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Otwayite and theophrastite from the Lord Brassey Mine, Tasmania

RECENT investigation of samples labelled zaratite from the Lord Brassey Mine, near Heazlewood, Tasmania, in the mineral collection of the Museum of Victoria revealed the presence of the rare nickel carbonate, otwayite, and the rare nickel hydroxide, theophrastite. X-ray diffraction, electron microprobe and infrared analysis were utilised in the study, which failed to confirm the presence of zaratite.

The Lord Brassey Mine is situated near the summit of Mt. Grey, 1.5 km northeast of the Waratah–Corinna Road bridge over the Heazlewood River, in western Tasmania. The mine is the type locality for two nickel-bearing minerals, heazlewoodite (Petterd, 1910; Peacock, 1947) and hellyerite (Williams *et al.*, 1959). The nickel ore occurs as narrow veins within a body of serpentinite 4 km long and 800 m wide, forming part of a large Cambrian ultrabasic complex consisting of pyroxenites and peridotites (Williams, 1958). The main ore consists of heazlewoodite with minor pentlandite and millerite generally intergrown with magnetite. In shear planes and fracture fillings a waxy, translucent, emerald-green amorphous mineral referred to as zaratite by Williams (1958) has been deposited along with thin coatings of pale blue hellyerite.

Given that the secondary nickel carbonates and hydroxides from Lord Brassey Mine transect massive magnetite and serpentine minerals, and given their associations in other deposits, it is most likely that they precipitated from meteoric fluids which permeated the nickel sulphide orebody via shear planes and fractures.

Otwayite

Otwayite is an orthorhombic nickel carbonate thus far recorded only from the Otway nickel prospect in the Nullagine region of Western Australia (Nickel *et al.*, 1977). A sheared ultramafic body contains otwayite as fibrous, late-stage infillings of narrow veinlets 0.5–1 mm in width, which transect massive serpentine, millerite, polydymite and apatite. Associated with the otwayite in veinlets are magnesite, gaspeite and pecoraite, with paraotwayite occurring in separate veins from otwayite (Nickel and Graham, 1987).

The Lord Brassey Mine sample (M2023) was presented to the Museum of Victoria in 1896. There are several small pieces with sparse coverings of otwayite and two larger specimens, measuring $5 \times 4 \times 1$ cm and $7 \times 6 \times 1.5$ cm, having excellent coverage. The otwayite occurs as a bright green clay-like coating, with a silky to waxy lustre, on serpentine. It is translucent in part although generally opaque. Dark patches in the serpentine were identified as magnetite by X-ray diffraction. A dark emerald green translucent waxy 'zaratite' is present on most samples and is amorphous to X-rays.

X-ray diffraction data for the otwayite are in good agreement with those reported by Nickel *et al.* (1977). Microscopic examination of polished sections of the otwayite, however, showed abundant small inclusions of another green phase. This phase was either X-ray amorphous, or contributed to the otwayite pattern. The generally diffuse X-ray diffractogram of the 'zaratite' follows the same pattern as the otwayite from Heazlewood (Fig. 1). However, it may be that that inclusions in the otwayite are the generally amorphous 'zaratite' phase and are contributing this diffuse background to the otwayite pattern.

Chemical analyses on the otwayite and the inclusions were obtained using a Cameca SX81 microprobe at 15 kV and 2 ηA, with Ni metal (Ni), MgO (Mg) and ZnS (S) as standards. CO_2 and water contents were calculated by stoichiometry. The presence of significant C in both phases was confirmed by non-quantitative methods on the microprobe. The average of 14 analyses of the main phase gave a formula $Ni_2(CO_3)_{0.84}(SO_4)_{0.16}(OH)_2.2H_2O$, close to the ideal otwayite formula $Ni_2(CO_3)(OH)_2.H_2O$ (Nickel *et al.*, 1977). The inclusions gave $Ni_2(CO_3)(OH)_2.1.9H_2O$, again close to the ideal

