Noélbensonite, a new BaMn silicate of the lawsonite structure type, from Woods mine, New South Wales, Australia

Y. Kawachi, D. S. Coombs

Geology Department, University of Otago, Dunedin, New Zealand

AND

H. Miura

Department of Earth and Planetary Science, Graduate School of Science, Hokkaido University, Japan

Abstract

Noélbensonite, a new mineral, is the barium manganese analogue of lawsonite. It is described from the Woods ornamental rhodonite mine, 30 km NNE of Tamworth, New South Wales, Australia, where it occurs as aggregates of blocky to sometimes lamellar crystals ranging from a few micrometres to (rarely) 100 μm in length. It replaces NaMn amphibole, namansilite, and pectolite, and also occurs as tiny monomineralic veinlets 0.05–0.25 mm thick. Rare euhedral crystals are dominated by {100} and {011}, with (011) ^ (01$\bar{1}$) = 68°. The mineral is orthorhombic, space group apparently $Cmcm$; a = 6.325(1), b = 9.120(1), c = 13.618(1) Å, V = 785.6(1) Å^3, with $a : b : c$ = 0.694 : 1 : 1.493. Noélbensonite is brittle, fracture irregular, Mohs hardness about 4, cleavage and twinning not observed, colour dark brown, streak paler yellow-brown, lustre earthy on some veinlet surfaces to brilliantly vitreous, calculated density 3.87 g/cm^3, refractive indices α = 1.82(1), β (calculated from 2V) = 1.835(10), γ = 1.85(1), biaxial negative $2V_\alpha$ = 46°(3°), strong dispersion $r > v$, straight extinction to plane of flattening, {100}, $\alpha \parallel c$, $\beta \parallel b$, $\gamma \parallel a$ with pleochroism in very thin sections: α = orange yellow, β = orange, γ = brownish orange, absorption $\gamma > \beta > \alpha$. The average of 23 electron microprobe analyses (wt.%) is SiO$_2$ 26.02, Al$_2$O$_3$ 0.17, TiO$_2$ 0.01, Fe$_2$O$_3$ 0.19, Mn$_2$O$_3$ 34.76, CaO 0.31, Na$_2$O 0.14, BaO 29.08, SrO 1.51, H$_2$O$_{calc}$ 7.87, total 100.06, leading to the simplified formula BaMn$_2^{3+}$[Si$_2$O$_7$](OH)$_2$·H$_2$O. Up to 15% Sr and 9% Ca substitute for Ba in the large-cation sites. The strongest lines in the X-ray powder diffraction pattern are [(I_{obs}) d_{obs}/Å hkl] (100) 4.85 111; (50) 4.557 020; (59) 4.322 021; (77) 3.416 113,004; (80) 2.869 202; (47) 2.849 114; (82) 2.729 024; (45) 2.543 132; (48) 2.428 222; (38) 2.255 223,041. The name is for William Noél Benson (1885–1957), in honour of his classic researches in the New England Fold Belt and of his tenure of the Chair of Geology at the University of Otago.

KEYWORDS: noélbensonite, new mineral, barium manganese silicate, lawsonite, Woods mine, Australia.

Introduction

THE Woods mine 30 km NNE of Tamworth, New South Wales, Australia, has been worked for ornamental rhodonite, and contains a range of other manganese-rich minerals including serandite (Kawachi, 1987), NaMn amphibole (Kawachi, 1991), namansilite and manganian aegirine (Kawachi and Coombs, 1993), sugilite (Kawachi et al., 1994), braunite, hausmannite, tephroite, rhodo-chrosite, and unidentified phases as well as quartz, albite, K-feldspar, barite, and apatite. In this paper we describe the BaMn^{3+} analogue of lawsonite, the SrMn^{3+} analogue of which, hennomartinite, was recently described from the Wessels mine, Kalahari, South Africa (Armbruster et al., 1992, 1993).

The name noélbensonite is given in honour of William Noél Benson (1885–1957), in recognition of his pioneering researches in the Great Serpentine Belt and New England Fold Belt of New South Wales,

where the mineral was found, and of his distinguished tenure of the Chair of Geology at the University of Otago (1916–1949), where the mineral has been characterized. He was known to close family as 'Noél' and was addressed by most others as 'Benson' or 'Professor Benson', depending upon their relationship. The mineral and name have been approved by the I.M.A. Commission on New Minerals and Mineral Names. Type material is deposited in the collection of the Smithsonian Institution, Washington, NMNH 171139, with co-types in the collections of the Museum of Victoria, Australia (M 43826), and the Geology Department, University of Otago (OU 63702, 63703).

