IRON-RICH AMESITE FROM THE LAKE ASBESTOS MINE, BLACK LAKE, QUEBEC

MEHMET FEVZI TANER* AND ROGER LAURENT

Département de Géologie, Université Laval, Québec, Québec G1K 7P4

ABSTRACT

Iron-rich amesite is found in a metasomatically altered granite sheet 20 to 40 cm thick emplaced in serpentinite of the Thetford Mines ophiolite complex at the Lake Asbestos mine (46°01′N, 71°22′W) in the Quebec Appalachians. The amesite is associated with a rodingite assemblage (grossular + calcite ± diopside ± clinozoisite) that has replaced the primary minerals of the granite. The Quebec amesite occurs as subhedral grains 200 to 600 μm in diameter that have a tabular habit. It is optically positive with a small $2V$, α 1.612, γ 1.630, ($\gamma - \alpha = 0.018$). Its structural formula, calculated from electron-microprobe data, is: $(Mg_{1.1}Fe_{0.9}Al_{0.9})(Al_{0.9}Si_{1.0})O_5(OH)_{3.7}$. X-ray powder-diffraction data yield d values that are systematically greater than those of amesite from Chester, Massachusetts, probably because of the partial replacement of Mg by Fe. The calculated unit-cell parameters are: a 5.385(6), b 9.291(5), c 14.124(16) Å and α 90.02(11)°, β 90.42(12)° and γ 89.96(8)°. To our knowledge, this is the first specimen of iron-rich amesite to be described. It formed during hydrothermal alteration of granite in serpentinite at the same low P–T conditions that prevailed during the formation of the rodingite suite and the chrysotile asbestos in the serpentinite.

Keywords: amesite, rodingite, ophiolitic complex, Thetford Mines, Quebec.

SOMMAIRE

On trouve une amésite riche en fer dans une écaille de 20 à 40 cm d'épaisseur de granite métasomatiquement altéré à la mine du lac d'Amiante (46°01′N, 71°22′W). Ce granite a été mis en place dans la serpentinite du complexe ophiolitique de Thetford Mines. L'amésite est associée à un assemblage rodingitique (grossulaire + calcite ± diopside ± clinozoisite) qui remplace les minéraux primaires du granite. L'amésite québécoise apparaît en grains subidiomorphes à faciès tabulaire de 200 à 600 m de diamètre. Elle est optiquement positive avec faible $2V$ et α 1.612, γ 1.630 ($\gamma - \alpha = 0.018$). Sa formule structurale est calculée à partir des données de la microsonde: $(Mg_{1.1}Fe_{0.9}Al_{0.9})(Al_{0.9}Si_{1.0})O_5(OH)_{3.7}$. Les données par diffraction des rayons X (méthode des poudres) indiquent que les espacements d sont systématiquement plus grands pour l'amésite du lac d'Amiante que pour celle de Chester, Massachusetts, ce qui est probablement dû au remplacement partiel de Mg par Fe. La maille élémentaire a pour paramètres calculés: a 5.385(6), b 9.291(5), c 14.124(16) Å,

α 90.02(11)°, β 90.42(12)°, γ 89.96(8)°. A notre connaissance, c'est la première fois qu'on décrit une amésite riche en fer. Elle s'est formée pendant l'altération hydrothermale du granite dans la serpentinite, dans les mêmes conditions de basses pression et température qui ont présidé à la formation de la rodingite dans le granite et de l'amiante-chrysotile dans la serpentinite.

Mots-clés: amésite, rodingite, granite, complexe ophiolitique, Thetford Mines, Québec.

