The stilpnomelane group of minerals.

By C. Osborne Hutton, M.Sc., Ph.D., F.G.S.
Shirtcliffe Fellow of the University of New Zealand.
Department of Mineralogy and Petrology, University of Cambridge.

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Contents.

Introduction.

Work which has been in progress during the last few years on the low-grade regionally metamorphosed rocks of western Otago, New Zealand, has shown that members of the stilpnomelane group, hydrous iron- (or manganese-) rich silicates, are exceedingly widespread in rocks with the most varied mineral assemblages. In many cases the mineral in question is in sufficient quantity to rank as an essential constituent and may even be the most abundant one present. Hence in view of the importance of this mineral in the rocks of this region, it was considered that exact analytical data were necessary, and preliminary work in this connexion was carried out by Dr. F. J. Turner and the writer in 1934, but at that time, owing to the difficulties of separation, the pure minerals could not be obtained for analysis.

The present paper includes the results of a petrographical, chemical, and X-ray investigation of stilpnomelane and stilpnomelane-bearing rocks, together with six new analyses of pure stilpnomelanes and seven of rocks. From these data it has been possible to show that the various minerals formerly classed as chalcodite or stilpnomelane really all belong to a series, to be termed the stilpnomelane series, varying between two end-members, the ferrous mineral for which the term ferrostilpnomelane is suggested, and the ferric type for which the name stilpnomelane is retained. As will be shown later, it is believed that parsettensite should be considered the manganiferous member of the group.

Occurrence.

The first occurrence of stilpnomelane in New Zealand was noted by Turner (1934) in quartz-albite-epidote-chlorite-schists from the Forbes Range, western Otago, but since then this series of minerals has been found to occur in each of the four sub-zones of the chlorite zone. Only in the Chl. 4 sub-zone, however, is it commonly well crystallized, sometimes forming plates up to 4·0 mm. in diameter which are usually oriented parallel to the plane of schistosity of the rocks; when the mineral is very abundant it may even form distinct bands consisting almost entirely of stilpnomelane. In some rocks the minerals may occur in clusters of radiating plates which lie across the schistosity planes. Stilpnomelane, with high Fe_2O_3 content, is the most usual member of the series occurring in these rocks, while ferrostilpnomelane is much less frequently developed, though when present is often abundant.

Of 600 specimens collected from the four sub-zones, stilpnomelanes occurred in 20 %, while in 8–10 % the mineral was in sufficient amount to rank as an essential constituent. The mineral assemblages of the rocks in which stilpnomelanes have been noted are widely variable, and a list previously published may be conveniently given again, together with additional assemblages observed during this subsequent investigation:

quartz-albite
quartz-muscovite
quartz-chlorite
quartz-garnet
quartz-muscovite-chlorite-garnet
quartz-albite-epidote-chlorite
quartz-albite-epidote-actinolite
quartz-albite-garnet-chlorite-epidote
albite-epidote-chlorite
albite-epidote-actinolite
albite-actinolite
albite-epidote-actinolite-chlorite
albite-chlorite-muscovite
chlorite-epidote
chlorite-epidote-magnetite
garnet-calcite
garnet-calcite-chlorite
garnet-pyrite-sphene
magnetite-garnet-actinolite-apatite

The following list shows the percentage of stilpnomelane-bearing rocks containing the minerals listed:

quartz	86	magnetite	67	tourmaline	9
albite	87	muscovite	65	garnet	16
chlorite	86	sphene	52	biotite	4
epidote[1]	94	pyrite	4	calcite	4
actinolite ...	48	apatite	28	rutile	1

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[1] Pumpellyite is very often present together with epidote in the rocks of sub-zones Chl. 1, 2, and 3.

Quartz, albite, chlorite, actinolite, and epidote may occur in important amount, though any one of these constituents may be reduced to the position of accessory or even fail altogether. Muscovite may be an essential mineral, but magnetite and sphene are rarely abundant except in some uncommon schists, viz. sphene-pyrite-garnet-schists and magnetite-garnet-actinolite-apatite-schists. A pale pink or colourless spessartine-garnet is sometimes important, especially in the quartz- and magnetite-schists. It is interesting to note, however, that stilpnomelane though an iron-rich silicate, was rarely found in magnetite-schists. Apart from apatite, the other minerals occur but rarely.

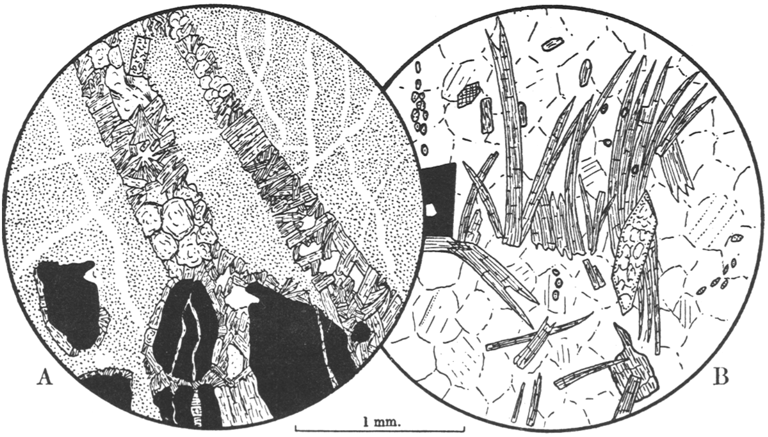

FIG. 1 A. Veinlets of stilpnomelane in garnet-magnetite-stilpnomelane-apatite-schist (no. 3205). One mile west of mouth of Three Mile Creek, Lake Wakatipu.

FIG. 1 B. Coarse red-brown stilpnomelane in albite-stilpnomelane-actinolite-schist (no. 2646). 56 chains east of the junction of Billy Goat Creek and Arrow River, western Otago.

The mineral appears to reach its greatest development in rocks of the green-schist type, i.e. in albite-epidote-chlorite-, albite-epidote-chlorite amphibole-, and albite-epidote-amphibole-schists, for in these types it is usually coarsely crystalloblastic (fig. 1 B) and often very abundant (fig. 2 B). Furthermore, its development may often be important in quartz-schists (fig. 3 B) in which spessartine is often an associated mineral, but generally the plates are not so coarse as in the green-schists. Again, the mineral may be abundantly developed in garnet-calcite- (fig. 2 A) and sphene-pyrite-garnet-schists, but the latter are very rare. In one specimen (no. 3205) of a garnet-amphibole-magnetite-stilpnomelane-

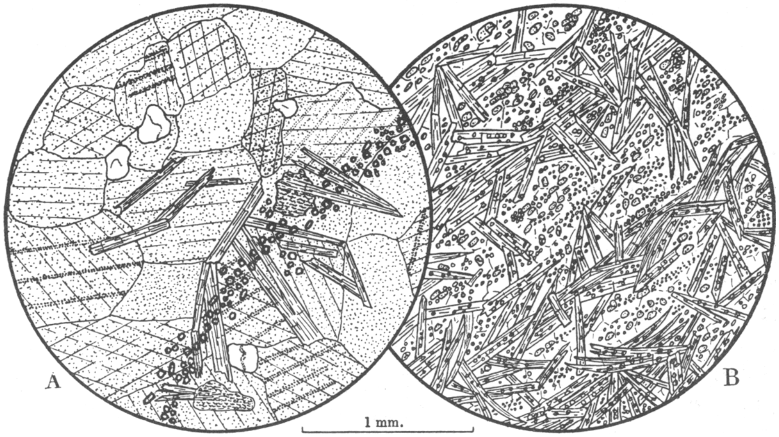

Fig. 2 A. Green ferrostilpnomelane in garnet-calcite-chlorite-ferrostilpnomelane-schist (no. 2702): calcareous band. Templeburn, Arrow Valley, western Otago.

Fig. 2 B. Albite-epidote-stilpnomelane-schist (no. 3230). Trignometrical station H, mid-Wakatipu survey district, western Otago.

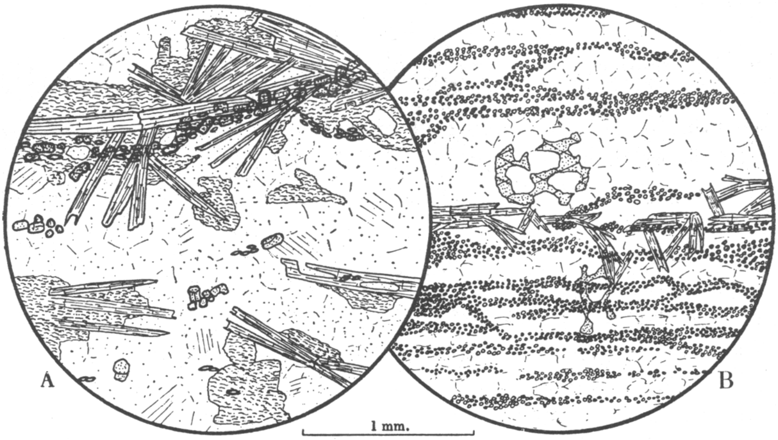

Fig. 3 A. Stilpnomelane developing from chlorite in albite-quartz-epidote-chlorite-stilpnomelane-schist (no. 2630). Half-mile north-east of Crown Peak, Crown Range, western Otago.

Fig. 3 B. Band of stilpnomelane in quartz-garnet-stilpnomelane-schist (no. 3202). 36 chains north of Staircase Creek, Lake Wakatipu, western Otago.

schist, the stilpnomelane occurs also as a vein mineral, this being the only specimen collected showing this feature (fig. 1 A). The writer has also observed stilpnomelane in the incipient stages of formation in a sheared pyroxenite from the Caples Valley, west of Lake Wakatipu, western Otago (Hutton, 1936, p. 235).

Nomenclature.

Much confusion exists in the specific naming of various members of the stilpnomelane group, the same name in the past having been applied to related but chemically distinct species, while again different terms have been employed for minerals of similar chemical composition. Thus Shannon (1920), followed by Grout and Thiel (1924) and Holzner (1933), terms a member richer in FeO than Fe_2O_3, stilpnomelane, which Genth (1885) and Winchell (1933) designate as chalcodite. On the other hand, this latter term is used by Brush (1858, following Shepard), Fromme (1902), and Shannon (loc. cit.) for minerals with high Fe_2O_3 content, which Hallimond (1924) and Berman (1937) refer to stilpnomelane. Kretschmer (1907) employs the term stilpnomelane for both types.

In order to clarify the situation it is necessary to consider the chemical analyses of the original stilpnomelane and chalcodite. The name stilpnomelane was originally applied by E. F. Glocker (1827) to a shining black mineral occurring at Obergrund near Zuckmantel in Austrian Silesia. Four analyses by Rammelsberg (1838), and one by Siegert (in Rammelsberg, 1853) showed it to be entirely a ferrous mineral, but analyses by the present writer of material from the same locality (see table 3, analyses D and E), which, while indicating total iron to be almost identical with Rammelsberg's FeO figures, gave values in which Fe_2O_3 is greater than FeO. It cannot be argued that the writer's specimens were more oxidized than Rammelsberg's material, for the latter's totals are very low; these, however, can be made to approach a reasonable figure if the total FeO figure is recalculated into FeO and Fe_2O_3 in the ratio found in my analyses. Clearly therefore, the term stilpnomelane must be reserved for minerals of such composition, i.e. in which $Fe_2O_3 > FeO$ (weight per cent.).