The Woods mine (UTM grid reference LL099906) lies 30 km NNE of Tamworth, New South Wales, within the Anaiwan Terrane of Late Devonian to Carboniferous age. This terrane is dominated by siliceous mudstone and chert forming part of a deformed subduction complex (Brown *et al.*, 1992) with regional greenschist facies metamorphism in the general area of the mine. The deposit consists of steeply-dipping manganese-rich pods up to a few metres thick and 10 m long enclosed in chert and mudstone with a hornblende hornfels facies thermal overprint associated with the early Permian Glenclair Adamellite which is exposed within a few hundred metres of the mine.

Occurrence of noélbensonite

Noélbensonite has been observed as a replacement of NaMn amphibole, namansilite, and serandite, and as the main or sole constituent of tiny veinlets 0.05–0.25 mm thick. Where such veinlets cut NaMn amphibole or namansilite, replacement by noélbensonite spreads from the vein into the mineral, but volumetrically larger quantities of replacement noélbensonite occur as patches disseminated through the rock, sometimes up to a millimetre in diameter. The noélbensonite is clearly of late-stage origin, following the metamorphic maximum. Where occurring as a replacement, the noélbensonite occurs as dense mosaics of anhedral or somewhat elongate blocky grains from a few micrometres to (rarely) about 100 μm in length. In the veinlets it occurs both as similar but mostly finer-grained aggregates, and sometimes as finely foliated sheaves up to 100 μm long. Some veinlets have a discontinuous inner filling of quartz, K-feldspar, and fluorapatite (Fig. 1), the apatite carrying about 1.5% SrO and 0.50% MnO. In a very few places, euhedral noélbensonite is found in recrystallized patches at the edges of veinlets with quartz, barian K-feldspar ($cn = 3.8–5.2\%$), and barite (Fig. 2).
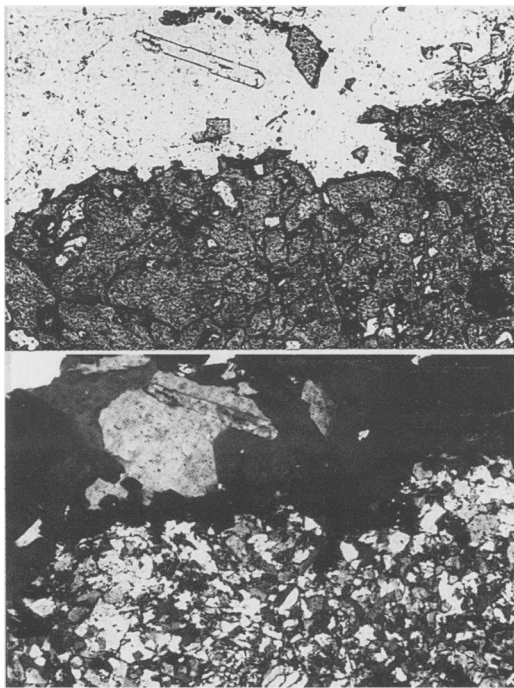
FIG. 2. Upper: Noélbensonite aggregate (medium dark) in a veinlet-related recrystallized patch containing granules of quartz (clear). The upper part of the field contains euhedral noélbensonite and barite (elongate outline) in a coarse mosaic of of quartz and barian K-feldspar. Lower: The same, crossed polars, showing blocky nature of the noélbensonite crystallites. Field of view: 0.75 × 0.53 mm.
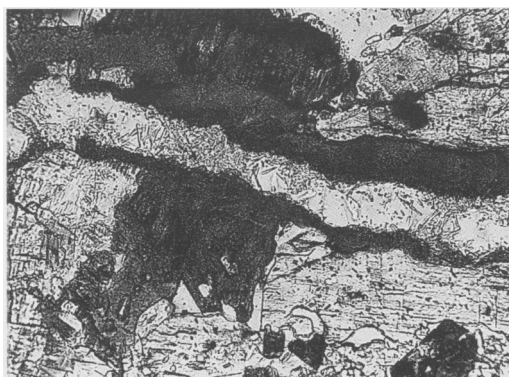

FIG. 1. Noélbensonite veinlet (medium dark) with inner filling of quartz, K-feldspar (flecks showing negative relief), and apatite (extremely fine needles) crossing serandite (light grey with cleavages) with quartz (clear), and NaMn amphibole (dark), the latter largely replaced by noélbensonite. Field of view: 0.44 × 0.32 mm.

