Lawsonite and pumpellyite from the Vestgötabreen Formation in Spitsbergen

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Lawsonite and pumpellyite have been found in a pre-Silurian blueschists-eclogites complex (Vestgötabreen Formation) in Oscar II Land, central-western Spitsbergen. Lawsonite is associated with glaucophane, pumpellyite, epidote and actinolite in the matrix of metabasites from the lower unit of the Vestgötabreen Formation. In the upper unit of that formation, jadeitic pyroxenes associated with quartz, and omphacite + garnet assemblage occur respectively in metasiliceous and metabasic rocks. The Vestgötabreen Formation thus contains both lower- and higher-grade rocks of the jadeite-glaucophane type series metamorphism of Caledonian age.

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Metamorphic rocks of the high-pressure facies series in the Caledonian metamorphic belts have been described from a few areas of the Appalachian zone (Zen 1974, Trzcienski 1976, Trzcienski et al. 1984, Jameison 1977, Laird & Albee 1981) and from two localities in Britain, at Knockormal, south Ayrshire (Bloxam & Allen 1958) and on Anglesey, Wales (Gibbons 1981). Glaucophane schists on Anglesey were apparently formed during the Cambrian (Gibbons 1981) and those in Knockormal are considered to be of lower Ordovician age (Bloxam & Allen 1958, Bluck et al. 1980). High-pressure minerals in the Appalachian belt were formed during the late Ordovician (Taconic Orogeny; Lanphere & Albee 1974). In the Caledonian belt, these high-pressure metamorphisms were ascribed to the subduction during Cambrian-Silurian times (Dewey 1969, Bird & Dewey 1970).

According to Horsfield (1972), the presence of the glaucophane schists and eclogites from the Caledonian rocks in Oscar II Land, central-western Spitsbergen, had been previously noted by the Cambridge Spitsbergen Expedition of 1957. Horsfield (1972) named the complex of glaucophane-bearing rocks, epidote-actinolite greenstones and mica schists, the Vestgötabreen suite, and described the areal extension, the outline of mineral assemblage, the bulk rock chemistry and the K-Ar ages of this suite. Ohta (1979) subsequently carried out field surveys in the same area, and renamed the Vestgötabreen suite, the Vestgötabreen Formation. He subdivided it into two structural units; the lower unit of greenschists to epidote-amphibolites, and the upper unit also containing glaucophane schists and eclogites. A preliminary petrologic and geochemical description has also been presented by this author.

In 1983, the Japanese Svalbard Expedition, in co-operation with Norsk Polarinstitutt, mapped in detail the Vestgötabreen Formation and the structurally underlying, though younger, Bulltinden Formation around Motalafjella (Mt. Motala) in Oscar II Land. In this survey, an overturned unconformity was discovered at the stratigraphic base of the limestone member of the Silurian Bulltinden Formation (Ohta et al. 1983). Subsequent petrographic work has revealed that not only the upper unit, but also the lower unit of the Vestgötabreen Formation contain high-pressure minerals such as lawsonite, pumpellyite and glaucophane. These data provide concrete evidence that the high-pressure metamorphism in central-western Spitsbergen was of pre-Silurian age, as is the case in other areas of the Caledonian belt. In this paper, lithological features of the Vestgötabreen Formation and the mode of the occurrence of the high-pressure minerals in the lower unit are described. In addition, the nature of the high-pressure metamorphism of the Vestgötabreen Formation will be briefly discussed.

