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CHROME MICAS

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ABSTRACT

Some optical, chemical and *x*-ray studies have been made on several chromium micas (fuchsite and mariposite) of the type associated with many pre-Cambrian gold deposits.

A study of available analyses of fuchsite, including a new one by Whitmore yields the following chemical formula:

$$(K,Na,Ca)_{3.64}(Al,Mg,Cr,Fe''',Fe'')_{7.92}(Al_4,Si_{12})O_{38.61}(OH)_{9.39},$$

which closely approaches the accepted muscovite formula, $K_4Al_8(Al,Si_3)_4O_{40}(OH)_8$, representing the ideal unit cell content. In fuchsite Cr replaces Al up to 4.81% Cr_2O_3, corresponding closely to 1 atom of chromium per unit cell. Optical properties of fuchsite show the following variation: $\alpha = 1.559$ to 1.569, $\beta = 1.593$ to 1.604, $\gamma = 1.597$ to 1.611; 2V 30°–46°, indices increasing with increase in chromium. *X*-ray studies confirm the structural identity of fuchsite with muscovite. The varietal name ***chromian muscovite*** is preferred to the name ***fuchsite***.

Available analyses of mariposite show a decidedly lower content of Cr_2O_3 and Al_2O_3 and higher SiO_2. The highest observed chromium content is 0.78% Cr_2O_3. The aluminum-silicon ratio in tetrahedral groups is between 2:14 and 1:15, compared with a ratio of 4:12 in fuchsite and muscovite. Published optical data show mariposite with higher indices than fuchsite and 2V 0°–14°. *X*-ray studies have not yet established the structural type of mica to which it belongs, but it is tentatively classed as chromian phengite.

Consideration is given to the association of these micas with hydrothermal carbonate zones and quartz-sulfide gold deposits.

INTRODUCTION

Chrome micas, classed variously as fuchsite, mariposite, and chromiferous muscovite are of wide distribution throughout gold-bearing districts of the Canadian Shield and have been noted in many other areas throughout the world. Because of their rather intimate association with ferruginous carbonate alteration zones and auriferous quartz veins, particularly in Canada, adjoining what have been recognized in recent years as prominent faults, a detailed investigation of this series of micas appears amply warranted.

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[1] Part of this investigation was carried out by D. R. E. Whitmore aided by a bursary from the National Research Council, Canada, 1940.

Problems related to these brilliant green minerals are of two types. Mineralogically there is the question of their exact identity and place in the mica family, and their variations chemically and optically. Geologically it is of interest to inquire into the conditions of their formation and their source and place in the sequence of ore and gangue minerals with which they are associated.

CHARACTER OF INVESTIGATION AND ACKNOWLEDGMENTS

The present investigation has included *x*-ray, chemical and optical studies of chromiferous micas. To Dr. Charles Palache of Harvard University the writers are greatly indebted for an excellent set of museum specimens representative of occurrences in California, Maine, Vermont, Quebec, Ontario, Manitoba, India, Russia, Silesia and the Tyrol. Grateful acknowledgment is also made to H. S. Spence, Mines Branch, Department of Mines and Resources, Ottawa, for an excellent specimen of fuchsite schist from Pointe du Bois, Manitoba, from which a pure concentrate was obtained of fuchsite which has been analyzed by Whitmore. In addition many other specimens from Porcupine and Larder Lake districts of Ontario have been examined and a thin-section study made of some from mines in these areas.

Due to the exceptionally fine-grained character of fuchsite and mariposite in most Canadian samples and our inability to secure pure concentrates from these, several chemical studies planned were not completed. Lack also of good crystals or fragments of mariposite have prevented any *x*-ray study of this mineral being made. There is obvious need for additional analyses and *x*-ray study when coarser-grained material is available.

X-ray studies were carried out with a Cu-target tube and Weissenberg *x*-ray goniometer.

Concentration of samples for analyses was effected both by careful crushing and screening—to remove ankerite—and by the use of Thoulet solution diluted to give specific gravities just above and below recorded gravities of fuchsite, 2.88 and 2.82 respectively.

The chemical analysis on Pointe du Bois fuchsite, by Whitmore, employed Washington's (1930) standard procedure for the determination of SiO_2, Fe_2O_3, Al_2O_3, CaO, Na_2O and K_2O. TiO_2 was determined gravimetrically using cupferron because of the considerable quantity present. MgO was determined by a method described by Fales (1925), while chromium was determined colorimetrically according to a method described by Groves (1937).

Minor constituents present in four fuchsites and in a number of ore and gangue minerals associated with chrome mica in specimens from the

Hollinger mine were determined using a Hilger E 316 spectrograph and copper electrodes. Optical studies were carried out with monochromatic light, in some cases using the double variation method of Emmons, and optic angles were measured on a Zeiss universal stage. The limit of accuracy of index determination was found to vary greatly with increasing fineness of the mica flakes, and for very fine-grained material may be as much as ±.005.

REVIEW OF THE LITERATURE

A bibliography on chrome micas is appended to this paper. Here only the more important references need be mentioned in order to show some of the ideas held with regard to their nomenclature. In many cases analyses are given without any or adequate optical data, in others the latter are available for unanalyzed material. In much of the Canadian literature the mica is named without adequate chemical or optical data to support it.

Fuchsite

The original fuchsite, named after the chemist J. H. von Fuchs, is from Schwarzenstein in the Zillerthal. An analysis by Schafhautl, appearing in Dana (1882), shows over 5 per cent Cr_2O_3. Five other analyses of chrome micas from Belgium, Maryland, Aird Island, L. Huron; Sysersk, Urals and Ouro Preto, are recorded in Dana (1892), the first four of which have been used in this work. Others have appeared since by Prior (1908), Partridge (1937) and Hutton (1940 and 1942).

The Cr_2O_3 content of these ranges from 0.84 to 3.95 per cent. Wherry (1916), notes that a fuchsite from Marble, Colorado, contains 6.08 per cent Cr_2O_3, the highest chromium content on record, but no optical data are given.

Optical studies include those by Szadeczky-Kardoss (1937) and by Partridge and Hutton on analysed material. Szadeczky-Kardoss concluded that fuchsite is a first grade mica, that the optical properties vary with depth of colour and hence, presumably with the chromium content, and that both refractive indices and birefringence increase with increasing colour.

