Fuchsite-bearing Schists from Dead Horse Creek, Lake Wakatipu Region, Western Otago.

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IN Dead Horse Creek (Glenorchy Survey District) a narrow band of fuchsite-bearing schists occurs interstratified with the normal quartzo-feldspathic types characteristic of the Chl. 4 subzone. These chromiferous rocks are on the line of strike of the Moke Creek lode of cupriferous pyrite and chalcopyrite, previously described by the writer (1934), but occur some 60–70 chains to the north. One of the fuchsite schists described in this paper was collected by McKay and described very briefly and somewhat inaccurately by Sollas (1906, p. 158). The occurrence of chrome-micas in considerable quantities in the Wakatipu region appears to be limited to this one occurrence in Dead Horse Creek, although during a recent trip to a tributary of Gill's Creek (northern boundary of Mid-Wakatipu S.D.) the writer observed vivid green spots of fuchsite in chlorite-muscovite schists.

Except for the presence of chromite-grains in dunite-serpentinite and harzburgite-serpentinite in the Springburn, a tributary of Gentle Annie Creek, Kawarau S.D. (Hutton, 1936), chromiferous minerals have not been found *in situ* in the country immediately east of Lake Wakatipu. Finlayson (1908) records the occurrence of a narrow dyke of serpentine, somewhat talcose, in Bushy Creek, 330 yards from its junction with the creek joining Lakes Kilpatrick and Moke. The present writer was unable to locate this serpentinite outcrop, even after very careful searching of the creek for its entire length. Nevertheless, in 1882, Cox reported the discovery of a boulder of chromite in the gravels of Moke Creek, and this would appear to strengthen the belief that serpentinites do occur in this region. However it must be pointed out that as some of the schists outcropping in Bushy Creek are highly chloritic and decidedly greasy to touch, an error may have been made in the identification of talcose serpentinites.

Composition and Properties of Fuchsite.

Fuchsite was separated from a fuchsite-oligoclase schist, first by crushing, then concentrating the mica on a cardboard tray, and finally centrifuging the concentrate in order to separate, in particular, pale green and colourless muscovite from the deep green fuchsite. The analysis made by Mr. F. T. Seelye is given in Table I, together with two analyses of fuchsite obtained from the literature; one of these analyses (column B) is of the original fuchsite from the Zillerthal Alps in the Tyrol.

TABLE I.

	A	B*	C
SiO_2	46.35	47.95	42.21
Al_2O_3	29.69	34.45	34.55
Cr_2O_3	4.60	3.95	2.03
Fe_2O_3	0.23	1.80	1.03
FeO	0.85	—	
MgO	1.93	0.71	3.13
CaO	tr.	0.59	0.47
Na_2O	0.78	0.37	0.82
K_2O	10.53	10.75	9.16
H_2O+	4.69	—	6.77
H_2O-	0.12	—	
TiO_2	0.28	—	—
P_2O_5	0.01	—	—
V_2O_3	tr.	—	—
S	0.05	—	—
MnO	0.01	—	tr.
BaO	0.15	—	—
F	0.04	0.36	—
	100.31	100.93	100.17

A. Dead Horse Creek, Glenorchy S.D. Anal.: F. T. Seelye.

B. Schwarzenstein, Zillerthal. Anal.: Schafhäutl, (Dana, 1904, p. 619).

C. Chrome pits, one mile west of Etchison Post Office, Montgomery County, U.S.A. Anal.: T. M. Chatard, (F. W. Clarke, 1890).

According to the X-ray work of Pauling (1930), who used fuchsite, and Jackson and West (1930, 1933), using muscovite, the structural formula for such micas may be expressed as $KAl_2(AlSi_3O_{10})(OHF)_2$; therefore the analysis of New Zealand fuchsite has been recalculated on this basis, that is of 12(O.OH.F) atoms to the unit cell (see Table 2).

TABLE II.

	wt. %	Metal Atoms		Metal Groups
SiO_2	46.35	3.125		4.00
			0.875	
Al_2O_3	29.69	2.356	1.481	1.99
Cr_2O_3	4.60	0.245		
TiO_2	0.28	0.014		
Fe_2O_3	0.23	0.011		
FeO	0.85	0.047		
MgO	1.93	0.195		
Na_2O	0.78	0.101		1.01
K_2O	10.53	0.906		
BaO	0.15	0.003		
H_2O	4.69	2.108		2.10

Formula: $(OH)_{2\ 1}\ (Mg, Fe'', Fe''', Ti,Al,Cr)_{1\ 99}\ [(Si,Al)_4O_{10}]\ (K,Na,Ba)_{1\ 01}$

It will be observed that good agreement is obtained with the ideal formula. Considering the distribution of the metal atoms, just slightly over one-third of the Al ions are required to make up the Y group to the theoretical value of 4 demanded by the structural formula, while all the chromium, together with the remainder of the Al is required to bring the X group of cations of co-ordination

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* There is a discrepancy between the analysis quoted by Dana (1904) and Bristow (1861, p. 145), in that the latter gives CaO = 0.42, and F = 0.35, with a summation of 100.75. The original publication, *Lieb. Ann.*, 44, 40, 1842, was not available to the present author.

number 6 to 1·99. Other points to note are the low percentage of Na_2O, the presence of a small amount of BaO, and the very low figure for fluorine.