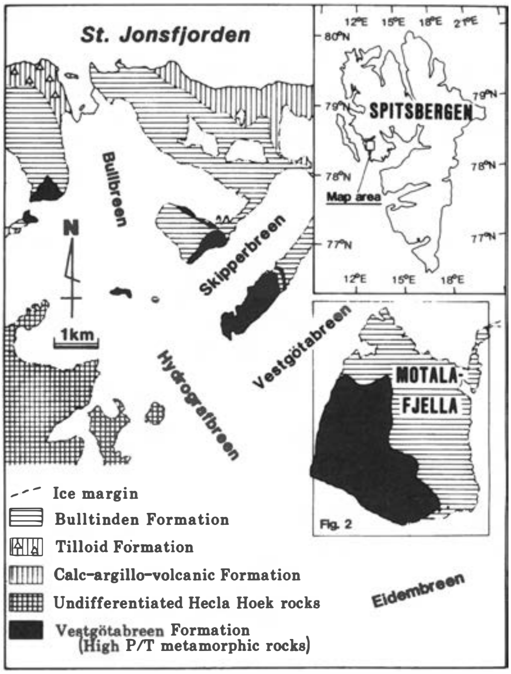

Fig. 1. Geological map of the area from St. Jonsfjorden to Motalafjella.

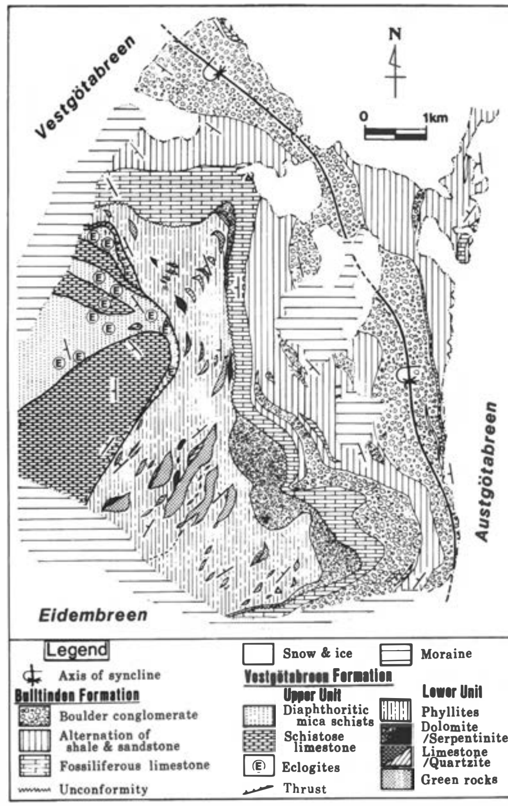

Fig. 2. Geological map around Motalafjella.

Geologic outline of Motalafjella

The Bulltinden Formation makes up roughly 2/3 of the north-eastern Motalafjella, and the Vestgötabreen Formation occupies the remainder of the massif. All planar structures, both bedding planes and schistosity, show a monoclinical structure with westward dips (Figs. 1&2).

The Bulltinden Formation consists of fossiliferous limestones, alternation of shale and sandstone, and thick polymictic boulder conglomerates. Well-preserved sedimentary structures including cross and graded bedding, as well as the spatial distribution of the above-mentioned lithologies of the Bulltinden formation, suggest a recumbent syncline (Fig. 2).

The Vestgötabreen Formation is lithologically subdivided into two units: a lower unit of mainly green, purple, and black phyllites, dolomites with subordinate amounts of metabasites (partly showing pillow structure), quartzites, and serpentinites, and an upper unit of mainly garnet-mica schists and schistose limestones with subordinate amounts of glaucophanites, eclogites, and metasiliceous rocks. The phyllites of the lower unit and the garnet-micaceous schists of the upper unit have very strongly diaphthoritic cleavages. The boundary between these two units is fairly sharp in the field, and is shown as a thrust in Fig. 2.

