

CHLORITOID-PARAGONITE-PYROPHYLLITE AND STILPNOMELANE-BEARING ROCKS NEAR BLACKWATER MOUNTAIN, WESTERN ROCKY MOUNTAINS, BRITISH COLUMBIA

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ABSTRACT

Metasedimentary rocks of the Middle Cambrian Chancellor Formation near Blackwater Mountain, British Columbia, contain paragonite-chloritoid assemblages and locally contain pyrophyllite. Rocks of more mafic composition interlayered with the aluminous metasediments contain stilpnomelane-biotite. Calcite (\pm dolomite) is present in most rocks, and calcite-dolomite geothermometry suggests a metamorphic temperature near 345°C, which is consistent with the stability of pyrophyllite + quartz, at $P(\text{H}_2\text{O}) = P_{\text{total}} = 5$ kbars, that is, $310 < T < 415^\circ\text{C}$. Mineral assemblages containing paragonite + chloritoid + calcite + dolomite could have equilibrated under slightly lower temperatures or slightly different (more CO_2 -rich) composition of the fluid phase (or both) than those rocks that contain chlorite + albite + calcite + dolomite.

Keywords: metamorphism, chloritoid, pyrophyllite, stilpnomelane, $T-X(\text{CO}_2)$ diagrams, geothermobarometry, British Columbia.

SOMMAIRE

Les roches métasédimentaires de la Formation Chancellor, d'âge cambrien moyen, provenant de près de la montagne Blackwater, en Colombie-Britannique, contiennent l'assemblage de paragonite + chloritoïde avec, par endroits, de la pyrophyllite. Des roches de composition mafique, interlitées avec les métasédiments hyperalumineux, contiennent stilpnomélane + biotite. La calcite (\pm dolomite) est présente dans la plupart des roches. L'application géothermométrique de l'assemblage calcite-dolomite indique une température métamorphique d'environ 345°C, ce qui concorde avec le champ de stabilité de pyrophyllite + quartz à une valeur de $P(\text{H}_2\text{O}) = P_{\text{total}} = 5$ kbars, c'est-à-dire $310 < T < 415^\circ\text{C}$. Les assemblages contenant paragonite + chloritoïde + calcite + dolomite pourraient témoigner soit d'une température légèrement inférieure, soit d'une phase fluide légèrement enrichie en CO_2 , en comparaison des roches ayant chlorite + albite + calcite + dolomite.

(Traduit par la Rédaction)

Mots-clés: métamorphisme, chloritoïde, pyrophyllite, stilpnomélane, diagrammes $T - X(\text{CO}_2)$, géothermobarométrie, Colombie-Britannique.

INTRODUCTION

Aluminous mineral assemblages such as pyrophyllite + paragonite are useful in the estimation of peak metamorphic conditions in the lower grades of metamorphism (e.g., Zen & Thompson 1974). Unfortunately, these mineral assemblages are relatively uncommon and as yet have not been well documented in the Rocky Mountain Fold and Thrust Belt, particularly in the western Rocky Mountains, where argillaceous and carbonate rocks of Lower Paleozoic to Late Precambrian age typically show pervasive slaty cleavage. In this paper, we document the occurrence of aluminous mineral assemblages, including chloritoid-paragonite-pyrophyllite, associated with more mafic assemblages containing stilpnomelane.

Although recognized on maps as a distinct geological unit, the western part of the Rocky Mountain Fold and Thrust Belt has clear structural and metamorphic affinities with the rocks of the Omineca Crystalline Belt to the west. For example, Craw (1978) reported that Lower Paleozoic to Late Precambrian rocks of the Park Ranges, British Columbia, were metamorphosed to sillimanite-zone conditions. These rocks are in contact along the Purcell Fault with rocks of the Omineca Crystalline Belt and were once part of a contiguous metamorphic complex.

Cruickshank & Ghent (1978) reported on chloritoid-paragonite assemblages in the Late Precambrian Horsethief Creek Group, approximately 50 km west of the area described in this paper. They examined metasedimentary rocks of Late Precambrian age near Lake Louise, Alberta, but found quartz-muscovite-chlorite assemblages with no aluminous assemblages.