INTRODUCTION

Amesite is a rare hydrated aluminosilicate of magnesium in which some ferrous iron usually is found replacing magnesium. The extent of this replacement can be appreciable in some cases, so that the ideal composition of amesite is given in terms of Al_2O_3, (MgO, FeO), SiO_2 and H_2O. Amesite, with chamosite, greenalite and cronstedtite, is related chemically to the chlorite group and structurally to the serpentine and kandite group of minerals. The name *septechlorite* has been proposed for these minerals (Nelson & Roy 1958) as they are structurally characterized by serpentine-like layers with $d_{001} \simeq 7$ Å. Largely on the basis of thermal studies, Orcel (1927) and Orcel *et al.* (1950) were the first to suggest that amesite must be regarded as distinct from the main group of chlorites. According to the AIPEA (Association Internationale Pour l'Étude des Argiles) Nomenclature Committee, amesite belongs to the kaolinite–serpentine group (Bailey 1980a); this committee recommended that the names *kandite* and *septechlorite* not be used for kaolinite- and serpentine-group minerals.

We found an iron-rich variety of amesite associated with grossular, calcite and, more rarely, diopside and clinozoisite in a rodingitized body of granite enclosed within the serpentinized peridotite of the Lake Asbestos mine, at Black Lake in the Quebec Appalachians. We report here the description of this occurrence.

GEOLOGICAL SETTING

The Lake Asbestos mine is located at 46°01′N, 71°22′W in the Black Lake area near Thetford Mines (Fig. 1). The serpentinized peridotite bearing the chrysotile-asbestos ore forms the lower structural unit of the Thetford Mines ophiolite complex (Laurent 1975a). This ophiolite was tectonically emplaced
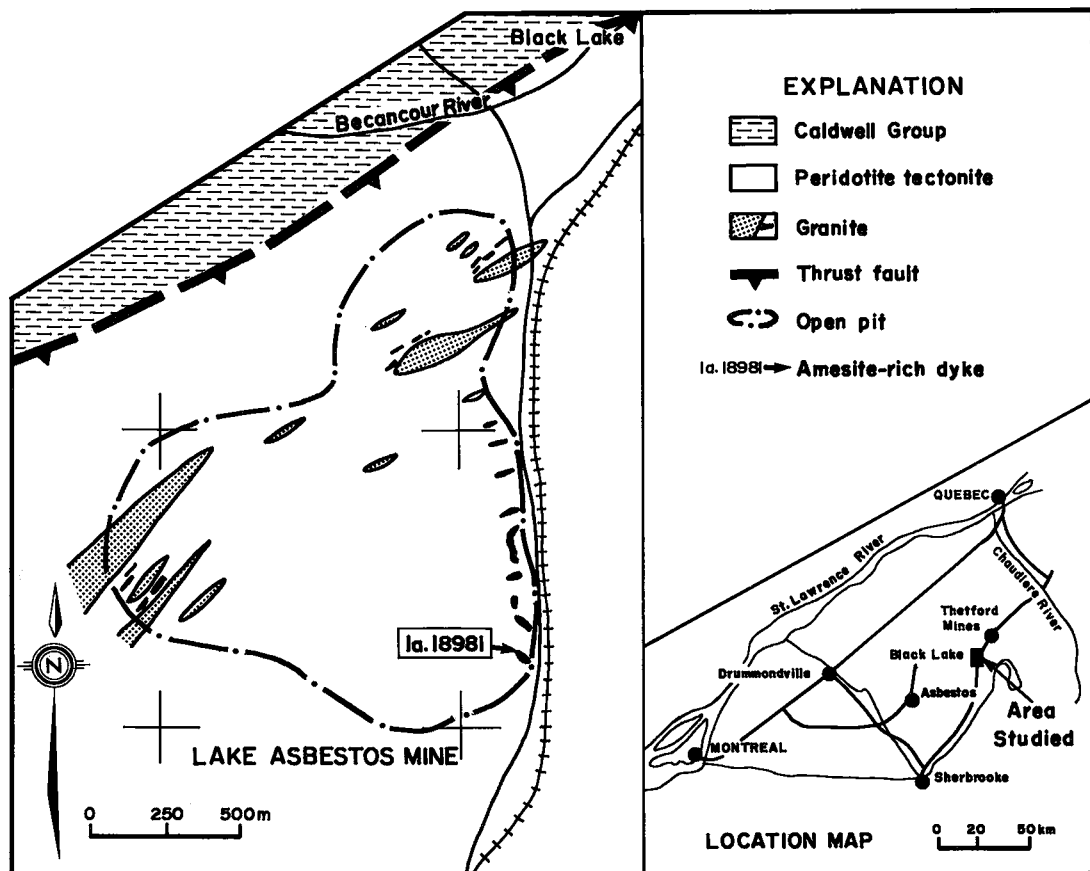
FIG. 1. Geological map of the Lake Asbestos mine at Black Lake and location of the amesite-bearing rodingite.
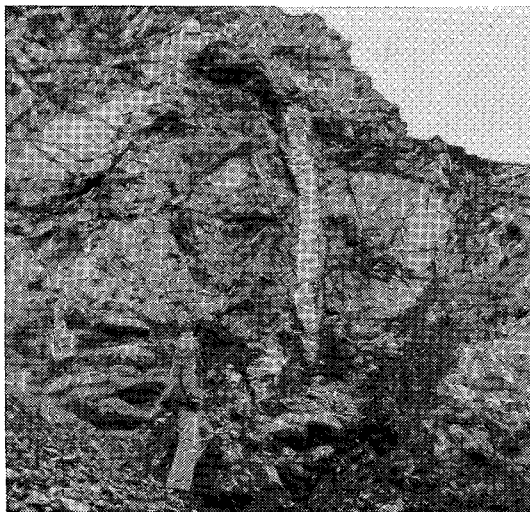