Shepard (1852) applied the name chalcodite to a mineral, later analysed by Brush (1858), in which the Fe_2O_3: FeO ratio was almost identical with that in the writer's analyses of the Zuckmantel stilpnomelane. The term chalcodite, having been applied to a mineral whose chemical composition is almost identical with that of stilpnomelane described 25 years before, must therefore disappear.

It seems clear after a study of all the reliable analyses, that any member of the stilpnomelane group (excluding manganese-bearing types) may be considered as a mixture of two end-members, these being the minerals characterized by Fe_2O_3 and FeO respectively. For the former the name stilpnomelane must be retained and for the latter the term ferrostilpnomelane is proposed. This may be simplifying the problem too greatly, but when a number of analyses is considered the variation in the constituents, other than Fe_2O_3 and FeO, is very small indeed. It seems quite probable from the X-ray data that parsettensite could be grouped as a manganiferous stilpnomelane, in which case any member of this group could be considered as a member of a ternary system of stilpnomelane, ferrostilpnomelane, and parsettensite.

Gruner (1937), who recently published chemical and X-ray data on stilpnomelane, states that a division of the stilpnomelane group into ferric-rich and ferrous-rich types respectively is untenable on chemical and structural grounds. While agreeing with the latter, the present writer holds that a division on a chemical basis is both possible and useful; and further it will be shown that there is a variation in the optical properties with change in chemical composition.

Petrography.

Stilpnomelane, the most abundant constituent in no. 3230 (table 1, analysis A), forms an intricate criss-cross arrangement of crystals, but a radiate grouping of somewhat curving plates is also common (fig. 2 B); inclusions of epidote and rarely sphene were noted. Intimate interlamination with a pale green, optically negative prochlorite is frequent. Albite with a little quartz, as xenoblastic grains with strong undulose extinction, form 20 % of the rock. Subidioblastic to idioblastic grains of ferriferous epidote are quite plentiful and almost entirely constitute some narrow bands. Clusters of granular sphene and pale needles of actinolite, often stabbing chlorite, make up the accessories.

Two schists (nos. 2658 and 2692; table 1, anal. B and F) contain plentiful chlorite in addition to stilpnomelane, the latter forming 25–30 % and 20–25 % of the rocks respectively. Stilpnomelane forms well-defined plates up to 2·5 mm. in diameter, often in radiate arrangement; intimate association with optically negative chlorite (no. 2692) or negative chlorite and rare muscovite (no. 2658) is noteworthy. Xenoblastic albite, Ab_{98}–Ab_{100}, and epidote are abundant in both specimens. Accessories include quartz, often as 'blebs' in felspar, rare iron-ores, apatite, sphene, and slender idioblastic prisms of bluish-green actinolite stabbing plates of chlorite.

No. 2646 (table 1, anal. C) is a coarsely crystalline schist with prominent folia of both felspar and stilpnomelane. In thin slice albite is the

Table 1. Analyses of stilpnomelane-bearing schists from western Otago, New Zealand. (Analyst, C. O. Hutton.)

	A.	B.	C.	D.	E.	F.	G.
SiO_2 ...	45·96	53·93	61·12	76·33	40·97	48·48	57·66
Al_2O_3 ...	12·80	11·16	14·61	6·96	10·05	11·88	5·00
TiO_2 ...	2·75	2·03	1·00	0·95	0·88	2·47	0·02
Fe_2O_3 ...	13·26	14·07	4·46	2·23	1·34	10·82	21·02
FeO ...	4·73	1·29	1·64	3·35	16·37	5·69	0·67
MnO ...	0·76	0·27	0·13	1·29	4·64	0·23	4·07
MgO ...	4·20	2·86	2·05	2·67	3·38	4·25	1·27
CaO ...	5·79	2·67	2·86	1·20	10·37	7·40	1·80
Na_2O ...	2·37	5·34	9·32	1·55	1·34	3·82	0·11
K_2O ...	0·30	0·66	0·51	0·53	0·58	0·42	0·37
H_2O+ ...	5·77	4·44	1·41	1·92	4·54	3·34	4·87
H_2O- ...	0·86	0·74	0·26	0·18	0·78	0·27	1·35
CO_2 ...	nil	nil	1·02	0·05	4·41	nil	nil
P_2O_5 ...	trace	0·29	0·13	0·18	0·02	0·76	1·43
ZrO_2 ...	nil	nil	nil	nil	trace	nil	nil
Cr_2O_3 ...	nil	nil	nil	trace	nil	trace	nil
BaO ...	nil	nil	nil	nil	nil	nil	nil
(Ni,Co)O ...	—	—	—	—	—	—	nil
FeS_2 ...	0·54	0·31	0·13	0·50	0·24	0·11	0·43
	100·09	100·06	100·65	99·89	99·91	99·94	100·07

Refractive indices of the stilpnomelane mineral in these rocks:

	A.	B.	C.	D.	E.	F.	G.
α	1·596	1·615	1·599	1·605	1·551	1·605	1·625
γ	1·686	1·706	1·680	1·690	1·594	1·689	1·735
$\gamma-\alpha$ ...	0·090	0·091	0·081	0·085	0·043	0·084	0·110

A. Albite-epidote-chlorite-stilpnomelane-schist (no. 3230), Trignometrical station H, mid-Wakatipu survey district.

B. Albite-chlorite-stilpnomelane-schist (no. 2658), 800 yards up pack track from Bracken Creek crossing, Arrow Valley.

C. Albite-stilpnomelane-actinolite schist (no. 2646), 56 chains east of the junction of Billy Goat Creek and Arrow River.

D. Quartz-muscovite-garnet-stilpnomelane-schist (no. 2629), 16 chains SE. of Kawarau bridge.

E. Garnet-calcite-chlorite-ferrostilpnomelane-schist (no. 2702), 70 chains up Templeburn from Arrow River.

F. Albite-epidote-chlorite-stilpnomelane-schist (no. 2692), 16 chains SE. of Kawarau bridge.

G. Quartz-garnet-stilpnomelane-schist (no. 3523), *one mile* from Queenstown along Frankton road, Lake Wakatipu.

most abundant component as rarely twinned xenoblastic grains, often full of inclusions of quartz, sphene, and epidote. Porphyroblastic bluish-green actinolite (2V 65°, $\gamma{:}c = 16°$) is often intergrown with well-developed coarse stilpnomelane, the plates of which usually lie parallel to the foliation plane, rarely across it. Calcite, quartz, epidote, apatite, and iron-ores are rare.

TABLE 2. Quoted analyses of rocks for comparison with analyses A, C, D, F of stilpnomelane-bearing schists.

	A1.	C1.	D1.	F1.	F2.
SiO_2 ...	44·77	60·39	73·71	49·07	50·04
Al_2O_3 ...	12·46	18·40	7·25	10·60	11·65
TiO_2 ...	5·26	0·80	0·50	—	1·93
Fe_2O_3 ...	4·63	1·03	2·63	12·03	2·63
FeO ...	12·99	3·50	0·44	6·57	15·76
MnO ...	0·17	0·08	—	—	—
MgO ...	5·34	1·27	1·47	4·68	5·58
CaO ...	10·20	1·53	1·72	8·58	7·89
Na_2O ...	2·47	8·79	1·19	2·56	3·08
K_2O ...	0·95	0·46	1·00	1·76	0·89
H_2O+ ...	0·48	1·37	6·94	1·70	0·19
H_2O- ...	0·12	0·20	2·88	—	—
CO_2 ...	0·37	1·70	trace	1·65	—
P_2O_5 ...	0·28	0·12	0·24	—	0·20
ZrO_2 ...	—	—	—	—	—
Cr_2O_3 ...	—	—	—	—	—
FeS_2 ...	(S) 0·26	0·02	(SO_3) 0·16	—	—
	100·75	99·66	100·13	99·20	99·84

A1. Gabbro, Lincoln Pond, Essex County, New York. (H.S. Washington's tables, 1917, p. 606.)

C1. Keratophyre, Hanging Rock, Nundle, New South Wales. (W. N. Benson, Proc. Linn. Soc. N.S.W., 1915, vol. 40, p. 139.)

D1. Diatomaceous shale from road near Hollywood Country Club, California. (Analyses of rocks and minerals, 1914–36. Bull. U.S. Geol. Surv., 1937, no. 878, p. 63.)

F1. Diabase, Rio de Janeiro, Brazil. (H.S. Washington's tables, 1917, p. 870.)

F2. Norite, St. Thomas Mount, near Madras, India. (Ibid., 1917, p. 624.)

No. 2629 (table 1, anal. D) is typical of the quartz-rich types, with xenoblastic grains of quartz making up about 75 % of the rock. Muscovite is interleaved with the chlorite from which a little biotite is developing. Stilpnomelane, though not as abundant as in the previous types, occurs as well-developed plates often intimately associated with chlorite and rarely biotite. Colourless idioblastic rhombic-dodecahedra of spessartine-garnet occur in strings and clusters, while spindle-shaped sphene, apatite, and a little iron-ore constitute the accessories.

Stilpnomelane with a composition of approximately $FeSt_{32}St_{68}$ is the most abundant constituent in a quartz-garnet-schist (no. 3523; table 1, anal. G), this rock differing from no. 2629 mainly in the relative proportions of quartz and stilpnomelane. Chlorite, epidote, and iron-ore are rare. Stilpnomelane with a composition close to the ferrostilpnomelane end of the series are also represented in the quartz-garnet-schists (nos. 3186, 3197; see fig. 3 B).

Ferrostilpnomelane, which constitutes at least 40% of no. 2702 (fig. 2 A), imparts to the hand-specimen a lepidoblastic texture. It occurs as sprays of stout plates (up to 3·5 mm. in diameter), sometimes interlaminated with deep-green negative chlorite, and often densely studded with tiny idioblastic garnets and rare epidote. Xenoblastic calcite, often showing multiple twinning and strain effects, is plentiful. Quartz, albite, sphene, and rare magnetite make up the accessories.

Though not analysed, no. 2637, an albite-epidote-chlorite-schist, may be noted here on account of the interesting association in it of well-developed stilpnomelane (α 1·594, γ 1·681) and a member near to ferrostilpnomelane. Both minerals occur as rather coarse radiating plates, lying in the schistosity plane as well as across it; rarely the two minerals are intimately interleaved with one another, but are more commonly interlaminated with a deep-green negative chlorite. A complete gradation from green ferrostilpnomelane to brown stilpnomelane may occasionally be seen. Epidote is plentiful as xenoblastic and idioblastic grains, the iron content of which varies greatly. Accessories include a little actinolite, sphene, quartz, apatite, calcite, and iron-ore.