The Blackwater Mountain area lies approximately 50 km northwest of Golden, British Columbia (Fig. 1) and was the subject of a structural and stratigraphic study by Ferri (1984). The rocks range in age from Late Precambrian to Middle Cambrian and belong to the Miette Group, Gog Group, and Chancellor Formation (Fig. 1).

The Chancellor Formation is composed of slate, calcareous slate, argillaceous limestone, limestone, and dolomite. The aluminous assemblages occur in the basal part of the Chancellor Formation, northwest of Blackwater Mountain (Fig. 1). The lower part of the Chancellor Formation is repeated by a thrust fault near Felucca Mountain (Fig. 1); within the fault zone, spectacular veins of coarse-grained (1-5 cm)

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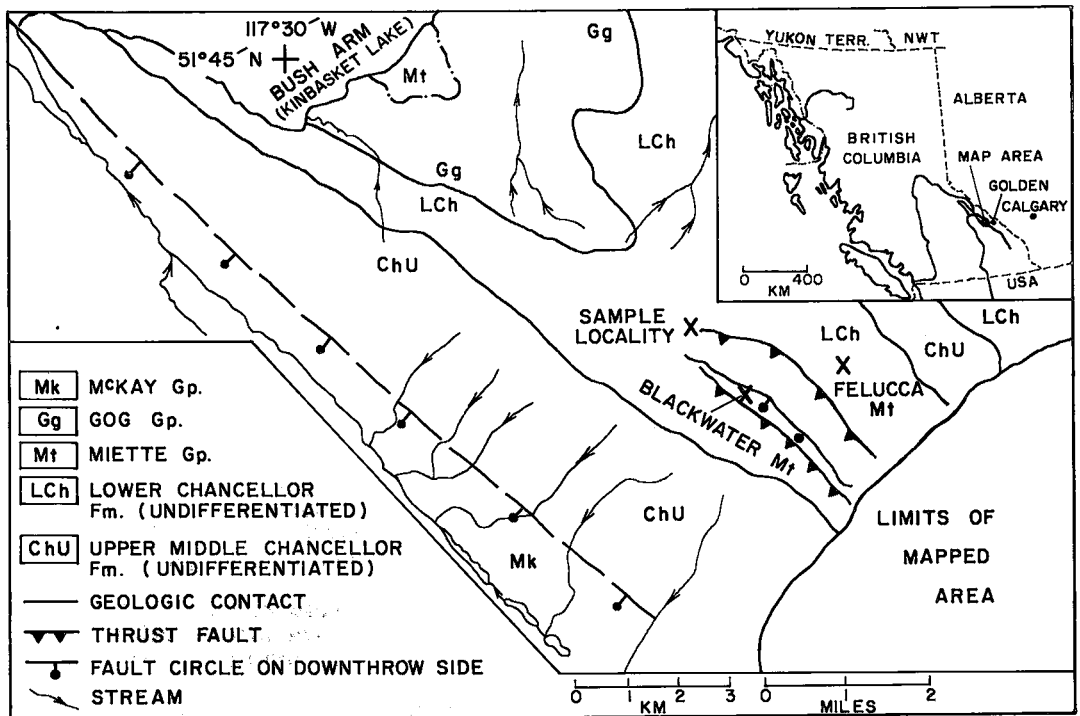


FIG. 1. Simplified geological map of the Blackwater Mountain area of British Columbia (after Ferri 1984), showing sample locations referred to in the text.

pyrophyllite occur. These veins formed after the principal phase of metamorphism.

PETROGRAPHY

The metasedimentary rocks considered in this paper contain three distinct mineral assemblages: one

TABLE 1. MINERAL ASSEMBLAGES IN ROCKS FROM BLACKWATER MOUNTAIN, BRITISH COLUMBIA

Mineral	84-FF -9	84-FF -10	84-FF -14	84-FF -16	84-FF -19	84-FF -20	F561
Cld		X	X			X	X
Dol	X	X	X			X	X
Cal		X		X	X		X
Ms		X	X			X	X
Pg		X	X			X	X
Pr1			X				X
Ch1	X			X	X		
Bt				X	X		
Stp				X	X		
Qtz	X	X	X	X	X	X	X
Pl	X			X	X		
Tur	X						
Rt			X	X	X	X	
Py			X		X		
Ilm				X			
Ttn				X			
Gr			X				

