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MARGARITE-BEARING PELITES FROM THE WESTERN ROCKY MOUNTAINS, NORTHWEST OF GOLDEN, BRITISH COLUMBIA

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ABSTRACT

Margarite [$CaAl_2(Al_2Si_2)O_{10}(OH)_2$] has been found in five pelitic and calcic schist samples in the Solitude Range of the western Rocky Mountains, British Columbia. It occurs with muscovite, chlorite and biotite in a lepidoblastic texture and is apparently stable in the garnet zone through the kyanite zone. X-ray-diffraction (XRD) analysis of lower-grade slates failed to detect margarite. Geothermobarometry of muscovite–plagioclase–biotite–garnet assemblages suggests temperatures near 580–600°C and pressures near 7 kbar. Margarite + calcite + quartz assemblages persist to temperatures thought to be at or near the stability limit of the assemblage. In the highest-grade occurrences, margarite + plagioclase is present rather than kyanite + clinozoisite, indicating that pressures were probably less than about 7.5 kbar. Fluids that equilibrated with margarite + calcite + plagioclase + clinozoisite were of mixed H_2O–CO_2 composition.

Keywords: margarite, geothermobarometry, phase equilibria, calc-silicate minerals, metamorphosed pelites, Rocky Mountains, British Columbia.

SOMMAIRE

Nous avons réussi à identifier la margarite $CaAl_2(Al_2Si_2)O_{10}(OH)_2$ dans cinq échantillons de schiste pélitique et calcique provenant de la chaîne de la Solitude, partie occidentale des montagnes Rocheuses, en Colombie-Britannique. Ce mica coexiste avec muscovite, chlorite et biotite dans une texture lépidoblastique, et serait stable dans les zones à grenat et à kyanite. Selon une analyse par diffraction X, la margarite semble être absente des ardoises, à faible degré de métamorphisme. Une analyse géothermobarométrique de l'assemblage muscovite – plagioclase – biotite – grenat indique une température et une pression de formation d'environ 580–600°C et 7 kbar. L'assemblage margarite + calcite + quartz persiste jusqu'à environ la température limite de sa stabilité. Dans les régions soumises aux plus degrés de métamorphisme, l'assemblage margarite + plagioclase est stable plutôt que kyanite + clinozoïsite, indication que la pression était inférieure à environ 7.5 kbar. La phase fluide en équilibre avec margarite + calcite + plagioclase + clinozoïsite était un mélange de H_2O et de CO_2.

(Traduit par la Rédaction)

Mots-clés: margarite, géothermobarométrie, équilibre des phases, minéraux calco-silicatés, pélites métamorphisées, montagnes Rocheuses, Colombie-Britannique.

INTRODUCTION

Winkler (1979) noted the common occurrence of margarite in some greenschist-facies rocks. This mineral is widespread in the Alps (*e.g.*, Frey *et al.* 1982), but very few occurrences have been reported from the Canadian Cordillera (*e.g.*, Jones 1971). Margarite is of interest because it participates in equilibria with many common minerals such as plagioclase, calcite, the aluminum silicates and clinozoisite in a range of bulk compositions. This note discusses the petrology of some margarite-bearing pelites and calc-pelites from the western Rocky Mountains.

In the Solitude Range, about 100 km northwest of Golden, British Columbia, margarite was identified in five samples of two Cambrian lithostratigraphic units (Fig. 1). Margarite occurs in schists of the Mahto Formation (greenschist to middle amphibolite facies), which is the uppermost unit of the Gog Group, and in the overlying Tsar Creek unit, which is the lowermost unit of the Chancellor Group. The structural geology and stratigraphy of the area are discussed in Gal *et al.* (1989) and Gal (1989).

PETROGRAPHY

Assemblages of margarite-bearing schists are listed in Table 1, and sample locations are shown in Figure 1. In all but one sample (88LG426), margarite coexists with muscovite. Margarite was differentiated from muscovite by its slightly higher relief and lower birefringence (Fig. 2). Subsequent analyses of four of the samples by electron microprobe confirmed the presence of a Ca-rich mica. No coexisting paragonite was detected by either X-ray diffraction or electron-microprobe analysis.

The margarite occurrences range in metamorphic grade from the garnet zone to the kyanite zone, although kyanite is not present in any of the samples. X-ray-diffraction studies of sub-garnet-zone slates and phyllites failed to detect margarite.