Stilpnomelane with a composition close to ferrostilpnomelane, spessartine-garnet, pyrite, and sphene are the constituents of a rare and unusual type of schist (no. 3216), which occurs as a narrow band at the junction of some stilpnomelane-bearing albite-epidote-chlorite- and quartzo-felspathic schists. The pyrite occurs as ragged grains more or less elongated in the plane of schistosity, while sphene in clusters of granules as well as a few idioblastic wedge-shaped crystals is important.

Magnetite, stilpnomelane, and manganiferous garnet are the essential components of an interesting schist (no. 3205, fig. 1 A), in which stilpnomelane (γ 1·693), as well as being associated with the other components, occurs as a vein mineral. These veins, varying from 2 to 7 mm. in width, are of two types, in which the mineral (1) has a fibrous aspect, the fibres being oriented perpendicularly to the vein-walls, and (2) is platy and has no obvious orientation. Other minerals include albite, crossite, epidote, sphene, and veins of manganiferous apatite (α 1·632, γ 1·636). Manganese determinations on the schist itself and the vein-forming stilpnomelane gave values: MnO 12·23 % in the rock, and MnO 4·53 % in the vein.

The seven rocks analysed contained members of the stilpnomelane group of minerals as the essential or even the predominant constituents, and their chemical affinities and origin might be briefly considered. In dealing with the latter field relationships should be considered; however, the nature of the country did not always permit close investigation over wide areas. A occurred in a narrow band, barely one foot wide, closely associated with a peculiar ferrostilpnomelane-garnet-pyrite-schist, at or close to the junction of a wide exposure of green-schists and quartzo-felspathic types. B, C, D, and F were associated with green-schists, while E and G occurred interstratified with quartzo-felspathic rocks.

The schists D and G, with over 50 % of normative quartz, have undoubtedly been derived from impure sandstones. The impurities, which vary in amount in the two rocks, would seem to have been in D mainly some shaly material; while G, on the other hand, containing 25 % of iron-ores (in the norm) and high MnO, is not far removed from the cummingtonite-garnet type of schist derived from impure iron-ores.

The remainder of the analyses may be considered together in that they present certain common features, viz.: (1) FeO and Fe_2O_3 are relatively high (except C); (2) MgO and CaO are rather low; and (3) soda is high, but potash low. Although analyses A and F are compared with A1 and F1 and F2 respectively (table 2), there are some noteworthy differences in the bulk composition which should be pointed out. Firstly, the total iron content of A and A1 is very similar, but most of the iron in A is in the ferric state while that in A1 is in the ferrous state. Again, there is a discrepancy in the CaO figures. Thus it may be suggested that the albite-epidote-chlorite-stilpnomelane-schist (analysis A) may have been derived from a doleritic type of rock from which much of the lime has been leached out and which has suffered some oxidation. Analysis F compares favourably with that of a weathered basic type (analysis F1) and also with F2, except for the state of oxidation of the iron in the case of F2. B shows a rather high percentage of normative quartz and haematite as well as very low lime and magnesia, features possibly indicating the original unmetamorphosed rock to be a tuff to which a moderate amount of sedimentary detritus had been added. The high MnO figure of E excludes direct origin from igneous rock types, but the schist might reasonably be considered a derivative of a highly impure siliceous iron-bearing sediment. C shows very high soda and may be compared with a keratophyritic rock (C1).

In some of the stilpnomelane-schists, ferrostilpnomelane has been observed to be zoned by a stilpnomelane-rich mineral, indicating an earlier formation of the FeO type. Therefore it is possible that ferrostilpnomelane has usually formed first, and this by oxidation has given rise to the Fe_2O_3-rich types. If this is so, then one must compare only the total iron content of a rock when making comparisons between analyses.

Optical Properties of the Otago Stilpnomelanes.

Two chemically and optically distinct members of the stilpnomelane group of minerals, viz. minerals near ferrostilpnomelane and stilpnomelane have been observed in the western Otago schists. When well developed they typically occur as thin micaceous plates, often with a radiate or sheaf-like arrangement. Basal sections are always irregular in outline. There is a perfect basal cleavage which is neither quite so regular nor so continuous as in micas, and an imperfect cleavage perpendicular to (001). Colour varies according to the composition from deep green (ferrostilpnomelane) to deep reddish-brown (stilpnomelane). In coarsely crystalloblastic examples in the schists of the Chl. 4 sub-zone, pleochroism is intense with absorptions according to the following schemes:

Ferrostilpnomelane.	Stilpnomelane.
α = clear pale yellow	α = bright golden-yellow
$\beta = \gamma$ = deep green	$\beta = \gamma$ = deep reddish-brown to nearly black
$\alpha < \beta = \gamma$	$\alpha < \beta = \gamma$

If basal plates of stilpnomelane are 0·05 mm. or more in thickness, basal sections are opaque. A uniaxial figure and a negative optical sign are characteristic, but rarely a biaxial figure has been noted in stilpnomelane. Refractive indices have been determined for a number of examples from Chl. 4 sub-zone schists, and these vary between the following limits: α 1·551 – 1·625, γ 1·594 – 1·735, $\gamma - \alpha$ = 0·043 – 0·110.

The similarity of the stilpnomelane group of minerals with green and brown biotites may be stressed here, and by reason of this it is probable that members of the group are more widely distributed than has hitherto been recognized. However, it is possible to distinguish these two minerals in thin section, and to assist in this the following points are brought forward:

(1) The cleavage in the stilpnomelanes is not so perfect as in biotite.
(2) The stilpnomelanes exhibit an imperfect cleavage perpendicular to (001).
(3) The strong golden-yellow tint for the α vibration-direction in the Fe_2O_3-rich members is characteristic.
(4) In the extinction position there is no mottled effect as is seen in micas.

If it is possible to extract a portion of the mineral from the rock, the following two points will assist in the identification:

(5) Stilpnomelanes are extremely brittle.

(6) Lauegrams of stilpnomelanes are especially characteristic (compare fig. 8 A and B).

Analytical Data.

The preparation of sufficient pure material for mineral analysis was rendered most difficult owing to the extremely brittle nature of the minerals dealt with. On crushing the rock, most of the desired material was reduced to a powder which passed through a 300-mesh sieve together with a good deal of the other minerals. However, by means of careful elutriation, a concentrate was obtained from which the pure mineral was finally only to be obtained by repeated centrifuging with bromoform, bromoform-benzene, and bromoform-methylene iodide mixtures. In all cases this material was then closely inspected under a microscope before analysis.

Analyses of stilpnomelanes from western Otago and type localities, together with their optical data, are given in table 3. Analysis B of a pure red-brown stilpnomelane verifies the conclusion previously reached (Turner and Hutton, 1935, p. 3) on the evidence given by a partial analysis of an impure concentrate (table 3, analysis A), that the common type in the western Otago schists has a high Fe_2O_3 and a low FeO content. Comparable analyses may be found in the literature, and a few of these are set down in table 4.

A study of the analyses B to G reveals a number of interesting points. It will be seen that the silica and alumina percentages are fairly constant, but the ratio $FeO:Fe_2O_3$ varies between wide limits. Magnesia may become quite an important constituent, as in B and C, while lime is constantly low. In regard to alkalis, potash, though in small amount, is constantly present, but soda is almost negligible and may be nil. While $H_2O > 105°$ is very constant, the rather high figures for $H_2O < 105°$ are noteworthy. Manganous oxide is important in only two analyses, C and G, and in both these cases the stilpnomelanes occurred in schists containing abundant spessartine-garnet.

Although potash is recorded in most reliable stilpnomelane analyses in the literature, it appears that this constituent may fail altogether (B1, B2, C1, table 4), in which case there does not seem to be any line, at least in chemical nature, between the non-potassic stilpnomelanes on the one hand, and the highly ferruginous serpentines and chlorites on the other.

Eighteen analyses of both biotites and of stilpnomelanes have been plotted on a ternary diagram (fig. 4) to show the relation of the fields

TABLE 3. New analyses of stilpnomelane. (Analyst, C.O. Hutton.)

	A.	B.	C.	D.	E.	F.	G.
SiO_2 ...	49·40	45·24	48·03	44·45	44·67	42·94	44·99
Al_2O_3 ...	6·22	6·73	6·48	7·26	6·83	7·59	6·99
TiO_2 ...	—	0·33	0·23	nil	trace	trace	st. trace
Fe_2O_3 ...	19·22	25·34	4·12	20·82	22·04	21·64	31·67
FeO ...	2·53	3·45	22·88	14·04	13·73	13·23	1·29
(Ni,Co)O	—	trace	—	trace	trace	—	—
MnO ...	—	0·60	2·67	0·05	0·06	0·11	2·57
MgO ...	—	7·67	4·94	2·77	2·33	2·80	2·89
CaO ...	—	1·91	0·83	0·53	0·83	0·91	0·36
Na_2O ...	2·26	0·03	nil	0·03	nil	0·10	0·39
K_2O ...	0·95	1·67	0·83	2·06	1·36	1·91	0·87
H_2O+ ...	—	6·72	6·90	6·41	6·74	6·95	7·94
H_2O- ...	—	0·76	2·64	1·35	1·57	1·94	0·44
Totals ...	80·58	100·45	100·55	99·77	100·16	100·12	100·40
α	1·592	1·599	1·551	1·595	1·595	1·597	1·625
$\beta=\gamma$ ...	1·680	1·680	1·594	1·690	1·685	1·692	1·735
$\gamma-\alpha$ ...	0·088	0·081	0·043	0·095	0·090	0·095	0·110
2V ...	0°	0°	0°	0°	0°	0°	0°
α	bright golden-yellow	bright golden-yellow	pale yellow	pale yellow	pale yellow	pale yellow	bright golden-yellow
$\beta = \gamma$ ...	deep yellowish-brown	deep reddish-brown	deep green	deep olive-brown	deep olive-brown	deep olive-brown	deep reddish-brown
Absorption	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$
Sp. gr. ...	—	2·78	2·62	2·84	2·84	2·85	2·83

A. Stilpnomelane from stilpnomelane-schist (no. 2092); partial analysis only. (F. J. Turner and C. O. Hutton, 1935, p. 3.)
B. Stilpnomelane from albite-stilpnomelane-actinolite-schist (no. 2646), western Otago.
C. Ferrostilpnomelane from garnet-calcite-chlorite-ferrostilpnomelane-schist (no. 2702), western Otago.
D. Stilpnomelane from vein, Zuckmantel, Silesia (no. 1410 in the mineral collection at Cambridge).
E. Stilpnomelane from vein, Zuckmantel, Silesia (no. 1411, ditto).
F. *Stilpnomelane, Anna mine, Baern, Moravia.*
G. Stilpnomelane from quartz-garnet-schist (no. 3523), western Otago.

of these minerals to one another. If K_2O is considered at the apex of the tetrahedron, it can be seen that the fields will not intersect.

