On a Serpentine-rock from the mass of the Tarnthaler-Köpfe, Tirol.

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THE rock-specimens here treated were collected in 1902 on a small plateau near the head of the Oberer-Bach, where the rock is in place. This stream, rising near the Röckner or Reckner, a summit of the Tarnthaler-Köpfe on the north of the Tuxerthaler mass, flows down a steep ravine southward to join the Schmirner-Bach: the locality is situated about 20 kilometres to the south-east of Innsbruck. The figures 2629 (height in metres) on the 'Generalstabskarte' probably represent the site of the plateau; it is on the right bank of the stream, close to, and some 12 or 15 metres above, a small frozen lake near the head of the stream. The point was reached by ascending the ridge from the Kreuzjöchl. There was much snow on the plateau and the geological relations of this particular occurrence were not observed.

The two specimens which I collected on the above-mentioned plateau of the Tarnthaler mass show considerable differences in the proportions of the minerals present. One is rich in colourless pyroxene, and contains but little amphibole and picotite. The other contains much amphibole (probably tremolite), clinochlore, much picotite, and little pyroxene. The conspicuous bastites are more numerous in the rock with much pyroxene. The serpentine-minerals exhibit similar characters in the two specimens.

Pyroxene.—The colourless pyroxene, as seen in thin sections of both the specimens, is remarkable for the complete absence of twinning and zoning. Sections of crystals showing the typical prismatic cleavage give, in convergent light, a positive interference-figure around one of the optic axes, and the optic axial plane is seen to bisect the acute angle between the cleavages. Sections which show the interference-figure of an optic normal give an extinction-angle $\mathfrak{c}: \grave{c} = 40°$.

Sometimes the pyroxene forms a core of the larger amphibole crystals to be mentioned below. Inclusions are present in some of the pyroxene crystals; they have the form of short rods arranged in swarms with their longer axes parallel to the orthopinacoid of the pyroxene, and their refractive index differs but little from that of the host. Or again, some of the pyroxene crystals show undulose extinction; whilst groups of small grains all differing in optical orientation are no doubt in many cases the displaced fragments of a single crystal ('Mörtelstruktur').

This pyroxene seems to be an original consolidation product of the igneous magma, and it resembles the sahlite noted by Hussak[1] in other Alpine serpentines. It has in part been altered to serpentine. Sinuous veins of a pleochroic serpentine traverse the pyroxene crystals in all directions, giving them quite the appearance of decomposing olivines. Only in the absence of iron oxide do these veins differ from those in the surrounding serpentine. The slides were carefully searched for olivine, but this mineral could not be detected[2]. Dull opaque masses of a dark-brown colour and traversed by numerous cracks are not infrequent, and sometimes suggest a derivation from olivine.

Rothpletz[3] records the presence of fresh olivine in the neighbouring serpentine-mass of the Röckner, and von Drasche[4] mentions kernels of the same mineral in serpentinous decomposition products in boulders (which may not, however, belong to this district) at Brixlegg. Reports of other occurrences of olivine in the serpentine-rocks of this district (e.g. at Matrei-am-Brenner and Pfons) appear to be based merely on the structures observed in the serpentinous decomposition products. Seeing, however, how closely the serpentine-veins in decomposing pyroxene crystals may simulate in form the network in altered olivines, the question arises as to how far such conclusions are justifiable.

Amphibole (*Tremolite*).—The mineral is colourless in thin sections, sometimes appearing in compact crystalline form, but more often showing the sheafy habit of secondary amphiboles. The prismatic cleavage is distinctly shown in some of the sections. The needles in the sheaves are sometimes twinned according to (100). Sections showing an emergence of an optic normal have not been found; the highest angle

[1] E. Hussak, 'Ueber einige alpine Serpentine.' Min. Petr. Mitt. (Tschermak), 1883, vol. v, pp. 61–81.

[2] The fact that the pinacoidal cleavage (010) of olivine is perpendicular to the optic axial plane helps to distinguish this mineral from pyroxene; for in sections of the latter, in which the prismatic cleavage is shown as parallel cracks, the trace of the optic axial plane is parallel to these.

[3] A. Rothpletz, 'Ein geologischer Querschnitt durch die Ost-Alpen.' Stuttgart, 1894, pp. 83, 84.

