Borate Minerals from the Penobsquis and Millstream Deposits of Southern New Brunswick, Canada

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Abstract

As one part of the study on borate mineral diversity, an investigation was carried out on the potash deposits of Penobsquis and Millstream, Kings County, New Brunswick. These deposits are marine evaporates and the borate assemblages occur in specific halite/sylvite layers. Species include: boracite, brianroulstonite, chambersite, colemanite, congolite, danburite, hilgardite, howlite, hydroboracite, penobsquisite*, pringleite*, ruitenbergite*, strontioginorite, szaibelyite, trembathite*, veatchite, volkovskite and walkerite* (*new species). In addition 41 other non-borate species have been identified from drill-core samples.*

The borate assemblages differ between the two deposits and in each deposit the borate minerals vary stratigraphically. At Millstream boracite is the most common borate in the sylvite + carnallite layers with hilgardite in the lower halite strata. At Penobsquis there is an upper unit of hilgardite + volkovskite in sylvite + halite, a middle unit of hydroboracite in halite and a lower unit of trembathite-congolite in sylvite. At both deposits the B isotope ratios are consistent with a seawater source without any need for a more exotic interpretation [$\delta^{11}B$(‰) range is 21.5–37.8 for 19 analyses]. The assemblage at Penobsquis is consistent with a fore-basin deposition by evaporation while that of Millstream, a more remote basin, is indicative of a late-stage periodic influx of concentrated salts from the fore-basin.

Structural classification of the borate minerals from southern New Brunswick (Burns et al. 1995, Grice et al. 1999) place most of them in the infinite framework class with a dominance for cross-linked rings in the fundamental building block. This high degree of polymerization is typical of borate mineral structures crystallizing from a hyper-saline solution.

