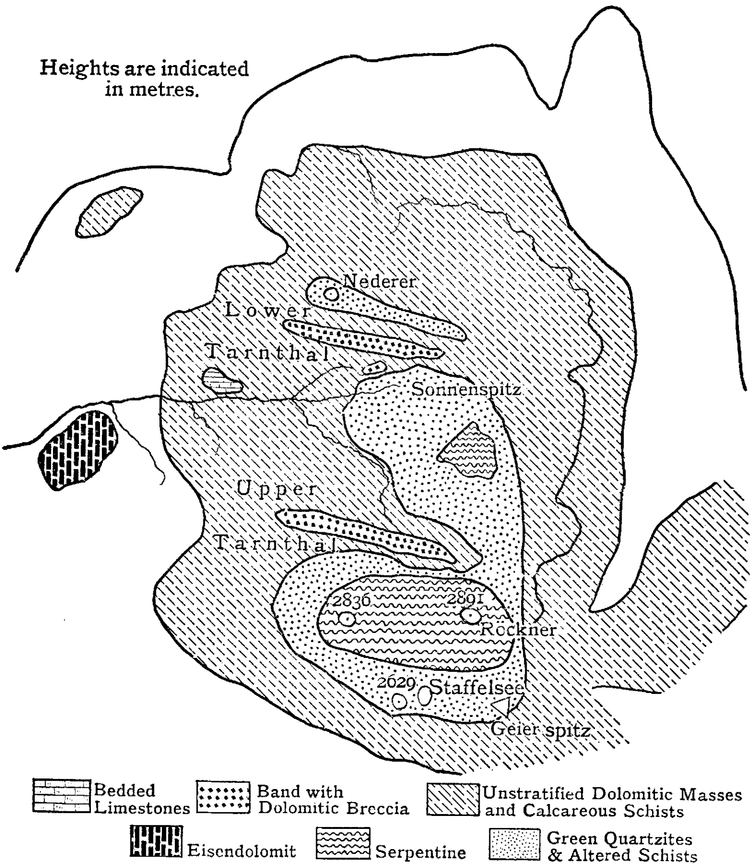
30. *On the* Stratigraphy *and* Structure *of the* Tarnthal Mass (Tyrol). By Alfred Prentice Young, Ph.D., F.G.S. (Read May 6th, 1908.)

The Tarnthaler Köpfe are an isolated mountain-mass in the north of the Tuxer Alps. The appended sketch-map (fig. 1), together

Fig. 1.—*Sketch-map of the Tarnthaler Köpfe.*

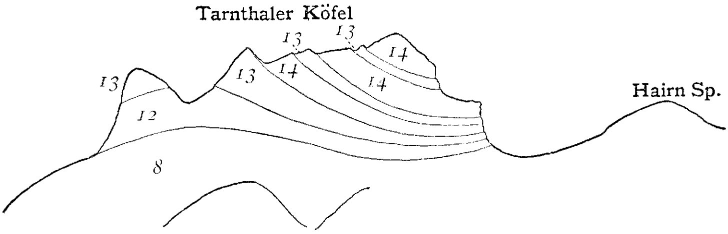


[Scale: $\frac{1}{37500}$, or 2·666 centimetres = 1 kilometre.]

with the sections (figs. 2 & 3) copied from Pichler and Rothpletz, affords a general idea of the geographical distribution of the rocks of which the mass is composed and the vertical section of their arrangement in the mountain-mass itself.

The stratigraphy of the mass has been very differently interpreted by various investigators. Their views will be found in the papers noticed below.

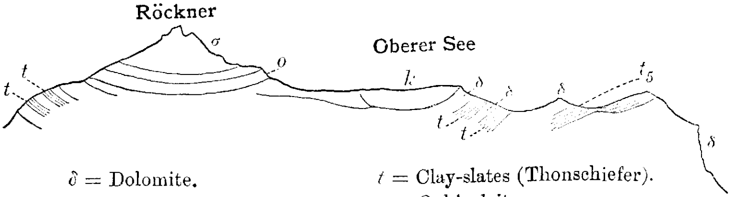
Fig. 2.—*Section taken from that published by A. Pichler in Zeitschrift des Ferdinandeums, ser. 3, pt. viii (1859) Profil xxviii.*



8 = Thonglimmerschiefer (mica-schists).
12 = Kalk & kalkschiefer des Lias (Liassic limestones and calc-schists).
13 = Bunte Schiefer (mottled slates).
14 = Ophicalcite and serpentine.

Adolf Pichler[1] in 1859 supposed the sequence of strata to be normal throughout, the capping mass of serpentine being treated as a sedimentary rock. He enumerates the following fossils, found in a grey limestone in place :—*Belemnites*, *Pentacrinus*, *Gervillia inflata*, *Lithodendron*, *Rhynchonella*. The whole mass of dolomite, with the calcareous schists above it, is shown in his section as Lias, in which formation the author includes the Rhætic.