Physical and optical properties

Many of the properties of noélbensonite are obscured by the generally fine grain size. It is orthorhombic, space group probably *Cmcm*. In the rare cases where euhedral crystals have been observed, these are dominated by {100} and {011}, with (011)^(01$\bar{1}$) = 68° as measured in thin section on the universal stage microscope. In aggregates, the generally blocky crystals tend to be flattened, occasionally even laminar, parallel to {100}, with straight extinction as seen in thin section. Cleavage and twinning have not been observed. Noélbensonite is brittle with an irregular fracture, Mohs hardness about 4. The colour is dark brown in hand specimen with a paler yellow-brown streak. Lustre ranges from earthy on some veinlet surfaces to brilliantly vitreous. The available material is too fine grained and intimately associated with other minerals for satisfactory measurement of density, but the calculated density is 3.87 g/cm^3.

Optical properties include: refractive indices α = 1.82(1), β (calculated from 2V) = 1.835(10), γ = 1.85(1), biaxial negative $2V_\alpha$ = 46°(3°), all for Na$_D$, with strong dispersion $r > v$. The optic axial plane is parallel to the plane of flattening in lamellar aggregates and in blocky euhedral grains, giving straight extinction in such sections, length fast or length slow; $\alpha \parallel c$, $\beta \parallel b$, $\gamma \parallel a$. In standard thin sections, the mineral is transluscent and brown, becoming more transparent and orange brown where sections are thinner, with pleochroism: α = orange yellow, β = orange, γ = brownish orange, and absorption $\gamma > \beta > \alpha$.

Chemistry

The chemical composition of noélbensonite in type material (Table 1, averaging 23 analyses) was obtained using wave-length dispersion methods (WDS) on a JEOL JXA 8600 electron microprobe. Operating conditions included beam diameter 2–3 μm, 15 kV and 20 nA probe current, and standard ZAF correction. Standards employed were natural albite, barite, and hematite for Na, Ba, and Fe, synthetic quartz, corundum, rutile, MnO, wollastonite, and SrTiO$_3$ for Si, Al, Ti, Mn, Ca, and Sr respectively. Mg, K, Cr, Ni, V, Zn, F, and Cl were below detection limits. In view of the isostructural relationship with lawsonite and hennomartinite revealed by X-ray study, atomic proportions are given in Table 1 for 8 O atoms on an anhydrous basis. In view of the difficulty of separating the mineral in adequate purity and quantity, H$_2$O is calculated by analogy with the lawsonite and hennomartinite structures. The simplified formula is BaMn$_2^{3+}$[Si$_2$O$_7$](OH)$_2$·H$_2$O with minor Al and Fe substituting probably for Mn^{3+} and up to 15% Sr, up

to 9% Ca, and very minor Na substituting for Ba in the individual analyses of noélbensonite that are included in the average. This can be compared with CaAl$_2$[Si$_2$O$_7$](OH)$_2$·H$_2$O for lawsonite and SrMn$_2^{3+}$[Si$_2$O$_7$]$_2$·H$_2$O for hennomartinite. Significant solid solution towards hennomartinite is indicated. Apart from marginally higher Al in one case, analyses from other specimens obtained at the Woods mine fall within the same range as those included in the average.

X-ray powder diffraction study and structure

About 50 lines in replicate goniometer XRD powder patterns using Cu-$K\alpha$ radiation and quartz contaminant as internal standard were indexed in conformity with requirements for a lawsonite-like structure with space group *Cmcm* and bearing in mind observed and calculated intensities given by Armbruster *et al.* (1993) for hennomartinite. Some additional weak lines could be attributed to identifiable impurities, namely minor serandite and trace NaMn amphibole