The only *x*-ray study of chrome-mica is one by Pauling (1930) made casually on fuchsite (as a variety of muscovite), by oscillation and Laue photographs.

Partridge (1936) reporting on chrome-mica from South Africa prefers the term *chrome-muscovite* to *fuchsite*. Odman (1938) favours *mariposite* for a low Cr-mica, despite the fact that his material is identical optically with low Cr-fuchsites. Again, in 1940, Hutton suggests the term *mariposite* be abandoned (apparently only on the basis of its low Cr content) and recommends the term *chromiferous muscovite* for those containing 1 per cent Cr_2O_3 and *fuchsite* for those with more. There is thus very obvious need of a clear statement of the characteristics of these minerals.

Mariposite

The type locality for mariposite is the Mariposa estate, in the southern part of the Mother lode district in California, described by Silliman (1868) and Turner (1895), and later by Knopf (1929). Analyses of this material by Hillebrand (1900, in Turner, 1895) include a white non-chromium-bearing mica and a green mariposite with 0.18 per cent Cr_2O_3. In these, as in alurgite, a manganiferous mica, as noted by Schaller[2] (1916), a high $SiO_2:Al_2O_3$ ratio is characteristic. Winchell (1925) using Hillebrand's analysis relates mariposite to high silica phengite and protolithionite and considers the continuity of the series of heptaphylite micas from muscovite to mariposite as established, in which case the chromium content is merely incidental. Later Winchell (1927) modifies his concept of the phengite molecule which is again revised by Volk (1939), but for muscovites *not* as siliceous as those used by Winchell.

Only one other analysis of mariposite by Moorehouse, described by Moore (1936) appears in the literature. Optical data is confined to that given by Knopf (1929) and Moorehouse.

In considering the relation of the chrome micas to the family to which they belong reference must be made to the work of Berman (1937), and Hendricks and Jefferson (1939), whose concepts of the structure of the micas have been followed in this paper.

Important papers dealing with the origin of chromiferous micas are those of Cooke (1922) and Partridge (1937) while many other descriptions of occurrences both in Canada and elsewhere give pertinent data in this respect.

RESULTS OF INVESTIGATION

X-RAY STUDY

The first and fundamental problem was to confirm the structural identity of fuchsite with muscovite by *x*-ray analyses which were carried out by L. G. Berry.

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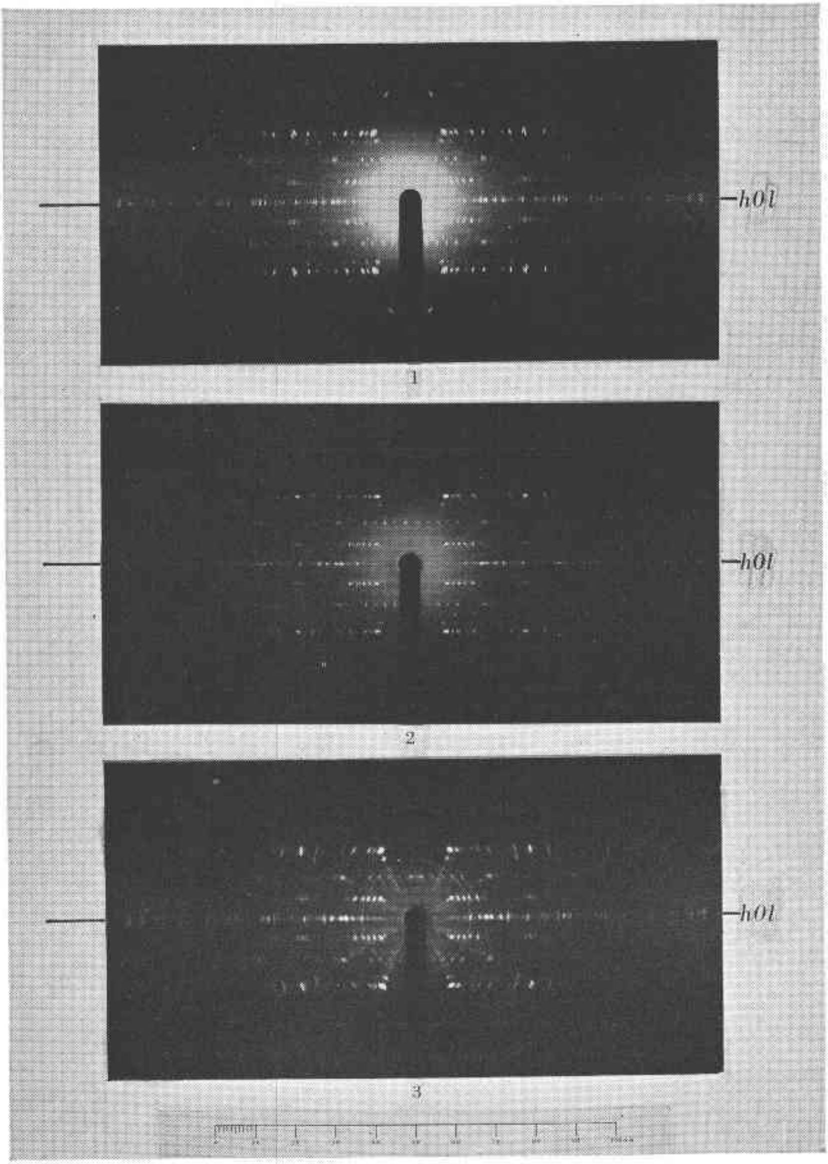
[2] A correction in Schaller's quotation of the original analysis of alurgite (Penfield, 1893) should be noted, since Mn_2O_3 content appears as Cr_2O_3.



FIGS. 1–3.—Rotation photographs [010], with unfiltered Cu-radiation, the scale gives millimetres on the film or degrees of θ. Fig. 1.—Muscovite, lot 6, concession II, Mattawan township, Nipissing District, Ontario (photograph by Ferguson (1943). Fig. 2.—Fuchsite, Pfitsch, Tyrol, HM 90948. Fig. 3.—Fuchsite, Pointe du Bois, Manitoba.

