian and Asta movements.

The Contrin and Buchenstein Anticlines.

The Permian and Werfen strata are widely exposed on the Contrin Alpe, and the essential features in the stratigraphy of the anticline are more easily obtained than in the Pocol and Monzoni Alpes farther west. According to my mapping, the original north limit of the Contrin anticline was an east-west fault through the present Bufaure Massive from Mazzin in Fassa Valley to Penia at the confluence of the Upper Avisio and the Contrin streams, the fault continuing eastward through the Upper Avisio Valley, westward through the Udai Valley. The original south limit of the Contrin anticline was the east-west fault north of the Campagnazza and Monzoni area. The present distance between these two faults is, as the crow flies, about 6¾ kilometres.

The Contrin anticline is succeeded on the north by another east-west anticline, that of Upper Fassa. It is the continuation of an anticline to which I previously gave the name of the Buchenstein anticline (Q.J.G.S., 1899, p. 583). In Upper Fassa the Triassic strata belonging to this anticline are exposed in the northern half of Bufaure, in the Upper Fassa slopes, in Rodella Mountain, in the slopes of Mount Donna, in the Sella Pass, and in the southern half of the Sella and Langkofl mountain-massives. The old east-west fault which forms the original limit of the Contrin anticline on the north, is the *southern* fault-limit of the Buchenstein and Upper Fassa anticline. The *northern* fault-limit of the Buchenstein anticline, as demonstrated by me in former papers, passes through the Langkofl and Sella limestone-massives, through Stuores Alpe and the north of Sett Sass, being at the same time the southern fault-limit of the Gröden anticline. The distance between the limiting-faults of this anticline in Upper Fassa is the same as the width of the Contrin anticline, viz. 6¾ kilometres. Both anticlines have undergone cross-deformation in virtue of the superposed Asta-Judicarian movements. In several cases that I have measured, the width of the complete wave-form of the Judicarian cross-movement is in this locality 5½ kilometres.

The Asta-Judicarian movements have produced a series of overthrust and downslip crust-slices following strike-curves, and cross-faulted as in the case of Monzoni. The porphyritic sheets have been injected in the downslip shear-zones behind the thrust-masses of Werfen and limestone strata, and in 'Judicarian' cross-faults;

they have locally broken through the thrust-masses as fault-sills and dykes, brecciating and altering the strata, the igneous and brecciose material thus replacing the strata along the strike of the thrust-masses. Accordingly I dissent from the opinion advanced by Mojsisovics and repeated in slightly different form by Salomon, that the igneous rocks of Bufaure, Belvedere, etc., constituted a volcanic Triassic facies of the Marmolata limestone. The massive sheets of porphyrite at Bufaure, etc., are wholly intrusive and run into radial and strike fractures associated with the Asta-Judicarian movements. The stratigraphy of the district will be fully set forth in the geological map and sections that are to accompany my complete paper.

Block-Porphyrite.

Some of the most puzzling problems concerning the mineralogy of the district are associated with the block-porphyrite ('Block-Porphyr' of Mojsisovics), or, as it has been frequently termed, the conglomerate or 'agglomerate' structure of the igneous rocks. The explanations offered by all who have surveyed in this district except myself have been based upon the assumption that the Bufaure and neighbouring sheets of porphyrite were contemporaneous Triassic lavas. During my own field-work I have had to make a close investigation of various sills of block-porphyrite, and find that the conglomeratic appearance is due to various causes. While in many cases the block-structure is simply a result of original segregation in concretionary lumps or lenticular patches and bands, there are others where the structure is superinduced. I found it necessary to determine the joint-cleavage systems in the porphyrite very carefully, as the later, more basic injections have frequently been injected along the joint-planes, and so encircle isolated masses of an earlier sill, just as the sill-magma itself enwrapt or infiltrated particular masses of strata when it was injected. I classify the different types of block-structure as follows :—

(a) *Original agglomeratic structure* dependent upon various forms of segregation products;

(b) *Joint-block structure* due to decomposition and weathering of the porphyrite along intersecting curved joints;

(c) *Superinduced brecciose structure* where a sill has after consolidation been subjected to differential shearing;

(d) *Combination-sill structure*, where intermittent injections have passed into the same fault-zone, and the later injections have broken up the older.

The Sella Pass.

The north wing of the Buchenstein anticline occupies a crust-zone in which old eruptive fissures of Triassic age occurred. I have previously determined the Buchenstein-Mahlknecht fault-zone extending east and west through this area, and have pointed out that the tufaceous as contrasted with the calcareous facies developed in the proximity of, and north of, this Triassic fracture-zone during the

Wengen-Cassian epoch, and that the northern area was especially subject to local variability during the Upper Cassian and Raibl periods (ant. Q.J.G.S. 1893, GEOL. MAG. 1894 and 1900, Verhandlungen 1900). In 1900 I prepared a transverse section through Sella Pass on the north of the fracture-zone, according to which the stratigraphical succession is as follows:—(1) *Wengen* tuffs and shales with the typical plants and bivalves; (2) *Cassian* limestones, marls, tufaceous shales and grits, containing the typical Stuores-Cassian fauna together with *Pachycardia rugosa* and several other species found at Seiser Alpe, but not, so far as yet known, at the Stuores locality near St. Cassian; (3) Upper Cassian limestones and tufaceous marls and breccias; the 'Cipit-Kalk' or reef-limestone lenticles are imbedded in tufaceous rocks containing a transitional Cassian-Raibl fauna, and passing conformably under the Schlern-dolomite rocks of the adjacent mountain-massives. At Sella Pass numerous specimens of *Pachycardia rugosa* occur at both the Cassian zones; on the other hand, certain forms such as *Trigonodus Rablensis* and certain species of *Avicula* make their first appearance in the Upper Cassian zones. The rich fauna found in the 'Pachycardia tuffs' of the Seiser Alpe (v. Zittel, Zeitschrift, 1899) is very well represented at Sella Pass. And comparing my Sella Pass section with my former sections in Enneberg and Ampezzo, the 'Pachycardia tuffs' are demonstrated to be *the time-equivalent of the whole St. Cassian series.*

It has previously been supposed that the Wengen-Cassian series were absent in Fassa, but I have found that although thinly developed, the Wengen and Stuores-Cassian zones are present at the base of the Vallaccia limestone massive between Fassa Valley and Monzoni, and at the base of the Punta di Costabella.

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