Margarite occurs as fine plates, aligned in the early bedding-parallel schistosity, and folded by a later crenulation fabric. It appears to be have crystallized early in the metamorphic history, with muscovite, biotite, and chlorite. The peak conditions of metamorphism are considered to have occurred syn-

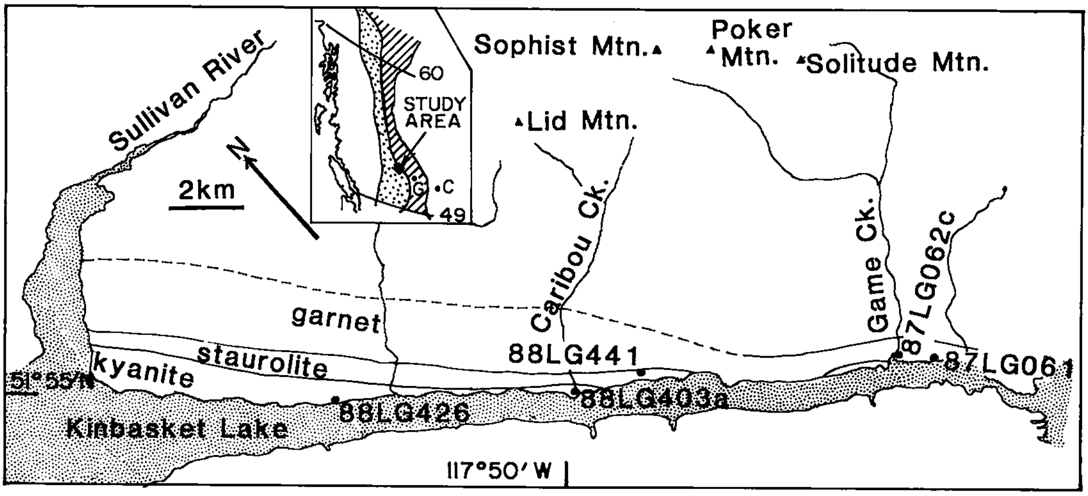

FIG. 1. Sample location map. Garnet, staurolite and kyanite zones are indicated. The dashed garnet isograd is approximately located. On inset map of British Columbia, 49 represents the forty-ninth parallel, 60, the sixtieth parallel, C, Calgary, G, Golden and V, Vancouver. Dot pattern is the Omineca Crystalline Belt, and the diagonal line pattern is the Rocky Mountain Fold and Thrust Belt. Samples were collected by LPG during 1987 and 1988, and are curated at the University of Calgary.

chronously to just after the formation of the crenulation fabric (Gal *et al.* 1989). The margarite, however, exhibits sweeping extinction across the microfolds, with no evidence of recrystallization.

The margarite is generally finer grained than the coexisting muscovite, though both phases may be intergrown on a fine scale (Fig. 2). This intimate association hampered microprobe analyses. In sample 87LG062c, late-formed (post-crenulation) muscovite appears to have partially replaced the earlier-crystallized, finer-grained muscovite + margarite.

TABLE 1. MINERAL ASSEMBLAGES OF MARGARITE-BEARING ROCKS, SOLITUDE RANGE, BRITISH COLUMBIA

Sample	Qtz	Ms	Mrg	Cal	Chl	Cld	Bt	Grt	St	Pl	Czo
87LG061	x	x	x	x	X_s		x	x		x	x
87LG062c	x	x	x	x	$X+X_s$	x		x		x	x
88LG441	x	x	x		X_s	X_i		x	x		
88LG403a	x	x	x	x	X_s		x	x	x	x	x
88LG426	x		x		x		x	x		x	x

X = present; X_s = secondary; X_i = inclusion
Abbreviations from Kretz (1983):
Qtz = quartz; Ms = muscovite; Mrg = margarite;
Cal = calcite; Chl = chlorite; Cld = chloritoid;
Bt = biotite; Grt = garnet; St = staurolite;
Pl = plagioclase; Czo = clinozoisite. Amphibole present in 87LG062c, ilmenite present in <u>all</u> samples <u>except</u> 87LG061; rutile present in 88LG426; pyrite present in 88LG441 and 88LG403a.

Except for fine-grained graphite, there are no inclusions in the margarite. Margarite was not observed as an inclusion in other minerals, except in 88LG426, where margarite needles occur in plagioclase xenoblasts. These needles have an orientation that is continuous with the external crenulations. In addition, small resorbed crystals of clinozoisite suggest the following equilibrium:

$$\text{mrg} + 2\ \text{czo} + 2\ \text{qtz} = 5\ \text{an} + H_2O \qquad (1)$$

in 88LG426, where abbreviations with lower-case letters refer to the *components,* and abbreviations that are capitalized refer to the *phase.* Mineral and phase abbreviations are listed in Table 1, except for an (= anorthite).