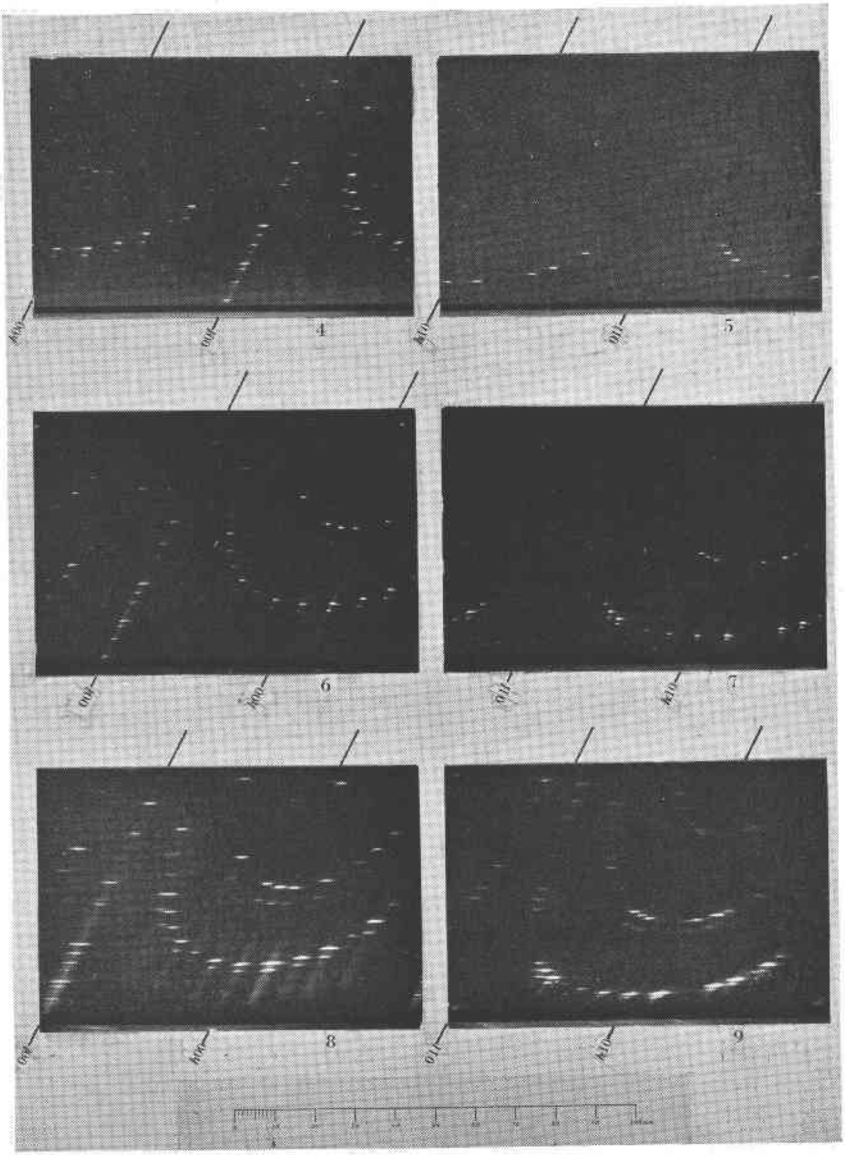
Single crystal *x*-ray photographs, including rotation, zero and first layer Weissenberg films about *b* [010] on flakes of fuchsite from Pfitsch, Tyrol (Harvard Museum Specimen 90948), and Pointe du Bois, Manitoba, establish these as belonging to the same two-layer, base-centered monoclinic mica structure, characteristic of muscovite as determined by Hendricks (1939).

The photographs are identical in position and intensity of diffractions with similar photographs taken by Ferguson (1943) of muscovite from Mattawan township, Ontario, which were kindly loaned for comparison by Prof. M. A. Peacock, University of Toronto (Figs. 1 to 9).

TABLE 1. FUCHSITE AND MUSCOVITE: CELL DIMENSIONS AND SPACE GROUP

	a	*b*	*c*	*β*	Space group
Fuchsite					
Pfitsch, Tyrol HM 90948	5.19 Å	8.99 Å	19.98 Å	95°52′	*C*2/*c*
Pointe du Bois, Manitoba	5.19	9.03	19.97	95 00	*C*2/*c*
Kerr Addison Mine, Ontario	5.2	8.97	19.98	95 30	—
Pauling (1930)	5.19	8.99	20.14	96	—
Muscovite					
Mattawan township, Ferguson (1943)	5.21	9.02	19.98	96 24	*C*2/*c*
North Carolina, Ferguson (1943)	5.20	9.03	20.04	95 54	*C*2/*c*
Jackson and West (1930)	5.18	9.02	20.04	95 30	*C*2/*c*
Mauguin (1927)	5.17	8.94	20.01	96	*C*2/*c*

A similar series of photographs were taken of a flake of Cr-mica from a Kerr Addison mine specimen, which peculiarly showed a small optic angle (15°–20°) but indices close to those of fuchsite (see Table 6). The flake used consisted of a sub-parallel growth or possessed some internal disorder, giving wavy extinction under crossed-nicols, and the resulting *x*-ray photographs were very poor, but values deduced from these are none the less comparable to those of fuchsite. Table 1 gives a comparison of the cell dimensions of the above micas with the previous determination by Pauling and with other determinations on muscovite by Ferguson (1943), Jackson and West (1930) and Mauguin (1927). All are in good agreement.



Figs. 4, 6, 8.—Weissenberg resolution of the zero layer line (*h*0*l*). Figs. 5, 7, 9.—Weissenberg resolution of the first layer line (*h*1*l*), all with unfiltered Cu-radiation, same scale as Figs. 1–3. Figs. 4, 5.—Muscovite, lot 6, concession II, Mattawan township, Nipissing District, Ontario (photograph by Ferguson (1943). Figs. 6, 7.—Fuchsite, Pfitsch, Tyrol, HM 90948. Figs. 8, 9.—Fuchsite, Pointe du Bois, Manitoba.

No samples of mariposite suitable for x-ray analysis have been available in the present study and none are on record by others.

CHEMICAL COMPOSITION

Fuchsite from Pointe du Boise, Manitoba.