FIG. 2. View of the thin and lenticular body of amesite-bearing rodingite within the highly serpentinized harzburgite of the Lake Asbestos mine (location of outcrop given in Figure 1).

in the internal tectonic domain of the Quebec Appalachians during late Early or Early Middle Ordovician time (St-Julien & Hubert 1975). The ophiolite has been thrust over regionally metamorphosed Cambrian rocks known as the Caldwell Formation. The thrust fault dips at a high angle to the southeast. The asbestos mines are located near this tectonic contact in the peridotitic lower unit of the ophiolite.

The serpentinized peridotite of the Lake Asbestos mine (Fig. 1) is a tectonite harzburgite grading locally to dunite. The rock is strongly serpentinized along shear zones, which trend in a northeasterly direction parallel to the basal tectonic contact. Sheet-like and lenticular bodies of granite, from less than 1 m to more than 100 m thick, occur especially within the shear zones. They are deformed and hydrothermally altered (Cooke 1937, Riordon 1953, De 1972, Laurent 1975b, Laurent & Hébert 1979, Laurent 1982, Laurent et al. 1984).

The iron-rich amesite is found in a rodingite located in the southeastern corner of the Lake Asbestos mine at 3500 N and 9250 E (Fig. 1). This rodingite occupies a northwest-striking fault plane (oblique to
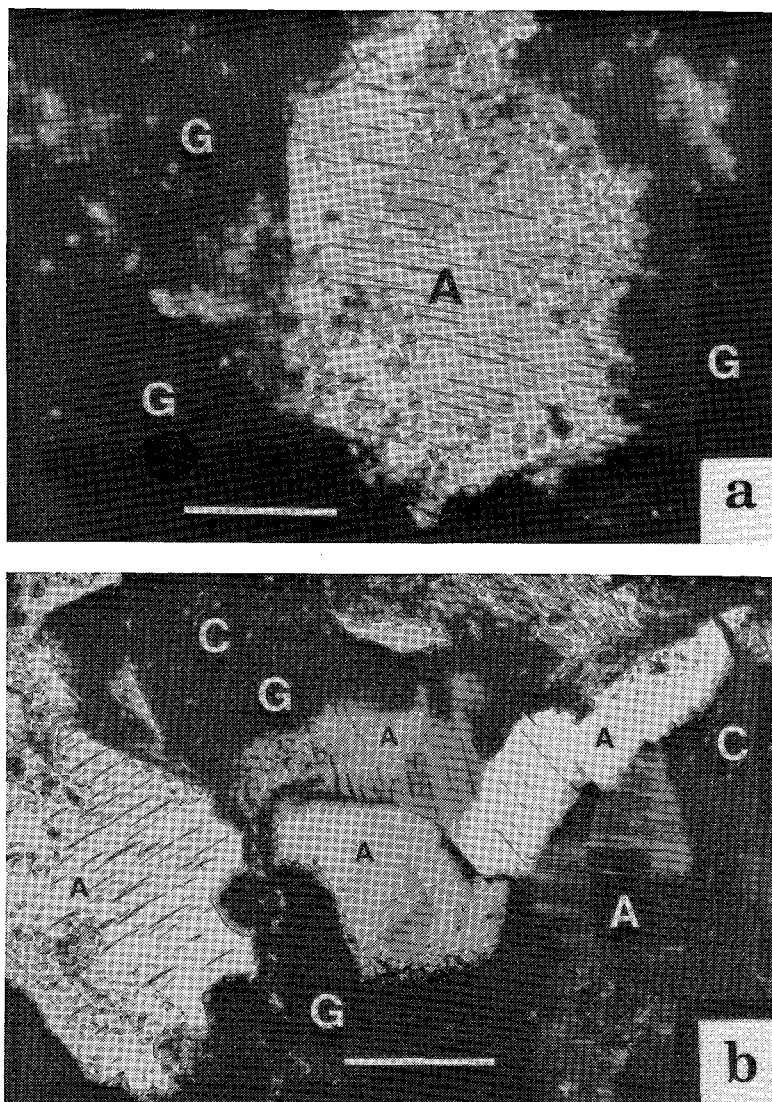
FIG. 3. Sample 1a.18981 of iron-rich amesite in thin section under crossed nicols. a. Single crystal showing a perfect cleavage parallel to (001) and sector twinning on (001), surrounded by isotropic grossular. b. Group of amesite crystals (A) with different optical orientations, showing cleavage and twinning, in association with calcite (C) and grossular (G). Bar represents 0.1 mm.