In Table I the analyses of two examples of fuchsite have been included for the sake of comparison with the Wakatipu specimen. The close similarity of these three analyses will be seen, and it is of interest to note that the Wakatipu specimen contains the highest percentage of Cr_2O_3 yet found in fuchsite, with the possible exception of fuchsite from Outokumpu, Eastern Finland, described by Eskola (1933, p. 30). In this latter case the chrome-mica was separated from a fuchsite-bearing quartzite in an impure state, containing, in Eskola's estimation about 25% of quartz. The impure sample on analysis gave 3·68% of Cr_2O_3 or a possibility of 4·90% of Cr_2O_3 in the pure mineral, if the estimation of the amount of quartz was a correct one.

Scant data are available to the writer on the optical properties of fuchsite or of the chromiferous micas generally. At this point it might be stated that the optical values given for the mineral mariposite are incorporated, although discussion on the validity of this mineral species will be deferred till later in this paper. In Table 3 the optical properties of the Otago fuchsite and of some chromiferous micas are set out; it will be apparent that considerable variation exists between the different specimens, and this seems not to depend entirely on the Cr_2O_3 content. However, as stated above, there is at present so little information available that generalisation is not possible. A consideration of the data determined for A and B in Table 3 suggests that an increase in Cr_2O_3 causes an increase in refractive indices and birefringence, but a decrease in the size of the optic axial angle. The refractive indices found for a specimen of mariposite (Table 3, column F) would seem to be high, but these figures are substantiated by data determined by Knopf (1929, p. 38) for mariposite from the 2,170 foot level of the Melones Mine ($\alpha = 1{\cdot}58$, $\gamma = 1{\cdot}63$). Nevertheless Knopf (1929, p. 38) shows that there is considerable variation in the optical properties of different mariposites. The range of the optic axial angle for fuchsite is 30°–40°, while mariposite appears to be uniaxial or at the most to have an optic axial angle of only a few degrees. Hulin (1925, p. 25), observes that mariposite from Randsburg may have an optic axial angle of any value between 0° and 40°. (Further, he notes that the dispersion is very strong, with $r > v$).

The robin's egg blue tint for the α vibration direction of the refractive index ellipsoid would appear to be a characteristic property of fuchsite, and in the case of the Dead Horse Creek specimen, this is the direction of maximum absorption. Winchell's absorption scheme (Table 3, column D) differs considerably from that determined for the New Zealand material, and unfortunately Larsen and Berman omit to record the relative strengths of the absorption tints. Finally, a distinct to very strong dispersion of the optic axes, with $r > v$ seems to be a characteristic feature.

TABLE III.

	A	B	C	D	E	F	G
% Cr_2O_3	4.60	0.27	2.03	—	—	—	—
Refractive Indices:							
α	1.5695±0.0005	1.5590	—	—	—	1.60	1.572
β	1.6040	1.5930	—	1.595	1.594	1.63	1.605
γ	1.6115	1.5973	—	—	—	1.63	1.607
$\gamma-\alpha$	0.0420	0.0383	—	as in muscovite	—	—	0.035
2V	37°±1°	46°	68° 16′ (2E)	68°–70° (2E)	40°	0°	30°–37°
Sign	negative	negative	—	negative	negative	negative	negative
Pleochroism:							
α	robin's egg blue	colourless	robin's egg blue	colourless to pale greenish-blue	robin's egg blue	—	greenish-blue
β	very pale yellowish-green	very palest yellow	yellowish-green	yellowish-green	yellowish-green	—	yellowish-green
γ	bluish-green	very palest yellow	bluish-chrome-green	dark bluish-green	chrome-green	—	bluish-green
Absorption:	$\alpha \geqslant \gamma > \beta$	$\gamma = \beta > \alpha$	—	$\gamma > \beta > \alpha$	—	Z < Y & X	—
Dispersion:	$r > v$ (strong)	nil	—	$r > v$ (distinct)	$r > v$ (strong)	—	$r > v$
Sp. Gr.	2.88	2.819	—	—	—	—	—