TABLE 1. Electron microprobe analysis of noélbensonite, Woods mine

Constituent	Wt.%	Range
SiO$_2$	26.02	25.01–27.01
Al$_2$O$_3$	0.17	0.09–0.23
TiO$_2$	0.01	n.d.–0.06
Fe$_2$O$_3$*	0.19	n.d.–0.64
Mn$_2$O$_3$*	34.76	33.11–37.02
CaO	0.31	n.d.–1.00
Na$_2$O	0.14	0.05–0.18
BaO	29.08	23.49–32.02
SrO	1.51	0.56–3.27
H$_2$O(calc)	7.87	
Total	100.06	
Cations, O = 8		
Si	1.983	
Al	0.015	
Ti	0.001	
Fe	0.011	
Mn	2.016	
Ca	0.025	
Na	0.021	
Ba	0.868	
Sr	0.067	
Total	5.007	

Average of 23 spot analyses.
* Total Fe, Mn as Fe$_2$O$_3$, Mn$_2$O$_3$
n.d. = not detected.
K, Cr, Ni, V, Zn, F, Cl below limits of detection.

and namansilite, and are discarded. After discarding poorly resolved peaks, the indexing leads to the following refined cell dimensions: $a = 6.325(1)$, $b = 9.120(1)$, $c = 13.618(1)$ Å, $V = 785.6(1)$ Å^3, with $a : b: c = 0.694: 1 :1.493$.

Following initial calculations, some additional peaks were discarded from further analysis because of overlap or possible overlap with other peaks, including contaminant peaks. Structural factors were calculated from powder diffraction intensities divided by Lorentz polarization factor and multiplicity factors. All observed reflections meet the non-extinction requirements that for *hkl*, $h + k = 2n$, and that for *h0l*, $h = 2n$, $l = 2n$. This allows possible space

groups *C2cm*, *Cmc2$_1$*, and *Cmcm*. Assuming space group *Cmcm* and using hennomartinite coordinates given by Armbruster *et al.* (1992) as a starting model, best fit calculation of atom coordinates and temperature factors was carried out using RSFLS-4 program (Sakurai, 1967). Positions of H atoms were not taken into account as the precision and accuracy of the original data were not adequate to justify that. R factors where $R = (\Sigma |F_{obs} - F_{calc}|)/(\Sigma F_{obs}))$ for 19 parameters became close to 9.1%, low enough to suggest that the assumptions were correct. The accuracy of the original data is not adequate to give reliable interatomic distances, but calculated intensities for powder lines are given in Table 2. It is clear

TABLE 2. XRD powder pattern for noélbensonite from the Woods mine

I_{obs}	d_{obs} (Å)	d_{calc} (Å)	I_{calc}	*hkl*	I_{obs}	d_{obs} (Å)	d_{calc} (Å)	I_{calc}	*hkl*
		6.809	7	002	5	1.8945	1.8944	5	044
9	5.20	5.197	5	110	5	1.8715	1.8714	3	313
100	4.85	4.856	100	111			1.8494	4	240
50	4.557	4.5600	55	020	18	1.8437	1.8440	21	206
59	4.322	4.3240	73	021	4	1.8332	1.8326	6	241
9	4.131	4.1314	10	112	2	1.8220	1.8220	6	117
10	3.789	3.7889	11	022			{1.7895	10	027
77	3.416	{3.4190	83	113	13	1.7852	{1.7848	16	242
		{3.4046	52	004	4	1.7583	1.7588	3	314
9	3.218	3.2171	9	023			{1.7483	5	045
*15	*(3.161)	3.1624	20	200	10	1.7477	{1.7479	3	136
80	2.869	2.8682	90	202	10	1.7326	1.7324	10	330
47	2.849	2.8480	42	114			1.7185	3	331
10	2.740	2.7399	18	130			{1.7127	9	243
82	2.729	2.7281	59	024	23	1.7092	{1.7095	23	226
16	2.687	2.6861	24	131			{1.7023	11	008
15	2.600	2.5986	13	220	9	1.6984	{1.6973	9	152
		2.5525	10	221	8	1.6788	1.6789	8	332
45	2.543	2.5419	53	132	6	1.6396	1.6400	6	315
48	2.428	2.4279	66	222	12	1.6247	1.6252	15	244
15	2.413	2.4125	26	115	5	1.6083	1.6086	6	046
3	2.346	2.3458	2	133	2	1.5935	1.5948	2	028
2	2.315	2.3171	1	204	10	1.5813	1.5812	11	400
		2.2799	2	040			{1.5582	5	154
		2.2698	2	006	5	1.5577	{1.5574	6	227
38	2.2545	{2.2553	36	223	6	1.5303	1.5301	6	245
		{2.2486	10	041	7	1.4833	1.4835	6	062
2	2.1615	2.1620	2	042	7	1.4463	1.4460	7	138
20	2.1345	2.1346	12	134	4	1.4345	{1.4341	10	404
1	2.0796	2.0800	1	116			{1.4337	5	246
		{2.0374	6	043	4	1.4199	1.4191	5	423
22	2.0322	{2.0320	17	311	4	1.4129	1.4125	4	317
*2	*(1.9335)	1.9317	5	135					