All samples from the Tsar Creek unit, except 88LG441, are characterized by calcite (ferrous dolomite or ankerite also is present). Sample 88LG441 is also the only sample lacking plagioclase and clinozoisite. In all samples, garnet is ubiquitous, and either chloritoid or biotite may be present. Chlorite is generally a retrograde phase after garnet and biotite, but there are samples that have apparently stable prograde chlorite (*e.g.,* 88LG426). The amphibole in 87LG062c is a ferrotschermakite (Gal, unpubl. data, 1989).

COMPOSITION OF THE MARGARITE

Analytical data on the margarite in samples 88LG426 and 88LG403a are presented in Table 2.

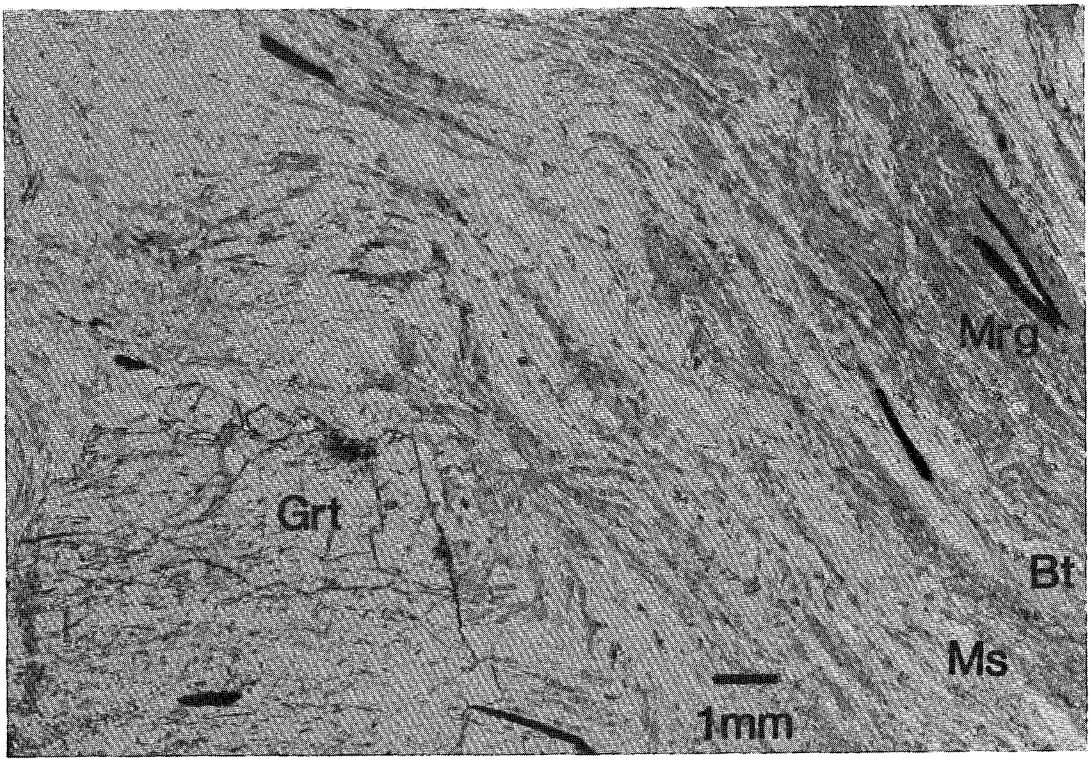

FIG. 2. Photomicrograph of margarite–muscovite schist 88LG403a. Margarite (Mrg), muscovite (Ms), biotite (Bt) and ilmenite (opaque) lie in the plane of schistosity. Garnet (Grt), plagioclase (cloudy, low-relief grains above garnet), clinozoisite (small, high-relief grains) and carbonate (upper left corner) are present. Note the higher relief and smaller grain-size of the margarite compared to muscovite.

Other samples either were not analyzed, or the fine grain-size of the muscovite–margarite intergrowths yielded poor results. Compositional data for other major phases in samples 88LG426 and 88LG403a are presented in Tables 3 and 4. Electron-microprobe data were reduced according to the principles outlined by Bence & Albee (1968). Details of the standards used and operating conditions are available from EDG.

There is considerably more sodium in crystalline solution in the margarite than in muscovite. This is analogous to the limited solution of the anorthite component in K-feldspar and is likely due to the size difference in the cations, as well as the difference in valence of the cations (Guidotti 1984).