The new analysis of fuchsite from Pointe du Bois, Manitoba, by Whitmore, is given in Table 2. TiO_2 determined on the sample amounted to 2.23 per cent, which has been deducted and the analysis recalculated, since most if not all of it is to be accounted for by abundant fine prisms and twins of a golden brown rutile intergrown in the fuchsite. Since the colour of these inclusions is similar to that described by Partridge (1937) for chromiferous rutile in fuchsite from Mashishimala, it is possible that this rutile also contains some chromium in which case total Cr_2O_3 attributed to the mica may be somewhat high. Spectroscopic analysis showed the presence of titanium, zirconium, and germanium. Amounts of all other constituents are comparable with those in other analyses, particularly silica, alumina, ferric oxide and potash. The Cr_2O_3 content is the highest of complete analyses on record.

TABLE 2. FUCHSITE FROM POINTE DU BOIS, MANITOBA: ANALYSIS AND CELL CONTENT

Analysis (Whitmore)		Cell content with $M=1628$		
SiO_2	45.97	Si	12.45	16.00
Al_2O_3	31.67	Al	10.10	8.34
Fe_2O_3	2.56	Fe‴	0.52	
Cr_2O_3	4.81	Cr	1.03	
FeO	0.53	Fe″	0.12	
MgO	0.31	Mg	0.12	
CaO	0.15	Ca	0.04	3.72
Na_2O	1.03	Na	0.54	
K_2O	9.07	K	3.14	
H_2O+	3.48	OH	7.21	48.10
H_2O-	0.51	O	40.89	
	100.09			

Structural formula:
$4[(K, Na, Ca)_{0.93}(Al, Cr, Fe''', Fe'', Mg)_{2.08}(Al_{0.89}Si_{3.11})O_{10.22}(OH)_{1.80}]$
Ideal formula of muscovite: $4[KAl_2(AlSi_3)O_{10}(OH, F)_2]$

The cell dimensions of this fuchsite, combined with the measured specific gravity, 2.88, give the cell content in Table 2, and the structural formula. This compares closely with the ideal formula of muscovite, with Cr taking the place of Al to the amount of 1 atom. The ratio of Al:Si in tetrahedral coordination is close to 1:3, and the total number of oxygen and hydroxyl ions is clearly 48.

TABLE 3. FUCHSITE: ANALYSES AND ANALYSES REDUCED TO ATOMIC PROPORTIONS ON THE BASIS OF O=48 ATOMS

	1	2	3	4	5	6	7	8	9	10
SiO_2	44.87	45.68	43.51	47.24	42.21	45.49	46.17	46.35	45.97	
Al_2O_3	37.72	34.17	36.86	31.86	34.55	31.08	29.71	29.69	31.67	
Fe_2O_3	0.54	2.35	2.05	—	1.03	tr.	2.03	0.23	2.56	
Cr_2O_3	0.27	0.84	0.85	0.87	2.03	3.09	3.51	4.60	4.81	
FeO	nil	—	—	0.56	—	—	—	0.85	0.53	
MgO	0.32	3.84	1.02	2.91	3.13	3.36	2.28	1.93	0.31	
CaO	0.36	0.27	0.55	0.58	0.47	0.51	—	tr.	0.15	
Na_2O	1.04	2.23	1.34	0.16	0.82	0.90	—	0.78	1.03	
K_2O	9.83	4.47	8.11	10.72	9.16	9.76	10.40	10.53	9.07	
H_2O+	4.72	4.65	5.80	5.37	6.77	5.85	5.42	4.69	3.99	
H_2O-	0.38	—	—	—	—	—	—	0.12	—	
F	nil	—	—	—	—	—	—	0.04	—	
	100.24[1]	98.50[3]	100.55[4]	100.41[5]	100.17	100.04	99.52	100.31[7]	100.09	

	1		2		3		4		5		6		7		8		9		10	
Si	11.76	16.00	12.05	16.00	11.40	16.00	12.42	16.00	11.02	16.00	12.00	16.00	12.35	16.00	12.45	16.00	12.43	16.00	12.00	16.00
Al	11.65		10.62		11.38		9.86		10.62		9.65		9.35		9.40		10.09			
Fe'''	0.10		0.47		0.40		—		0.20		—		0.41		0.05		0.52			
Cr	0.06	7.72[2]	0.17	8.82	0.18	7.76	0.18	7.90[6]	0.42	7.48	0.64	7.61	0.74	7.76	0.98	7.90[8]	1.03	8.31		7.92
Fe''	—		—		—		0.12		—		—		—		0.19		0.12			
Mg	0.13		1.51		0.40		1.17		1.22		1.32		0.91		0.77		0.12			
Ca	0.10		0.08		0.15		0.16		0.13		0.14		—		—		0.04			
Na	0.53	3.92	1.14	2.72	0.68	3.54	0.08	3.84	0.41	3.59	0.46	3.88	—	3.54	0.41	4.04[9]	0.54	3.70		3.64
K	3.29		1.50		2.71		3.60		3.05		3.28		3.54		3.61		3.12			
OH	9.19		8.17		10.12		9.41		11.80		10.30		9.65		8.63		7.19		9.39	
O	38.81	48.00	39.83	48.00	37.88	48.00	38.59	48.00	36.20	48.00	37.70	48.00	38.35	48.00	39.34	48.00	40.81	48.00	38.61	48.00
F	—		—		—		—		—		—		—		0.03		—		—	

1. Westland, South Island, New Zealand; anal. Seelye (in Hutton, 1940); [1]incl. TiO_2 0.02, V_2O_3 0.09, MnO tr., Li_2O tr., P_2O_5 0.08; [2]incl. Ti 0.003, V 0.02. 2. Salm Chateau, Belgium; anal. Klement (1888) (in Dana, 1892); [3]incl. Li_2O tr. 3. Mashishimala, Transvaal, South Africa; anal. Partridge (1937); [4]incl. Cs_2O tr. 4. Binnenthal, Switzerland; anal. Prior (1908); [5]incl. Li_2O 0.14; [6]incl. Li_2O 0.15. 5. Montgomery Co., Maryland; anal. Chatard (in Gill, 1889, in Dana, 1892). 6. Aird Islands, Lake Huron; anal. Cairns (in Chester, 1887). 7. Sysersk, Urals; and Damour (1882). 8. Dead Horse Creek, Lake Wakatipu region, Western Otago, New Zealand; anal. Seelye (in Hutton, 1942); [7]incl. TiO_2 0.28, MnO 0.01, BaO 0.15, P_2O_5 0.01. V_2O_3 tr., S 0.05; [8]incl. Ti 0.06, Mn'' 0.002; [9]incl. Ba 0.02. 9. Pointe du Bois, Manitoba; anal. Whitmore. 10. Average numbers of atoms.