* Interference from contaminant.
Non-observed lines with I_{calc} less than 4 are not listed for spacings less than 1.70 Å.

TABLE 3. Comparison with structurally related species $W^{2+}Y_2^{3+}[Si_2O_7](OH)_2 \cdot H_2O$

	Noélbensonite	Hennomartinite	Lawsonite
W, Y in formula	Ba, Mn	Sr, Mn	Ca, Al
Space group	*Cmcm*	*Cmcm*	*Cmcm*
Cell dimensions: *a*	6.325(1)	6.255(1)	5.847(1)
b	9.120(1)	9.034(1)	8.795(1)
c	13.618(1)	13.397(2)	13.142(6)
Density, g/cm^3	3.87	3.68	3.05–3.12
Strongest XRD lines (Å)	4.85, 2.87, 2.73, 3.42	2.83, 2.69, 4.80, 2.40	2.72, 2.62, 2.13, 6.56
Refractive indices	1.82, 1.835, 1.85	>1.82	1.665, 1.675, 1.685
Optic axial angle	$2V_\alpha = 46°$	$2V = 63°$	$2V_\gamma = 76–87°$
Pleochroism	orange yellow to brownish orange	yellowish brown to dark red-brown	colourless

that Ba replaces Ca of the lawsonite structure and Sr of hennomartinite, Mn replacing Al, with corresponding increases in cell dimensions on account of the larger size of the Ba ion as compared with Sr and Ca. The intensity calculations led to improvements in the provisional indexing and indicated several potential lines not clearly resolved in the observed powder patterns as a result of the proximity of neighbouring stronger lines or contaminant phases. A notable omission from the observed pattern is an 002 reflection, prominent in the patterns of lawsonite and hennomartinite and with a calculated intensity of 7 for noélbensonite.

Libowitzky and Armbruster (in press) show that below 273 K the space group of lawsonite changes from *Cmcm* to *Pmcn* as a result of rotation of water and hydroxide groups causing the loss of a mirror plane. A further reduction in space group symmetry occurs below 155 K. Resulting reflections for lawsonite forbidden by C-centreing are weak, and although even the strongest of them, 017, is too weak to be expected in any corresponding powder pattern, the possibility arises that, like lawsonite, noélbensonite may have the symmetry of a subgroup of *Cmcm* such as *Pmcn*, as a result of a similar displacive phase transition. However, *Cmcm* can be regarded as the most probable space group, at least at the temperature of formation.

Discussion

Noélbensonite is the BaMn member of the lawsonite group of sorosilicates of general formula $W^{2+}Y_2^{3+}[Si_2O_7](OH)_2 \cdot H_2O$. Features of the three known members of the group are summarized in Table 3. The previously-known minerals nearest in

composition to noélbensonite are ericssonite and orthoericssonite, from the Långban, Sweden, deposit (Moore, 1971). These have composition $BaMn_2^{2+}(Fe^{3+}O)[Si_2O_7](OH)$, lamprophyllite structure, and a higher temperature paragenesis than noélbensonite.

Lucchetti *et al.* (1988) reported an unidentified BaMn silicate intergrown with $NaMnSi_2O_6$ pyroxene (namansilite) and pectolite at the Cerchiara mine, north Apennines. If total Mn and Fe were treated as trivalent, their published analysis would yield a lawsonite-type formula as follows when calculated on the basis of 8 oxygen atoms excluding H_2O and (OH): $(Ba_{0.628}Ca_{0.197}Sr_{0.179}Na_{0.019})_{1.014}$ $(Mn_{2.020}Fe_{0.017}Al_{0.023})_{2.060}[Si_{1.948}O_7](OH)_2 \cdot H_2O$. This is slightly deficient in Si, but otherwise conforms well with noélbensonite with which it can probably be identified*. It would slightly extend the solid solution series between noélbensonite and hennomartinite as recorded above for the Woods mine locality, and would more markedly extend the range of substitution of Ca for Ba.