Substitutions involving octahedrally coordinated Fe and Mg also occur, although they are somewhat less important in margarite than in muscovite. This is because such substitutions enlarge the 12-coordinated site and, as a result, the highly charged, though relatively small Ca ion is unstable in such a structure. Substitution involving Fe and Mg

TABLE 2. COMPOSITION OF MARGARITE FROM THE SOLITUDE RANGE, BRITISH COLUMBIA

sample analyses	89LG426 (31)	88LG403a (7)	89LG426 No. of atoms	88LGA03a No. of atoms
SiO_2	32.14	32.26	Si 2.183	2.188
TiO_2	0.17	0.10	Al 1.817	1.812
Al_2O_3	46.74	47.40	Sum 4.000	4.000
FeO	1.26	0.38	Al 1.925	1.977
MnO	bdl	bdl	Ti 0.009	0.005
MgO	0.93	0.20	Fe 0.072	0.022
CaO	9.72	10.72	Mg 0.094	0.020
Na_2O	1.75	1.26	Sum 2.100	2.024
K_2O	0.38	0.64	Ca 0.707	0.779
BaO	bdl	bdl	Na 0.230	0.166
Cl	bdl	bdl	K 0.033	0.055
F	0.06	0.05	Sum 0.970	1.000
H_2O	4.70	4.74		
	97.86	97.76		
-O = F	.02	.02		
Sum	97.84	97.74		

All Fe treated as ferrous. H_2O from stoichiometry. bdl = below detection limit. Numbers in parentheses are the numbers of spot analyses in the average. No. of atoms = number of atoms calculated on the basis of - 22 anionic charge.

TABLE 3. COMPOSITIONS OF BIOTITE, MUSCOVITE, CHLORITE AND GARNET FROM THE SOLITUDE RANGE, BRITISH COLUMBIA

	Bt	Bt	Ms	Chl	Grt	Grt
sample	LG426	LG403a	LG403a	LG426	LG426	LG403a
analyses	(9)	(15)	(13)	(12)	(15)	(11)
SiO_2	36.43	35.55	46.03	25.12	37.81	37.25
TiO_2	1.82	1.58	0.30	0.08	0.02	0.06
Al_2O_3	18.62	19.14	34.26	22.98	21.12	20.42
FeO	16.13	17.84	1.20	19.48	30.80	31.76
MnO	bdl	bdl	bdl	0.07	1.46	0.57
MgO	13.26	11.97	0.87	19.18	3.89	2.81
CaO	0.03	0.06	0.01	n/a	n/a	n/a
Na_2O	0.22	0.08	0.84	n/a	n/a	n/a
K_2O	8.33	8.91	9.83	bdl	n/a	n/a
BaO	bdl	0.27	0.58	n/a	n/a	n/a
Cl	bdl	bdl	bdl	n/a	n/a	n/a
F	0.35	0.49	0.06	n/a	n/a	n/a
H_2O	4.03	4.00	4.43	11.64	---	---
	99.22	99.86	98.38	98.56	100.34	100.19
-O = F	0.15	0.21	0.03	n/a		
sum	99.07	99.65	98.38	98.56	100.34	100.19
			Atoms per formula unit			
Si	2.710	2.667	3.114	2.587	2.997	3.005
Al	1.290	1.333	0.886	1.413	0.003	
Al	0.343	0.359	1.847	1.378	1.971	1.942
Ti	0.102	0.089	0.015	0.006	0.001	0.004
Fe^{2+}	1.004	1.120	0.068	1.678	2.042	2.143
Mg	1.470	1.338	0.087	2.945	0.459	0.338
Mn	bdl	bdl	bdl	0.006	0.098	0.039
Ba	bdl	0.008	0.015	n/a	n/a	n/a
Ca	0.002	0.004	0.001	n/a	0.445	0.550
Na	0.032	0.011	0.110	n/a	n/a	n/a
K.	0.790	0.852	0.848	bdl	n/a	n/a

All Fe treated as ferrous. H_2O from stoichiometry. bdl = below detection limit. n/a =not analyzed. Biotite, muscovite, and chlorite number of atoms based upon -22 anionic charge; garnet based upon -24 anionic charge. Numbers in parentheses below sample number is number of spot analyses.