A. Dead Horse Creek, Glenorchy Survey District, Glenorchy Subdivision.

B. Chromiferous muscovite, Whitcombe Valley, Toaroha S.D., Mikonui Subdivision, Hutton, 1940.

C. Analysis No. 58, Dana's *System of Mineralogy*, 6 ed., pp. 617 and 619, 1904.

D. Properties of fuchsite, as stated by A. N. Winchell, pp. 269–270, 1933.

E. Properties of fuchsite, as stated by E. S. Larsen and H. Berman, p. 165, 1934.

F. Properties of mariposite, as stated by A. S. Eakle, pp. 197–198, 1923; some data from Larsen and Berman, 1934.

G. Properties of fuchsite. Velem, Koszeg Mts., given by E. Szadeczky-Kardoss, 1937.

Nomenclature of the Chrome-micas:

Considerable confusion appears to exist in the literature in regard to the terms mariposite, alurgite, and fuchsite, and it is pertinent to discuss this question now and to make some attempt to clarify the position. The term "fuchsite" was applied to a highly chromiferous mica from the Zillerthal Alps in 1845, and later Silliman, jun. (1868) described a new mineral for which he proposed the name mariposite, from the gold belt of the Sierra Nevada. The latter author mentioned positive qualitative tests for Fe, Ca, Mg, K, Cr, and Al, but published no optical properties or complete quantitative data. Later Hillebrand analysed two specimens of mariposite collected by Turner (1896), one of which was green and contained 0·18% Cr_2O_3, while the other was white and contained no Cr_2O_3. In regard to this white non-chromiferous mica, the writer must agree with Knopf (1929, p. 38) that it is not at all clear how such a mariposite is to be distinguished from sericite or muscovite. Mariposite has also been described by Hulin (1925, p. 25), but beyond stating that the mineral is green with an optic axial angle that may vary from 0° to 40°, no further data are given. In a paper on mariposite and alurgite, Schaller (1916) concludes that these two micas are identical, and later in a personal communication to Webb (1939, p. 127) Schaller states that "the names alurgite and mariposite may have some justification as varietal names, but certainly not as distinct species names."

Knopf (1929) in his study of the Mother Lode System of California, does not mention the term fuchsite, although he discusses mariposite at length. He states that the most conspicuous feature of this mica is its green colour, and some optical data are given. Finally Knopf defines the mineral mariposite as a green chromiferous sericite. Pabst (1938, p. 251) described fuchsite as an emerald-green chrome-muscovite while mariposite (*loc. cit.*, p. 252) is described as "a muscovite with a characteristic green colour due to the presence of chromic oxide." Murdock and Webb (1938, pp. 353-354) in some notes of Southern Californian minerals describe mariposite occurring in talc-sericite and talc-actinolite-schists and point out that the mica flakes are sometimes 10—12 mm. in diameter. Recently Webb (1939) has discussed mariposite in the light of Schaller's and Knopf's statements but there is little to add from this to the present discussion.

Unfortunately no exact optical or chemical data are available for mariposite and it seems clear that no definite ideas exist as to the exact properties of this mineral. Knopf (1929) states very clearly that the mica is a sericitic type, that is, if the present writer's interpretation is correct, the mica occurs in a very fine flaky form. But Murdock and Webb (1938), however, have used the term mariposite for a green chrome-mica occurring in flakes up to 10—12 mm. in diameter. Certainly such a coarsely crystalline mica is not sericitic in the generally accepted meaning of the term. In the European literature available to the writer the term mariposite has not been used for the description of green chrome-micas, whether in coarse plates or in a fine flaky form, but instead the term fuchsite appears always to be employed. If the term mariposite is intended to imply green chromiferous potash micas, with a composition otherwise similar to that of muscovite, then it should be abandoned, for the term fuchsite has definite priority.

The question now arises as to the amount of Cr_2O_3 necessary in a mica to warrant the title of fuchsite, for the writer has shown (1940, p. 330B) that only a very small percentage of Cr_2O_3 will cause a very considerable green colouration of muscovite. However, as a result of the writer's investigations of these micas, an important content of chromium is necessary before the characteristic robin's egg blue tint is developed along the α vibration direction. Therefore it is suggested that

(1) the term mariposite be abandoned;

(2) potash micas with less than 1% of Cr_2O_3 be described as chromiferous muscovites and,

(3) micas with 1% or more of Cr_2O_3 be described as fuchsite.

Such examples (3) as have so far been described are characterised by the robin's egg blue tint for the α direction and by distinct or strong dispersion ($r > v$).