The fact that the Cerchiara mine mineral is intergrown with Mn-poor pectolite rather than serandite, the Mn^{2+} analogue of pectolite, may indicate higher f_{O_2} during metamorphism at the Cerchiara mine than at Woods mine.

The occurrence of noélbensonite as a replacement of manganese pyroxene, NaMn-amphibole and serandite and in veinlets associated with barian K-feldspar and minor barite and apatite, implies the

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*Professor Lucchetti has now provided X-ray powder diffraction data for the Cerchiara BaMn silicate that confirms that it is noélbensonite.

activity of fluids that locally introduced H_2O, Ba, and minor P and Sr, probably at a temperature significantly below that of the thermal maximum of this polymetamorphic assemblage. Although the earlier-formed minerals identified in the Woods mine assemblage are not rich in Ba or Sr, these elements are so characteristically abundant in similar manganese-rich deposits world-wide, that they are likely to have been derived from within the deposit itself. Hennomartinite also occurs in veinlets believed to be of hydrothermal origin (Armbruster *et al.*, 1993), but in its case, the veinlets themselves contain a member of the serandite-pectolite series and sugilite. Whereas lawsonite quite specifically has a stability field restricted to relatively high pressures at low temperatures, noélbensonite has formed at relatively low temperatures under conditions suggesting normal or even high thermal gradients.

References

Armbruster, T., Oberhänsli, R. and Bermanec, V. (1992) Crystal structure of $SrMn_2[Si_2O_7](OH)_2 \cdot H_2O$, a new mineral of the lawsonite type. *Eur. J. Mineral.*, **4**, 17–22.

Armbruster, T., Oberhänsli, R., Bermanec, V. and Dixon, R. (1993) Hennomartinite and kornite, two new Mn^{3+} rich silicates from the Wessels Mine,

Kalahari, South Africa. *Schweiz. Mineral. Petrogr. Mitt.*, **73**, 349–55.

Brown, R.E., Brownlow, J.W. and Krynen, J.P. (1992) Manilla-Narrabri 1:250 000 Metallogenic Map SH/56-9, SH/55/12: Metallogenic Study and Mineral Deposit Data Sheets. Geological Survey of New South Wales, Sydney, 319 pp.

Kawachi, Y. (1987) Rhodonite and serandite in the manganese deposits in Tamworth-Manilla region, New South Wales, Australia. In *Preliminary report on the geology of the New England Fold Belt, Australia. No. 1*. (M. Iwasaki, project leader), Cooperative Research Group of Japan and Australia, 159–77.

Kawachi, Y. (1991) 'Rhodonite'-bearing manganese deposits in the New England fold belt of eastern Australia, with special reference to the deposit of Woods mine. In *Bending of the Great Serpentine Belt and Tectonic History of the Arc-type Crust around the Belt, Eastern Australia. Preliminary report on the geology of the New England Fold Belt, Australia. No. 2*. (H. Honma, project leader), Cooperative Research Group of Japan and Australia, 55–61.

Kawachi, Y. and Coombs, D.S. (1993) Namansilite, $NaMn^{3+}Si_2O_6$, a widespread clinopyroxene? *Mineral. Mag.*, **57**, 533–8.

Kawachi, Y., Ashley, P.M., Vince, D. and Goodwin, M. (1994) Sugilite in manganese silicate rocks from the Hoskins mine and Woods mine, New South Wales, Australia. *Mineral. Mag.*, **58**, 671–7.

Libowitzky, E. and Armbruster, T. (in press) Low temperature phase transitions and the role of hydrogen in lawsonite. *Amer. Mineral.*

Lucchetti, I., Cortesogno, L. and Palenzona, A. (1988) Low-temperature metamorphic mineral assemblages in Mn-Fe ores from Cerchiara mine (northern Apennine, Italy). *Neues Jahrb. Mineral., Mh.*, 367–83.

Moore, P.B. (1971) Ericssonite and orthoericssonite, two new members of the lamprophyllite group, from Långban, Sweden. *Lithos*, **4**, 137–45.

Sakurai, T. (ed.) (1967) *Universal Crystallographic Program System*. Crystallographic Soc. Japan.