TABLE 4. COMPOSITION OF PLAGIOCLASE AND CLINOZOISITE FROM THE SOLITUDE RANGE, BRITISH COLUMBIA

	plagioclase		clinozoisite	
sample	LG426	LG403a	LG426	LG403a
analyses	(19)	(10)	(12)	(10)
SiO_2	59.19	51.60	39.42	39.43
TiO_2	n/a	n/a	0.12	0.09
Al_2O_3	25.83	31.16	30.23	30.22
FeO	0.19	0.07	5.83[a]	6.02[a]
MnO	n/a	n/a	bdl	0.05
MgO	bdl	bdl	0.06	0.04
CaO	7.63	13.14	23.96	23.95
Na_2O	7.42	3.92	n/a	n/a
K_2O	0.04	0.06	n/a	n/a
H_2O	n/a	n/a	0.96	0.87
Sum	100.29	99.94	100.58	100.67
		Number of atoms		
Si	2.636	2.341	2.99	2.99
Al	1.356	1.668	0.01	0.01
Al	0.000	0.000	2.69	2.70
Fe	0.007	0.003	0.33	0.34
Ca	0.364	0.639	1.95	1.94
Na	0.640	0.344	n/a	n/a
K	0.002	0.004	n/a	n/a
sum	5.005	4.999	7.99	8.00
X_{an}	0.362	0.649		
X_{ab}	0.636	0.347		
X_{or}	0.002	0.004		
X_{ps}			0.11	0.11
a_{czo}			0.67	0.67

H_2O from stoichiometry; a = total Fe as Fe_2O_3; n/a = not analyzed; bdl = below detection limit. Numbers in parentheses are the number of spot analyses. Number of atoms calculated on the basis of -16 anionic charge for plagioclase and -25 anionic charge for epidote. X_{an} = mole fraction of anorthite; X_{ab} = mole fraction of albite; X_{or} = mole fraction of orthoclase; X_{ps} = mole fraction of pistacite; a_{czo} = activity of clinozoisite component. See text for explanation. Clinozoisite analyses carried out by M. Z. Stout.

is very minor in paragonite (Guidotti 1984). Thus, although there is considerable solution between paragonite and margarite, these two end members show considerably less substitution in the octahedrally coordinated sites compared to muscovite.

THERMODYNAMIC DATA AND ACTIVITY MODELS

Except where otherwise noted we have calculated all phase equilibria using the program PTA of Brown *et al.* (1989) and the thermodynamic data-base of Berman (1988). Thermodynamic data for annite are given by Berman (1990).

There is significant crystalline solution in margarite, chlorite, biotite, plagioclase and garnet. Activity models used for garnet and plagioclase solutions are those of Berman (1990) and Fuhrman & Lindsley (1988), respectively. The solution model for biotite is that of Indares & Martignole (1985), and that for muscovite–paragonite solutions is taken from Eugster *et al.* (1972) and Chatterjee & Froese (1975). Chlorite solution is treated as being ideal; the activity model of Chernosky *et al.* (1988) for mixing on octahedrally coordinated sites in daphnite has been used for the clinochlore end-member. The equation is $a_{cch} = [(Mg/6)/(5/6)]^5 \cdot [(Al/6)/(1/6)]$, where a_{cch} is the activity of clinochlore component in chlorite, and Mg and Al are the number of Mg and Al atoms, respectively, per formula unit. The solution model for clinozoisite–pistacite solutions is the ideal solution model of Skippen & Carmichael (1977); see also Jenkins *et al.* (1985). The equation is $a_{czo} = (1-3X_{ps})$, where a_{czo} is the ideal activity of clinozoisite component in epidote, and X_{ps} is the mole fraction of pistacite in the epidote. A simple activity-model for margarite is presented below.

The major substitution in margarite is Ca + Al ⇌ Na + Si, which reflects the crystalline solution between paragonite and margarite. Muscovite solution and Fe–Mg substitution in octahedrally coordinated sites are minor and can be ignored (Guidotti 1984; also see Table 3). An ideal coupled substitution expression for the activity of margarite would be $a_{mrg} = Ca/(Ca + Na) = X_{mrg}$, where Ca and Na are the number of Ca and Na atoms, respectively, and X_{mrg} is the mole fraction of margarite. Solution between margarite and paragonite is not ideal, and the solvus has been studied using synthesis experiments by Franz *et al.* (1976). They stated (1976, p. 308), "Altogether our experiments do not allow unequivocal conclusions for the position of the binodal curve for the paragonite–margarite solvus." They estimated that the critical point was near 600°C at a composition near mrg_{40}. They suggested that the solvus should be rather insensitive to pressure, over their experimental range of 1–6 kbar, since the molar volumes of the two mica end-members are very similar. An activity model including two Margules parameters (W_G) is required to describe solution involving a nonsymmetrical solvus (*e.g.*, Nordstrom & Munoz 1985). Because the solvus is poorly constrained and the margarite from the Solitude Range has a composition ($0.71 < X_{mrg} < 0.78$) far removed from the estimated limb of the solvus, we will use a regular solution-model, which requires only one Margules parameter. This assumption will probably overestimate the nonideal behavior of margarite-rich crystalline solutions. Consequently, we have also performed calculations in which we have assumed ideal behavior of margarite-rich crystalline solutions. These calculations should bracket the "true" solution model. If the critical temperature T_c of the solvus is known, then W_G can be estimated from:

$$T_c = W_G/2R \text{ (Nordstrom \& Munoz 1985)} \qquad (2)$$

where W_G is the Margules parameter and R is the

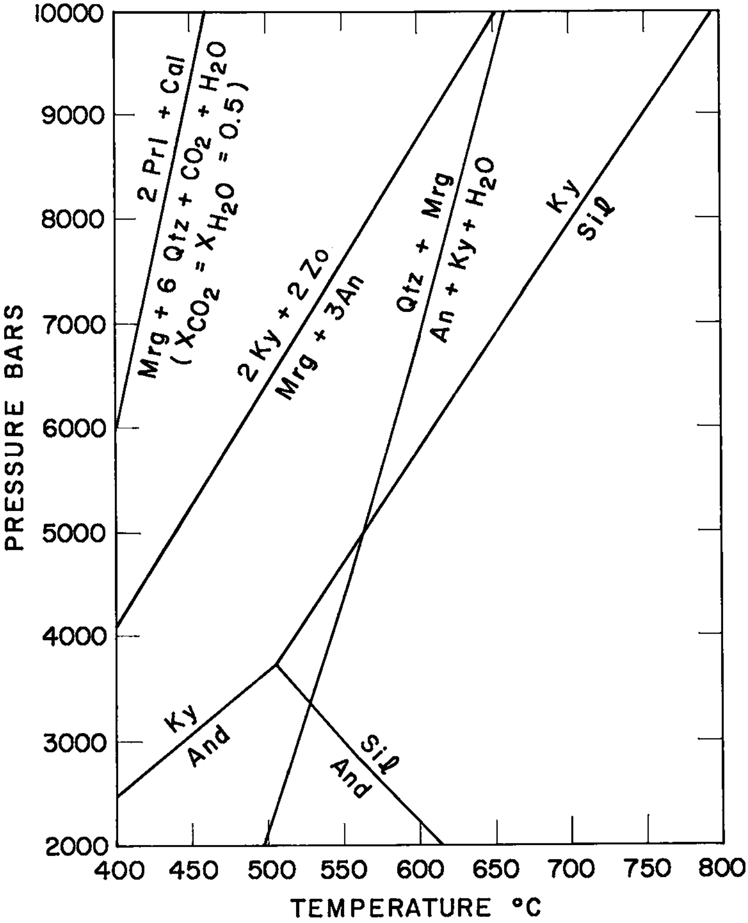

FIG. 3. P–T diagram showing representative equilibria for the system CaO–Al_2O_3–SiO_2–H_2O–CO_2. See text for methods of calculation and activity models used. Abbreviations (after Kretz 1983) are listed in Table 1; in addition, Prl = pyrophyllite, Ky = kyanite, and Sil = sillimanite.

gas constant. The critical temperature of the solvus can be conservatively estimated from the data of Franz *et al.* (1976) at about 600°C, over a pressure range of 1–6 kbar. Substitution into equation (2) yields a W_G of 14.5 kJ/mol. The expression for G_{ex} (excess Gibbs free energy of mixing) of a binary solution is:

$$G_{ex} = W_G X_1 X_2 \qquad (3)$$

(Nordstrom & Munoz 1985, p. 159), where X_1 and X_2 are the mole fractions of components 1 and 2, respectively. Then for a binary solution, in which $X_2 = 1-X_1$, we have

$$RT\ln\gamma_1 = W_G(1-X_1)^2 \qquad (4)$$

where γ_1 is the activity coefficient of component 1 (Nordstrom & Munoz 1985, p. 136). With our estimate of W_G, the activity coefficient for margarite with a composition X_{mrg} of 0.75 can be estimated from (4). From the data of Franz *et al.* (1976), at temperatures of 873, 823, and 773 K, the activity coefficients are, respectively, 1.13, 1.14, and 1.15. The activity coefficient can then be approximated as being 1.14 over the temperature range 500–600°C. The activity of margarite in crystalline solution can then be calculated from:

$$a_{mrg} = X_{mrg} \cdot 1.14 \qquad (5)$$

PHASE EQUILIBRIA INVOLVING MARGARITE

Margarite was not found in pelites below the garnet zone in the Solitude Range. In the Alps, Bucher-Nurminen *et al.* (1983) suggested that the incoming of margarite in the lower greenschist facies occurs through the reaction:

$$2\ \text{Pyr} + \text{Cal} = \text{Mrg} + 6\ \text{Qtz} + CO_2 + H_2O \qquad (6)$$

No pyrophyllite was found in the low-grade samples, though an occurrence was described by Ghent *et al.* (1989) in rocks similar to the lowest grade rocks in the Solitude Range (biotite zone), about 10 km to the southeast. Using the solution models described above for margarite, the presence of margarite + calcite + quartz assemblages suggests minimum temperatures in the range of 415–425°C at 7 kbar and $X(CO_2) = 0.5$ (Fig. 3).