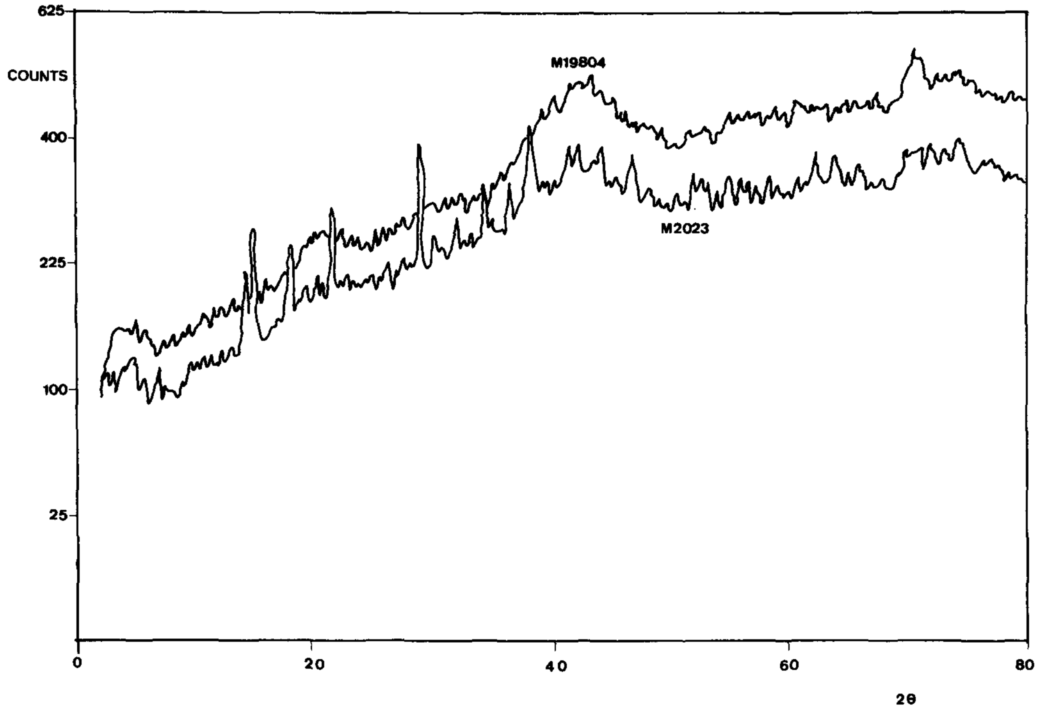

FIG. 1. X-ray diffractogram for otwayite (M2023) and 'zaratite' (M19804) from the Lord Brassey Mine, Heazlewood, Tasmania.

otwayite formula (Table 1), but without the small S content of the host otwayite.

Infrared spectra were obtained using KBr pellets on a Fourier Transform Infrared Spectrometer (Fig. 2). Strong absorptions are present for OH, H_2O, CO_3^{2-} and So_4^{2-}. This spectrum is similar to that obtained from the amorphous 'zaratite'.

Theophrastite

The hexagonal nickel hydroxide theophrastite was first recorded from magnetite–chromite–millerite ore in the Vermion region of Greece (Marcopoulos and Economou, 1981). Subsequently it was recorded by Livingstone and Bish (1982) as blue-green and opaque, and bright emerald-green, gel-like coatings on chromitite specimens from the Hagdale Quarry, Unst, Scotland. There it is associated with zaratite, reevesite, honessite and very rare pentlandite and heazlewoodite.

The theophrastite from Greece is very close to pure $Ni(OH)_2$, similar in properties to synthetic $Ni(OH)_2$ (Marcopolous and Economou, 1981). In contrast, unit cell data for the Unst material suggested that a series exists between theophrastite and brucite with compositions ranging from $(Ni_{88.4}Mg_{11.6})(OH)_2$ up to $(Mg_{57.9}Ni_{42.1})(OH)_2$ (Livingstone and Bish, 1982). They noted considerable discrepancies between the calculated MgO compositions and those obtained by microprobe. Infrared data for the Unst material suggested that the theophrastite was intimately mixed with poorly crystalline hydroxides of the pyroaurite- and carrboydite-types. The inhomogeneity of the material was borne out by the microprobe data with NiO values ranging from 72.8% to 54% and MgO ranging from 7.9 to 0.3%, but with one sample giving 35.5% NiO and 19.1% MgO.

The Lord Brassey Mine sample (M26244) measures 6 × 4 × 1 cm and contains theophrastite as a dull blue-green to olivine green, compact, vein-filling in massive magnetite-chromite within serpentinite. Associated with the theophrastite are patches of the same amorphous, vitreous dark emerald green 'zaratite' occurring with the otwayite on M2023.

The Lord Brassey Mine theophrastite gives an almost identical IR spectrum to the Unst material (Fig. 2) with strong absorptions at 3644.9 cm^{-1} due to OH^- stretching, a CO_3^{2-} absorption band

TABLE 1

	1	2	3	4	5	6	7
MgO	0.10	0.02- 0.28	0.12	0.08- 0.165	1.66	0.38- 2.84	0.07
NiO	58.68	56.32- 61.21	60.78	59.48- 62.75	61.72	59.05- 66.15	61.08
SO_3	4.92	3.75- 5.37					
CO_2*	14.62		18.01				18.04
H_2O**	21.68		21.09		36.62		20.81
TOTAL	100.00		100.00		100.00		100.00