COMPARISON OF ANALYSES

All available analyses with the exception of one from the Zillerthal (Dana) in which no water is listed, have been reduced to atomic proportions on the basis of (O, OH, F) = 48 and are presented in Table 3 for comparison. These are arranged in order of increasing Cr content which varies from 0.06 to 1.03 atoms per unit cell, the equivalent of 0.27% to 4.81% by weight. The average is given in the last column in which Si = 12.0, Al (tetrahedral coordination) = 4.0, Al, Cr, etc. (octahedral) = 7.92, K, Na, etc. = 3.64, and (OH, F) = 9.39, all agreeing well with the ideal structural formula of muscovite. Fuchsites covering this range of composition are thus established as identical with muscovite.

CHEMICAL COMPOSITION OF MARIPOSITE

The three available analyses of mariposite by Hillebrand (Turner, 1895) and Moorehouse (Moore, 1936) are given in Table 4, as calculated in atomic proportions on the basis of (O, OH, F) = 48 atoms, and are compared with similarly calculated analyses of alurgite (Penfield, 1893) and fuchsite (Manitoba).

All mariposites show a low Cr_2O_3 content (0%–0.78% by weight) resembling in this respect some of the low-chrome-fuchsites, but this is no reason to eliminate the term mariposite, as suggested by Hutton (1940), especially since the three analyses show a consistently low Al:Si ratio compared with fuchsite. In mariposite the Al:Si ratio for atoms in tetrahedral coordination is between 2:14 and 1:15 as against 4:12 in fuchsite, and as noted previously by Winchell (1925) this feature appears characteristic of mariposite and phengite. Compared with either alurgite or the phengite molecule, Winchell (1927), mariposite is more siliceous than both and differs still more in this respect from the revision suggested for the phengite molecule by Volk (1939) who obviously dealt with muscovites of a more normal silica content.

Though the layer structure of mariposite is unknown, the analyses have been reduced to atomic proportions with (O+OH) = 48 atoms (Table 4). The average structural formula can be expressed as follows: Mariposite—

$$x[(K, Na, Ca,)_{1.68}(Al, Mg, Fe''', Fe'', Cr, Ti)_{3.96}(Al_{0.69}Si_{7.31})O_{20.3}(OH)_{3.7}].$$

This formula in which *x* represents the unknown number of layers may be compared with the structural formula of alurgite established as a 3-layer structure by Hendricks (1939) and with the ideal structural formula of phengite.

Table 4. Mariposite: Analyses Compared with Alurgite and Fuchsite, and Reduced to Atomic Proportions on the Basis of O=48 Atoms

	1		2		3		4		5	
SiO_2	56.79		55.35		56.00		53.22		45.97	
Al_2O_3	25.11		25.62		23.52		21.19		31.67	
Fe_2O_3	0.63		0.63		3.30		1.22		2.56	
Cr_2O_3	—		0.18		0.78		—		4.81	
Mn_2O_3	—		—		—		0.87		—	
FeO	0.92		0.92		0.51		—		0.53	
MnO	—		—		—		0.18		—	
MgO	3.29		3.25		2.12		6.02		0.31	
CaO	0.07		0.07		0.37		—		0.15	
Na_2O	0.17		0.17		2.72		0.34		1.03	
K_2O	8.92		9.29		7.03		11.20		9.07	
H_2O	4.72		4.52		3.52		5.75		3.99	
	100.80[1]		99.95[3]		99.87		99.99		100.09	
Si	14.61	16.00	14.43	16.00	14.85	16.00	14.04	16.00	12.43	16.00
Al	7.61		7.89		7.35		6.58		10.09	
Fe'''	0.12		0.12		0.66		0.24		0.52	
Cr	—		0.04		0.16		—		1.03	
Mn'''	—	7.80[2]	—	7.94[4]	—	7.97	0.17	7.43	—	8.31
Fe''	0.20		0.20		0.11		—		0.12	
Mn''	—		—		—		0.04		—	
Mg	1.26		1.26		0.84		2.36		0.12	
Ca	0.02		0.02		0.11		—		0.04	
Na	0.08	3.03	0.06	3.16	1.40	3.89	0.17	3.94	0.54	3.70
K	2.93		3.08		2.38		3.77		3.12	
OH	8.10	48.00	7.85	48.00	6.22	48.00	10.11	48.00	7.19	48.00
O	39.90		40.15		41.78		37.89		40.81	

1 and 2. Mariposite, Mariposa region, California; anal. Hillebrand (1900) (in Turner, 1895); [1]incl. TiO_2 0.18, [2]incl. Ti 0.03, [3]incl. TiO_2 0.18, [4]incl. Ti 0.03. 3. Ross Mine, Hislop township, Ontario, anal. Moorehouse (in Moore, 1936). 4. Alurgite, St. Marcel, Piedmont, Italy; anal. Penfield (1893). 5. Fuchsite Pointe du Bois, Manitoba; anal. Whitmore.

Alurgite—

$$3[(K, Na)_{1.97}(Al\ Mg, Fe''', Mn''', Mn'')_{3.71}(Al_{0.92}Si_{7.02})O_{18.95}(OH)_{5.05}];$$

Phengite—

$$2\ (?)[K_2(Al, Mg, Fe'')_4(Al, Si_7)\ O_{20}(OH, F)_4].$$

The similarity of mariposite to both alurgite and phengite is thus readily apparent. Since alurgite characteristically contains manganese, and has practically the same Al:Si ratio as phengite, it seems best to restrict this term to manganiferous phengites, and to regard mariposite essentially as a chromiferous phengite. Further comparison must await determination of the layer structure, but in the meantime we have no reason to disagree with Winchell (1925) in his statement that "the continuity of the series from muscovite to mariposite can no longer be questioned."