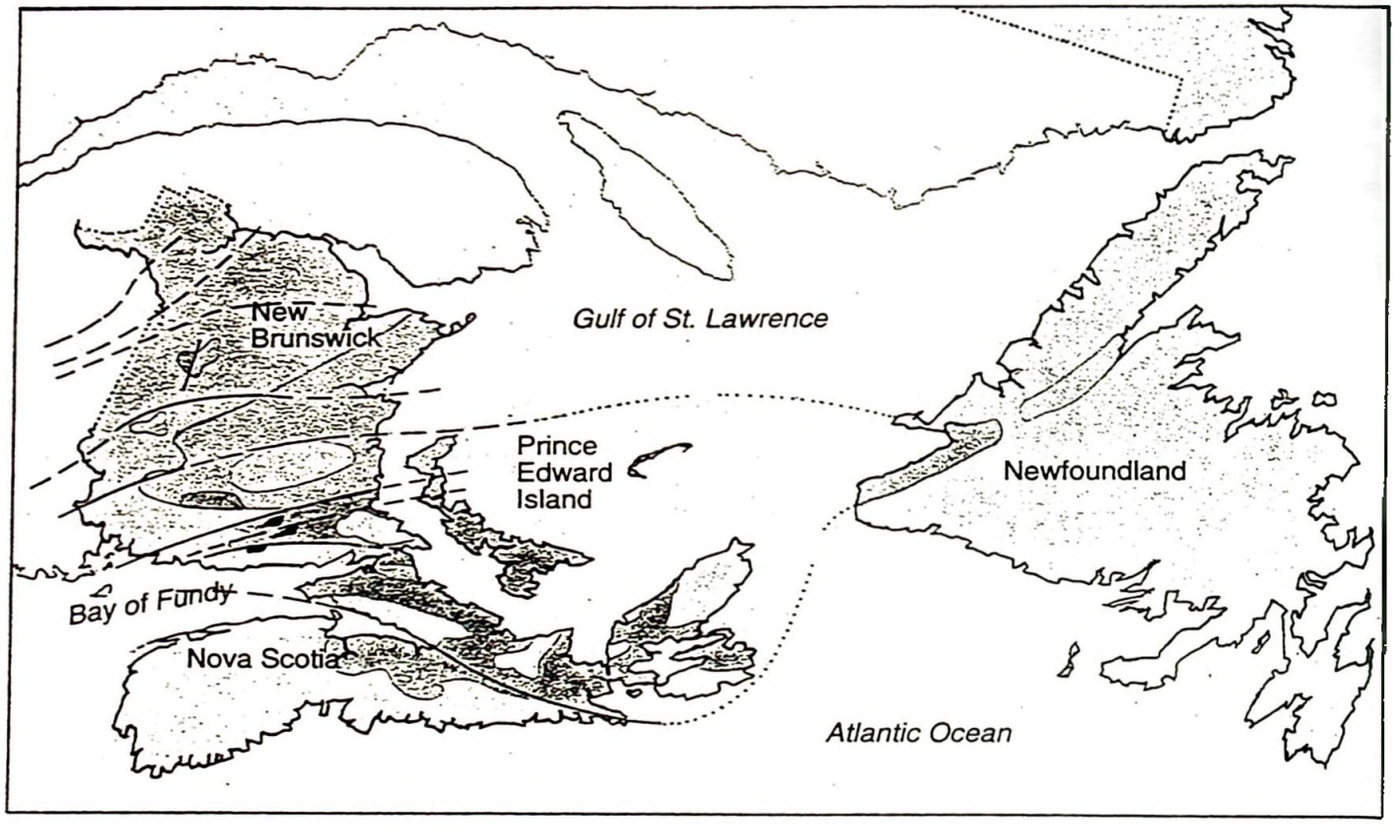
Sammendrag på norsk

Det er foretatt en studie av diversiteten av boratmineraler ved forekomstene Penobsquis og Millstream, King County, New Brunswick. Forekomstene er marine evaporitter, og boratene opptrer i bestemte lag av halitt og sylvitt. Det er påvist 18 ulike borater, herav brianroulstonitt, penobsquisitt, pringleitt, ruitenbergitt, trembathitt og walkeritt som nye mineraler. I tillegg er det påvist 41 andre mineraler i forekomstene. B-isotopforholdet viser at forekomstene er dannet av sjøvann. De fleste boratene fra New Brunswick er av en strukturtype som er typisk for boratmineraler som er dannet fra overmettede løsninger.

Introduction

Borate mineralization in eastern Canada was first documented by How in1857 who identified ulexite and ginorite in the gypsum deposits of Windsor, Nova Scotia. How later reported a new mineral from Noel, Hants Co., Nova Scotia which he named "silicoboro-calcite" (now howlite) occurring as nodules in the gypsum

Location map: New Brunswick potash deposits
(after Webb and Roulston 1994)



Basement highs

Carboniferous deposition (excluding Windsor Group evaporites)

Carboniferous deposition (including Windsor Group evaporites)

Fault (defined, assumed)

New Brunswick potash deposits

formation. Later in 1957 Goodman reported danburite at White Head, Victoria Co. and inyoite from Wentworth area, Hants Co., Nova Scotia. Howlite and ulexite have been reported from several other localities in the gypsum formations of Nova Scotia, New Brunswick and Newfoundland.

In 1971 a provincial government exploration project for high-grade salt deposits made the initial discovery of potash in the Sussex, New Brunswick area. The importance of the potash discovery as an important source of potassium for the fertilizer industry precluded any immediate interest in salt. Further exploration outlined three important sylvite deposits: (1) Penobsquis, 12 km NE of Sussex is owned and operated by Potash Corporation of Saskatchewan Incorporated (New Brunswick Division); (2) Clover Hill (Salt Springs) is owned by Potash Corporation of Saskatchewan Incorporated (New Brunswick Division) but is not presently operating; and (3) Millstream, 10 km west of Sussex has never been mined and the mining lease is held by the provincial government of New Brunswick. As these deposits were mined or developed it became evident that they contained a significant concentration of borate minerals. The borate mineral assemblage was discussed by Roulston & Waugh (1981) for the Penobsquis and Salt Springs deposits. The present study for the Penobsquis and Millstream deposits (drill core for the Salts Springs deposit was not available) looks at the various assemblages in several cores and correlates them with the host strata.

Mineral Descriptions

Boracite $Mg_3B_7O_{13}Cl$

Orthorhombic

Boracite is commonly found at both Penobsquis and Millstream deposits. It occurs as pseudo-cubic, -dodecahedral, -tetrahedral crystals of millimetric size and as multifaceted spheroids of fine-grained aggregates to 40 mm. It is colorless, white, gray, pale yellow to orange and pale blue to pale green. The crystals are translucent to transparent with a vitreous luster. Boracite is brittle with no cleavage and an uneven to conchoidal fracture.

