

## TREMBATHITE, (Mg,Fe)<sub>3</sub>B<sub>7</sub>O<sub>13</sub>Cl, A NEW BORATE MINERAL FROM THE SALT SPRINGS POTASH DEPOSIT, SUSSEX, NEW BRUNSWICK

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### ABSTRACT

The new mineral species *trembathite*, ideally (Mg,Fe)<sub>3</sub>B<sub>7</sub>O<sub>13</sub>Cl, from the Salt Springs potash deposit, Sussex, New Brunswick, is the Mg-analogue of congolite and the rhombohedral dimorph of boracite. The mineral occurs as rhombohedra seldom exceeding 2 mm in maximum diameter. Trembathite is associated with halite, hilgardite and clay minerals. It is transparent, colorless to light blue with a vitreous luster and a white streak, it shows no cleavage, and has a conchoidal fracture and a Mohs hardness estimated at 6–8. The measured densities range from 2.84 to 3.34 g/cm<sup>3</sup>; the calculated density is 3.14 g/cm<sup>3</sup>. Macroscopic twinning was not observed in trembathite, but an optical examination indicates that the crystals are polysynthetically twinned. Trembathite is uniaxial negative,  $\omega$  1.684(2),  $\epsilon$  1.668(2), and is not pleochroic. It is hexagonal, space group *R3c*, with *a* 8.574(2), *c* 20.99(1) Å, *V* 1336.6(6) Å<sup>3</sup> and *Z* = 6. The strongest six lines of the X-ray powder-diffraction pattern [diffractometer; *d* in Å(1)(*hkl*)] are: 3.497(34)(202,006), 3.028(100)(024), 2.711(66)(122,116), 2.144(37)(220,208), 2.050(73)(131,223,217,119), 1.828(25)(042,226). The electron-microprobe composition based on O + Cl = 14 is (Mg<sub>2.29</sub>Fe<sub>0.79</sub>Mn<sub>0.03</sub>)<sub>Σ3.11</sub>B<sub>6.89</sub>O<sub>12.90</sub>Cl<sub>1.10</sub>. The name honors Lowell T. Trembath, professor at the University of New Brunswick.

**Keywords:** trembathite, borate, new mineral species, properties, X-ray data, chemical composition, Sussex, New Brunswick.

### SOMMAIRE

La trembathite, dont la composition idéale est (Mg,Fe)<sub>3</sub>B<sub>7</sub>O<sub>13</sub>Cl, est une espèce minérale nouvelle découverte dans le gisement de potasse de Salt Springs, à Sussex, au Nouveau Brunswick. C'est l'analogue magnésien de la congolite et le dimorphe rhomboédrique de la boracite. Le minéral se présente en rhomboèdres, généralement moins de 2 mm de diamètre. La trembathite montre une association avec halite, hilgardite et des argiles. Elle est transparente, incolore à bleu pâle, avec un éclat vitreux et une rayure blanche. Elle semble sans clivage; sa fracture est "concoïdale", et sa dureté (échelle de Mohs), entre 6 et 8. La densité mesurée varie entre 2.84 et 3.34, tandis que la densité calculée est égale à 3.14. Nous n'avons vu aucun signe de la présence de macles, mais un examen optique montre que les cristaux sont maclés de façon polysynthétique. C'est un minéral uniaxe négatif,  $\omega$  1.684(2),  $\epsilon$  1.668(2), sans pléochroïsme. La trembathite est hexagonale, groupe spatial *R3c*, *a* 8.574(2), *c* 20.99(1) Å, *V* 1336.6(6) Å<sup>3</sup> et *Z* = 6. Les six raies les plus intenses du spectre de poudre, tel qu'obtenu au diffractomètre [*d* en Å(1)(*hkl*)], sont: 3.497(34)(202.006), 3.028(100)(024), 2.711(66)(122,116), 2.144(37)(220,208), 2.050(73)(131,223,217,119), et 1.828(25)(042,226). Les données à la microsonde électronique, normalisées sur 14 atomes O + Cl, mènent à la formule (Mg<sub>2.29</sub>Fe<sub>0.79</sub>Mn<sub>0.03</sub>)<sub>Σ3.11</sub>B<sub>6.89</sub>O<sub>12.90</sub>Cl<sub>1.10</sub>. Le nom honore Lowell T. Trembath, professeur à l'Université du Nouveau Brunswick.