[4] R. von Drasche, 'Ueber Serpentine und serpentinähnliche Gesteine.' Min. Petr. Mitt. (Tschermak), 1872, Jahrg. 1871, pp. 1–12.

of extinction observed is 17°, the axis of less elasticity being nearer the axis of the needle.

The larger crystals of amphibole are traversed by sinuous veins of serpentine, whilst the needles are decomposed at the ends into a bastite-like mineral to all appearance identical with the mineral *A* described below.

The occurrence of amphibole with a core of pyroxene recalls a similar relation in the diabases of Vahrn, near Brixen in southern Tirol. In the tendency to form sheaf-like aggregates the mineral resembles more nearly that of the amphibolites, and is probably to the same extent an original product, either a first crystallization or a very early product of molecular reconstruction in a deep-seated rock-mass.

The decomposition into serpentine-like products proves this amphibole to be older than the serpentine. Lindemann[1] considers an amphibole in a rock of the serpentine group near Sterzing in the Tirol to be secondary and contemporary with the serpentine.

Clinochlore.—A colourless, non-pleochroic mineral of the chlorite group is found only in the slide with much amphibole. It gives low grey polarization-tints and has an index of refraction distinctly higher than that of the serpentines, but lower than that of the amphibole. Twinning with the basal plane as face of composition is frequent. Extinction angles up to 5° have been measured against the trace of (001). The axis of less elasticity is always normal to the cleavage plane, and the 'isogyres' of Becke give indications of a positive optical character for the crystals.

The mineral occurs intimately associated with amphibole, the finer needles of which tend to lie in the plane of cleavage of the clinochlore. The bastite-like mineral accompanying these groups is evidently derived from the amphibole.

Titanite is found in small, angular grains. *Picotite,* in minute grains, is especially abundant in the rock with much amphibole.

Magnetite, in a finely divided state, is disseminated through the rock, accompanying more especially the highly pleochroic serpentine. Higher powers show innumerable trichites and globulites, probably of the same mineral.

Chromic iron-ore may be represented by the dull, opaque masses already mentioned—these never show the forms of chromite; they are probably derived from pyroxene, olivine, or perhaps garnet.

[1] B. Lindemann, 'Petrographische Studien in der Umgebung von Sterzing in Tirol.' Neues Jahrb. Min., 1906, Beilage-Band xxii, pp. 454–554.

Iron-pyrites is found in small quantity in the rock with much pyroxene.

A carbonate, probably *Magnesite*, without twin-lamellae, occurs frequently in both the rock-specimens.

Serpentine-minerals.—The ground-mass in which the above-mentioned minerals are embedded consists of serpentine in two forms: (1) a conspicuously pleochroic mineral, seen most frequently in the veinlets of the net-like structures, and never appearing as compact crystals; (2) a mineral almost colourless in thin sections, often filling the meshes with groups of parallel fibres resembling bastite, and more rarely simulating on a very minute scale the trellis-work figured by von Drasche. This latter form is held to be one of the varieties of serpentine to which the name antigorite has been given, and is here called the 'mineral *A*', the more pleochroic serpentine being called *S*.

A mineral to all appearance identical with *A* is well shown in the section of a rock-specimen from Sprechenstein near Sterzing, Tirol, belonging to my collection of 1905. This specimen furnished the material for the following description of the mineral *A*. The slide contains an abundance of lath-like forms like those represented in von Drasche's fig. 2, and also the pavement or mosaic-structure shown in the same author's fig. 3 [1].

In the Sprechenstein rock the forms in the groups similar to those of von Drasche's fig. 3 show little or no cleavage, whilst with moderately high magnification a very perfect cleavage, like that of the micas, can be recognized in the lath-like forms.

In polarized light the laths present the appearance of twinning after the manner of clinochlore. Extinctions up to 3° have been measured. In convergent light the laths showing the most perfect cleavage give the interference-image of a positive bisectrix with a wide angle of the optic axes: this is probably the acute bisectrix. The negative bisectrix has not been observed.

Individuals showing little cleavage have been found giving the image of an optic axis. The dark bar of the hyperbola appears in this case to be only very slightly curved; the convexity seems to be towards the c bisectrix, again indicating a positive crystal with an axial angle approaching 90°.

The slide of the Sprechenstein rock is too thin to show the pleochroism, but pleochroic colours have been observed in the powdered mineral

[1] These forms are recognized by von Drasche (loc. cit.) to be sections respectively transverse and parallel to the cleavage of the antigorite.

of this rock; bluish-green for vibrations parallel to the cleavage, and brownish-yellow for those transverse to the cleavage. The direction of the bluish-green absorption agrees with that given for antigorite by Hussak and by Weinschenk[1].