The upper stability limit of margarite + quartz is constrained by the equilibrium,

$$\text{mrg} + \text{qtz} = \text{ky} + \text{an} + H_2O \qquad (7)$$

This equilibrium (7) lies at approximately 580°C and 5.9 kbar (Fig. 3). Crystalline solution of paragonite in margarite and albite in plagioclase will tend to offset one another, and calculation verifies that the temperature changes very little when we apply the solution models of margarite and plagioclase. Margarite + quartz in 88LG426, 88LG441 and 88LG403a was probably at or near its upper limit of thermal stability in the Solitude Range pelites. Thermobarometric estimates from kyanite- and staurolite-zone pelites yield maximum temperatures near 570°C, depending upon which calibration of the garnet–biotite geothermometer is used, and pressures near 6–7 kbar (Gal & Ghent, in prep.). For 88LG403a we have a muscovite–biotite–garnet–plagioclase assemblage. Applying the garnet–biotite geothermometer and the muscovite–biotite–garnet–plagioclase geobarometer (*e.g.*, Ghent & Stout 1981), we estimate a temperature near 580°C and a pressure near 7 kbar. For 88LG426, the garnet–biotite geothermometer yields about 605°C at about 7 kbar.

Bucher-Nurminen *et al.* (1983) identified critical low-pressure (margarite + anorthite) and high-pressure (kyanite + clinozoisite) stability fields based on the topology of the CASH + CO_2 system. The shrinking of the plagioclase + margarite field of stability with respect to that of kyanite + clinozoisite was estimated to occur at about 6 kbar, regardless of temperatures, but only for calcic plagioclase (> 50 mol% An). Sample 88LG403a has an average plagioclase composition of An_{65} and lacks kyanite. For the pure end-members, the equilibrium,

$$2\ \text{zo} + 2\ \text{ky} = \text{mrg} + 3\ \text{an} \qquad (8)$$

is near 6.7 kbar at 550°C, where zo is zoisite. The activity of clinozoisite is 0.67 (Table 4), and the equilibrium between clinozoisite of this composition and pure zoisite lies at about 400°C at 7.6 kbar. Zoisite is favored by higher temperature; consequently, we have used the thermodynamic data on zoisite in subsequent calculations. Crystalline solution in plagioclase, margarite and clinozoisite (zoisite) would raise the *maximum* possible pressure at which this latter assemblage is stable to about 7.5 kbar at 550°C (Fig. 3), which is consistent with the estimates made above.

We next consider other equilibria in the system $CaO\text{-}Al_2O_3\text{-}SiO_2\text{-}H_2O\text{-}CO_2$. For 88LG426 and 88LG403a we have the assemblage plagioclase – calcite – clinozoisite – margarite – quartz. This assemblage would be in equilibrium with an $H_2O\text{-}CO_2$ fluid with $X(H_2O)$ near 0.57 at 531°C and 7 kbar (88LG426), and the equilibrium would be near 541°C with $X(H_2O)$ near 0.46 (88LG403a, also see Fig. 4). These results were calculated using an ideal solution model for margarite; the effects of using the non-ideal solution model for margarite are presented in Figure 4 for sample 88LG426 as dashed lines. In this example there is very little difference between the results using the different models.