In the lower unit, metabasites, quartzites, dolomites and serpentinites occur as lenticular bodies surrounded by diaphthoritic phyllites. The long axis of each body varies from about 1 kilometre to decametres in length. Sketch figures of such a schistose metabasite body and quartzite lenses surrounded by black phyllite are given in Figs. 3 & 4. In the upper unit, many eclogitic and glaucophanitic bodies are surrounded by micaceous or calcareous schists. Some eclogites and glaucophanites preserve gabbroic textures. A number of glaucophanitic bodies are composed of an alternation of garnet-glaucophane schists and siliceous schists, suggesting derivation from the alternation of basaltic tuff and siliceous sedi-

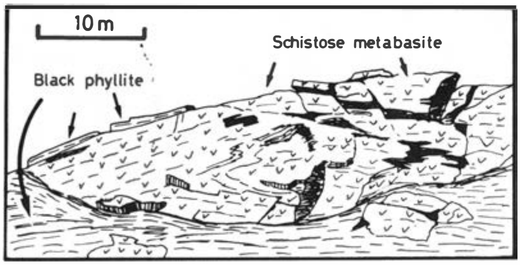

Fig. 3. Sketch figure of a metabasite body enclosed by phyllites in the lower unit of the Vestgötabreen Formation.

ments (Ohta 1979). The planar structures of the phyllites in the lower unit and the garnet-mica schists in the upper unit are usually disconcordant to those of enclosed blocks. Such a mode of occurrence of blocks can be explained in terms of the sedimentary melange (Silver & Beutner 1980).

However, the strong diaphthoritic cleavages of both phyllites and garnet-mica schists, together with the difference in the metamorphic grade or in the degree of recrystallization among blocks which occur within a local spatial extent in the same unit to be mentioned later, suggest that the Vestgötabreen Formation, as a whole, suffered more or less shearing and tectonic mixing after the peak of the regional high-pressure metamorphism. The thrust between the lower and upper units of the Vestgötabreen Formation is thought to be typical of one such shear plane. A more detailed account of the geology of Motalafjella, as well as of the new fossils found in the Bulltinden Formation, will be presented elsewhere.

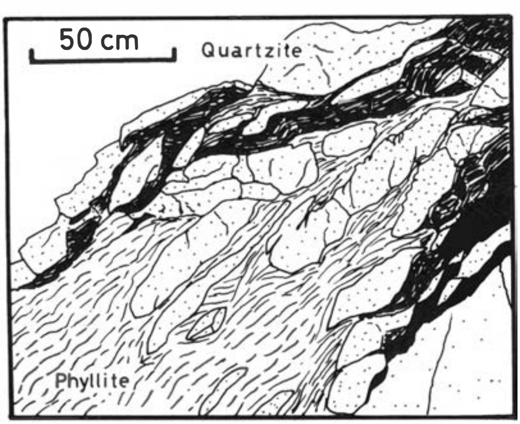

Fig. 4. Sketch figure of quartzite lenses enclosed by phyllites in the lower unit of the Vestgötabreen Formation.

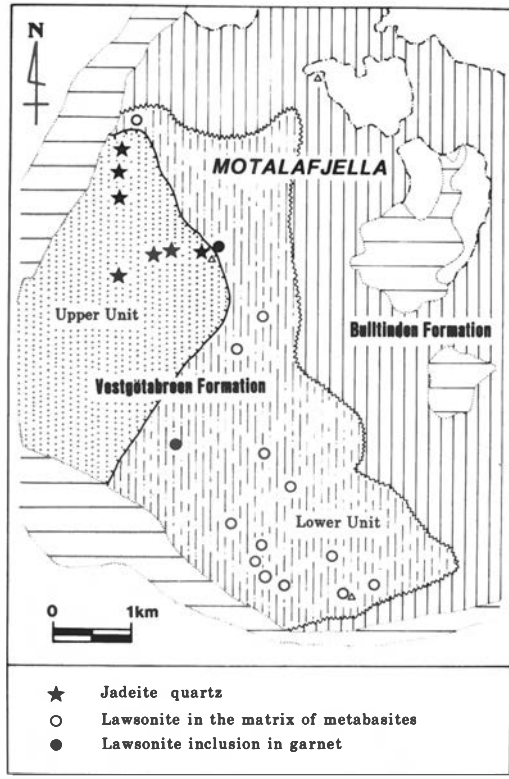

Fig. 5. Localities of jadeite- and lawsonite-bearing rocks in the Vestgötabreen Formation.