Relationship between Optical Data and Chemical Composition.

In order to show the relationship between chemical composition and optical data, the following points must be brought forward:

(1) There is a change in the colour of the mineral from green to

TABLE 4. Quoted analyses of stilpnomelane and parsettensite for comparison with analyses B, C, E.

	B1.	B2.	C1.	E1.	E2.
SiO_2 ...	44·64	45·12	44·08	43·74	42·90
Al_2O_3 ...	6·75	6·29	4·74	6·36	4·35
TiO_2 ...	—	—	—	nil	n.d.
Fe_2O_3 ...	23·59	23·67	5·27	22·47	0·35
FeO ...	nil	5·93	23·31	15·74	n.d.
MnO ...	—	trace	0·87	0·50	34·43
MgO ...	9·86	9·36	8·36	1·43	2·70
CaO ...	—	trace	trace	0·53	trace
Na_2O ...	—	trace	—	trace	0·20
K_2O ...	—	trace	—	0·75	0·94
H_2O+	7·14	9·12	10·28	6·36	9·66
H_2O-	6·21		2·21	2·59	3·15
Totals ...	98·19	99·49	99·12	100·47	99·27

B1. 'Chalcodite' in trap rocks, Westfield, Massachusetts. (E. V. Shannon, 1920.)

B2. 'Chalcodite', Lambertville, New Jersey. (E. V. Shannon, Proc. U.S. Nat. Mus., 1920, vol. 58, p. 453.)

C1. 'Stilpnomelane' in trap rocks, Westfield, Mass. (E. V. Shannon, 1920.)

E1. Stilpnomelane in vein, Pen-y-rallt, North Wales. (A. F. Hallimond, 1924.)

E2. Parsettensite, Alp Parsettens, Val d'Err, Graubünden. Also HCl 0·02, CO_2 0·25, V_2O_5 0·32. Sp. gr. 2·590. α 1·546 (clear yellow to colourless), γ 1·576 (light greenish-yellow), $\gamma-\alpha$ 0·030, 2V 0°, negative. (J. Jakob, 1923.)

deep reddish-brown with increase of Fe_2O_3 and concomitant decrease of FeO.

(2) An increase in the Fe_2O_3 content causes a rise in the values of α and γ and also in the birefringence. The extreme values are shown in analyses C and G (table 3).

Unfortunately various authors have not given full optical data with their analyses, but with the chemical and optical data available it has been possible to construct curves to show the relationship between these properties; only reliable analyses, however, have been used. It should be emphasized that the α and γ values must be determined on the material analysed and not on plates of the mineral obtained from another part of a large specimen or another specimen altogether. This appears to be the explanation of many cases in which there is a poor correspondence of optical and chemical data. The writer has found that, owing to a variation in chemical composition, there can be a difference of as much as 0·01 in the values for α and γ in material obtained from different parts of the same specimen, if it is a large one. Thus the values for α, β, and γ given by Winchell (1933, p. 435, column 6) for a 'chalcodite' from New York, are clearly not those of a mineral having the

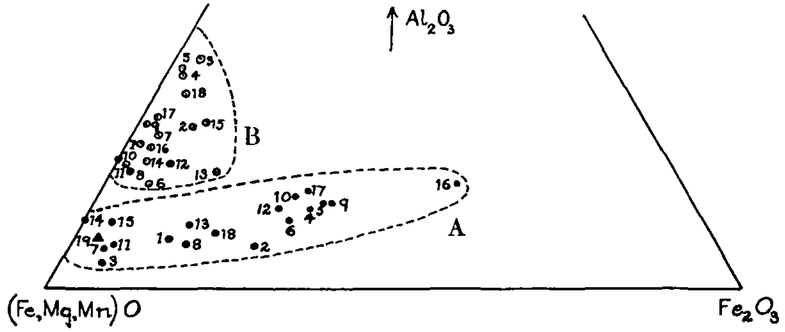

FIG. 4. Plot of analyses of stilpnomelanes and biotites.
A = field of stilpnomelanes; B = field of biotites.

KEY TO ANALYSES IN FIGS. 4 AND 5.

Stilpnomelanes.

1. Mesabi Range, Minnesota. F. F. Grout and G. A. Thiel (1924, p. 230, anal. no. 2).
2. Sterling, New York. G. J. Brush (1858).
3. Trap quarries of Westfield, Mass. E. V. Shannon (1920, p. 400, average of anal. nos. 1 and 2).
4. Pen-y-rallt mine, Merionethshire. A. F. Hallimond (1924, p. 194, anal. no. 1).
5. Trap quarries of Westfield, Mass. E. V. Shannon (1920, p. 402, anal. no. 1).
6. Lambertville, New Jersey. E. V. Shannon, Proc. U.S. Nat. Mus., 1920, vol. 58, p. 453, anal. no. 1.
7. Sterling iron mine, New York. F. A. Genth (1886).
8. Theodor mine, Aumenau, Lahn. J. Holzner (1933, p. 216, anal. no. 4).
9. From schist no. 2646, western Otago, New Zealand. C. O. Hutton (anal. B, table 3).
10. Zuckmantel, Austrian Silesia. C. O. Hutton (anal. D, table 3, plotted in fig. 4; and E in fig. 5).
11. Kohlerloche, Harzburg. F. Fromme (1902).
12. Baern, Moravia. J. W. Gruner (1937, p. 913, anal. no. 4).
13. Nadezda mine, Pertniemi, Aunus, Karelia, Russia. P. Eskola (1925, p. 58, anal. no. 1).
14. Recalculated from analysis of 'Schwarzfels'. C. W. Carstens (1924).
15. From schist (no. 2702), western Otago. C. O. Hutton (anal. C, table 3).
16. From schist (no. 3523), western Otago. C. O. Hutton (anal. G, table 3).
17. Anna mine, Baern, Moravia. C. O. Hutton (anal. F, table 3).
18. Mont Chemin, Wallis. J. Jakob, Schweiz. Min. Petr. Mitt., 1927, vol. 7, p. 311.
19. Parsettensite, Alp Parsettens, Val d'Err. J. Jakob (1923, p. 228).

Biotites.

1. Ballochandrian, Cowal, Argyllshire. F. C. Phillips, Min. Mag., 1930, vol. 22, p. 255, anal. no. 7.
2. Hill of Strone, Forfarshire. Ibid., anal. no. 8.

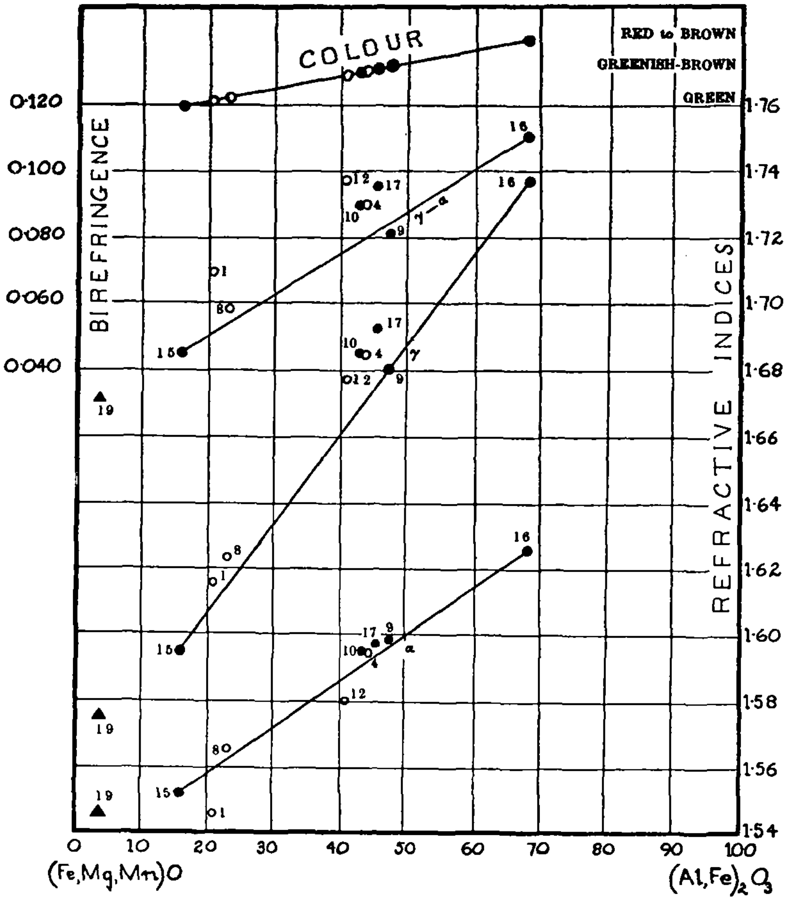

FIG. 5. Variation of optical properties with chemical composition in the stilpnomelane group of minerals.

Solid circles: new analyses and optical determinations. Circles: data from the literature. Solid triangle: typical parsettensite (J. Jakob, 1923).

3. NE. Forfarshire. Chemical analyses of igneous rocks, metamorphic rocks and minerals. Mem. Geol. Surv. Great Britain, 1931, p. 149, anal. no. 596.
4. NE. Forfarshire. Ibid., anal. no. 597.
5. De Lank quarry, 2 miles ESE. of St. Tudy, Cornwall. Ibid., anal. no. 598.
6. Kekequabic granite, Minnesota. F. F. Grout, Amer. Min., 1924, vol. 9, p. 161, anal. no. 1.
7. Vermilion granite, Minnesota. Ibid., anal. no. 2.
8. Quarry north of Mora, Minnesota. Ibid., anal. no. 3.
9. Rockville, Minnesota. Ibid., anal. no. 4.

KEY TO ANALYSES IN FIG. 4 (*cont.*).