the main shear-zone) that dips subvertically within highly serpentinized harzburgite. The body of rodingite is thin and lenticular (Fig. 2), between 20 and 40 cm thick and at least 10 to 20 m long. The protolith of the rodingite was a calcalkaline biotite-rich granite similar in composition to the thick and well-preserved sheets of granite that crop out in the mine; they have been described recently by Laurent et al. (1984). In those granite sheets that are thicker than 2 m, hydrothermal alteration is limited to their margins. This alteration is thought to be associated with the episode of serpentinization that led to the development of chrysotile-asbestos in the enclosing peridotite (Laurent & Hébert 1979, Laurent 1980, Laurent et al. 1984).

PETROGRAPHY

Rodingite sample 1a. 18981 containing the iron-

TABLE 1. CHEMICAL COMPOSITION OF AMESITE-BEARING RODINGITE
          AND OF GROSSULAR

	Sample 1a.18981 Sample zone:		Grossular in contact with amesite	
	core	margin		
SiO_2	37.35	33.18		
TiO_2	0.07	0.09	SiO_2	40.20	40.27
Al_2O_3	23.38	24.71	Al_2O_3	22.04	20.65
Fe_2O_3	0.33	0.34	FeO	0.28	0.44
FeO	1.61	0.87	MnO	0.09	0.17
MgO	1.21	0.97	CaO	37.84	38.45
MnO	0.19	0.11		
CaO	34.24	34.51	TOTAL	100.45	99.97
Na_2O	–	0.31	No. of ions on the basis of 24(O)	
K_2O	0.09	0.19	Si	6.01	6.07
H_2O	1.15	4.10	Al	3.88	3.67
CO_2	0.57	0.43	Fe	0.03	0.05
TOTAL	100.27	100.23	Mn	0.01	0.02
			Ca	6.07	6.21