(Traduit par la Rédaction)

**Mots-clés:** trembathite, borate, nouvelle espèce minérale, propriétés, données au rayons X, composition chimique, Sussex, Nouveau Brunswick.

### INTRODUCTION

During the examination of residual material obtained by dissolving halite drill cores from the Salt Springs deposit, Denison Potash potash mines, Sussex, New Brunswick, several small crystals of an unknown phase were observed. Work

on the unknown material resulted in the characterization of the new magnesium-iron borate mineral described here. We name this mineral trembathite after Dr. Lowell T. Trembath, Professor of Mineralogy at the University of New Brunswick, in recognition of his dedication to mineralogical research and teaching. The mineral

and mineral name have been approved by the Commission on New Minerals and Mineral Names, International Mineralogical Association. The cotype specimen of trembathite has been deposited at the Royal Ontario Museum, Toronto, Ontario, under catalogue number M44741.

#### OCCURRENCE AND ASSOCIATED MINERALS

A significant number of borate minerals occur in the potash deposits of southern New Brunswick. Several studies have characterized the occurrences of these borate minerals (*i.e.*, Roulston & Waugh 1981, Rachlin *et al.* 1986, Mandarino *et al.* 1990). Roulston & Waugh (1981) described the geology of the evaporite deposits in the Sussex area, New Brunswick. The Mississippian deposits occur in the Windsor Group in the Moncton sub-basin, a part of the northeasterly trending Fundy geocline. The two evaporite deposits that are presently mined in the Sussex area are the Penobsquis (Potash Company of America) and the Salt Springs (Clover Hill, Denison Potican Potash Company) deposits. Each deposit consists of a Basal Anhydrite unit, a Lower Halite member, a "sylvinite" (this is the name given by Roulston & Waugh 1981) ore zone, a Middle Halite member, an Upper Anhydrite unit and an Upper Halite member. Most borate minerals occur in the Middle Halite member; the list includes boracite, colemanite, hilgardite-4M, hydroboracite, priceite, szaibelyite, veatchite and volkovskite (Rachlin *et al.* 1986).

The trembathite samples were found in drill core 86-9 from the Denison Potican Potash Company. The hole was drilled on the mine property in the Clover Hill area (Salt Springs potash deposit). The samples occur in the Upper Halite member, 19

metres above the Upper Halite - E-zone ("sylvinite") contact. Trembathite is associated with halite, hilgardite and clay minerals (not identified owing to their scarcity). This is the first report of borate minerals in the Upper Halite member.

#### PHYSICAL PROPERTIES

Trembathite occurs as isolated rhombohedra less than 2 mm across. Crystals also occur in clusters contained in massive halite, as shown in Figure 1. Trembathite is colorless to light blue with a vitreous luster, is transparent, and has a white streak. The hardness of trembathite could not be determined accurately owing to the small size of the crystals, but is estimated at 6-8 on the Mohs scale. Trembathite has no cleavage, and the fracture is typically conchoidal. The crystals do not fluoresce in either long- or short-wave ultraviolet radiation. Morphological examination did not reveal any macroscopic twins. However, all crystals of trembathite examined show polysynthetic twinning in thin section.