Redingtonite:

Occurring in specimen P. 1792 is a deep lilac or purple coloured earthy material that is intimately associated with folia of fuchsite. Microscopically it is usually granular, though rarely prismatic. The prismatic crystals have straight extinction and positive elongation. Refractive indices were determined as follows: $\alpha = 1{\cdot}475$ and $\gamma = 1{\cdot}485$; $\gamma - \alpha = 0{\cdot}010$. The optical character could not be determined owing to fine grain-size. Microchemical tests indicated that the substance is water-soluble and strong reactions were obtained for Cr, Fe''', (SO_4) and H_2O. Hence the mineral is believed to be a hydrated chromium sulphate with some ferric sulphate. The only recorded mineral with closely similar properties is redingtonite, a mineral described by Melville and Lindgren (1890) from the Redington Mine, Knoxville, California. The writer's mineral is, therefore, tentatively identified as redingtonite until sufficient material is available for a complete quantitative analysis.

Petrology:

Fuchsite, in the Lake Wakatipu district, is an important constituent of two distinct types of schists that are found interbedded with quartzo-feldspathic schists of the Chl. 4 subzone of Hutton and Turner (1936), viz., oligoclase-fuchsite schists (P. 1792) and fuchsite-chlorite-schists (P. 1793). Both of these rock types are closely associated with one another in Dead Horse Creek. In hand-specimen, the first group of rocks is strongly schistose and coarsely foliated, bands of fuchsite alternating with bands of plagioclase and minor quartz. Striated cubes of limonite pseudomorphous after pyrite occur up to 5 mm. in length.

P. 1792: A thin section of a fuchsite-rich folium from this schist was briefly described by Sollas (1906, p. 158) but more representative sections have now been cut and are described here. Quartz occurs in water-clear, xenoblastic grains, averaging 0·15 mm. in diameter, with undulose extinction noticeable in some grains. The feldspar, an important constituent, occurs in grains of similar dimensions and shows some variation in composition from grain to grain, and also within the same grain. Universal stage measurements indicate a composition usually varying from $An_{19} - An_{27}$, that is medium to basic oligoclase. Zoning was measured in two examples and gave data as follows: inner zone An_{27}, outer narrow zone An_{31}; in a second crystal, inner zone An_{25}, outer narrow zone, An_{30}. The peripheral zones have, therefore, in some cases, a composition of acid andesine, while the nuclear or central zones may be as sodic as medium oligoclase. Twinning on the albite law was developed rarely. This feldspar is apparently the unidentified mineral mentioned by Sollas (1906, p. 158). Fuchsite occurs in strongly pleochroic plates, 0·8 – 3·0 mm. in diameter, that exhibit considerable bending and even some fracturing due to later shearing movements. Associated with this deep-green mica are plates of colourless or pale green mica, which have the usual properties of muscovite. Zoning of muscovite or fuchsite was not observed. Twinning of the fuchsite on the mica law with (001) as composition plane, is commonly developed but it is not clearly seen until one orients the plates on the universal stage for determination of the pleochroism. In such cases the tints for α and β, and α and γ show on opposite sides of the composition plane. Of the accessory minerals, chromite is important, occurring in strings of tiny, coffee-brown octahedra (text-fig. 1) and also rarely in rounded grains up to 0·5 mm. in diameter (text-fig. 2A). These strings of grains either lie along the cleavage planes of the fuchsite or else they wind sinuously along the junction of mica plates. Rutile occurs in slender needles or prismatic grains, usually lying within the cleavage planes of the mica. Dense aggregates of dust-like particles of magnetite, grains of pyrite and pyrrhotite, complete the mineral association. Redingtonite, owing to its solubility in water, was not observed in thin section.

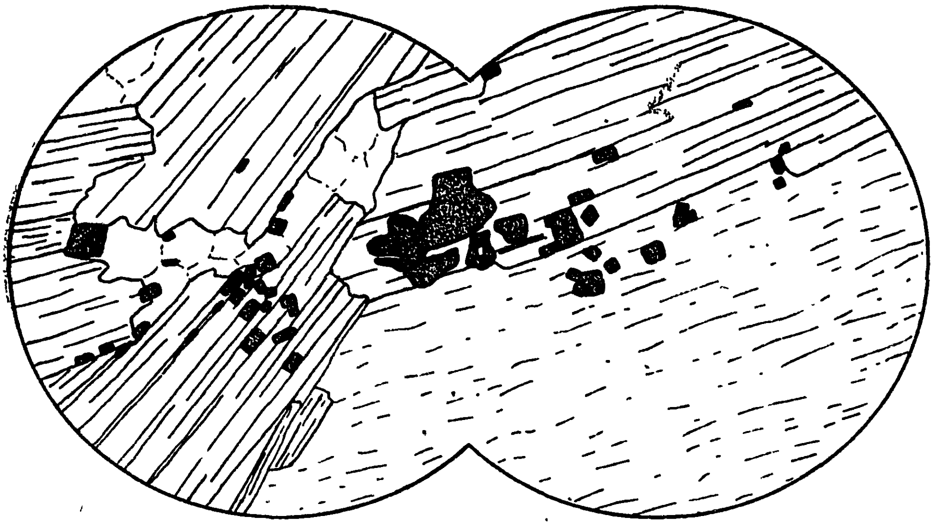


FIG. 1.—A fuchsite-oligoclase-schist (P. 1792) showing clusters of chromite grains in plates of mica; some oligoclase is also seen. × 110.