OPTICAL PROPERTIES

Fuchsite

In Table 5 the important optical properties of twelve specimens of fuchsite are arranged in order of increasing Cr_2O_3 content. Data on seven other samples, the Cr_2O_3 content of which is not known, are also included. All are optically negative, with the optic plane ⊥ (010) as far as determined. Indices of refraction range from 1.559 for α to 1.6115 for γ. The average β for 12 analyzed specimens is 1.598.

In general the indices rise with increasing tenor of Cr_2O_3. Birefringence is very strong, 0.035–0.042, and affords a ready method of distinguishing these micas from similarly coloured chlorites. Optic angle (2V) determinations show a range from 32°–46° with an average value of 36°. Absorption formula $= X < Y < Z$; Pleochroism is noted by some authors as very distinctive, with

α = robin's egg blue
β = yellow, yellowish green
γ = blue green.

In thick flakes dispersion is distinct with $r > v$.

Examination of material from the Hollinger and McIntyre Mines, Porcupine District, Ontario, and from Plymouth, Vermont (HM 90940), shows that green micas of two types are present—one with a small optic angle, another with a larger $2V$, characteristic of fuchsite. As noted above the green mica from the Kerr Addison Mine also shows a small optic angle though *x*-ray analysis suggests it is similar to fuchsite. All of these micas with small $2V$ show wavy extinction and either consist of subparallel aggregates or have a somewhat disordered structure, possibly due to shearing movements. As shown in Table 6 indices of refraction are similar to those of fuchsite rather than mariposite, and it seems best to classify them as fuchsites, until such time as analyses show their true chemical character. Thus, while an appreciable optic angle (36°) is diagnostic of fuchsite, a smaller optic angle ($<20°$) does not necessarily establish a chrome-mica as mariposite.

TABLE 5. FUCHSITE: OPTICAL PROPERTIES

No. and Locality	$\%Cr_2O_3$	2E	2V	Indices			biref.	
				α	β	γ		
1 Westland, N. Z. Hutton (1940)	0.27		46°	1.5590	1.5930	1.5973	.038	*G.*=2.821
2 Belgium Klement (1888)	0.84							*G.*=2.819
3 Mashishimala, S. A. Partridge (1937)	0.85		35°	1.563	1.596	1.598	.035	$r>v$ strong, $X<Y<Z$
4 New Consort Mine, S. A. Partridge (1937)	tr.		36°		1.596	1.600		
5 Binnenthal, Switzerland	0.87							
6 Montgomery Co., Md. Gill (1899)	2.03	68° Na 71° Li						$r>v$
7 Aird Is., L. Huron Chester (1887)	3.09							
8 Sysersk, Urals Damour (1882)	3.51	67° gr. 69° yel. 72° red.						$r>v$ *G.*=2.88
9 Zillerthal, Austria HM 11568, Whitmore	(3.95)	53°	32°		1.604	1.608	.037	
10 Zillerthal, Austria HM 90949, Hawley					1.598	1.606		
11 Otago, N. Z. Hutton (1942)	4.60		37°	1.5695	1.6040	1.6115	.042	*G.*=2.88
12 Pointe du Bois, Manitoba	4.81		36°		1.602	1.603	.038	$r>v$ *G.*=2.88
Unanalyzed materials								
13 Credo Porcupine Ontario, Whitmore	tr.	63°	38°		1.598	1.603	.039	
14 Trabau, Silesia HM 90947, Whitmore		56	34		1.595	1.601	.037	
15 Brunswick, Maine HM 11572, Whitmore		57	35		1.596	1.601	.036	
16 Plymouth, Vermont HM 90940, Whitmore		61	37		1.597	1.603	.038	
17 Pfitsch, Tyrol HM 90948, Whitmore		54	33		1.597	1.602	.035	
18 Rendek, Hungary Szad-Kardoss		59	36		1.602	1.609	.0355	$r>v$
19 Velem, Hungary Szad-Kardoss			30-38				.0357	

Mariposite

Optical data available on mariposites and determined on two new specimens are given in Table 7. One specimen from California is described by Knopf (1929) as uniaxial. That from Washington, noted by Larsen (1934), $2V=40°$, is exceptional compared with values of 12°–14° for mari-

TABLE 6. UNCERTAIN Cr-MICAS WITH SMALL OPTIC ANGLES BUT INDICES OF FUCHSITE

Locality	Optic Angle 2V	Indices			Biref.
		α	β	γ	
1. Hollinger Mine, Ontario	v. small	1.561	1.594	1.596	.035
2. Plymouth, Vermont HM 90940	v. small	1.568	1.598	1.599	.031
3. Kerr Addison Mine, Ontario	16°–19°	1.561	1.597	1.601	.040

posites from the Rawhide and Hollinger mines. While some of the indices for mariposites overlap those of high-Cr fuchsites, they are somewhat greater than for fuchsites of comparable tenor of Cr_2O_3, and in some cases even exceed those with large amounts. Colour is described by Knopf as emerald green for some samples, apple green for others and white for one sample which lacks any Cr_2O_3. Mariposite from the Rawhide Mine (HM 86911) shows $X=$ deep blue green, and $Y=Z$ paler green. Dispersion has not been determined. In view of the discovery that some apparent fuchsites, listed in Table 6, have also small optic angles, and since the differences in indices of refraction of fuchsites and mariposites are slight, it is apparent that the optical distinction of mariposite, particularly when very fine grained, must be made with considerable care.

TABLE 7. MARIPOSITE: OPTICAL PROPERTIES

No. and Locality	% Cr_2O_3	2V	Indices			biref.	Author
			α	β	γ		
1 Mother Lode, Cal.	nil						
2 Mother Lode, Cal.	0.18	0			1.60		Knopf (1929)
3 Mother Lode, Cal.	+test	($2E=36°$)	1.56 to 1.58		1.61 to 1.63		Knopf (1924) includes Rawhide Mine
4 Rawhide Mine, Cal. HM86911	+test	12°	1.565	1.601	1.605		Hawley
5 Ross Mine, Ont.	0.78	very small		1.624			Moorehouse in Moore (1936)
6 Washington		40°			1.63		Larsen (1934)
7 Hollinger Mines	+test	14°		1.617	1.621	.033	Whitmore

SUMMARY

By means of *x*-ray, chemical, and optical studies fuchsites with a range in composition of 0.27%–4.81% Cr_2O_3 are identified as chromiferous muscovites, for which the varietal term *chromian muscovite* is preferred to *fuchsite*. Well formed flakes give an average $2V = 36°$ and an average $\beta = 1.598$. Finer grained material, either sub-parallel growths or strained crystals show smaller $2V$ ($<20°$) but indices of other fuchsites.