Densities measured on crystals using a Berman balance range from 2.84 to 3.34 g/cm<sup>3</sup>, presumably owing to variations in proportion of Mg and Fe. The density, calculated using a weighted average bulk composition for the crystal characterized by electron-microprobe analysis, is 3.14 g/cm<sup>3</sup>. Several crystals were crushed for optical examination in immersion oils. The crystals are colorless and nonpleochroic in the immersion oil. Trembathite is uniaxial (-), with  $\omega$  1.684(2) and  $\epsilon$  1.668(2) measured for  $\lambda = 589$  nm. Gladstone-Dale constants (Mandarino 1979, 1981) were used to calculate a compatibility index of 0.007, indicating superior agreement of optical, physical and chemical data.

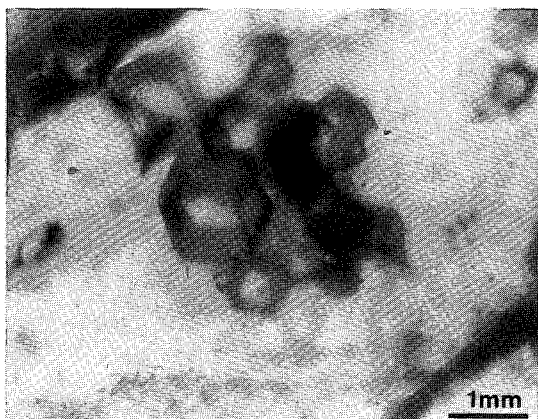
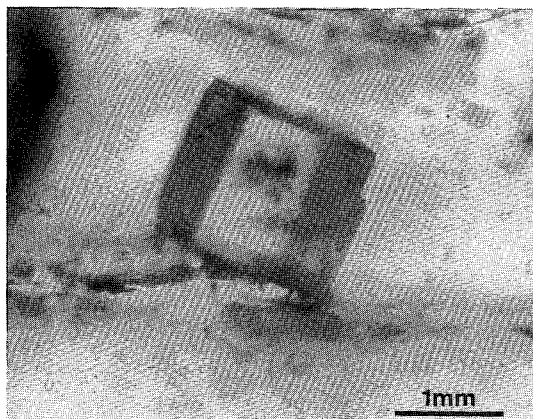


FIG. 1. Transmitted-light photomicrographs showing rhombs of trembathite in a halite matrix.

## CRYSTALLOGRAPHY

Single-crystal X-ray precession work was attempted but was unsuccessful owing to the complex polysynthetic twinning present in trembathite. X-ray powder diffractograms were collected using a Philips PW1710 automated diffractometer (at the University of New Brunswick) equipped with a theta-variable incident-beam slit and a diffracted-beam monochromator. Patterns were obtained using  $\text{CuK}\alpha$  X radiation, 40 kV and 20 mA, a step width of  $0.02^\circ 2\theta$ , and a count time of 5 s/step over the angular range  $3\text{--}135^\circ 2\theta$ . Halite was then added as an internal standard, and the pattern was recollected using the same parameters as above. The step-scanned powder data were analyzed using the program MICRO-PEAK (Materials Data, Inc. 1987).

The powder-diffraction pattern for trembathite is similar to that of congolite, defined as  $\text{Fe}_3\text{B}_2\text{O}_{13}\text{Cl}$  by Wendling et al. (1972). The powder pattern of congolite is indexed on a hexagonal unit-cell, with the space group  $R3c$ . Dowty & Clark (1973) completed a single-crystal structure refinement of a mineral referred to as "the trigonal analogue of ericaite,  $\text{Fe}_3\text{B}_2\text{O}_{13}\text{Cl}$ "; *i.e.*, congolite. The powder pattern of trembathite may be indexed using a hexagonal unit-cell with space group  $R3c$ . The powder pattern of trembathite also is rather similar to that of boracite,  $\text{Mg}_3\text{B}_2\text{O}_{13}\text{Cl}$ , which is orthorhombic, space group  $Pca2_1$  (Dowty & Clark 1973). X-ray powder patterns were therefore calculated using the program MICRO-POWD (Smith & Smith 1987) for both structures using the Mg/Fe ratio determined from the electron-microprobe study (see below). The calculated patterns indicate that the space group of trembathite is  $R3c$  and not  $Pca2_1$ , as also indicated by the optical properties.