Sample 1a.18981: grossular (~90%), diopside, amesite, calcite,
clinozoisite, biotite (primary), chlorite, sphene, zircon
(primary), opaque phase.
Grossular analyzed by electron microprobe, rodingite analyses
by XRF and AA.

rich amesite is a white, homogeneous, fine-grained rock with a granoblastic texture. A dark margin that is a few millimetres thick, composed of chlorite and vermiculite, is present at the contact with the serpentinite. The rodingite consists of about 90% euhedral to anhedral grains of grossular 50 to 100 μm in diameter, replacing the much larger grains of feldspar. The grossular is closely associated with amesite and calcite, which occupy spaces between clusters of garnet grains (Fig. 3) and constitute less than 10% of the material. Small amounts of diopside, titanite and clinozoisite are locally associated with this rodingitic assemblage. Rare relics of primary biotite and zircon of the granite protolith can be observed. Locally, amesite appears to have grown at the expense of primary biotite and may be regarded as its replacement product. Table 1 gives the chemical composition of the amesite-bearing rodingite and of the grossular in contact with amesite.
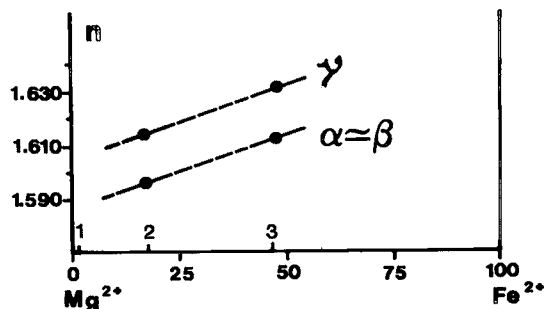
FIG. 4. Graph of the inferred relationship between the indices of refraction and the Mg:Fe ratio of amesite. 1. Saranovskoye chromite deposit, Northern Urals, USSR (Anderson & Bailey 1981). 2. Chester, Massachusetts (Gruner 1944). 3. Lake Asbestos mine (this study).

HABIT AND OPTICAL PROPERTIES

Gruner (1944) described the macroscopic and physical properties of amesite. Because of the small size of the Quebec crystals, our observations of the iron-rich amesite are limited to their microscopic features.

The iron-rich amesite occurs as groups of euhedral to anhedral crystals of tabular habit, 200 to 600 μm wide and 50 to 100 μm thick, occupying the interstices between clusters of grossular grains. The amesite crystals have a perfect cleavage parallel to {001} typical of phyllosilicates, and display sector twinning on (001) as well as hourglass texture (Fig. 3a, b). The amesite is biaxial positive, with a $2V$ of about 20° and positive elongation. It has weak dispersion, $r < v$.

Indices of refraction were measured with immersion oils calibrated with a refractometer: α 1.612, γ 1.630 ($\pm$ 0.002), $\alpha - \gamma$ 0.018. The small crystal-size of our samples has allowed us to measure only the maximum and the minimum indices. Because of the very small $2V$ angle observed and the pseudo-hexagonal symmetry of the crystals, β has been considered equal to α. Its ideal space-group is $P6_3$ (Steinfink & Brunton 1956). The indices given for the Chester amesite (Gruner 1944) are: $\alpha = \beta = 1.597$, $\gamma = 1.612$. The inferred relationship between the indices of refraction of amesite and the ratio of Fe^{2+} and Mg is summarized in Figure 4.