Brianroulstonite

$Ca_3B_5O_6(OH)_7Cl_2 \bullet 8(H_2O)$

Monoclinic

First described from the Penobsquis deposit by Grice *et al.* (1997), which remains the only known locality. It is very rare being found as a few flakes in two samples in this deposit. It is found in halite intimately associated with hilgardite, pringleite, trembathite, sellaite, fluorite, hematite, penobsquisite, a mica group mineral and a clay group mineral. It occurs as cleavable masses to 2 mm with individual micaceous crystals to 0.2 mm. The thin colorless to white {010} lamellae are flexible, transparent to translucent, with a vitreous luster and a white streak. It has a perfect {010} cleavage. It has a unique sheet structure among borate minerals (Grice *et al* 1999).

Chambersite $Mn_3B_7O_{13}Cl$

Orthorhombic

Chambersite, a member of the boracite group, was found in only one sample from the Penobsquis deposit and thus it must be considered very rare. It is found in orange halite associated with hydroboracite, hilgardite, volkovskite, szaibelyite, anhydrite, a mica group mineral, magnesite and quartz. It occurs as 0.5 to 1.5 mm euhedral, light-blue, flattened tetrahedrons. There is no cleavage and the fracture is uneven.

Colemanite $Ca_2B_6O_{11} \bullet 5(H_2O)$

Monoclinic

Colemanite is found as a common accessory in the Penobsquis deposit but it was found in but one sample at

Millstream. It occurs as single pseudo-rhombohedral to short prismatic crystals up to 3 mm and as groups of crystals or nodules to 1 cm. It is colorless, pale yellow, pale to dark orange and brown. Crystals are translucent to transparent, often etched and with a vitreous to dull luster. Mohs' hardness is 4½ and it has a perfect {010} cleavage.

Congolite $Fe_3B_7O_{13}Cl$
Orthorhombic

Congolite, a member of the boracite group, occurs as zones within congolite-trembathite crystals. Although it occurs at both deposits it is much more common at Penobsquis. It is found as pseudo-cubes of a few mm and is often grey to mauve in color. Common associations include hilgardite and trembathite.

Danburite $CaB_2(SiO_4)_2$
Orthorhombic

It occurs as massive, fine-grained, white nodules up to a few cm. Nodules are difficult to distinguish from similar fine-grained nodules of strontioginorite, anhydrite or boracite group minerals. It was only found at Penobsquis is in association with howlite, volkovskite, hilgardite, strontioginorite, hydroboracite and boracite.

Hilgardite $Ca_2B_5O_9Cl{\bullet}H_2O$
Monoclinic and Triclinic

Hilgardite is very common at Penobsquis and common at Millstream. At Penobsquis it is associated with hydroboracite and volkovskite while at Millstream it occurs with boracite. It forms tabular to platy crystals to 5 mm; sometimes as aborescent clusters or multiple parallel growths to 1 cm. It is colorless, tan, pale yellow and pale to bright orange. Crystals are transparent and vitreous. Mohs' hardness is 5 and it has perfect {010} and {100} cleavage.

Howlite $Ca_2B_5SiO_9(OH)_5$
Monoclinic

Howlite occurs rarely at Penobsquis. It is associated with danburite boracite, hydroboracite, hilgardite and volkovskite. It has elongate [001], flattened {010} and striated crystals up to 0.3 mm and as nodules to 1.5 cm. Crystals are transparent, colorless with a vitreous luster and nodules are a porcellanous white. Mohs' hardness of 3 and a perfect {010} cleavage.

Hydroboracite $CaMgB_6O_8(OH)_6{\bullet}3H_2O$
Monoclinic

Hydroboracite is very common at Penobsquis but rare at Millstream. It is commonly associated with volkovskite, hilgardite and trembathite. It forms crystals of long to short prismatic, flattened on {100} and elongated on [001] up to 2 cm., often with serrated termination's. It is colorless, pale to dark yellow, light orange, light green with a vitreous to silky luster. It has a Mohs' hardness of 3 and is fibrous when crushed with a perfect {001} cleavage. May be cavernous with large fluid inclusions or solid inclusions of boracite, clay, and mica. Strontioginorite observed to spear hydroboracite. It is difficult to distinguish from strontioginorite in small crystals.

Penobsquisite
$Ca_2Fe[B_9O_{13}(OH)_6]Cl{\bullet}4(H_2O)$
Monoclinic

Penobsquisite has been found only at Penobsquis. It forms hemimorphic, triangular single crystals to 1.5 mm in length [010] and flattened on {100}. Forms observed are; pinacoids {100}, {101} and $\{10\bar{1}\}$; and the sphenoids {111}, $\{1\bar{1}0\}$, $\{\bar{1}\,1\,2\}$ and $\{\bar{1}\,\bar{1}2\}$. It is dark yellow to dark orange, transparent to translucent, with a vitreous luster. It has a Mohs' hardness of 3 and is brittle with a conchoidal fracture. It was first described from the Penobsquis deposit by Grice *et al.* (1996).