In order to verify that trembathite is isostructural with congolite, the X-ray-diffraction data were recollected for a Rietveld structure refinement using a Philips PW1710 automated diffractometer (at the University of Manitoba) equipped with a fixed  $1^\circ$  incident-beam slit and a diffracted-beam monochromator. The data were collected using  $\text{CuK}\alpha$  X radiation, 40 kV and 40 mA, a  $0.05^\circ 2\theta$  step-width and a count time of 5 s/step over an angular range  $20\text{--}135^\circ 2\theta$ . The crystal structure was refined with the program LHPM1 (Hill & Howard 1986, a modified version of the program reported by Wiles & Young 1981) in the space group  $R3c$  using the structural parameters of congolite (Dowty & Clark 1973) as a starting model. The refinement converge to  $R$  values of  $R_{\text{Bragg}} = 5.1\%$ ,  $R_p = 11.4\%$ ,  $R_{\text{wp}} = 16.3\%$  ( $R_p = \sum_i \{|I_{\text{obs}} - I_{\text{calc}}| / \sum_i \{I_{\text{obs}}\}\}$ ,  $R_{\text{wp}} = [\sum_i \{w_i(I_{\text{obs}} - I_{\text{calc}})^2\} / \sum_i \{w_i(I_{\text{obs}})^2\}]^{1/2}$ ). The refinement results indicate that trembathite is

TABLE 1. POWDER-DIFFRACTION DATA FOR TREMBATHITE\*

I	d(meas)	d(calc)	hkl
13	6.065 Å	6.062 Å	012 <sup>+</sup>
12	4.285	4.286	110, 104 <sup>+</sup>
34	3.497	3.499	202, 008 <sup>+</sup>
100	3.028	3.031	024 <sup>+</sup>
66	2.711	2.711	122, 116
23	2.475	2.474	300 <sup>+</sup> , 214, 018
37	2.144	2.144	220, 208
73	2.050	2.049	131, 223, 217, 119
8	2.021	2.021	312, 308 <sup>+</sup> , 1010
7	1.917	1.917	134, 128 <sup>+</sup>
25	1.828	1.828	042, 226
20	1.749	1.750	404 <sup>+</sup> , 0012
12	1.682	1.681	232, 2110
10	1.621	1.620	410, 324 <sup>+</sup> , 318, 1112
11	1.578	1.579	143, 235, 229, 1211
8	1.516	1.516	048 <sup>+</sup>
13	1.470	1.470	502, 416, 1310, 0114
10	1.430	1.429	054, 238, 3012
7	1.399	1.400	241, 333, 3111, 2113
7	1.390	1.391	422, 4010, 2014
14	1.356	1.356	244, 2212
1	1.323	1.323	152, 336, 1214
6	1.293	1.292	514, 508 <sup>+</sup> , 1016
5	1.271	1.271	155, 247, 2311
11	1.237	1.238	600, 428 <sup>+</sup> , 0216

\* The powder pattern is indexed on a hexagonal unit-cell, space group  $R3c$ ,  $a$  8.574(2),  $c$  20.99(1) Å. The data have been corrected using halite as an internal standard.

+ Indices used to derive the cell dimensions. Each index was chosen based on intensity data from the calculated powder pattern.

isostructural with congolite, and that the space group is  $R3c$ . Thus trembathite is the Mg-analogue of congolite and the rhombohedral dimorph of boracite. The powder pattern for trembathite is given in Table 1, as corrected using halite as the internal standard. The indices correspond to the hexagonal unit-cell refined using 12 indexed reflections with the program CELREF (Appleman & Evans 1973) with  $a$  8.574(2),  $c$  20.99(1) Å,  $V$  1336.6(6) Å<sup>3</sup>.