TABLE 2. CHEMICAL COMPOSITION OF AMESITE

	Lake Asbestos (1a.18981)		Chester, Massachusetts
	1	2	3
SiO_2	20.32	20.11	20.95
TiO_2	–	0.03	–
Al_2O_3	31.68	31.14	35.21
FeO [1*]	21.74	22.48	8.28
MnO	0.41	0.34	trace
CaO	0.43	0.47	0.58
MgO	14.88	14.59	22.88
H_2O [2*]	10.54	10.84	13.02
TOTAL	100.00	100.00	100.92

Numbers of ions on the basis of 5 (O) and 4 (OH)

Si	1.057	1.047	1.006 [3*]
Al^{iv}	0.943	0.953	0.994
Al^{vi}	0.999	0.960	0.999
Fe	0.945	0.979	0.330
Mn	0.017	0.014	–
Ca	0.023	0.025	–
Mg	1.153	1.132	1.637
OH	3.656	3.765	4.00

1. $(Mg_{1.15} Fe_{0.94} Al_{0.99})(Al_{0.94} Si_{1.05})O_5 (OH)_{3.65}$
2. $(Mg_{1.13} Fe_{0.97} Al_{0.96})(Al_{0.95} Si_{1.04})O_5 (OH)_{3.76}$
3. $(Mg_{1.63} Fe_{0.33} Al_{0.99})(Al_{0.99} Si_{1.00})O_5 (OH)_{4.00}$

1* All iron considered as FeO;
2* H_2O determined by difference;
3* Calculated by Deer et al. (1962)
(Analyst: J.-P. Tremblay)

CHEMISTRY

Two single crystals of amesite were analyzed with an ARL electron microprobe utilizing an operating voltage of 15 kV and a beam current of 0.15 μA. The standards used are orthoclase for Al and Si, and kaersutite (Kakanui hornblende, Smithsonian Institution) for Fe and Mg. Integration time was ten seconds, and four points were examined per analysis. The data were corrected using a ZAF program. H_2O was calculated by difference. Repplicate analyses of standards indicate that the determinations have a relative accuracy of $\pm$ 1 to 2% for major elements. Samples are considered to be relatively pure and homogeneous. No visible inclusions of opaque minerals were observed. Only trace amounts of grossular and calcite (Fig. 3a, b) are present, as suggested by the Ca content recorded (Table 2). However, it should be noted that the Chester amesite has the same concentration of calcium.

The oxidation state of iron was not determined; for the calculation of the structural formula, all the iron was considered to be Fe^{2+} and to substitute for Mg^{2+} in the amesite structure. Thus, the ideal structural formula of amesite becomes $[(Mg,Fe)Al](Si,Al)O_5(OH)_4$. The amesite from the Lake Asbestos mine contains about 22% FeO and 15% MgO. It is an iron-rich amesite.

Our electron-microprobe data give structural formulae (Table 2) that are consequently different in composition from that of typical magnesian amesite. For example, the structural formula of the amesite-$2H_2$ from the Saranovskoye chromite deposit, northern Urals, USSR, analyzed with the electron microprobe by Anderson & Bailey (1981), gives: $(Mg_{1.936}Al_{0.943}Fe^{2+}_{0.025}Cr_{0.074}\square_{0.022})(Si_{1.027}Al_{0.973})(OH)_4$ on the basis of seven oxygen atoms. For comparison, we give (Table 2) the composition of the Chester amesite (Gruner 1944), whose structural formula has been calculated by Deer et al. (1962). In the calculation of the structural formula of the Black Lake amesite, we have followed the procedure of Deer et al. (1962).

CRYSTALLOGRAPHY

Gruner (1944) showed that the amesite structure is based on a 1:1 type layer. Presently, amesite is classified by AIPEA Nomenclature Committee as a species of the subgroup serpentine, type 1:1 (Bailey 1980a). The unit cell of amesite was considered to be hexagonal and to contain two kaolin-type layers (Brindley et al. 1951). Steinfink & Brunton (1956) made the first detailed structural study of amesite; by assuming an ideal hexagonal symmetry of $P6_3$, they determined the cation distribution to be random. Bailey (1980b) has confirmed this finding. More recently, a triclinic symmetry was shown by