Mariposite, apparently less plentiful, and less well studied, conforms, chemically with phengite and is regarded as a chromiferous variety of this mica. With one exception $2V$ is always small while indices are higher than for fuchsites of similar Cr_2O_3 content, and in some cases are even higher than for Cr_2O_3-rich fuchsites. Considerable care is thus needed in distinguishing it with certainty.

OCCURRENCE AND ORIGIN OF CHROME-MICAS

OCCURRENCE AND ASSOCIATION

As far as can be determined, chrome-micas, much like sericite, have invariably been formed either by metasomatic processes or deposited directly with other minerals in veins. Minerals associated with them suggest they were formed under conditions ranging from moderate to fairly high temperatures and pressures, and give rise to a tentative three-fold classification, in all of which fine rutile is commonly present.

1. With ankerite, quartz, sulfides and gold.
2. With biotite and actinolite.
3. With corundum, biotite, cyanite.

Of these the first association is by far the most common, and is that which prevails in the numerous deposits throughout the Ontario and Quebec portions of the Canadian pre-Cambrian shield, as well as in the Mother Lode district of California, and in Western Australia. In the first area either fuchsite or mariposite may be present but nowhere is there record of both being found together in a single specimen, nor do descriptions of occurrence indicate any reason for the one forming in preference to the other.

Type 1. Ankerite-quartz-sulfide-gold association

The most notable occurrences of chrome-micas in Canada are in the Larder Lake and Porcupine Districts of Ontario, described by Wilson (1909), Cooke (1922) and Burrows (1915 and 1924). Others have been noted by Thomson (1935) in Lake of the Woods district, Ontario, by

Hawley (1929) in the Rainy River District, and by several authors along faults zones to the east of Larder Lake in Quebec. Other outstanding deposits of this type are in the southern part of the Mother Lode Deposit (mariposite, Knopf 1929), and in Western Australia (fuchsite, Simpson 1935).

In all of these the mica is developed in rusty weathering carbonatized and pyritized zones which replace a great variety of rocks, most of which have been previously rendered more or less schistose. In some, the chrome-mica carbonate zones appear to have suffered further shearing and in all cases quartz stock works penetrate the zones, in a highly irregular manner.

In recent years such zones have come to be regarded as marking either large fault zones or their close proximity, east and west of Kirkland Lake, Ontario, and in adjacent parts of northwestern Quebec.

Rock types so replaced consist of various schists, lavas, commonly andesitic to basaltic; tuffs and agglomerates; sediments, including conglomerate, quartzite, greywacke, and slate, and intrusives particularly siliceous quartz porphyries as in the Porcupine District, diorite porphyry, and even pegmatitic dykes as at Larder Lake and Pointe du Bois, Manitoba. Three occurrences have been noted in peridotites or serpentinized ultrabasic intrusions, namely fuchsite (?) in Deloro Twp., Ontario (Burrows, 1915), mariposite in a section of the Mother Lode deposit, California (Knopf, 1929) where its distribution is restricted to that part of the lode occurring in serpentine, and fuchsite in pyritiferous quartz cutting peridotite at L. Saganaga, Ontario (Whitmore). All descriptions are unanimous in ascribing a replacement or hydrothermal origin to the mica.

Detailed studies of the paragenesis of such deposits, as might be expected from their complex history and as detailed closely by Cooke (1922), show a somewhat variable position for chrome micas. At Larder Lake, Cooke notes that dolomite is cut by numerous fractures which are filled in many places by quartz, calcite or other carbonates, and locally with albite. Along these veins the dolomite is altered or replaced by fuchsite which gradually fades into gray dolomite away from the vein. The veins themselves where they narrow down to a hair-line are filled with fuchsite. From his studies Cooke concludes there was a progressive change in the carbonate-rich solutions, with a decrease first in Mg and Fe and later of Ca, with an increase in SiO_2, Cr, and sulfur.

Examination of gold-bearing specimens from the Hollinger and McIntyre mines by Whitmore show chrome-mica intergrown with ankerite as a fine felt. It replaces the carbonate, rounded remnants of which are left. Though pyrite in many schistose specimens appears to replace chrome-mica as it does other schistose minerals, veinlets containing mariposite, some containing gold, some containing both minerals occur cutting quartz. Relations between gold and mariposite are conflicting and suggest overlapping or contemporaneity. In a number of instances gold occurs on small spurs jutting out from and is interrupted by veins of mariposite. In other cases veins of gold cut squarely across others of mariposite.

Specimens from the Credo Porcupine (Arcadia) Mine indicate early quartz was much fractured and replaced by a series of carbonate veinlets, and fuchsite was introduced after ferruginous carbonates but before later quartz-calcite veins which cut the mica. This suggests that Cr was being carried contemporaneously with iron and magnesium in CO_2-rich vein fluids and when deposition of iron either as carbonates or pyrite was completed, so was that of Cr.

On the other hand Moore (1936) notes that at the Ross Mine mariposite was formed at an early stage in the mineralization and is cut by stringers of quartz and ankerite and is impregnated with auriferous pyrite. At Pointe du Bois, Manitoba, Spence (1930) described mica schist as replaced by fuchsite and cut by later quartz-carbonate veins, while in the Mother Lode deposits of California Knopf indicates that the mariposite-ankerite masses are traversed by a network of veinlets of coarse, milky quartz.

That chromium was present in the hydrothermal solutions responsible for these complex replacement deposits during the deposition of many, if not most, of the minerals is supported by spectrographic examination of ore and gangue minerals from the Hollinger mine. Samples of ankerite, quartz, scheelite, chalcopyrite, gold and petzite from specimens in which no chrome-mica was visible, were tested, and all but the telluride yielded traces of chromium. Though the possibility of natural contamination cannot be denied, the results are certainly suggestive.