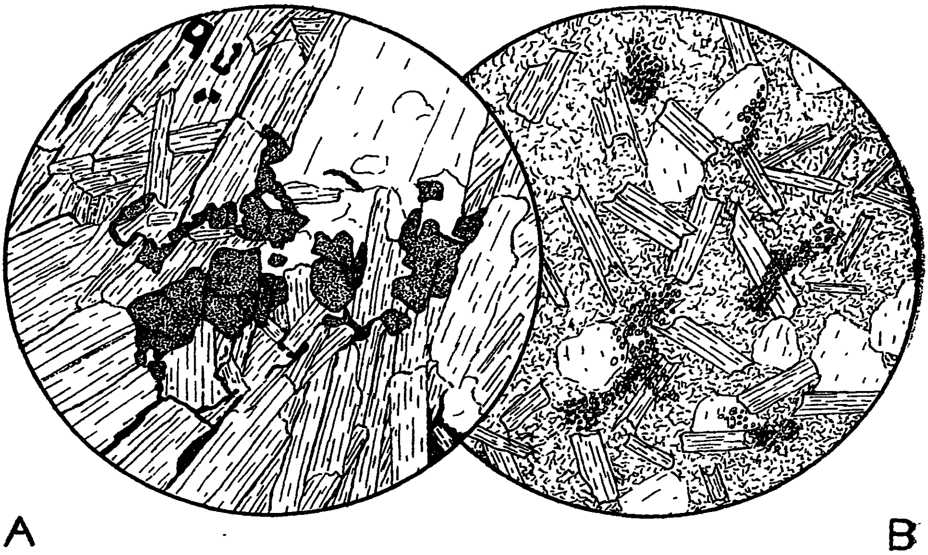
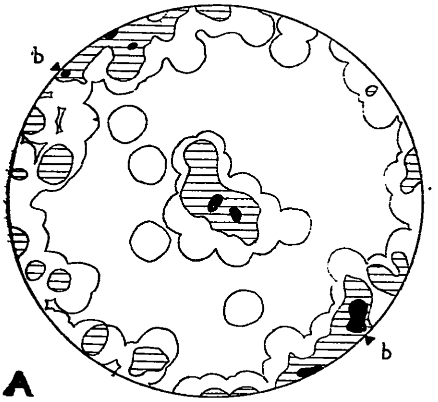


FIG. 2A.—Chromite and fuchsite in fuchsite-oligoclase-schist. P. 1792. Note the manner in which chromite has penetrated along the cleavage planes of the mica or along the boundaries between mica plates. × 26.

FIG. 2B.—A section of a fuchsite-chlorite-schist, P. 1793, cut parallel to *ab*, in order to show the unoriented habit of the mica, but strong alignment of prochlorite flakes. × 26.

P. 1793: Macroscopically this rock is also strongly schistose but only poorly foliated, the green mica being intimately associated with prochlorite and not segregated into well defined folia. Fuchsite, with similar properties to that in P. 1792, occurs in plates that average 0·3 mm. in diameter. The orientation of this mica is discussed later. Titanite is an important minor constituent and is present in the form of spindle—or " insect-egg "—shaped grains, grouped into strings or dense clusters. Many of the grains are oriented with Bx_a approximately normal to the plane of schistosity. This feature has been observed before (Turner, 1936, p. 215; Hutton, 1940A, p. 52), and it has been suggested by the writer (1940A, p. 63) that it may be brought about in crystals showing an important development of an orthodome (102). The fuchsite and sphene are embedded in an almost isotropic base of a uniaxial, negative, chlorite with the following refractive indices: $\alpha = \beta = 1{\cdot}606$, $\gamma = 1{\cdot}610$, $\gamma - \alpha = 0{\cdot}004$. The chlorite is colourless with very faint dispersion and pale brown anomolous interference tints. These properties, according to the tables of Winchell (1936, p. 649), point to the mineral being a member of the prochlorite group or a variety with a composition lying just on the boundary separating the fields of rumpfite and prochlorite. The aluminous nature of the chlorite, however, is clearly seen in the analysis of this rock (Table 4, analysis B). Accessory constituents include pyrite, now partly limonitized, calcite ($\gamma = 1{\cdot}655$–$1{\cdot}660$), strings and clusters of clinozoisite or poorly ferriferous epidote, and tremolite in colourless acicular prisms. The amphibole has the following optical properties: $\alpha = 1{\cdot}622$, $\gamma = 1{\cdot}640$. $\gamma - \alpha = 0{\cdot}018$; $Z \wedge c = 16° - 17°$, and it is optically negative; these properties would seem to indicate that the amphibole was non-aluminous and poor in iron.