TABLE 3. X-RAY POWDER-DIFFRACTION DATA FOR AMESITE

Lake Asbestos Mine			Chester, Massachusetts [2*]		
$d_{obs}(A°)$	I_{obs}	hkl	$d(A°)$	I/10	hkl
7.06	100	002	7.06	100	002
4.63	20	020	4.54	20	02*
3.53	90	004	3.52	100	004
2.640	60	201	2.61	20	201
2.512	70	202	2.48	60	202
2.332	30	203	2.32	50	006,203
2.132	10	204	2.11	30	204
1.938R	30	205	1.925	70	205
1.761R	5	008	1.749	50	206,008
1.609	5	207	1.596	60	207
1.549	20	060	1.531	60	060
1.515R	5	062	1.495	20	062
1.472	5	208	1.461	60	208
1.418	5	064	1.401	60	064,0010
1.336	5	307	1.342	50	209
1.317R	10	262	1.304	10	262
1.290	5	263	1.276	10	263
			plus 22 lines to 0.0788		

Data on Quebec amesite obtained on a polycrystalline sample using Gandolfi 114.6 mm camera utilizing nickel-filtered CuKα X-radiation. Intensities estimated visually. [2*] PDF 9-493. *See PDF remark. R: diffraction lines showing significant differences between the calculated and observed 2θ values. The structural interpretation of the observed differences requires new work now in progress.

Anderson & Bailey (1981) to be more in keeping with the biaxial character of amesite and the intensity distribution of its diffraction lines.

The iron-rich amesite was colleced from a thin section under the microscope. The microsample, which represents a polycrystalline aggregate of several crystals of apparently pure amesite, was analyzed with a 114.6-mm Gandolfi camera using Ni-filtered CuKα X radiation at room temperature. The X-ray-diffraction data are reported in Table 3 together with the original data of Brindley et al. (1951). The comparison shows that the d values of the iron-rich amesite are systematically greater than the d values of the magnesian amesite. This reflects the substitution of Mg^{2+} by Fe^{2+}, the ionic radius of Fe^{2+} (0.71 Å) being larger than that of Mg^{2+} (0.66 Å) in six-fold coordination (Whittaker & Muntus 1970). It should also be noted that the lines at 2.733 Å and 1.995 Å in the pattern of the magnesian amesite were assigned by Brindley et al. (1951) to impurities: these correspond to the lines 2.741Å and 1.988Å in the Black Lake amesite. They probably reflect impurities also.

The refined values of the unit-cell dimensions determined by Anderson & Bailey (1981) are: a 5.307(1), b 9.195(2), c 14.068(3) Å, α 90.09(2)°, β 90.25(2)°, γ 89.96(2)°. The unit-cell parameters of the Black Lake amesite were calculated using the cell-refinement program of Appleman & Evans (1973): a 5.385(6), b 9.291(5), c 14.124(16) Å, α 90.02(11)°, β 90.42(12)° and γ 89.96(8)°; V 706.71(1.43) Å³. It is probable that the differences are due to the partial replacement of Mg by Fe.

DISCUSSION

The iron-rich amesite is closely associated with grossular and calcite. This mineral assemblage developed through metasomatism at the expense of quartz, feldspars and biotite of the granite protolith. In this occurrence, amesite may be regarded as a replacement product of the primary biotite.

The transformation of the granite into a rodingite through calcium metasomatism is a byproduct of the serpentinization of the enclosing peridotite (Laurent et al. 1984). Thus the episode of hydrothermal alteration responsible for rodingitization of the granite is also responsible for the development of the chrysotile-asbestos ore in the enclosing peridotite. It is therefore probable that the P–T conditions controlling the amesite and rodingitic paragenesis are similar to those that promoted the concomitant serpentinization. Retrograde serpentinization usually occurs at temperatures in the 200–400°C range at 1 to 5 kbar water pressure (Evans 1977). This range in temperature and pressure allows the development of both lizardite and chrysotile that make up more than 50% of the country rock at the contact with the rodingite. The amesite is thought to have formed under similar P–T conditions.

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