1. Microprobe analysis of bright green otwayite from Lord Brassey Mine, Tasmania. M2023, Museum of Victoria collection. Average of 14 analyses.
2. Range of values from 14 analyses of bright green otwayite given in column 1.
3. Average of three microprobe analyses of inclusions in otwayite from Lord Brassey Mine, Tasmania. M2023, Museum of Victoria collection.
4. Range of values from 3 analyses of inclusions in otwayite in column 3.
5. Average of 4 microprobe analyses of blue-green theophrastite from Lord Brassey Mine, Heazlewood, Tasmania. M26244, Museum of Victoria collection.
6. Range of values for theophrastite analysis in column 5.
7. Analysis of waxy amorphous 'zaratite' from Lord Brassey Mine, Heazlewood, Tasmania. M19804, Museum of Victoria collection.

CO_2* Calculated H_2O** by difference.

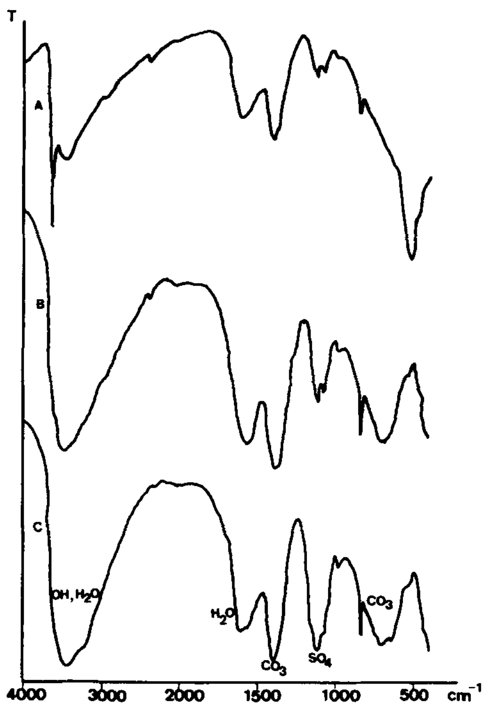

FIG. 2. Infrared absorption spectra for (A) theophrastite (M2023), (B) amorphous 'zaratite' (M19804) and (C) otwayite (M2023) from the Lord Brassey Mine, Heazlewood, Tasmania.

at 1399 cm^{-1} characteristic of pyroaurite-type mixed hydroxides, and SO_4^{2-} absorption at 1110.6 cm^{-1} typical of carrboydite-type mixed hydroxides (Livingstone and Bish, 1982). In contrast the Vermion material gives only the OH absorption band at 36740 cm^{-1}.

Microprobe analysis of the Lord Brassey Mine material, like the Unst material, reveals some inhomogeneity but only minor Mg was detected (Table 1). The theophrastite therefore appears to be close to pure $Ni(OH)_2$, but is mixed with poorly crystalline pyroaurite- and carrboydite-type phases.

X-ray diffraction data for the Lord Brassey theophrastite are in closest agreement with those of the Vermion material. The variance in *d*-values between the Lord Brassey Mine theophrastite and the Unst material is probably a reflection of the higher Mg values in the Unst mineral.

Given the brucite-like structure of carrboydite (Nickel and Clark, 1976), it would seem likely that the carrboydite and pyroaurite-like mixed hydroxides occur as random layers in the theophrastite, as suggested by Livingstone and Bish (1982).

Zaratite

The dark emerald-green vitreous to greasy, translucent material on Heazlewood specimens has generally been referred to as zaratite

$Ni_3(CO_3)(OH)_4.4H_2O$ (Williams, 1958). X-ray diffraction did not confirm the presence of zaratite on specimens from the Lord Brassey Mine as they all appeared very poorly crystalline. Analysis of this material gave compositions similar to otwayite, as did samples of supposed zaratite from Pennsylvannia (Table 1), and the infrared spectra of otwayite and the amorphous 'zaratite' are very similar (Fig. 2). Issacs (1963) suggested that zaratite is an amorphous basic nickel carbonate that undergoes crystallization with loss of water to form a number of hydrated nickel carbonates. It may well be that the otwayite at Lord Brassey has formed from the dehydration of zaratite.

Hellyerite

Hellyerite was initially described from the Lord Brassey Mine at Heazlewood by Williams *et al.* (1959). They suggested that the mineral was relatively rare as it was probably metastable. Specimens obtained in 1977 by the Museum of Victoria, and which gave sharp, well-crystalline X-ray diffraction patterns at that time, have now decomposed to a poorly crystalline phase with a pattern unlike that of hellyerite.

Conclusions

At the Lord Brassey Mine, so-called 'zaratite' specimens may consist of a sulphate-bearing otwayite containing abundant small inclusions of S-free otwayite or possibly zaratite, or of theophrastite mixed with pyroaurite- and carrboydite-like phases.

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