The orientation of the mica has been studied in the three principal sections of the fabric; the poles of the (001) cleavage were measured for 100 flakes in each case.* The procedure adopted in this investigation is identical with that used by Turner and Hutton (1941, p. 231), but only the fabric diagrams of sections parallel to *ab* are reproduced here (fig. 3). From a careful study of all the diagrams it is concluded, on account of the fortuitous nature of the maxima, and absence of any girdle pattern,† that except for a faint tendency for some flakes to lie parallel to *S* in particular layers, the fuchsite fabric lacks preferred orientation. The slight tendency for orientation of the flakes parallel to the schistosity in narrow zones only, is clearly seen by rapid inspection of sections perpendicular to *a* or *b*. It should be noted that the maximum *Z* (fig. 3B) represents flakes subparallel to *S*, but in all probability it should be spread outwards in all directions, since in any crystal subparallel to the section it is difficult to locate Bx_a (the normal to the cleavage) exactly. The prochlorite fabric, on the other hand, shows a strong



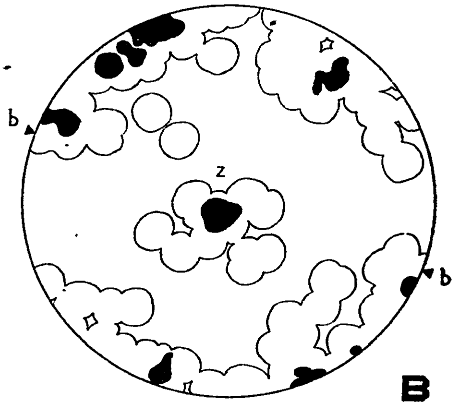


FIG. 3A.—P. 1793, a section approximately perpendicular to *c*. Fuchsite, poles of (001) in 100 flakes. Contours at 6, 3, and 1% per 1% area. The direction *bb* is that of the strings of sphene and epidote (probably = *b* of the megascopic fabric).

FIG. 3B.—P. 1793. The poles of (001) in 100 flakes of fuchsite in a section cut exactly perpendicular to *c*. Contours, 5 and 1% per 1% area. Direction *bb* is the trend of lines of sphene and epidote granules; this direction is parallel to a faintly developed *b* direction of the megascopic fabric.

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* These sections are normal to the *a*, *b* and *c* fabric axes respectively, where *ab* is parallel to the schistosity (*s*), *b* is parallel to the lineation in *s*, and *c* is normal to *s*.

† The apparent girdles of Fig. 3 are due entirely to the tabular habit of the crystals measured. Equally strong apparent girdles appear in diagrams for sections normal to *a* or *b*.

parallelism of flakes with the schistosity and the strings of grains of epidote and sphene. The size of the platelets was, however, too small to allow any exact statistical estimate of the preferred orientation. The random orientation of the fuchsite is most readily observed in a section cut perpendicular to *c*, for here the high birefringence of the disarranged mica plates stands in marked contrast to the nearly isotropic base composed of basal flakes of prochlorite. Dr. F. J. Turner has checked the fabric diagrams and agrees with the above interpretation.

Table IV.

	A.	B.
SiO_2	56.03	40.16
Al_2O_3	25.64	23.29
Fe_2O_3	1.97	0.52
FeO	0.55	6.68
MgO	0.25	11.26
CaO	2.74	1.40
Na_2O	5.69	0.25
K_2O	3.47	6.04
H_2O+	1.46	7.44
H_2O-	0.48	0.20
CO_2	nt. fd.	tr.
P_2O_5	0.01	0.04
TiO_2	0.21	0.85
ZrO_2	nt. fd.	nt. fd.
S	1.30	0.05
SO_3	0.13	—
MnO	tr.	0.13
NiO	0.09	0.09
Cr_2O_3	0.21	1.61
V_2O_3	0.01	0.04
BaO	0.05	0.07
SrO	0.02	0.001
Cl	nt. fd.	nt. fd.
F	0.01	0.06
	100.32	100.18