Type 2. Fuchsite with biotite or actinolite

This type is represented solely by three fuchsite specimens from the Zillerthal, Tyrol, HM 11568, 90949, 86918. The first consists of fine-grained, brilliant green fuchsite which forms a groundmass for randomly oriented books of biotite with a diameter of about 5 mm. The second is intergrown with both biotite and actinolite, and the third with biotite and quartz. Other specimens from the Tyrol contain fuchsite in dolomite resembling Type 1, but those with biotite or actinolite cannot but indicate somewhat higher conditions of temperature and pressure than likely existed during the development of the carbonate type. Unfortunately further information on these is not available to the writers.

It is possible that an occurrence at the Boliden Deposit, Sweden, (Ödman, 1941) belongs to this type. Here the green mica surrounds a lamprophyric dyke, in narrow zones, which become prominent as the dyke peters out. Where the dyke ends the green mica "follows on as an independent dyke for several meters."

Type 3. Fuchsite with corundum and cyanite

Two occurrences of fuchsite have been described with associated corundum and one with corundum and cyanite. Hutton (1940) describes fuchsite as bright green scales in corundum-bearing schist from Whitcombe Valley, Mikonui, Westland New Zealand. In the northeastern Transvaal, Partridge (1937) describes fuchsite from Mashishimala as surrounding rudely lenticular bodies of corundum-bearing rock in hornblendite near its contact with granite. The mica is intergrown in various to equal proportions with cyanite, rutile, ruby corundum, biotite and plagioclase. The reddish brown rutile shows spectroscopic traces of Cr. Though in neither case is a detailed paragenesis available, these associations of fuchsite suggest its formation under still higher temperature and pressure conditions than in types 1 and 2.

GENESIS

As a product of hydrothermal metasomatism and possibly also as a true vein mineral, chrome mica may obviously owe some of its constituents to the original rocks which it replaces or in which it is found as vein fillings. On the other hand, keeping in mind the great variety of rock types in which it occurs, and the fact that no clear cut case of pseudomorphism, as of sericite after feldspar, has been cited, it is possible that most of its constituents and particularly the chromium, have had their origin in solutions derived from some magmatic source. Since only the chromium is at all distinctive we may consider the views held with respect to it.

Chromium derived from replaced rocks

As indicated above only three cases have been found where chrome-micas occur in ultrabasic rocks or their serpentinized equivalents. The close spatial relations of mariposite in the Mother Lode, and of fuchsite in one example in the Porcupine District, led Knopf and Burrows, respectively, to the inference that the chromium had its origin in these rocks, and it would obviously be difficult to prove otherwise. We may note however, that arguments by Sampson (1929) and Ross (1929) point to the fact that chromium in chromite of ultrabasic intrusives is not always indigenous in such rocks and may have been introduced as *late* chromite by hydrothermal solutions.

Chromium derived from magmatic solutions

The great majority of occurrences of chrome-micas suggest strongly a deriviation in part from hydrothermal solutions arising from magmas. In only one case of this type cited by Hutton (1942), is fuchsite considered the result of "chromium metasomatism of quartz—feldspathic schists by emanations from deep-seated ultrabasic intrusives." One example has already been noted (Ödman) where chrome mica is closely related to a lamprophyre dyke but the mineralization at Boliden is attributed to the Revsund granite outcropping south of the mine. In all others the solutions are attributed to cooling siliceous magmas ranging from pegmatite quartz-porphyry to granite.

Two occurrences in S. E. Manitoba show fuchsite associated with pegmatite. According to Stanton[3] fuchsite occurs in pegmatite zones in the granite near the Poundmaker vein which is also reported to contain chrome mica. The Pointe du Bois fuchsite is developed in mica schist along a pegmatite dyke and has associated with it chromite, some quartz and dark red rutile.

In the Larder Lake district Cooke (1922) has noted spatial relations between the chrome-mica-carbonate alteration and pegmatitic dykes (McGarry Twp.) and quartz porphyry (McVittie Twp.), and in the latter case considers the presence of carbonates in a replaced fragment of country rock within a dyke, evidence that the solutions came from the dyke itself. After noting the absence of this alteration adjacent to red syenite porphyries, syenite and diorite of the Kirkland Lake district, he concludes that wet magmas of the type supplying pegmatite, quartz porphyry and abundant quartz veins were the source. Jenny (1941) at the Omega mine in this district, attributes the solutions which caused the carbonate alteration to the same magma that produced the intrusives other than granite, and that they were introduced soon after the pegmatites.

In the Porcupine district, while many such carbonate zones appear spatially related to intrusive quartz-porphyries, some of the porphyry bodies themselves have been extensively carbonated, as at Preston East Dome Mines, and locally chrome micas are developed in or adjacent to them. The alteration is thus clearly later than some of the porphyries of this district, but since Gustafson (1945) has indicated at least two and possibly three ages of porphyry in the district it is perhaps premature

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[3] Stanton, M. S., Personal communication.

to say that the alteration is younger than all of them. As indicated in the study of the Hollinger ores, a good case may be made for a direct relation between the ore-bearing solutions and the earlier or contemporaneous deposition of ankerite and chrome-mica, whatever their source. Viewing the complex alterations and mineralization of the area as a whole, there is no reason to depart from the orthodox view that the source lay in some cooling siliceous magma at depth.

It is to Partridge (1937) that we are indebted for a method of attack on the source rocks of the chrome micas (and ores which may be associated) as well as for an excellent case of their relation to granite intrusives. In both the Mashishimala and New Consort Mine occurrences of chrome mica he notes the close relation to granite contacts. Spectroscopic examination of the various minerals in many granite occurrences throughout north and northeastern Transvaal has shown traces of Cr in all.

Accordingly it may be concluded that, while locally chromiferous ultrabasic rocks may contribute Cr to the formation of chrome micas, the great majority of cases favour its derivation, as well as that of associated ore minerals, from a siliceous magmatic source. A careful spectroscopic study of the constituents of nearby acidic intrusives may aid in relating these minerals to their actual source. Such a study should be of considerable benefit where porphyries and granites of different ages may be present.

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