It appears from the above that the lath-like forms of the mineral *A* have the characters of individual crystals and not of fibrous aggregates. As regards optical properties, the mineral resembles the biotites, and perhaps some penninites in the optical orientation, the $\mathfrak{a}$ bisectrix being nearly normal to the plane of cleavage. In the low index of refraction, the low double refraction, and the nature of the absorption (the greenish ray vibrating parallel to the cleavage) the mineral resembles the chlorites.

The optical scheme for the mineral *A* given in fig. 1 differs somewhat from that given by Hussak and by Weinschenk for antigorite (fig. 2). Hussak's observations were made on a mineral described as highly pleochroic with leek-green absorption parallel to the cleavage. Weinschenk's mineral was also distinctly pleochroic[2].

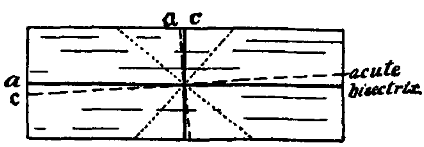

Fig. 1.—Optical orientation of mineral *A*.

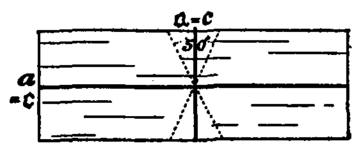

Fig. 2.—Optical orientation of antigorite, according to Hussak and Weinschenk.

The differences can perhaps be explained by supposing the last-named minerals to contain an isomorphous constituent richer in iron oxide, the presence of which determines a wandering of the optic axes towards the *c* axis.

[1] E. Weinschenk, 'Beiträge zur Petrographie der östlichen Centralalpen speciell des Gross-Venedigerstockes.' Abhandl. bayer. Akad. Wiss., 1895, vol. xviii, pp. 651–746. (See p. 661.)

[2] The antigorite of the Antigorio valley diverges in optical properties still more, though in the same direction, from the mineral *A*, the axial angle varying from 0° to 36°. (C. Klein, Sitzungsber. preuss. Akad. Wiss., 1894, p. 768.)

Tschermak gives 20° or more for the axial angle of the Sprechenstein mineral, but says (p. 255), apparently quoting Hussak, 'die kleinste Elasticitätsaxe ist senkrecht zur Spaltebene'—which is, perhaps, a clerical error. (G. Tschermak, 'Die Chloritgruppe.' Sitzungsber. Akad. Wiss. Wien, math.-nat. Classe, 1890, vol. xcix, Abth. I, pp. 174–267.)

In the slides of the Tarnthaler rock the more pleochroic veinlets of the mineral *S* forming the 'network' of the serpentine ground-mass appear to have a slightly higher index of refraction. The polarization-tints are also higher than those of the fibrous mineral in the meshes.

The pleochroism is seen in the thinnest sections, the colours being about the same as in the nearly colourless mineral *A*. The strongest contrast of pleochroic tints is observed when the axis of the vein is respectively parallel and transverse to the principal section of the nicol, being bluish-green for the first and brownish-yellow for the second position. The extinctions also take place in these positions. The axis of greater elasticity is transverse to the axis of the veinlet, coinciding with the yellowish absorption.

The veinlets often show a median longitudinal suture as if they had grown symmetrically by accretion from the walls inwards after the manner frequent in mineral-veins. In polarized light there is often an appearance of fibrous structure, the threads being often at right angles to the walls but occasionally lying obliquely to the walls. There is no break of continuity at the curves of the veinlet. All these facts suggest that the veinlets are built up of ultra-microscopic crystal-elements placed with the axes of elasticity parallel and at right angles to the walls of the veinlets.

It does not appear that the visible fibres represent the ultimate structure of the veinlets of *S*. If it be assumed that these are composed of minute plates of a mica-like mineral with the cleavage planes parallel to the walls of the vein, the mineral will be found to agree in all important respects with the mineral *A*. On this assumption the mineral *S* would approximate closely to the antigorite of Hussak and to that of Weinschenk, both of which are distinctly pleochroic.

Bastite.—Numerous pseudomorphs measuring up to 4 mm. across show the schiller of bastite and are found to resist weathering better than the mass of the rock. On the plateau, where they form numerous prominences on the exposed surfaces, some of these pseudomorphs were seen to be coated with a film of a mineral with bright, silvery lustre.