10. Black Cascade, Tripyramid Mountain, New Hampshire. R. W. Chapman and C. R. Williams, Amer. Min., 1935, vol. 20, p. 512, anal. no. 1.
11. One-third of mile NW. of Ames station, Belknap Mountains, New Hampshire. Ibid., anal. no. 2.
12. Quarry one mile south of Beech Hill, Percy quadrangle, New Hampshire. Ibid., anal. no. 3.
13. Brevik, Norway. C. Doelter's Handbuch der Mineralchemie, 1917, vol. 2, pt. 2, p. 698, anal. no. 160.
14. Mt. Hoffmann, California. Ibid., p. 696, anal. no. 141.
15. Felka Valley, Tatra Mts. Ibid., p. 695, anal. no. 126.
16. Osborne's Flat, Yackandandah, Victoria, Australia. C. M. Tattam, Bull. Geol. Surv. Victoria, 1929, no. 52, p. 37, anal. no. 15.
17. Kergunyah Gap, Victoria, Australia. Ibid., anal. no. 16.
18. Noorongong, Victoria, Australia. Ibid., anal. no. 17.

chemical composition stated, and have probably been obtained from a different specimen, though from the same locality as the analysed specimen. Great care must be taken in the determination of the γ value and only the smallest of flakes which are completely translucent must be used. A basal flake of stilpnomelane more than 0·05 mm. in thickness is opaque and the error in the determination of γ in such a specimen may be large. As an example of the variation in composition and optical data, the following values obtained from three specimens of a stilpnomelane from Baern, Moravia, are interesting:

	α.	γ.	$\gamma-\alpha$.	K_2O.
Grout and Thiel (1924)	1·58	1·640	0·060	2·62 %
Gruner (1937)	1·58	1·677	0·097	3·31
Hutton (table 3) ...	1·597	1·692	0·095	1·91

In plotting the values of α, γ, and $\gamma-\alpha$ against (Mg,Fe,Mn)O and $(Al,Fe)_2O_3$ it is found that all the points do not lie exactly on the curves drawn (fig. 5), though it is interesting to note that the values obtained for the three stilpnomelanes separated from the western Otago schists, practically do so (nos. 9, 15, 16). The α value obtained by Grout and Thiel (no. 1) would seem to be much too low for a mineral of that composition. It is clear, however, from a study of the available analyses that the constituents other than Fe_2O_3, Al_2O_3, MgO, FeO, and MnO also vary. For example, $H_2O > 105°$ and K_2O, though not taken into account in these curves, probably have a marked effect on the values for α and γ.

Winchell (1936, p. 644) in his third study of chlorites, states that natural chlorites rich in ferric iron oxidized from ferrous iron have higher refractive indices than that appropriate for their composition;

also the birefringence increases. The stilpnomelane series as here described would appear to bear out Winchell's contention. The artificial oxidation of a stilpnomelane was carried out and the data obtained are also in support of his hypothesis. For this 0·3 gm. of stilpnomelane from Zuckmantel (specimen no. 1411) was heated in a platinum bucket in an electric furnace for 24 hours at 350° C. An FeO determination then showed that complete oxidation had taken place and the optical constants had risen, but the mineral was still uniaxial and negative. The data follow:

	Before heating.	After heating.
FeO ...	13·73 %	nil
Fe_2O_3 ...	22·04 %	37·29 %
α ...	1·595	1·606
γ ...	1·685	1·803
$\gamma-\alpha$ ...	0·090	0·197
α ...	yellow	golden-yellow
γ ...	greenish-brown	reddish-brown

On the diagram (fig. 5) a mineral of this final composition calls for the values α 1·645, γ 1·780, $\gamma-\alpha$ 0·130. These figures do not agree at all well with the experimental data, but it must be pointed out that after being subjected to 350° C. for 24 hours, the mineral has lost 4–5 % of water of a total of 6–7 %.

The large increase in the values of α and γ obtained in the case of the Zuckmantel mineral is not in accord with the data obtained by Dschang (1931, p. 433) when he artificially oxidized a 'chalcodite' from Bärenstein, Harz. His results were:

	Before heating.	After heating.
FeO ...	10·15 %	0·835 %
Fe_2O_3 ...	31·16 %	42·66 %
γ ...	1·701	1·726

It would be convenient now to consider the mineral parsettensite,[1] a hydrous micaceous manganese silicate described by Jakob (1923, pp. 227–231) from the Alp Parsettens in the Val d'Err. The analysis (E2, table 4) corresponds closely with that of a stilpnomelane with most of the iron replaced by manganese and its optical data are very similar to a stilpnomelane with an FeO value equivalent to the MnO in the parsettensite. When the values of α, γ, and $\gamma-\alpha$ are plotted against composition, the points lie almost on the refractive index curves (fig. 5) obtained for the ferrostilpnomelane-stilpnomelane series. Further,

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[1] The writer wishes to thank Professor J. Jakob for his generous gift of parsettensite.

X-ray work has shown that stilpnomelane and parsettensite are very closely allied.

It has been seen that, when a schist has a high MnO content, the stilpnomelane mineral in that rock also contains considerable MnO, and it is therefore suggested that any stilpnomelane mineral containing manganese may be considered to belong to a ternary system with the components stilpnomelane-ferrostilpnomelane-parsettensite.

Chemical Data and Dehydration.

The stilpnomelanes are slowly dissolved by digesting with ½ *N* hydrochloric acid for eight hours on the water-bath, leaving a residue of colourless plates of silica. The same behaviour was observed with biotite. A warm mixture of dilute H_2SO_4 and HF immediately and vigorously dissolved the minerals.

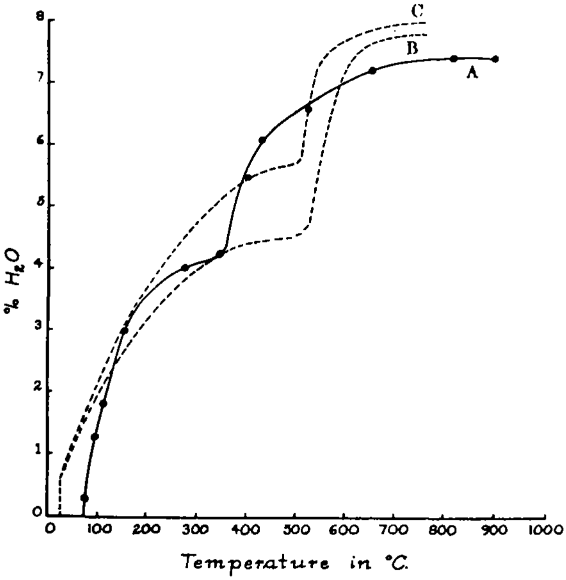

Fig. 6. Dehydration curves of stilpnomelanes. Curve A determined by the present writer; B and C by Armstrong (Gruner, 1937).

Dehydration of two specimens of stilpnomelane have been carried out by L. C. Armstrong (Gruner, 1937, pp. 915–916) in vacuo with a tensi-eudiometer, and two curves (B and C in fig. 6), differing somewhat in the region between 300° and 500° C., obtained. The writer, with the object of obtaining data under different conditions, dehydrated a sample of Zuckmantel stilpnomelane in air in an electric furnace. A series of estimations were subsequently carried out to find the amount of oxidation that had taken place as the mineral was dehydrated. The curve (fig. 6, curve A) obtained by gradual dehydration up to 900° C., though strictly not a true dehydration curve by reason of the oxidation of FeO to Fe_2O_3, does show some similarity with those accurately determined by Anderson in vacuo. The main break in the curve is at 350° C. and, at this point, oxidation was complete. A steep slope is present from 350–425° C., and during this range 2 % of H_2O is given off. Between 800–900° C. no more H_2O remained to be driven off and the mineral was then almost black. In addition to the above experiment, stilpnomelane was placed in a desiccator over pumice soaked in concentrated H_2SO_4, for four months, a loss of weight of 3·04 % being recorded. This weight of water was entirely regained on exposure to the atmosphere for eight hours.

Formula of the Stilpnomelanes.

Hallimond (1924) derived the empirical formula $4(R_2O_3,RO),6SiO_2+$ aq. after consideration of a number of analyses. Berman (1937, p. 383), following Hallimond in separating the minerals of the stilpnomelanes series into two groups, a ferrous and a ferric member, gives them the formulae $(Mg,Fe'')_{13}Al_4Si_{18}O_{50}(OH)_{10}.10H_2O$ and $(Mg,Fe'')(Al,Fe''')_2Si_3O_{10}.H_2O$ respectively. Holzner (1936, p. 447) derived the formula $(Fe,Mg)_2(Fe,Al)_{1\cdot333}[Si_4O_{10}](OH)_4$, but attempts no subdivision. Gruner (1937, p. 914) holds that as 'chalcodite' and stilpnomelane are not different from one another structurally or chemically, except for the oxidation of the iron, any subdivision is untenable. He suggests, after averaging seven analyses and on the results of dehydration and X-ray work, the formula $(OH)_{16}(K,Na,Ca)_{0-2}(Fe,Mg,Al)_{29}Si_{32}O_{93}.13H_2O$. Gruner calculates his formula on the basis of $32SiO_2$ 'molecules' in four unit cells, obtaining the groups $[Si_{32}O_{93}]$, $[(Si,Al)_{16}O_{43}]$, and $[(Si,Al)_{16}O_{42\cdot5}]$; or in an ideal case $[(Si,Al)_{16}O_{44\cdot5}]$. These groupings are not in accord with $[Si_4O_{10}]$, $[AlSi_3O_{10}]$, or $[Si_2Al_2O_{10}]$, which 'represent the contribution of the linked sheets of tetrahedra, whose composition is $n(Si_2O_5)$' universally found in the mica and chlorite minerals (Bragg, 1937, p. 204).

The writer therefore accepts, in part, Holzner's formula, based on the groupings $[Si_4O_{10}]$, but would add to it the ions K and Ca. The structure of stilpnomelane has not yet been completely worked out; therefore the writer, in searching for the most probable formula, has calculated out a number of analyses on the basis of 12, 14, and 18 (O,OH) atoms to the unit cell; however, from a study of the figures obtained, a value (O,OH) = 14 appears to be most suitable, giving with fair constancy the formula:

$(OH)_4K_{0.33}(Al,Fe,Mg,Mn)_{3.33}Si_4O_{10}$ or $(OH)_{12}K(Al,Fe,Mg,Mn)_{10}Si_{12}O_{30}$.

Aluminium in most cases replaces a little Si to make up the ideal number of 12; Mn in view of its intermediate ionic radius may be spread between the (Fe,Mg) and (K,Ca) groups.

In hornblendes, a replacement of (OH) by O appears to take place along with a replacement of Fe'' by Fe''', that is, in the analyses of brown basaltic hornblendes the percentage of water is always low (see E. S. Larsen and others, 1937, p. 898). Analyses of stilpnomelanes do not show any variation consistent with this feature, though when calculated on the basis of 14(O,OH) all members of the series give reasonable formulae. Nevertheless, it is clear that extra oxygens will be required in the types with high Fe''' content. It is suggested that, as Fe''' replaces Fe'', O replaces (OH), as is postulated in the case of the Fe'''-rich amphiboles. Further dehydration work must be carried out on any stilpnomelane to show the true content of (OH), and it is very probable that the value of this factor will decrease as one passes from the ferrostilpnomelane to the stilpnomelane end of the series. Thus, for a pure Fe''' stilpnomelane mineral O will be high while (OH) will be correspondingly low.