Mode of occurrence of high-pressure minerals from the lower unit of the Vestgötabreen Formation

There are no previous descriptions of the high-pressure minerals from the lower unit of the Vestgötabreen Formation. During the course of our petrologic study, lawsonite, glaucophane and pumpellyite have been found in the metabasites of the lower unit. We have also confirmed the occurrence of impure jadeite associated with quartz in siliceous schists of the upper unit as described by Kanat (1984). The localities of lawsonite- and jadeite-bearing rocks are shown in Fig. 5.

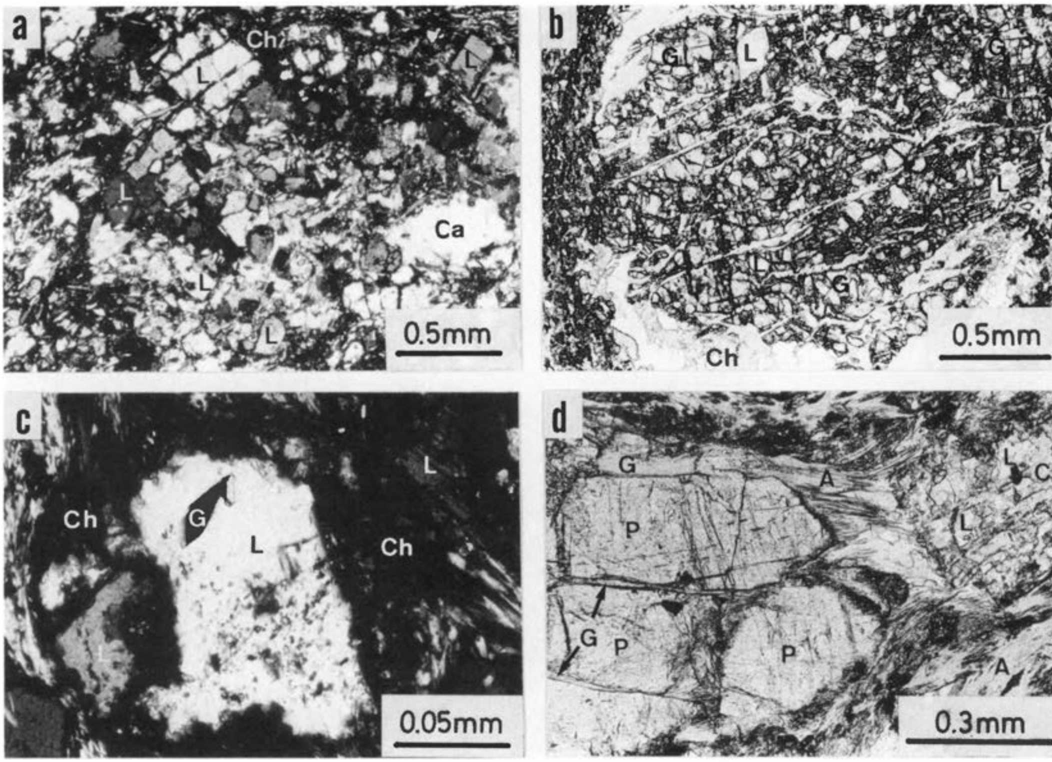

Fig. 6-a. Photomicrogaph of lawsonite(L)-bearing metabasites in the lower unit of the Vestgötabreen Formation. Rock No. 70–2. Ca = carbonate, Ch = chlorite.

Fig. 6-b. Photomicrograph of lawsonite(L) included in garnet grain(G). Chlorite(Ch) replaced garnets along cracks and margins. Lawsonite was not found in the matrix of garnet-bearing metabasites. Rock No. 83–1.