Sections of these pseudomorphs transverse to the lamellae show, under the microscope, numerous very thin parallel streaks of a mineral with a higher index of refraction and much brighter polarization-tints than those of the antigorite. These streaks, often less than 1 μ and seldom more than 2 μ in thickness, are crowded together to the number of thirty-five or more to the millimetre. The interspaces are filled with the mineral *A*, usually in the bastite form. Veins of the mineral *A* are seen traversing the pseudomorphs in all directions, independently of the position of the streaks of the more refringent mineral.

The pseudomorphs, consisting mainly of the same material as the ground-mass of the rock, show no very distinct boundaries, especially when the striae are absent.

The mineral composing the striae, really sections of films, shows polarization-tints as high as those of the amphibole, and extinguishes when the striae make a high angle with the principal sections of the crossed nicols. The orientation of the mineral in the films is not known.

It is apparently this mineral which confers the power of resistance to weathering exhibited by these pseudomorphs. A single film cannot be the cause of the silvery reflexions. It is thought that the mineral *A* between the films has been gradually removed by atmospheric influences leading to an accumulation of films by the resulting collapse. The process would go on here with little interruption, as the site is rarely visited.

The bastite pseudomorphs are probably derived from aggregates of the nature of diallage consisting of two minerals in alternating lamellae.

Geologic relations.

A serpentine-rock with olivine has been reported by Rothpletz[1] from the Röckner, close to which is the site of the pyroxene-bearing serpentine here described. This intrusion may thus be compared with those of the Rettenkopf and Todtenköpfe in the Hohe Tauern, described by Becke[2] and Weinschenk[3], and that of the Geisspfad in the Swiss Alps reported by Preiswerk[4], in both of which pyroxene-bearing rocks follow on those rich in olivine.

The serpentine of the Röckner and of the other Tarnthaler summits is found in close proximity to rock-masses showing the typical foliation of the phyllites and containing talc and other magnesian minerals.

The phyllites occupy the crest of the ridge over the chain of frozen

[1] A. Rothpletz, loc. cit.

[2] F. Becke, 'Olivinfels und Antigorit-Serpentin aus dem Stubachthal (Hohe Tauern).' Min. Petr. Mitt. (Tschermak), 1894, vol. xiv, pp. 271–6.

[3] E. Weinschenk, loc. cit.

[4] H. Preiswerk, 'Der Serpentin am Geisspfad (Oberwallis).' Eclogae geologicae Helvetiae, 1901, vol. vii, pp. 123–5.

lakes in the high valley which drains to north and west into the Navis-Thal. They show vertical, plane-parallel joints, which cross the foliation and the axis of the ridge at right angles. The joints are not carried downward into the younger underlying rocks, which include Triassic limestones and the dolomite-breccia of Rothpletz.

The present position of the rocks can only be accounted for by movements of faulting, folding, and overthrust, according to F. E. Suess[1]. According to P. Termier, these rocks form part of a long, recumbent fold[2].

The geologic relations of the Tarnthaler mass show that the intrusion of the serpentines was completed before the commencement of the movements which brought the rocks into their present position. The last great movement was not concerned in producing the foliation of the crystalline schists.

The same relation between serpentine and phyllite is seen to hold at Matrei-am-Brenner and at Pfons, where Blaas traced a complete transition from the ophicalcites and serpentines with little or no foliation to the highly foliated schists.

The masses of the Röckner and of Matrei-am-Brenner are igneous intrusions, the borders of which have been foliated in the same degree as the crystalline schists, whilst the cores have been preserved almost intact. The intrusion of these masses commenced at a period immediately preceding the close of the processes which brought about the foliation of the crystalline schists. The intrusions were continuous and contemporaneous, or nearly so, for margin and core. Before the cores of the masses could be influenced the conditions and activities determining foliation ceased to be effective, and have not since been renewed in this portion of the crust.

[1] F. E. Suess, 'Das Gebiet der Triasfalten im Nordosten der Brennerlinie.' Jahrb. geol. Reichsanstalt, Wien, 1894, vol. xliv, pp. 589–668.

[2] P. Termier, 'Les Nappes des Alpes orientales et la synthèse des Alpes.' Bull. Soc. géol. de France, 1904, sér. 4, vol. iii, pp. 711–65.