Fig. 3.—*Section taken from fig. 51, p. 149, in Prof. Rothpletz's 'Querschnitt durch die Ost-Alpen' Stuttgart, 1894.*



δ = Dolomite.
σ = Serpentine.
k = Kalkplatten (flaggy limestones).
t = Clay-slates (Thonschiefer).
o = Ophicalcite.
t_5 = Kössen Beds.

In 1894 Prof. A. Rothpletz[2] announced a further discovery of Rhætic fossils in this locality—*Terebratula gregaria*, *Modiola*

[1] 'Beiträge zur Geognosie Tirols' Zeitschr. des Ferdinandeums, ser. 3, pt. viii, pp. i–viii, 1–232, with map & 29 sections.
[2] 'Ein geologischer Querschnitt durch die Ost-Alpen' p. 75.

minuta, and several others. The igneous character of the serpentine is recognized; but otherwise the descriptions and sections seem to assume a normal and continuous succession of beds, from the Triassic dolomite below to the youngest 'Kalk-thon' and Wetzschiefer above.

In the same year Dr. F. E. Suess[1] published the results of his own studies in this region. The serpentine and quartzite-schists are held to be older than the calcareous schists and dolomites, and it is supposed that they were brought into their present position by a thrust or long fold with a push towards the north; the beds below the thrust-plane are held to be in normal sequence.

In 1903 appeared Prof. Termier's[2] paper on the structure of the Eastern Alps. The author accounts for the presence of these rocks by means of one or more recumbent folds (nappes), the roots (racines) of which are to be sought in the region of the Zillerthal Alps.

In 1905 appeared Prof. Frech's[3] work on the structure of the Central Alps of Tyrol. He adopts the explanation of the structure of the Tarnthal mass already given by Dr. Suess.

Description of the Rocks of the Tarnthal Mass.

The whole of the lower ground of this district, over a wide area to the west and south of the mountain, is occupied by calcareous schists, the 'Brenner Schiefer.' These rocks reach up to the floor of the great cirque, at a level of 2100 metres above the sea on the western slope of the Tarnthal mass. From this point a continuous section is exposed up to the summit of the 'Nederer,' marked 2758 m. on the 'Generalstabskarte.'

The series commences with a massive dolomite, usually identified with the 'Hauptdolomit.' This rock shows no bedding-planes; it covers the slope for the next 330 metres (1082 feet).

Above this rock, and resting upon the dolomite at the level of 2480 metres, is the bedded limestone, the probable source of a fossil which I found on the slopes below, apparently of Liassic age. These cliffs must also include the site of the Rhætic fossils discovered by Prof. Rothpletz. The beds dip north-eastwards at an angle of about 20°. The softer bands of the rock appear to have been affected by shearing; the fossils also present evidences of distortion and faulting; but the more massive bands cannot have been very much disturbed. The thickness of these inclined beds is estimated at 15 or 20 metres (50 to 65 feet).

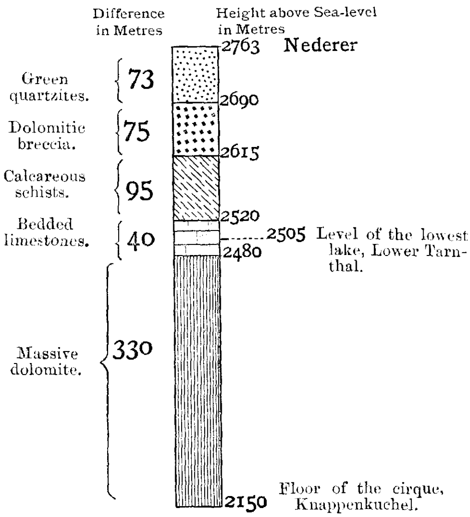
[1] 'Das Gebiet der Triasfalten im Nordosten der Brennerlinie' Jahrb. d. k. k. Geol. Reichsanst. vol. xliv, p. 589.

[2] 'Les Nappes des Alpes Orientales & la Synthèse des Alpes' Bull. Soc. Géol. France, ser. 4, vol. iii (1903) p. 711.

[3] 'Ueber den Gebirgsbau der Tiroler Zentralalpen' Wissensch. Ergänzungshefte zur Zeitschr. des D. u. Ö. Alpenvereins, vol. ii, pt. i.

Between these limestones and the conspicuously-foliated calcareous schists above them is a tolerably well-marked line of division, which is probably of significance as regards the interpretation of the tectonic relations. In passing from the bedded limestones to the calcareous schists there is no marked change of dip; and some thin bands of solid limestone appearing at intervals in the schists may be taken to show that the plane of bedding here coincides approximately with that of foliation.