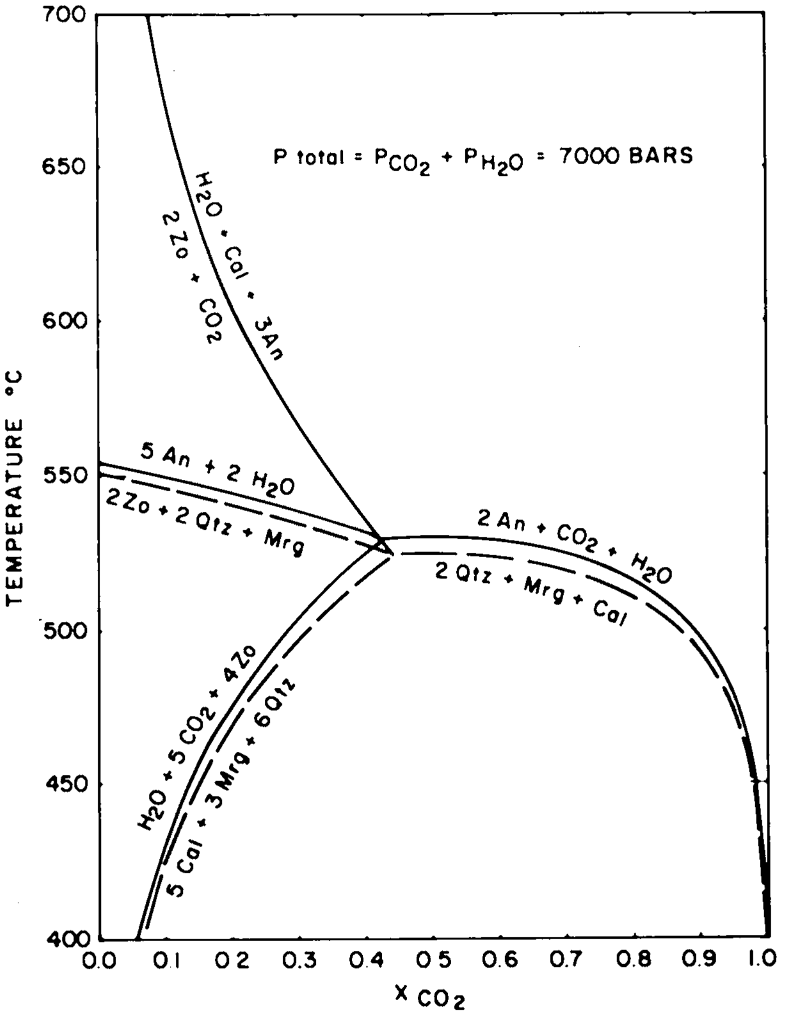

FIG. 4. T-$X(CO_2)$ diagram at P (total) = 7000 bars for equilibria in the system CaO-Al_2O_3-SiO_2-H_2O-CO_2. Abbreviations after Kretz (1983); also, see Table 1. Methods of calculation and activity models are discussed in text. Solid curves calculated with $a_{mrg} = 0.71$ (ideal solution model); dashed curves are calculated with $a_{mrg} = 0.81$ (non-ideal solution model).

In sample 88LG403a there is a large number of phases present in a thin section (Table 1). Clearly, not all of these phases can be touching and indeed not all of the phases are present in a single field of view (about 500 μm) on the electron microprobe (*e.g.*, Fig. 2). Examination of the P-T-X relations in the KFCMASH (K_2O-FeO-CaO-MgO-Al_2O_3-SiO_2-H_2O) system among the phases garnet, muscovite, plagioclase, biotite, margarite, zoisite (clinozoisite), quartz, and a fluid phase consisting of H_2O yields a number of intersections of equilibrium curves on the $P(H_2O) = P$(total) diagram. This scatter could be due to a number of factors; for example, (a) all of the phases did not equilibrate at a unique $P(H_2O) = P$(total) and T; (b) there are errors in the solution models. Adding calcite to the system and examining the equilibria on a $T - X(CO_2)$ diagram at 7 kbar also results in wide scatter of intersections of the equilibrium curves.

Sample 88LG426 also contains a large number of phases; equilibria involving chlorite, garnet, margarite, plagioclase, quartz, clinozoisite (zoisite), and an H_2O phase produces intersections near 640°C and 9 kbar. This estimate is in disagreement with estimates based upon other geothermobarometers discussed above.

CONCLUSIONS

Margarite-bearing pelites of the Solitude Range in the western Rocky Mountains equilibrated in middle greenschist to middle amphibolite facies conditions, in calcic and carbonate-absent rocks. Though the margarite-forming reaction is unknown, the margarite + calcite + quartz assemblage persisted into kyanite zone, probably in equilibrium with plagioclase and clinozoisite. *P–T* estimates based on phase equilibria in simple subsystems yielded plausible results, even with a simple solution-model for margarite. Inferred compositions of the fluid indicate that margarite (+ calcite + plagioclase + clinozoisite) equilibrated with a mixed H_2O–CO_2 fluid. These occurrences of margarite are of interest because of the abundance of other aluminous minerals in Cambrian metapelites in the Rocky Mountains (Gal 1989, Ghent *et al.* 1989, Craw 1978, Cruickshank & Ghent 1978).

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