A. Oligoclase-fuchsite-quartz-schist, P. 1792.

B. Fuchsite-prochlorite-schist, P. 1793.

The analysis of the oligoclase-fuchsite-quartz-schist is interesting in that a considerable percentage of CaO is shown and since apatite and sphene are only very minor constituents, most of the lime represents the anorthite molecule of the plagioclase; this supports the data obtained microscopically that the plagioclase may be as calcic as acid andesine. The SO_3 reported in this analysis is, Mr Seelye reports, that of the sulphate soluble in hot water, and this is considered to represent the acid radicle of the rare mineral redingtonite. Further the analyst reports that "on treating the sample with hot dilute HCl (1 HCl : 5 H_2O) in an atmosphere of CO_2, H_2S is evolved in amount equivalent to 0·57% of sulphur; this is probably derived from pyrrhotite." The presence of this not inconsiderable amount of pyrrhotite is important and, it will be suggested later, has some bearing on the origin of these rocks. The second analysis (Table 4, analysis B) clearly indicates the aluminous nature of the chlorite but it is also evident that the prochlorite is much more highly magnesian than those previously described (Hutton, 1940A, pp. 18–19) from the schists of the Wakatipu area. It is possible that the chlorite may be chromiferous, but if so the Cr_2O_3 content will be low as there is no evidence of the tints characteristic of kammererite. In both analyses the presence of nickel is interesting, even although the quantities are low. There is no evidence of the part taken by nickel but the writer would suggest that it is possibly in the form of nickeliferous pyrrhotite.

Origin of the Fuchsite-bearing Schists.

Before discussing the origin of fuchsite in the Wakatipu rocks, it might be of value to consider very briefly the associations and origin of chrome-micas in other localities.

West Australia: Fuchsite has been very frequently described from this region, but it must suffice to give only a few of the better known instances. The mineral has been recorded as a constituent of schists of the Sherlock River in the Hammersley Range (Maitland, 1909), in quartz veins at Lennoxville (Jutson, 1914, p. 96), and in altered porphyries and porphyrites, of the Boulder Belt, Kalgoorlie (Stillwell, 1929). But the majority of the records describe this mica occurring in, or associated with, the altered and carbonated basic and ultrabasic rocks of the Kalgoorlie and Coolgardie areas *vide* Gibson, 1911, pp. 21–29; Simpson and Gibson, 1912, pp. 138–139; Farquharson, 1912A, pp. 79–80; Farquharson, 1912B (in Blatchford and Jutson); Farquharson, 1913 (in Feldtmann and Farquharson); and Thomson (1914, p. 636). Farquharson (1912A, p. 89; 1912B, pp. 94–95) is definitely of the opinion that the fuchsite-quartz-carbonate rocks have developed from very basic gabbros or peridotites by means of CO_2-bearing waters. In the south part of the Mount Margaret Goldfield, Clarke (1925, pp. 30 and 47) has described fuchsite-quartz-carbonate rocks that are closely associated with serpentinites and greenstones, and lenses of cupriferous pyrite (the Anaconda Copper Lode); it is Clarke's opinion (1925, p. 50) that the copper has originated from solutions emanating from the ultrabasic rocks, now represented as serpentinites, but states that there is no evidence of the origin of the fuchsite.

In America many accounts have been given of the association of chrome-micas with basic and ultrabasic rocks and Knopf's descriptions (1929, pp. 38–39) of the occurrence of "mariposite" in the rocks of the Mother Lode System is one of the most noteworthy. Knopf states that the fuchsite-ankerite rocks have resulted from hydrothermal alteration of serpentinites. In addition, Ferguson and Gannett (1932, pp. 47, 57, and 75) have described mariposite in quartz veins of the Alleghany District of northern California, and their field evidence leads them to conclude that the controlling factor in the distribution of the mica is the presence, or proximity, of serpentine.

In Europe Eskola (1933) and Lodnochnikow (1936) both describe fuchsite occurring in association with other secondary minerals, in altered ultrabasic intrusives, and these authors believe that the crystallization of the mica is the result of late solutions that brought about the serpentinization of the ultrabasic rocks.

In Rhodesia, Zeally (1915, p. 66) describes "green (?) talcose material," which Sampson (1931, p. 666) has determined as mariposite, occurring in association with large chromite bodies in talc schists. In the same region, Keep (1929, p. 66), Tyndale-Briscoe (1931, pp. 68–69), and Ferguson and Wilson (1937, pp. 30–32) record the occurrence of fuchsite in a variety of rocks, but in no case is the author clear as to the origin of the mica.

Fuchsite, containing an important amount of vanadium (0·48%), has been described by Chatterjee from quartzites in the Bhandara District, Central Provinces of India, but no statement is made as to the origin of the mica.

Therefore, in the majority of cases, when fuchsite is associated with ultrabasic rocks or their altered equivalents, the mica appears to have crystallized as a result of the action of solutions in some way associated with the late phases of ultrabasic intrusion.