Mineral symbols (after Kretz 1983): Chd chloritoid, Dol dolomite, Cal calcite, Ms muscovite, Pg paragonite, Pr1 pyrophyllite, Ch1 chlorite, Bt biotite, Stp stilpnomelane, Qtz quartz, Pl plagioclase, Tur tourmaline, Rt rutile, Py pyrite, Ilm ilmenite, Ttn titanite, Gr graphite.

has chloritoid with paragonite and muscovite ± pyrophyllite, the second is characterized by stilpnomelane with biotite and albite, and the third lacks chloritoid or stilpnomelane but has moderately abundant colorless tourmaline (Table 1). All samples have one or two carbonate minerals and quartz.

The chloritoid-bearing rocks generally have a good foliation defined by finely intergrown muscovite and paragonite, locally outlined by graphitic material. The chloritoid occurs both as clusters of radiating prisms and as individual porphyroblasts from 0.4 to 2 mm long. Lamellar twinning and optical zoning, evident from patterns of inclusion and variable extinction under crossed polarizers, are common in chloritoid. Chloritoid is choked with fine-grained inclusions of quartz, carbonate, and opaque minerals. Some of the chloritoid is cut by veins and blebs of quartz and carbonate. Chloritoid porphyroblasts grew across the early foliation defined by oriented flakes of white mica and also across the later crenulation cleavage, suggesting that crystallization took place after deformation. Pyrophyllite is locally abundant and coarse grained in sample F561, but it is not commonly in contact with muscovite and paragonite.

The stilpnomelane-bearing samples lack foliation and contain randomly oriented bladed albite, and green stilpnomelane mainly in radiating clusters up

to 2 mm long and 0.05 mm wide (Fig. 2). Calcite, quartz and albite are generally less than 1 mm in diameter. The chlorite is very finely grained and occurs in vermiform patches up to 1 mm long. Opaque minerals (ilmenite, rutile, \pm titanite \pm pyrite) are moderately abundant.

Colorless tourmaline occurs both as inclusions in ferroan dolomite and in the quartz-chlorite matrix. Tourmaline is up to 0.5 mm long and locally occurs as aggregates of crystals. Ferroan dolomite occurs as porphyroblasts up to 4 mm long. Quartz-feldspar veins locally cut across the foliation.

MINERALOGY

Chloritoid

A representative chemical composition of chloritoid is presented in Table 2. Complete sets of analytical data are available from the Depository of Unpublished Data, CISTI, National Research Council of Canada, Ottawa, Ontario K1A 0S2. These analytical data were collected on an 8-channel ARL-SEM-Q electron-probe microanalyzer, using an online data-reduction system with Bence-Albee correction procedure (Bence & Albee 1968, Albee & Ray 1970). Although chloritoid porphyroblasts show optical zoning, chemical zoning within individual crystals is near the limits of analytical precision. Chloritoid from near Blackwater Mountain has a narrow range of Mg/(Mg + Fe) (atomic), ranging only from 0.125 to 0.153; Ti, Mn and Ca are low to below detection limits. For comparison, chloritoid from the Late Precambrian Horsethief Group in the Omineca Belt has a similar Mg/(Mg + Fe) value (0.13–0.14; Cruickshank & Ghent 1978); however, this chloritoid exhibits more pronounced zoning in Mn and Mg.

Chloritoid from the present study is nearly stoichiometric in Si and Al (Table 2) with 2.00 ± 0.03 Si atoms per formula unit and 4.00 ± 0.02 Al atoms per formula unit (Table 2). These data suggest little ferric iron in octahedral coordination. Ashworth & Evirgen (1984), Cruickshank & Ghent (1978), and Ghent *et al.* (1987) reached similar conclusions regarding the ferric iron content of chloritoid. The occurrence of ilmenite + graphite in several of the samples (Table 1) is consistent with a relatively low oxygen fugacity during metamorphism and relatively low ferric iron in chloritoid.