Fig. 4.—*Section from Knappenkuchel to the Nederer summit.*



Still higher up the steep slope, on the right bank of the Lower Tarnthal, is a very irregular band of massive dolomitic rock, freely traversed by quartz-veins and containing masses of closely-cemented breccia, the 'dolomitic breccia.' In this zone the effects of shearing and crushing are displayed at their highest. Softer bands of the rock have taken on a platy structure simulating bedding, and are seen winding through and round the harder masses in directions which bear no relation to the dip of the schists. Otherwise the rock has shown itself to be singularly tenacious, and to have resisted the shearing forces by which it has been kneaded into the more pliant schists. The breccia is quite undistorted; in the arrangement of the fragments no one direction is predominant.[1] Some fragments seem to show the original bedding of the rock from which they are derived.

The schists are continued above the dolomitic breccia; they become richer in micas—bands and lenticles of green schist appear among the grey. At about 2700 metres without sensible break the rocks begin to take on the characters of the crystalline schists. These include the green 'Tarnthaler Quarzit-Schiefer,' the 'Wetzstein- und Dachstein-Schiefer,' which occupy the summit-ridges of the Nederer and the Sonnenspitz. The green rocks are dense quartzites of exceedingly fine grain like that of a chert or hornstone. By the addition of abundant minute plates of chlorite in parallel

[1] Dr. F. E. Suess, however, notes distortion in the fragments of a similar breccia at the Hippold Joch.

arrangement, and of tourmaline, they approach in character the so-called 'older phyllites,' from which they are distinguished by their finer grain. The induration and the fine puckering of some calcareous rocks associated with this group are no doubt due to contact-alteration by the neighbouring igneous rocks.

Dark red quartzitic rocks are found in several places, along with the green schists.

The green quartzitic rocks often exhibit sharp little folds marked by thin mineral bands, which may indicate the original bedding-planes. A strong southerly dip, due to foliation, predominates over the whole of the Upper Tarnthal between the Sonnenspitz and Röckner ridges.

The Nederer section terminates with the quartzitic schists. No actual occurrence of serpentine has as yet been observed on this ridge, but the relation of the serpentine to the schists is well shown in the neighbouring Upper Tarnthal and on the Röckner ridge.

Between the altered schists and the serpentine are seen some remarkable forms of 'ophicalcite.' Masses of calcareous schist, several feet in thickness, have been injected along the foliation-planes with the basic magma now represented by serpentine. Thin bands and lenticles of serpentine alternating with the schist impart to the rock a parallel structure, which gives the appearance of true bedding and suggests a relation of conformity with the schists below. These are, no doubt, some of the occurrences that led Pichler to include ophicalcite and serpentine in a conformable succession of sedimentary rocks.

But at Matrei and Pfons, where the rock-series resembles that of the Tarnthal, the ophicalcite is not in a form such as to suggest the explanation here given of its origin. The parallel structure is absent or imperfectly developed, and the calcite often appears in veins. The mode of formation of these mixtures of serpentine and calcareous rock is evidently subject to variation.

The general dip of the schists under the serpentine-mass of the Röckner led Prof. Rothpletz to the conclusion that the serpentine was in the form of a sill resting upon the syncline of schists. But the intrusive masses are very irregular in shape. This is well seen in the case of the small serpentine-mass in the Upper Tarnthal, on the southern slope of the Sonnenspitz ridge.

In view of the more recent hypotheses of Alpine structure, which assume a translation from a distance of some or all of the rocks composing this mass, it seems important to distinguish between characters impressed on the rocks in their original site (here called œcogenous characters) and those which may have been acquired during the movement (apœcous characters).

Superimposed or Apœcous Characters of Rocks of the Middle Zone.

The distortion and partial foliation of the bedded limestones just above the dolomite may have been imposed during a movement of translation, but it does not appear that the fossils here are more deformed than those from the Lias of Southern Tyrol, where there is no question about the rocks being in their original site. But the conspicuous mechanical shearing of the calcareous rocks just above the bedded limestones, as also the strong folding and crushing in the region of the dolomite-breccia, may and probably has been acquired during movement.

Original or Œcogenous Characters of Rocks of the Upper Zone.

The topmost layer of quartzite and other altered schists and the serpentine bear many characters which must have been acquired before any movement of translation began.

The parallel arrangement of the minute plates of chlorite in the quartzitic rocks (which also contain tourmaline) is a feature that must have been acquired at deep levels, under conditions similar to those determining the structure of the older crystalline phyllites.

The tourmaline is in the form of single, undistorted, minute rods, bounded by faces of the prism and often showing a terminal pyramid—characters which prove it to be the most recent addition to the minerals composing the quartzitic rock.