Fig. 6-c. Photomicrograph of glaucophane(G) included in lawsonite grain(L). Also visible is lawsonite surrounded by chlorite(Ch). Rock No. 150–1.

Fig. 6-d. Photomicrograph showing glaucophane(G) and actinolite(A) growing along the margins of relict augite(P). Also visible is lawsonite(L) replaced by chlorite(Ch). Rock No. 120–1.

Lawsonite

Lawsonite commonly occurs in the matrix of the metabasites in the lower unit of the Vestgötabreen Formation: epidote-actinolite greenrock of Horsfield (1972) or epidote-amphibolite of Ohta (1979). It is associated with glaucophane, pumpellyite, actinolite, epidote, chlorite, white mica, albite, quartz, sphene and opaque minerals. In general, lawsonite is euhedrally tabular shaped, up to 0.5 mm in long diameter, though it has sometimes an anhedral rounded shape (Fig. 6–a). Aggregates of anhedral lawsonite occasionally make up rounded colonies about 1 mm in diameter with carbonates and opaque minerals. Some lawsonites are replaced by epidote, and chlorite (Fig. 6–d). In the garnet-bearing metabasites, lawsonite occurs as inclusions in garnet (Fig. 6–b). All the analyzed lawsonites contain less than 1.5 wt % Fe_2O_3, (Table 1).

Sodic amphibole

In the metabasites of the lower unit, sodic amphiboles often occur as isolated irregular crystals surrounded by actinolite and chlorite in the matrix, or as small prismatic inclusions in lawsonite (Fig. 6–c). However, they also occur as prismatic crystals along the margin of relict augite (Fig. 6–

Table 1. Microprobe analyses of high-pressure minerals in the Vestgötabreen Formation.

Rock.No.	70-2	70-2	70-2	70-2	120-1	120-1	5-11
Point No.	-2	-18	-20	-29	-1	-5	-1
Mineral.	Law	Gl	Gl	Act	Pum	Pum	Jd
SiO2	37.33	56.89	57.57	54.17	36.55	36.21	58.81
TiO2			.19				
Al2O3	31.52	8.83	9.58	1.69	25.27	24.43	23.15
FeO*	1.20	13.84	13.48	12.65	6.85	5.25	1.78
MnO		.20	.17	.39	.13	.19	
MgO		8.98	8.73	16.48	1.49	2.85	.70
CaO	16.99	1.10	.41	10.55	22.84	22.51	1.09
Na2O		6.55	6.78	1.08			14.22
Total	87.04	96.39	96.91	97.01	93.13	91.44	99.75
O=	8	23**	23**	23	49	49	6***
Si	1.922	8.001	8.010	7.829	11.915	11.946	2.004
Al	1.982	1.464	1.571	0.287	9.709	9.499	0.930
Ti			0.020				
Fe3+	0.048	0.416	0.419				0.001
Fe2+		1.212	1.150	1.528	1.868	1.448	0.050
Mn		0.024	0.020	0.048	0.036	0.053	
Mg		1.883	1.811	3.550	0.724	1.402	0.036
Ca	0.971	0.166	0.061	1.633	7.978	7.957	0.040
Na		1.786	1.829	0.302			0.940
Total	4.993	14.952	14.890	15.179	32.230	32.305	4.000

Rock. No.70-2, and No.120-1 are metabasites in the lower unit.
Rock. No.5-11 is a metasiliceous rock in the upper unit.
* :Total iron as FeO.
** :Recalculated total cations in M and T sites in amphiboles as 13.000.
*** :Recalculated total cations as 4.000.
Abbreviations: Law=Lawsonite, Gl=Glaucophane, Act=Actinolite, Pum=Pumpellyite, Jd=Jadeite, O=Numbers of oxygens in the formula unit.

d). They are glaucophane, ferro-glaucophane and crossite in composition, similar to those from eclogitic rocks and glaucopanites of the upper unit, reported by Ohta (1979). The chemical compositions of sodic amphiboles are shown in Table 1.