Pyrophyllite

A representative chemical composition of pyrophyllite is presented in Table 2. Most of the analyzed crystals contain detectable amounts of Fe, Mg, Ca, Na and K. Structural formulas calculated on the basis of 44 positive charges per formula unit suggest limited substitution of Al for Si in tetrahedral sites

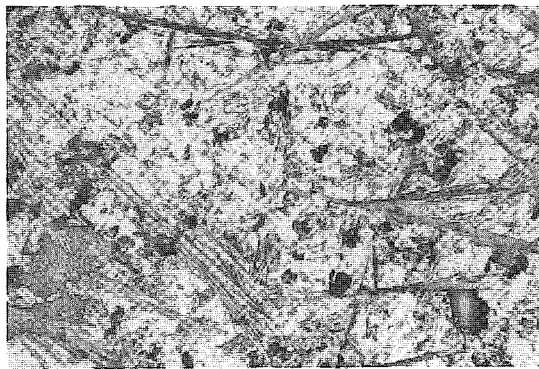


FIG. 2. Randomly oriented blades and radiating clusters of stilpnomelane in a matrix of albite, quartz, calcite, minor biotite, vermiform chlorite, and opaque phases (ilmenite and rutile). The dark, slightly curved stilpnomelane crystal at the top of the figure is 2 mm in length.

(Table 2). Deer *et al.* (1962b) suggested that there is limited substitution of Fe and Mg for Al in octahedral sites. They also suggested that Na and K may exist in the sites occupied by the same elements in muscovite and paragonite and they would compensate electrically for minor Si-for-Al substitution. This scheme would indicate solid solution between pyrophyllite and muscovite-paragonite. Presumably, Ca would play a similar role and would indicate solid solution toward margarite. Examination of the excess negative charge in the tetrahedral site, produced by Al-for-Si substitution, shows that it is much larger than the positive charge produced by the sum of the interlayer cations Na, K and Ca. One possible explanation is the substitution of small amounts of Mg and Fe into trioctahedral sites, which are normally vacant in pyrophyllite. Comparison of these results with published data in Deer *et al.* (1962b, p. 118) indicates that several of their analyzed specimens also have negative tetrahedral charges that are not simply compensated by positive charges from interlayer cations.

K-Na micas

Muscovite and paragonite have been identified by X-ray diffraction in all of the chloritoid-bearing rocks (Table 1). We were unable to obtain satisfactory electron-microprobe analyses of the coexisting micas because the grain size is clearly less than the spatial resolution of the electron microprobe. Cruickshank & Ghent (1978) also were unable to obtain electron-microprobe analyses of coexisting muscovite and paragonite because of the fine grain-size. Because the amount of "Na-phengite" type of sub-

TABLE 2. REPRESENTATIVE ELECTRON-MICROPROBE COMPOSITIONS OF MINERALS FROM BLACKWATER MT., B.C.

	F561	F561	F561	F561	84- FF-9	84- FF-9	8-4 FF-16	84- FF-16
	Cl1 ¹	Pr1	Ca1	Do1	Ch1	Tur	Stp	Bt
SiO ₂	24.14	65.89			27.89	36.67	48.33	37.34
TiO ₂	<0.02	<0.02			0.51	0.11	0.03	2.02
Al ₂ O ₃	40.82	28.41			27.76	36.41	6.03	14.06
Fe ₂ O ₃ ²		0.12						
FeO	24.40		1.37	12.20	9.06	1.72	22.45	17.06
MnO	0.06	<0.06	0.09	0.19		<0.06	0.25	0.08
MgO	2.37	0.05	0.54	12.76	24.10	10.04	11.35	14.86
CaO	<0.01	0.06	54.17	29.41	0.02	0.36	0.31	0.20
BaO						<0.11	1.16	0.41
SrO			<0.05	<0.05				
Na ₂ O		0.10			0.02	1.90	0.03	0.02
K ₂ O		0.04			<0.01	<0.01	0.74	7.95
F						<0.08	<0.09	1.08
CO ₂			44.00	44.61				
H ₂ O	7.00	5.11			10.48	11.06 ³	9.02	4.77
Total	98.79	99.78	100.17	99.17	99.84	99.27	99.70	99.85
Tot-F								99.40