As true dehydration curves have not been made for the minerals analysed, *all* the $H_2O > 105°$ has been included in the calculations and, when necessary, oxygen has been added to the (OH) group to make up the total oxygens in the molecule to 14 (or if multiplying by 3, 42). Nevertheless, from the two dehydration curves given by Gruner (1937, p. 916) it is interesting to note that the percentage of H_2O given off above 500° C. is less in the mineral with the higher amount of Fe_2O_3. Gruner's no. 3 gives off approximately 3 % of H_2O above 500° C., while his no. 4 gives off approximately 2 %. The Fe_2O_3 and FeO values for these specimens are:

	No. 3.	No. 4.
Fe_2O_3 ...	11·60 %	20·79 %
FeO ...	20·00	12·83

Although it is unwise to place too much reliance on results derived from so little data, it is clear that in these two specimens the amount of firmly held water is decidedly less in the more highly oxidized mineral. Therefore, in the formula of a mineral such as no. 4, if the reasoning as given above is correct, appreciable oxygen would be present replacing the (OH); thus we would have $(\mathrm{O}_x,\mathrm{OH}_y)$ where $x+y = 12$. The amount of $\mathrm{H_2O} > 105^\circ$ in parsettensite, however, is much higher than in stilpnomelanes, and it is possible that a good deal of this is not in the structure of that mineral.

The formulae derived by calculation from several analyses on the basis of 42(O,OH) atoms to the unit cell are set out below.

1.[1] $[\mathrm{O}_{2\cdot1}(\mathrm{OH})_{9\cdot9}]\mathrm{K}(\mathrm{Fe,Mg,Mn,Ti,Al})_{10}\mathrm{Si}_{12}\mathrm{O}_{30}$.
4. $[\mathrm{O}_{1\cdot1}(\mathrm{OH})_{10\cdot9}](\mathrm{K,Ca})_{0\cdot39}(\mathrm{Fe,Mg,Mn,Al})_{10}(\mathrm{Si,Al})_{12}\mathrm{O}_{30}$.
8. $(\mathrm{OH})_{11\cdot6}(\mathrm{K,Na,Ca})_{1\cdot1}(\mathrm{Fe,Mg,Al})_{9\cdot8}(\mathrm{Si,Al})_{12}\mathrm{O}_{30}$.
9. $[\mathrm{O}_{1\cdot1}(\mathrm{OH})_{10\cdot9}](\mathrm{K,Ca})_{0\cdot99}(\mathrm{Fe,Mg,Mn,Ti,Al})_{9\cdot3}(\mathrm{Si,Al})_{12}\mathrm{O}_{30}$.
10. $[\mathrm{O}_{1\cdot1}(\mathrm{OH})_{10\cdot9}](\mathrm{K,Ca})_{0\cdot78}(\mathrm{Mg,Fe,Al})_{9\cdot6}(\mathrm{Si,Al})_{12}\mathrm{O}_{30}$.
13. $[\mathrm{O}_{2\cdot5}(\mathrm{OH})_{9\cdot5}](\mathrm{K,Mn})_{0\cdot97}(\mathrm{Mg,Fe,Mn,Al})_{10}(\mathrm{Si,Al})_{12}\mathrm{O}_{30}$.
15. $(\mathrm{OH})_{11\cdot7}(\mathrm{K,Ca})_{0\cdot48}(\mathrm{Mg,Fe,Mn,Ti,Al})_{10}\mathrm{Si}_{12\cdot1}\mathrm{O}_{30}$.
16. $(\mathrm{OH})_{12\cdot8}(\mathrm{K,Ca,Na,Mn})_{1\cdot05}(\mathrm{Mg,Fe,Al})_{8}(\mathrm{Si,Al})_{12}\mathrm{O}_{30}$.
17. $(\mathrm{OH})_{11\cdot9}(\mathrm{K,Ca,Na})_{0\cdot57}(\mathrm{Mg,Fe,Mn,Al})_{9\cdot3}(\mathrm{Si,Al})_{12}\mathrm{O}_{30}$.
18. $(\mathrm{OH})_{12\cdot1}(\mathrm{K,Na})_{0\cdot9}(\mathrm{Mg,Fe,Mn,Ti,Al})_{10}(\mathrm{Si,Al})_{12}\mathrm{O}_{30}$.
19. $(\mathrm{OH})_{16\cdot8}(\mathrm{K,Na})_{0\cdot39}(\mathrm{Mn,Fe,Mg,Al})_{9\cdot3}(\mathrm{Si,Al})_{12}\mathrm{O}_{30}$.

Origin of the Stilpnomelane Minerals.

Any hypothesis advanced in an attempt to explain the origin of stilpnomelane in the western Otago schists must answer the following facts:

(1) The widespread distribution of members of the group.
(2) Their occurrence in schists of all types of mineral assemblage, except the doubtfully restricted case of the quartz-muscovite-piedmontite-schists.
(3) The occurrence, though rarely, of stilpnomelane as infillings to narrow veins.
(4) The coarse radiate or sheaf-like habit of the flakes and their occasional orientation across planes of foliation.
(5) The apparent development of the mineral from chlorite and the not infrequent occurrence as a border to porphyroblastic grains of magnetite.
(6) The occasional narrow bands of schists in which stilpnomelane minerals form 50 to 80 % of the rock.
(7) The occurrence of the mineral as an accessory constituent in an otherwise normal rock type.
(8) Restriction of the mineral, so far as is at present known, to the rocks of the chlorite zone.

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[1] Numbers refer to analyses given in key to figs. 4 and 5 (p. 186).

The usual mode of occurrence of stilpnomelane appears to be as a vein mineral or associated with iron-ore formations. Grout and Thiel (1924), while recording this type of occurrence, have also drawn attention to its widespread development in grey-green carbonate-slates and amphibole-magnetite-slates as radiating or plumose growths, the plates tending to follow the schistosity. They attribute its association with apatite and specularite to high temperature and pressure, but do not suggest any theory as to the origin of the mineral in the slates. Eskola (1925, pp. 56–57) finds the mineral frequently replacing tremolite in copper-bearing veins which cut the greenstones in the Karelia region. Here stilpnomelane itself forms veins in the green-schists and Eskola believes that these schists have been in places 'stilpnomelanized'. If sediments rich in ferrous minerals and poor in potash suffer reconstitution by regional metamorphism, Hallimond (1924) postulates that stilpnomelane minerals rather than biotite will form.

In the case of the schists of Otago only three theories of origin of the stilpnomelane can be advanced:

(1) That we appeal to peculiar initial composition of the rocks in which the stilpnomelanes are developed.

(2) That the stilpnomelane series are truly metamorphic minerals, formed under conditions of temperature and stress characteristic of the chlorite zone.

(3) That the minerals have been formed through the agency of dilute aqueous solutions from a source other than the schists themselves; that is, they are the result of pneumatolysis.

In the region under discussion, surrounding Lake Wakatipu and extending east to Lake Wanaka and west towards Lakes Te Anau and Manapouri, the schists are all characterized by typical chlorite zone assemblages. They have been observed to contain tourmaline which, it is believed, is possibly due to emanations from subjacent granite batholiths. Metallic sulphides such as chalcopyrite, nickeliferous pyrrhotine, arsenopyrite, and stibnite, in addition to numerous barren and auriferous quartz veins, are distributed widely over the area (Hutton, 1934). Thus this region has clearly been affected to a great extent by solutions coming from deep within the crust as well as by the dilute aqueous solutions usually postulated to be abundantly present during a period of dynamothermal metamorphism (Harker, 1932, p. 18).

Let us deal with the hypotheses in turn. Only in a few cases can we consider that initial composition of the original rocks might have been the prime factor in the development of stilpnomelane. Scattered throughout the region are narrow bands of schists, usually of rather unusual composition, interbedded with normal quartzose, quartzo-felspathic and green-schists, in which a member of the stilpnomelane group is often the most important constituent. Such schists for example are:

stilpnomelane-spessartine-pyrite-sphene
stilpnomelane-spessartine-calcite
stilpnomelane-spessartine-quartz
calcite-chlorite-spessartine-stilpnomelane
magnetite-spessartine-stilpnomelane-actinolite.

Chemically these rocks are similar in containing high iron and manganese oxides, with SiO_2, CaO, and FeS_2 reaching a high figure in individual cases. It is therefore believed that schists with these mineral assemblages have been developed from highly impure bedded iron-ores or perhaps bog-iron-ores, which are notoriously variable in bulk composition, by low-grade dynamothermal metamorphism. Professor Tilley (1936, p. 341), describing eulysites and allied rocks from Ross-shire, notes that Van Bemmelen has found bog-iron-ores containing $FeCO_3$ associated with notable ferric oxide and $MnCO_3$, while Carstens (1924, p. 248) considers bog-iron-ores to be the original material from which a 'Schwarzfels' or magnetite-stilpnomelane-rock occurring in the Trondhjem region has developed by metamorphism. It is difficult to conceive a pneumatolytic origin for these schists, particularly when their limited lateral distribution is taken into account.

More difficult of interpretation are those rocks, and they constitute the most usual type of occurrence, in which stilpnomelane is usually an accessory constituent, but may not infrequently rise to the rank of an essential mineral. One cannot appeal in this case to unusual initial composition, for the bulk analysis of normal albite-epidote-chlorite- or quartz-albite-epidote-chlorite-muscovite-schists containing 5 % of well-developed stilpnomelane will not show any particular characteristic which could be construed as being the factor promoting development of stilpnomelane. In sheared greywackes of sub-zone Chl. 1 and 2, stilpnomelane minerals are often present, but the properties of these minerals differ from those present in the equivalent quartz-albite-chlorite-epidote-schists of the Chl. 4 sub-zone in grain-size only. It has been stated previously (Turner and Hutton, 1935, p. 7) that the birefringence of the stilpnomelanes increased with increase of metamorphic grade within the zone of chlorite, but after further study this generalization does not appear to hold good. The stilpnomelanes occurring in Chl. 1, 2, and 3 sub-zone rocks may be the brown ferric-rich types with high birefringence or varieties close to the ferrostilpnomelane end of the series with correspondingly lower birefringence; greenish-brown intermediate types have also been noted. In schistose rocks of Chl. 1 and 2 sub-zones, tiny platelets of red-brown stilpnomelane may often be interleaved with a very small amount of chlorite, when, except under very high power magnification, an apparent lower birefringence may be observed. The conclusion reached by the inspection of many slices of rocks from the four sub-zones is that the grain-size of the stilpnomelanes definitely increases with increase of metamorphism.

If we are to hold that the stilpnomelane minerals have really crystallized under chlorite zone metamorphic conditions, in what manner are we to explain their occurrence in one albite-epidote-chlorite-schist of normal mineralogical composition and not in another with a similar composition? If pneumatolytic solutions had been active enough to cause crystallization of stilpnomelane it would be expected that other signs of such a factor would be in evidence, but this is not the case. In the writer's opinion (and if this be true), the solutions and vapours given off from the granitic batholiths situated in the deep zones of this region, although they have caused development of tourmaline throughout the schist area, cannot be held to have in any way assisted in the formation of stilpnomelane. It might be argued that the increase in grain-size of the stilpnomelane minerals with increase of metamorphic grade was evidence that these granitic vapours did play some role; that is, the deeper zones (higher metamorphic grade) were more affected, and hence larger crystals were produced, while the poorly schistose greywackes of the upper zones were but slightly affected, development therefore being restricted. If this held, then one would expect to find tourmaline very much more abundant in the higher grade rocks than in the lower, but this does not appear to be the case. Hence the physico-chemical conditions prevailing in the chlorite zone during dynamothermal metamorphism must be held to be the prime factor in the development of stilpnomelane. Under such conditions the chemical composition of the aqueous solutions within the rocks does in all probability vary greatly, producing in one locality an environment suitable for the formation of stilpnomelanes, and in another locality conditions under which they would not be stable.