Pumpellyite

Pumpellyite occurs only rarely as irregular aggregates of fine needles around lawsonite. The typical pale-green colour and negative elongation distinguish the pumpellyites from the other Ca-Al silicates. The chemical composition of pumpellyite is inhomogeneous even within the same aggregates (cf. Table 1).

Discussion

High-pressure metamorphism of the Vestgötabreen Formation

Horsfield (1972), Manby (1978), Hjelle et al. (1979) and Ohta (1979) suggested that the Hecla Hoek rocks, i.e., metamorphosed Caledonides, which crop out in Oscar II Land and Prins Karls

Forland in the western Spitsbergen, suffered medium-pressure metamorphism and are characterized by stilpnomelane, chloritoid, staurolite, and sillimanite. An exception to this was thought to be the upper unit of the Vestgötabreen Formation, which belongs to the high-pressure facies series, and is characterized by glaucophane, omphacite and garnet.

Although the metabasites in the lower unit of the Vestgötabreen Formation are mainly composed of actinolite, epidote and chlorite, the occurrence of minor amounts of lawsonite, glaucophane, and pumpellyite indicates that both units of the Vestgötabreen Formation suffered high-pressure metamorphism. Lawsonite and glaucophane in the metabasites of the lower unit are partly decomposed to epidote and chlorite, respectively. The high modal amounts of actinolite and epidote in these rocks can probably be attributed to the overprinting of the medium-pressure metamorphism upon an older high-pressure metamorphism.

Metamorphic facies series of the Vestgötabreen Formation

Glaucophane, epidote and zoisite occur in the metabasites of the lower unit and in the eclogites and glaucophanites of the upper unit, though these minerals are much more abundant in the upper unit than in the lower one. In the upper unit they are idiomorphic and tabular, coarse-grained (cm scale), while those in the lower unit are anhedral and fine-grained. On the other hand, lawsonite occurs only in the metabasites of the lower unit. Garnet rarely occurs in the metabasites of the upper part of the lower unit, but it is common in most of the lithofacies of the upper unit. Glaucophane is seen as inclusion in lawsonite, whereas the inclusions in garnet are mainly lawsonite, actinolite and chlorite in the lower unit, and epidote, sodic pyroxene, glaucophane, chloritoid and micas in the upper unit. These textural features of minerals indicate that the assemblage lawsonite + glaucophane + actinolite + chlorite was stable in the metabasites from the lower part of the lower unit. In the upper unit, the predominant minerals in the eclogites and glaucophanites are omphacite, garnet, glaucophane, epidote and rutile, and those in the metasiliceous rocks are garnet, phengite, paragonite, and the jadeite + quartz assemblage. The mineral assemblages of the lower and upper units are quite analogous to those of the lawsonite zone and the omphacite zone in New Caledonia (Black 1977, Brothers & Yokoyama 1982), respectively.

In New Caledonia, the epidote zone which is characterized by the assemblages of epidote, omphacite, glaucophane, garnet, and chlorite in basic schists occur between the lawsonite and the omphacite zones (Brothers & Yokoyama 1982). In the Vestgötabreen Formation, the mineral assemblages epidote + garnet + actinolite + chlorite and epidote + garnet + glaucophane + chlorite sometimes occur in the metabasites cropping out in the upper part of the lower unit. They are probably comparable to the assemblages of the epidote zone in New Caledonia.

Therefore, three grades of high-pressure metamorphism can be distinguished in the Vestgötabreen Formation. The upper unit of omphacite zone grade is thrust over the epidote zone or lower grade rocks of the lower unit. The structural relationship between the epidote zone grade and lawsonite grade rocks of the lower units is uncertain. However, the apparent absence of the transitional mineral assemblages between them combined with the wide spread diaphthoresis suggests that their contact is also tectonic.