## CHEMICAL DATA

Electron-microprobe analyses were carried out using a JEOL instrument (Research and Productivity Council, Fredericton, New Brunswick) with an operating voltage of 10 kV and a sample current of 50 nA, as measured on a Faraday cup. The electron beam was defocused to 20  $\mu\text{m}$  as the mineral was not stable under a smaller beam; the mineral was found to be quite stable under these conditions. Energy-dispersion spectra were collected to identify the elements present. Wavelength-dispersion data were then collected using the following standards: dolomite (Mg), rhodochrosite (Mn), hematite (Fe), calcite (Ca), sylvite (Cl) and boron nitride (B). The collection time for each element was a function of the peak-to-background ratio, with a maximum collection time of 20

TABLE 2. CHEMICAL COMPOSITION OF TREMBATHITE<sup>§</sup>

Volume	Zone 1 (1%)	Zone 2 (33%)	Zone 3 (60%)	Zone 4 (6%)	Average <sup>#</sup>
MgO (wt%)	21.49	21.26	23.32	13.33	22.02
MnO	0.34	0.48	0.44	1.04	0.49
FeO	13.15	13.79	12.54	23.04	13.59
CaO	0.00	0.01	0.01	0.01	0.01
Cl	8.86	8.89	8.55	8.36	8.29
B <sub>2</sub> O <sub>3</sub> *	57.39	57.21	57.68	54.44	57.33
Cl=O	-2.02	-2.03	-2.15	-1.89	-2.09
Total	99.30	99.71	101.39	98.33	100.63
Mg <sub>2</sub> <sup>2+</sup>	2.25	2.23	2.40	1.48	2.29
Mn <sup>2+</sup>	0.02	0.03	0.03	0.07	0.03
Fe <sup>2+</sup>	0.77	0.81	0.72	1.43	0.79
Ca <sup>2+</sup>	0.00	0.00	0.00	0.00	0.00
Cl <sup>-</sup>	1.08	1.07	1.12	1.08	1.10
B <sub>2</sub> <sup>3+</sup>	8.95	8.93	8.86	7.00	8.89
O <sup>2-</sup>	12.94	12.93	12.88	12.95	12.90
Σ <sup>[6]</sup>	3.04	3.07	3.15	2.98	3.11
Mg/(Mg+Fe)	0.74	0.73	0.77	0.51	0.74

\* B<sub>2</sub>O<sub>3</sub> has been calculated based on stoichiometry. # The average is weighted based on zone volumes estimated from back-scatter photographs. § Other crystals of trembathite studied indicate that the composition and zones vary considerably from crystal to crystal.

seconds for each element. Analyses were reduced using the  $\phi(\rho z)$  data-correction program. Boron concentrations are in the range 50–60 wt% B<sub>2</sub>O<sub>3</sub>. Owing to an inadequate standard, the boron analyses are considered to be systematically low; the proportion of B<sub>2</sub>O<sub>3</sub> given in Table 2 was calculated from stoichiometry.

A 1-mm crystal of trembathite was selected for electron-microprobe study. It shows concentric Mg–Fe zoning; four zones were analyzed (Table 2). Weighted averages of the zones, based on their estimated volumes (from back-scatter photographs), were used to determine the overall formula of the crystal: zone 1 (inner core) 1%; zone 2 (outer core – inner rim) 33%; zone 3 (outer rim) 60%; zone 4 (small sector zone) 6% (Table 2). The volume-weighted average composition was recast to the trembathite formula based on O + Cl = 14. The empirical formula is (Mg<sub>2.29</sub>Fe<sub>0.79</sub>Mn<sub>0.03</sub>)B<sub>6.89</sub>O<sub>12.90</sub>Cl<sub>1.10</sub>, and the ideal formula is (Mg,Fe)<sub>3</sub>B<sub>7</sub>O<sub>13</sub>Cl.

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