The close vicinity of rocks, presently to be described, which have been modified by contact with the serpentine, suggests that the tourmaline may be a contact-mineral. The serpentine, however, does not contain tourmaline. If not a contact-mineral, the tourmaline must be older than the serpentine-intrusion. In either case the tourmaline, the youngest product, was formed before the rock-mass left its original site.

Serpentine.

The association of green schists with serpentine in several distinct occurrences (Mieselkopf, Matrei) has been noted by previous observers, as well as the occurrence of talc and magnesian minerals in the schists adjoining the serpentine.[1]

The igneous intrusion appears to have commenced at a time when the rocks were still under the influence of causes producing foliation. Recrystallization under stress is indicated by the formation of talc in the schists, by the presence of sheafy amphibole in parts of the serpentine-mass near the contacts.

That violent movements were in progress during the period of activity covered by the serpentine-intrusion is shown by the mode of injection of the serpentine in the ophicalcite, and by the numerous detached masses of altered calcareous rock found embedded in the serpentine at all levels up to the summits of the Röckner and the Little Röckner. Among these torn-off fragments

[1] See J. Blaas, 'Ueber Serpentin & Schiefer aus dem Brennergebiete' Nova Acta Leop.-Carol. Akad. der Naturforscher, vol. lxiv (1894) no. 1.

are some which show the ophicalcitic structure, and thus bear witness to the ingress and complete consolidation of a portion of the serpentine-magma at a date prior to a final stage of the eruption in which the fragments were detached and carried off.

Last Stage of the Intrusion.

The final accession of fluid magmas is represented by a core of serpentine which has crystallized by slow cooling in a state of rest, unsolicited by forces of shearing or stress. This is proved by the abundant remains of large pyroxene-crystals showing no direction in their arrangement, and by numerous pseudomorphs in bastite after pyroxene in composite crystalline growths which evidently still retain their original forms.

In the younger parts of the rock an occasional slight strain in the pyroxenes and some instances of cataclastic structure are the only indication of the survival of forces, which were at the last too attenuated to impose schistose structure on the rock.

The rock must have consolidated nearly in its present form while still in communication with the main magmatic reservoir, and before the commencement of the journey from the original to the present site.

The original igneous rock has been affected chemically, notably by serpentinization on an extensive scale. Some of the changes may possibly have taken effect during translation, but the change of form has been unimportant. The ophicalcite obviously acquired its banded structure on the original site, and has been translated without perceptible deformation. The same is true of the masses of indurated contact-schist.

It appears to me to be evident that the whole mass of serpentine, ophicalcite, and indurated schist still hangs together with the original relative positions of its parts, and that in the course of translation it has undergone no deformation and no interruption of continuity, beyond that due to minor faults and fractures.

Summary of Conclusions.

As respects the general structure of the Tarnthal mass, my reading of it is as follows :—

The rock-series of the mass may be divided into three parts :—

(1) A lower section consisting of (1 *a*) principal dolomite (Rhætic) and (1 *b*) Liassic limestone, the upper beds being the youngest. This lowest portion is in normal position, and is scarcely disturbed.

(2) A middle section consisting of (2 *a*) calcareous schists, (2 *b*) a band of massive dolomite and dolomitic breccia, and (2 *c*) calcareous schists with green bands. This section shows marks of violent distortion and crushing.

(3) An upper section, consisting of more or less altered quartzite-schists, with calcareous schists, ophicalcite, and serpentine. This section retains most of its original character and form, and has undergone little mechanical disturbance since it left its 'root.'

This is summarized in the following synopsis:—

ZONE 3	Serpentine. Ophicalcite. Tarnthal Quartzites, etc.
ZONE 2	Calcareous schists with green bands. Dolomitic breccia. Calcareous schists.
ZONE 1	Liassic limestone. Principal dolomite (Rhætic).

The explanation of the structure now suggested is as follows:— The distinct line of division between the bedded limestones and the calcareous schists—that is, between Zones 1 & 2—marks approximately the lower limb of a long fold, the dolomitic breccia being thus a repetition in a highly attenuated form of the principal dolomite below.

As regards the relations between Zones 2 & 3, the interpretation is not so clear; the absence of any line of demarcation between these two series of rocks, which have been affected in different degrees by dynamic activity, gives rise to some difficulty. But the hypotheses that present themselves are:—

(*a*) The collective mass 2 & 3 is in inverted sequence, the serpentine and green schists belonging to an older series normally and immediately below the dolomite—the dolomitic breccia belonging to the lower limb of a fold, the upper limb of which is marked by an air-line above the serpentine.

Or (*b*) The dolomitic breccia represents the whole of the principal dolomite in a flattened fold, the nappe. The serpentine and quartzites have been brought into their present position by a long overthrust, the traîneau écraseur of Prof. Termier. The relation of 1 and 2 in this case is one of enforced conformity, instances of which are known elsewhere.