In considering the problem of the rocks of Dead Horse Creek, any hypothesis that is advanced to explain their origin must take into account the following facts:

1. The great development of the chromiferous mica, fuchsite, and the not unimportant development of chromite and minor redingtonite.
2. The occurrence of a calcic plagioclase with reversed zoning in rocks of the chlorite zone.
3. The occurrence of pyrrhotite.
4. The presence of minor amounts of nickel, possibly as nickeliferous pyrrhotite.
5. The unoriented nature of the fuchsite but strongly oriented prochlorite in the fuchsite-prochlorite-schist.
6. The occurrence of muscovite or poorly chromiferous muscovite in schists containing fuchsite.
7. The occurrence of zones of schists in nearby localities, heavily impregnated with chalcopyrite, cupriferous pyrite, and nickeliferous pyrrhotite.

It is the writer's hypothesis that all these facts point to one conclusion, and that is that the fuchsite-schists are the result of chromium metasomatism brought about by the penetration and soaking of narrow zones of quartzo-feldspathic schists by solutions at high temperature, or aqueous chromium-bearing vapours, above the critical temperature of water, emanating from deep-seated intrusions of an ultrabasic nature; and further, that the chalcopyrite and nickeliferous pyrrhotite fahlbands have likewise originated from the same deep-seated source. Certainly the gangue minerals in the sulphide veins, quartz and sericite, are evidence that the sulphide emanations have penetrated a considerable distance from their source (Lindgren, 1933, p. 748). The occurrence of octahedra of chromite in nests and strings in one of the fuchsite schists excludes all possibility of this mineral being an original constituent of the sediments from which the schists have been derived, while the presence of pyrrhotite, a sulphide so frequently genetically associated with basic and ultrabasic rocks, strengthens the hypothesis that the solutions originate from intrusions of an ultrabasic nature.

This hypothesis for the origin of chromite is not new but has been stressed by Sampson (1929, 1931), Ross (1929), Rynearson and Smith (1940), and Allen (1941). Sampson found that very considerable amounts of chromite may pass into the residual solutions of crystallizing basic or ultrabasic magmas and that these solutions are capable of very considerable migration. Further, Sokolov (1937, pp. 176–177) has pointed out that the rôle of water is very important for the formation of chromium ore bodies, and that the volatiles retain much of the chromium during the earlier stages of crystallization of an ultrabasic magma. In addition, Sokolov states that experimental work has shown that chromium is transported in water when the latter is above its critical temperature. If the chromite has its origin in this manner, it is reasonable to call upon a similar origin for the chrome-mica. It is believed that the chromiferous solutions reacted with any original muscovite in the original quartzo-feldspathic schists, resulting in a slight replacement of Al_2O_3 by Cr_2O_3 and subsequent formation of some of the fuchsite; the remainder of the mica is believed to have crystallized directly from the metasomatic fluids, the orientation of the mica plates bearing little or no relation to the existing schistosity. That the temperature at which this metasomatic replacement occurred was higher than that usually obtaining in the chlorite zone, is indicated by the calcic nature of the plagioclase and the reversed zoning displaced therein. In rocks of the chlorite zone the pressure-temperature conditions facilitate the development of an acid plagioclase, almost invariably albite with not more than 4% of the anorthite molecule (Hutton, 1940A, p. 63), but not until the oligoclase or garnet zone is reached does the anorthite content of the plagioclase begin to rise (Turner, 1933, pp. 244–246). In addition, the pyrrhotite must have been introduced into the schists by these hydrothermal solutions.*

As stated earlier, it is the writer's belief that the neighbouring chalcopyrite and pyrrhotite zones are genetically related to the chromium-bearing schists, and that they have been derived ultimately from the same source. This association of fuchsite, chromite, pyrrhotite and chalcopyrite is not dissimilar to that observed in the region of the Outokumpu copper mines in Eastern Finland (Eskola, 1933) and in the Anaconda district of Western Australia (Clarke, 1925). In order to explain the paragenesis at Outokumpu, Eskola advances the hypothesis that these minerals are in all probability hydrothermal in origin and are derived ultimately from the associated serpentinites.

No further evidence can be advanced at present as to the age of the basic and ultrabasic rocks and the genetically associated

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* Recently Turner (1942, p. 311) has noted the late introduction of nickeliferous pyrrhotite into the low-grade metamorphic rocks of Manuka Gorge, Otago; Turner finds that the pyrrhotite post-dates the formation of the quartzose veins.

chromiferous zones and sulphide veins of Western Otago, but Turner (1933, pp. 276–277) has suggested that the period of ultrabasic intrusion is possibly Lower Cretaceous; this date, it is the present writer's opinion, must still be accepted.

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