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References

Bird, J. M. & Dewey, J. F. 1970: Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen. *Bull. Geol. Soc. Am. 81,* 1031–1060.

Black, P. M. 1977: Regional high-pressure metamorphism in New Caledonia: phase equilibria in the Quegoa district. *Tectonophysics 43,* 89–107.

Bloxam, T. W. & Allen, J. B. 1958: Glaucophane schists, eclogite, and associated rocks from Knockormal in the Girvan-Ballantrae complex, south Ayrshire. *Trans. Roy. Soc. Edin. 64,* 1–17.

Bluck, B. J., Halliday, A. N., Aftalion, M. & McIntyre, R. M. 1980: Age of the Ballantrae ophiolite and its significance to the Caledonian orogeny and the Ordovician time-scale. *Geology 8,* 492–495.

Brothers, R. N. & Yokoyama, K. 1982: Comparison of the high-pressure schist belts of New Caledonia and Sanbagawa, Japan. *Contrib. Mineral. Petrol. 79,* 219–229.

Gibbons, W. 1981: Glaucophanic amphibole in a Monian shear zone on the mainland of N Wales. *J. Geol. Soc. London 138,* 139–143.

Hjelle, A., Ohta, Y. & Winsnes, T. S. 1979: Hecla Hoek rocks of Oscar II Land and Prins Karls Forland, Svalbard. *Nor. Polarinst. Skr. 167,* 145–169.

Horsfield, W. T. 1972: Glaucophane schists of Caledonian age from Spitsbergen. *Geol. Mag. 109,* 29–36.

Jameison, R. A. 1977: The first metamorphic sodic amphibole identified from the Newfoundland Appalachians – its occurrence, composition and possible tectonic implications. *Nature 265,* 428–430.

Kanat, L. H. 1984: Jadeite from southern Oscar II Land, Svalbard. *Min. Mag. 48,* 301–303.

Laird, J. & Albee, A. L. 1981: High-pressure metamorphism in mafic schist from northern Vermont. *Am. J. Sci. 281,* 97–126.

Lanphere, M. A. & Albee, A. L. 1974: $^{40}Ar/^{39}Ar$ age measurements in the Worcester Mountains: evidence of Ordovician and Devonian metamorphic events in northern Vermont. *Am. J. Sci. 274,* 545–555.

Manby, G. M. 1978: Aspects of Caledonian metamorphism in central western Svalbard, with particular reference to the glaucophane schists of Oscar II Land. *Polarforschung 48(1/2),* 92–102.

Ohta, Y. 1979: Blue schists from Motalafjella, western Spitsbergen. *Nor. Polarinst. Skr. 167,* 171–217.

Ohta, Y., Hiroi, Y. & Hirajima, T. 1983: Additional evidence of pre-Silurian high-pressure metamorphic rocks in Spitsbergen. *Polar Research 1 n.s.* 215–218.

Scrutton, C. T., Horsfield, W. T. & Harland, W. B. 1976: Silurian fossils from western Spitsbergen. *Geol. Mag. 113,* 519–523.

Silver, E. A. & Beutner, E. C. 1980: Melanges. *Geology 8,* 32–34.

Trzcienski, W. E. Jr. 1976: Crossitic amphibole and its tectonic significance in the Richmond Area, southestern Quebec. *Can. J. Earth Sci. 13*, 711–720.

Trzcienski, W. E. Jr., Carmichael, D. M. & Helmstaedt, H. 1984: Zoned sodic amphibole: petrologic indicator of changing pressure and temperature during tectonism in the Bathurst Area, New Brunswick, Canada. *Contrib. Mineral. Petrol. 85,* 311–320.

Zen, E-An 1974: Prehnite- and pumpellyite-bearing mineral assemblages, west side of the Appalachian metamorphic belt, Pennsylvania to Newfoundland. *J. Petrology 15,* 197–242.