However, this mode of origin does not necessarily explain various other features of the occurrence of stilpnomelane:

(1) The habit of the mineral when it forms coarse sheaf-like aggregates lying across the foliation planes.

(2) The partial rejoining of stilpnomelane-rich bands which have been cut by quartzo-felspathic veinlets.

(3) The occurrence of sharply crystallized stilpnomelane within micro-folds and contortions, the mineral itself showing no sign of distortion.

(4) The crystallization of the mineral in what appears to have been open fissure veins.

Stilpnomelane belonging to the above categories is free from the effects of any stress during crystallization and does undoubtedly belong to a period of post-tectonic crystallization. Its development thus suggests a process of segregation by solutions. In the stilpnomelane occupying veins there certainly is a correspondence between the chemical nature of the mineral and that of the rock, which would not be expected should its origin be attributed to solutions from some external source. Segregation veins of other minerals, such as quartz, albite, and epidote, are not uncommon throughout the entire region. The other modes of occurrence noted above are believed to be merely a recrystallization, perhaps in places of least pressure in response to the Riecke principle, after complete cessation of movement.

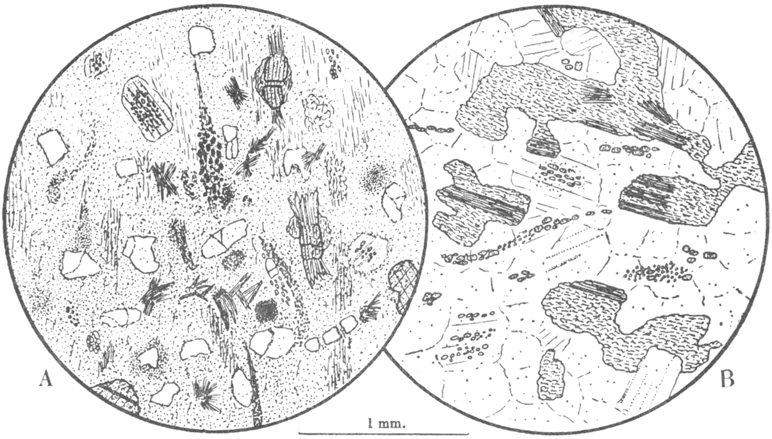

FIG. 7 A. Development of stilpnomelane as tufts in Chl. 2 sub-zone greywacke (no. 3239), near Mount Nicholas station wharf, on shore of Lake Wakatipu, western Otago.

FIG. 7 B. Development of stilpnomelane from chlorite in albite-epidote-chlorite-schist (no. 2642). Half-mile NW. of Crown Peak, Crown Range, western Otago.

We have yet to consider the chemical reactions involved in the production of stilpnomelane in chemically normal schists of this region. Clearly a lack of potash is not an essential condition, for stilpnomelane may be abundantly developed in rocks fairly rich in muscovite. In most cases the mineral certainly develops from chlorite (fig. 3 A; fig. 7 A and B), but in a few instances stilpnomelane and chlorite appear to have crystallized independently of one another.

As development from chlorite is the most usual feature, the chemical composition of the groundmass chlorites and stilpnomelanes must be compared; two groundmass chlorites have been separated and analysed and these analyses are compared with those of two stilpnomelanes in table 5.

TABLE 5. Analyses of chlorites from Otago, New Zealand, compared with those of stilpnomelane.

	A.	B.	C.	D.
SiO_2 ...	25.62	26·69	48·03	45·24
Al_2O_3 ...	21·19	19·57	6·48	6·73
TiO_2 ...	0·88	0·30	0·23	0·33
Cr_2O_3 ...	trace	nil	—	—
Fe_2O_3 ...	3·88	3·49	4·12	25·34
FeO ...	21·55	21·80	22·88	3·45
NiO ...	nil	0·13	—	—
MnO ...	0·35	0·30	2·67	0·60
MgO ...	15·28	16·23	4·94	7·67
CaO ...	0·16	0·17	0·83	1·91
Na_2O ...	nil	trace	nil	0·03
K_2O ...	nil	trace	0·83	1·67
H_2O+ ...	10·87	11·19	6·90	6·72
H_2O- ...	0·19	0·12	2·64	0·76
Totals ...	99·97	99·99	100·55	100·45
Sp. gr. ...	2·96	2·96	2·62	2·78

	$\alpha = \beta$.	γ.	$\gamma - \alpha$.	Absorption.	2V.	Sign.
A	1·622 clear green	1·626 pale yellow	0·004	$\alpha = \beta > \gamma$	0°	+
B	1·623 clear green	1·625 pale yellow	0·002	$\alpha = \beta > \gamma$	0°	+

A. Chlorite from albite-chlorite-schist (no. 2586), alongside Springburn serpentine outcrop, Kawarau survey district, western Otago. Analyst, C. O. Hutton.

B. Chlorite from albite-epidote-chlorite-actinolite-calcite-schist (no. 2718), summit of Coronet Peak, Wakatipu region, western Otago. Analyst, C. O. Hutton.

C. Stilpnomelane, table 3, analysis C.

D. Stilpnomelane, table 3, analysis B.

The analyses A and B are recalculated below on the basis of 18(O,OH) atoms to the unit cell.

	A.				B.			
SiO_2	25·62	2·692		4·00	26·69	2·790		4·00
Al_2O_3	21·19	2·610	1·308 1·302		19·57	2·396	1·210 1·186	
TiO_2	0·88	0·063		5·99	0·30	0·025		5·95
Fe_2O_3	3·88	0·302			3·49	0·263		
FeO	21·55	1·885			21·80	1·900		
NiO	—	—			0·13	0·013		
MnO	0·35	0·031			0·30	0·025		
MgO	15·28	2·408			16·23	2·539		
H_2O+	10·87	7·602		7·60	11·19	7·810		7·81

Formula (A):—$(OH)_{7\cdot6}(Mg,Fe,Al,Ti,Mn)_6(Al,Si)_4O_{10}$.
Formula (B):—$(OH)_{7\cdot8}(Mg,Fe,Al,Ti,Mn,Ni)_6(Al,Si)_4O_{10}$.

Refractive index determinations of numerous other chlorites in the western Otago schists indicate that the typical chlorites found in these rocks are highly aluminous and rich in iron; such chlorites lie either in the field of ripidolites in Winchell's diagram (1936, p. 649) or with change of sign in the diabantite field. The production of a stilpnomelane of composition C (table 5) from a chlorite of composition such as A or B involves addition of silica and in some cases iron oxides, with subtraction of alumina and some magnesia. Iron oxides may come from iron-ores, but an additional source of iron may be obtained from the ferruginous epidotes, which show a tendency to change over to clinozoisitic types with rejection of iron-ore as metamorphism of the schists becomes more severe. Thus, if iron is thrown out from epidote, the aluminium freed by the chlorite → stilpnomelane reaction will be taken up by it to form the clinozoisite molecule. Excess MgO might readily assist together with epidote or calcite in the production of actinolitic amphiboles or even green biotite in green-schists approaching the biotite isograd.[1] In this connexion it should be pointed out that 65 % of the schists in which stilpnomelane is more or less an important constituent, but excluding those rocks of peculiar initial composition in which it is abundant, actinolite or actinolitic amphiboles are present. Nevertheless, it is not considered necessary that MgO should remain in the immediate neighbourhood of the reaction as postulated above, but would in many cases migrate together with other substances, assisting in the development of amphiboles elsewhere. The small amount of K_2O which is usually present in stilpnomelane minerals might readily be supplied by the aqueous solutions in the rocks or from muscovite

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[1] It must be pointed out, however, that there is no direct evidence that these reactions do take place, though in Chl. 2 sub-zone rocks tufts of stilpnomelane have been observed closely associated with actinolite forming from relics of hornblende.

itself. In the case of stilpnomelane forming rims to magnetite porphyroblasts, a reaction between the iron-ore and the rock solutions may be envisaged.

The reactions which are considered to bring about development of stilpnomelane are given in diagrammatic form below:

(1) $(OH)_8(Mg,Fe,Al)_6(Al,Si)_4O_{10}+SiO_2+K_2O \rightarrow$ stilpnomelane $+ MgO + Al_2O_3$.
(2) $2(OH)Ca_2(Al,Fe)_3Si_3O_{12}+3Al_2O_3 \rightarrow 2(OH)Ca_2Al_3Si_3O_{12}+3Fe_2O_3$.
(3) Epidote (?) (or calcite) $+ MgO + SiO_2 \rightarrow$ actinolite or biotite.

The production of a ferrostilpnomelane has alone been considered, but by far the most important members of the series in the schists are the red-brown ferric types. In several schists the transition of the green mineral to the red has been noted, a feature pointing to the earlier development of the green or FeO variety, which with subsequent oxidation passes into the typical red-brown type.

If stilpnomelane minerals develop by a normal process of dynamothermal metamorphism over wide tracts of country, why has its presence not been recorded from other areas, such as the Dalradian succession in Scotland, where rocks similar to those in western Otago are exposed? Two reasons may be suggested for this:

(1) That on account of the close similarity with biotite it has been dismissed as such. The writer has examined thin slices of metamorphosed spilites, porphyry breccias, and diabases from the Tayvallich Peninsula and Castle Sween across Loch Sween, and recognized in them typical red-brown stilpnomelane as well as a greenish-brown biotite abundantly developing at the expense of the chlorite. The stilpnomelane is well crystallized, often as radiating sprays, and in a felspar-porphyry from Castle Sween (no. 30453)[1] with checker-albites, it is the only other important constituent. In the Geological Survey Memoir on this area, Flett (1911, p. 89) has described well-crystallized, clear brown and yellow-brown 'biotites' in epidiorites from Eilean Traighe. From the colour given this 'brown biotite' is very possibly stilpnomelane, for the usual colour of the mica in these rocks is a rather deep brownish-green. Again (1911, p. 77) he describes a rich brown mica in long needle-like pointed forms suggesting aegirine; likewise this may be a Fe_2O_3 type of stilpnomelane mineral. Further, Wiseman (1934, p. 376) has recorded a golden-brown mineral with γ 1·758, which he believes to be stilpnomelane, in a low-grade epidiorite from Cnoc-na-Faire, north of Tayvallich. An examination of this rock proves that the mineral is definitely stilp-

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[1] The number refers to a section in the Harker Collection in the Department of Mineralogy and Petrology, Cambridge.

without any trace of crater) are very numerous in south Osetia (central Caucasus). The rocks erupted, which are mainly basalt and andesite, are characterized by the presence of numerous xenocrysts of quartz and alkali-felspar and it is suggested that some of them are the products of assimilation of the surrounding rocks by the magma. Several analyses are given. S. I. T.