	Number of Ions							
Si	2.006	7.947			5.235	5.96	8.00	5.684
IVAl		0.053			2.765	6.04	1.18	2.316
		8.000			8.000	12.00		8.000
VIAl	3.997	3.986			3.377	0.75		0.207
Ti					0.072	0.01		0.231
Fe ³⁺		0.011						
Fe ²⁺	1.695		0.038	0.335	1.422	0.23	3.11	2.172
Mn	0.004		0.003	0.005			0.03	0.010
Mg	0.293	0.009	0.027	0.625	6.743	2.37	2.80	3.372
Ca		0.008	1.933	1.035	0.004	0.06	0.05	0.033
Ba							0.08	0.024
Sr								
Na		0.023			0.007	0.58	0.01	0.006
K		0.006					0.16	1.544
F								0.520
CO ₃			2.000	2.000				
OH	4.000	4.000			16.000			3.480

1. See Table 1 for mineral abbreviations; 2. Recalculated from FeO; 3. Includes B. Ch1 formula calculated on the basis of 24 positive charges, 4 OH; Pr1 calculated on the basis of 44 positive charges, 4 OH; Ca1 and Do1 calculated on the basis of 4 positive charges, 2 CO₃; Ch1 calculated on the basis of 56 positive charges, 16 OH; Tur calculated on the basis of 16 cations without B; Stp calculated on the basis of 8 Si; Bt calculated on the basis of 44 positive charges, 4 (OH + F).

stitution is much less than the phengitic substitution in muscovite (*e.g.*, Guidotti 1984), we attempted to estimate the compositions of the micas by plotting the wt.% K₂O and Na₂O against other chemical variables. In theory, K should show a positive correlation with Mg + Fe, and a negative correlation with the number of Si atoms per formula unit and Na should show exactly the opposite relationship. These plots show a wide scatter, suggesting that the micas are inhomogeneous on the scale of the analysis, or that at least one other phase is involved. Composition of the K-Na micas can be recast into reasonable structural formulas, suggesting that the latter explanation is not the case.

Feldspar

Plagioclase has been detected in only two samples, associated with stilpnomelane-chlorite-biotite (Table 1). The plagioclase is nearly pure albite.

Biotite

Biotite occurs as light reddish brown irregular

platy crystals (~0.1–0.15 mm) in two samples (Table 1) and is locally altered to chlorite and opaque minerals. Biotite is locally in contact with stilpnomelane, but there is no evidence suggesting a reaction relationship.

Biotite has a rather low sum of interlayer cations (Ca + Ba + Na + K), between 1.46 and 1.61, suggesting the possibility of low-temperature leaching of these cations (Table 2). Compared with low-grade biotite from the Late Precambrian metasedimentary rocks of the Esplanade Range, B.C. (Ghent 1975), this biotite has higher Ti, Ba, and Mg and lower Al (Table 2).

Chlorite

Chlorite occurs in only three samples (Table 1), and some of this chlorite is clearly in reaction relationship with other Fe-Mg phases. Patches of chlorite are locally penetrated by stilpnomelane needles, suggesting a possible reaction relationship (samples 85-FF-16 and -19). Chlorite is an alteration product of biotite, but none of this chlorite has been analyzed. Chlorite in 84-FF-9 occurs as isolated microporphyroblasts and appears to be a stable member of the mineral assemblage. Chlorite from Blackwater Mountain is slightly less aluminous (Table 2) than chlorite from the Esplanade Range and Blackwater Ridge (Ghent 1975, Cruickshank & Ghent 1978).

Stilpnomelane

Stilpnomelane apparently has not been reported previously from the Canadian Rocky Mountains. This occurrence is of interest because the stilpnomelane occurs in close proximity to Al-rich mineral assemblages.

Most of the stilpnomelane is green, but color changes from green to reddish brown occur over distances of a few mm, and, in a few instances, along the length of a single crystal. Color zoning has been reported by Brown (1971) in stilpnomelane from other areas; he attributed the brown color to oxidation of iron during weathering.

Compared to compositions listed by Brown (1971), stilpnomelane from Blackwater Mountain has a higher Mg/Fe value and lower amounts of K and Mn. Stilpnomelane from Blackwater Mountain has appreciable Ba (Table 2), and some crystals have measurable F (but neither element was determined by Brown).

Tourmaline

Colorless tourmaline is present in one sample (Table 1), in which it occurs as microporphyroblasts. The microprobe composition was normalized to 16 cations, omitting B (Table 2). The normalized cations