[LEVINSON-LESSING (F. Y.)] Левинсон-Лессинг (Ф. Ю.). Армянское вулканическое нагорье. [*The Armenian volcanic uplands.*] Природа [Priroda], Leningrad, 1928, no. 5, pp. 430–446, 9 figs.

—— Андезито-базальтовая формация центральной части Армении.—LOEWINSON-LESSING (F. J.). *Andesite-basalt lavas of central Armenia.* Бассейн оз. Севан (Гокча), Акад. Наук СССР (The Basin of lake Sevan (Gokcha), Acad. Sci. USSR), 1929, vol. 1, pp. 95–113 (Russian), pp. 501–504 (English summary), 10 figs.

The effusive types of the Armenian plateau are as follows: (1) plateau lavas, which are generally understood to be connected with fissure eruptions, although no fissure-feeders have ever been observed in Armenia; (2) polygenetic volcanoes with a central crater; (3) monogenetic extrusive cones without associated lava flows; (4) parasitic slag cones. The lavas from the region of Novo-Bayaset and Erivan, described in the second paper, are mainly vitrophyric andesite-basalts with phenocrysts of andesine and occasionally of olivine and pyroxene. Seven analyses of rocks are given. S. I. T.

[LICHKOV (B. L.)] Личков (Б. Л.). К характеристике геоморфологии и стратиграфии Алагеза.—LIČKOV (B.). *Beiträge zur geomorphologischen und stratigraphischen Charakteristik des Alagös.* Алагез, потухший вулкан Армянского нагорья. Том I, под ред. акад. Ф. Ю. Левинсон-Лессинга [*Alagez, an extinct volcano of the Armenian uplands.* Vol. I, edited by F. Y. Loewinson-Lessing], Труд. Сов. Изуч. Произв. Сил., Сер. Закавказская, Вып. 3 (Trans. Council Research Econ. Res., Transcaucasian Series, no. 3), Leningrad, 1931, pp. 3–113, 3 pls., 35 text-figs. (Russian with German summary.)

[LEBEDEV (P. I.)] Лебедев (П. И.). Вулкан Алагез и его лавы.—LEBEDEV (P.). *Der Vulkan Alagös und seine Laven.* Ibid., pp. 117–379, 9 pls., 53 text-figs. (Russian with German summary.)

This volume contains an extensive account of one of the largest extinct volcanoes of Armenia. The preface is supplied by F. Y. Loewinson-Lessing, who directed the expedition. The first part (pp. 3–113) satisfactory, on account of the ferriferous nature of the minerals investigated and also the large cell dimensions. The use of the longer wave-length iron radiation permitted of somewhat more accurate spacing determinations. Indexing of the films was carried out by means of a Bernal chart (Bernal, 1926).

The only direct X-ray investigation previously carried out on the stilpnomelane group of minerals is the recent work of Gruner (1937), who based all his observations on powder photographs. It is somewhat surprising that his material did not afford single crystals large enough for oscillation or Weissenberg photographs seeing that some of it came from Baern, Moravia. On the evidence of powder photographs Gruner (1937, p. 924) obtained the following cell dimensions, assuming that the mineral is monoclinic (pseudo-hexagonal): *a* 5·23—5·27, *b* 9·08—9·12, *c* 12·07—12·18 Å. The *c*-spacing was obtained from measurements on the powder photographs, but the length of the *a*-axis was deduced simply from an apparent similarity with biotite. (On account of the pseudo-hexagonal nature of the lattice, $b = \sqrt{3}\,a$.)

The Lauegrams obtained from members of the stilpnomelane group of minerals are most interesting, but unusual in that true spots were not obtained; instead, all photographs showed almost complete asterism with 6-fold symmetry (fig. 8 A). In order to determine if other minerals, characterized by flaky structure, easy cleavage, and pseudo-hexagonal symmetry, that is, minerals based on sheets of linked silicon-oxygen tetrahedra, produced this effect, Lauegrams were taken of a number of minerals. Of these minerals, phlogopite, biotite (fig. 8 B), muscovite, and brucite produced Lauegrams with sharp spots, while pennine and clinochlore gave sharp spots as well as faint streaks. Talc and chloritoid showed marked asterism with poor development of spots, while pyrophyllite and the three members of the stilpnomelane group showed almost perfect asterism.

The cell dimensions deduced from single-crystal oscillation photographs are:

	Orthohexagonal			Rhombohedral	
	a.	*b.*	*c.*	*a.*	angle.
Stilpnomelane	22·0	38·0	37·9	17·9	76°
Ferrostilpnomelane ...	22·1	38·1	36·2	17·6	78°
Parsettensite	22·5	39·0	38·0	—	—

The Lauegrams (fig. 8 A) suggest that the three end-members of the stilpnomelane group of minerals are either hexagonal or rhombohedral. The single-crystal oscillation films confirm this suggestion. The photographs obtained by mounting the specimens about an axis in the c-plane with the X-rays perpendicular to that plane and oscillating 15° from that position are rather unusual (figs. 9 A and B). They are characterized by (1) the large number of closely spaced, comparatively weak reflections which indicate that the unit cells are very large, and (2) the presence of three very intense reflections in stilpnomelane and ferrostilpnomelane and six in parsettensite, of spacing 2·6 Å.

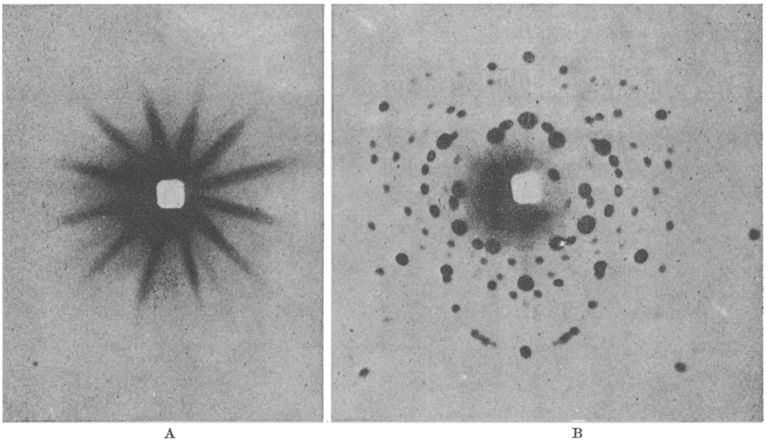

FIG. 8 A. Lauegram of stilpnomelane from Baern, Moravia.
FIG. 8 B. Lauegram of biotite.

These observations suggest that all three minerals possess structures that are essentially a packing of somewhat distorted mica-like sheets. By a mica-like sheet we mean an extended double layer of linked SiO_4 tetrahedra whose vertices point inwards. The interstices between the two component layers are filled with metallic ions, usually Al, Mg, or Fe. The sheets possess hexagonal symmetry, but they are most conveniently referred to orthogonal axes, in which case the units are rectangular $5{\cdot}2 \times 9{\cdot}0$ Å. (Bragg, 1937, pp. 143 and 206). The thickness of the sheets, that is, the distance between the planes passing through the centres of the external oxygen atoms is 6·6 Å. In all three minerals, the packing of the sheets repeats every third layer. In stilpnomelane and ferrostilpnomelane two observations suggest that the packing of the sheets is rhombohedral: (*a*) the reflections from the basal plane occur only for $l = 3n$; (*b*) in *c*-axis oscillation films, on any given row-line, reflections occur only on every third layer-line. In parsettensite condition (*a*) is fulfilled. The *c*-axis oscillation photograph is not very good, but it appears that while on any given row-line every third reflection is intense, yet some very faint intermediate reflections occur. Also the oscillation film (fig. 9 B) has six intense reflections, while stilpnomelane and ferrostilpnomelane have only three. Parsettensite, therefore, is probably hexagonal with marked pseudo-rhombohedral arrangement of the layers.

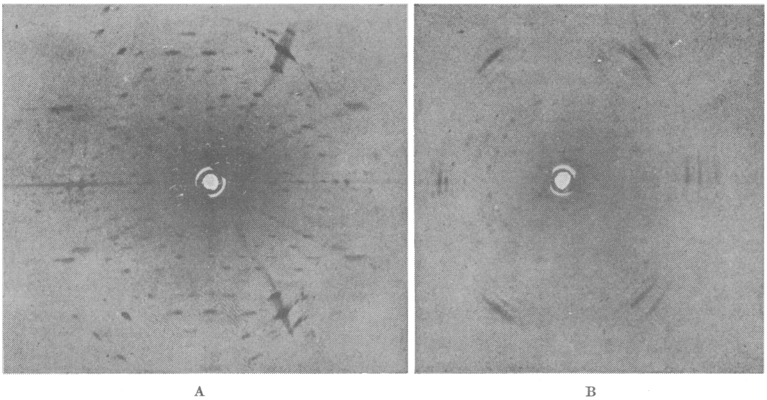

FIG. 9 A. X-ray oscillation photograph of stilpnomelane from schist no. 2646, western Otago, New Zealand.

FIG. 9 B. X-ray oscillation photograph of parsettensite from Alp Parsettens, Switzerland.

The structure of the layers is interesting. As a first approximation they may be considered, by analogy with other minerals, as a packing of rectangular mica units 9 × 5 Å. in size, with distortion and disorientation, and possibly variations in the sub-units, resulting in the presence of a two-dimensional super-lattice. The reflections due to the super-lattice are very weak (figs. 9 A and B) and it is easy to see why Gruner, using powder methods, failed to observe them.

In each case the two-dimensional super-lattice unit, that is, the true unit referred to the orthohexagonal axes in the sheets, contains sixteen rectangular mica units of dimensions *a* 5, *b* 9 Å. From the X-ray films (figs. 9 A and B) it can be inferred that in stilpnomelane and ferrostilpnomelane, the *a*- and *b*-axes are parallel respectively to the *a*- and *b*-axes of the sub-units, while in parsettensite they are respectively perpendicular. The *c*-axes are too long to be due to three layer-structures of mica sheets alone. The structure is probably like chlorite in consisting of an interleaved structure of alternate distorted mica sheets and layers containing K, OH, and Mg.

The character of the reflections suggests a possible explanation of the asterism in the Laue photographs. The intense sub-lattice reflections are spread out along Debye-Scherrer curves. This indicates some disorientation of the sub-units. The weak super-lattice spots in the *c*-axis oscillation photographs show smearing along the direction of the row-lines. Such effects could be produced by lack of perfect regularity in the packing of the sub-units. The 16 sub-units which compose the unit cell are not identical and it is possible that the arrangement of the sub-units varies somewhat from cell to cell. This would produce reflections smeared in the direction of the *c*-axis, and in the case of the Laue photographs asterism would result. A complete determination must await a more detailed analysis of the intensities of the X-ray reflections.

We are greatly indebted to Professor J. D. Bernal for his interest and advice.

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