Priceite, $Ca_4B_{10}O_{19}•7(H_2O)$
Not observed in submitted core sections, reported elsewhere it occurs as 5-16mm white to very light orange clusters, unevenly distributed over a 50cm interval. In lower halite as soft, chalky white modules to 1mm resembling danburite.

Pringleite
$Ca_9B_{28}O_{34}(OH)_{24}Cl_4•13H_2O$ Triclinic
Pringleite has been found only at the Penobsquis deposit, It occurs as colourless, pale orange to tan, platy, subhedral to anhedral cleaved masses to 4 mm in size. As single crystals to 2 mm and groups of crystals to 4 mm, it is clear and colorless to white-translucent, flattened on {010}. Crystals have a pearly to satin luster, and are brittle with a good cleavage {110}. Mohs' hardness is estimated to be 3 to 4. Often pringleite is included with hilgardite and rarely with volkovskite. The mineral was first described by Roberts *et al.* (1993) from Penobsquis, the type locality.

Ruitenbergite
$Ca_9B_{28}O_{34}(OH)_{24}Cl_4(H_2O)_{13}$ Monoclinic
Ruitenbergite occurs as a polymorph with pringleite and the physical properties are nearly identical. It is platy, perfect {100} cleavage. The mineral was first described by Roberts *et al.* (1993) from Penobsquis, the type locality. It is not know to occur at the Millstream deposit.

Strontioginorite
$(Sr,Ca)_2B_{14}O_{23}•8(H_2O)$
Monoclinic
Strontioginorite is found commonly in small amounts at Penobsquis associated with hilgardite, volkovskite, hydroboracite and trembathite. It occurs as colourless, transparent to translucent crystals, elongate on [001], flattened and with perfect {010} cleavage, small (<1mm) crystals may display forms {111}, {010}, {100}, larger crystals often display serrated terminations striated parallel to [001].

Szaibelyite $MgBO_2(OH)$ Monoclinic
Szaibelyite is found as a rare constituent in several sections at Penobsquis, associated with hilgardite, walkerite, hydroboracite and pringleite. It occurs as fine acicular, to flattened crystals on {010}. It is colourless, transparent to translucent with a silky luster. Dense nodules measure up to 4 mm with some to 1cm and single crystals are <1mm with mica group and thin films of Fe oxides. It is fibrous when crushed.

Trembathite, $(Mg,Fe)_3B_7O_{12}Cl$
Trigonal
Trembathite is relatively common at Penobsquis but rare at Millstream. Crystals of a few mm are translucent, colorless, white, gray, very pale green and most commonly in shades of pale blue. Rarely transparent, water clear, often translucent, pseudo-cubic single crystals and groups, with repeated inter-penetrative twinning gives the appearance of a dodecahedron. Tetrahedra show other modifying forms and with occasional inter-penetrative twins. Simple pseudo-cubes modified by {111} rarely show epitactic growths on corners while rarely there are compact, perfect spheres showing no forms. Colorless to pale-green spheres are concentrically zoned about congolite. Single crystals are described as pseudo-cubic forms, {100}, {010}, {001} most common, {111}, {110}, less common. Some specimens display exaggerated {111} forms modified by {110}. The type locality is the nearby Salt Springs deposit (Burns et al. 1992).

Veatchite $Sr_2B_{11}O_{16}(OH)•5(H_2O)$
Monoclinic
Veatchite was observed in several Penobsquis core sections as a rare constituent associated with hilgardite, boracite, strontioginorite and danburite. Translucent, platy crystals up to 2 mm

have a vitreous to pearly luster and are light to dark orange to orange-red in color.

Volkovskite $(Ca,Sr)B_6O_{10}\bullet 3H_2O$
Triclinic

Volkovskite is abundant at Penobsquis and widespread in small quantities at Millstream. At Penobsquis it is associated with hydroboracite and hilgardite plus many minor borate minerals while at Millstream the main associate is hilgardite and trembathite. It occurs as granular masses to 5 cm and as single, pseudo hexagonal, equant to elongate platy crystals. Crystals are vitreous, translucent, colorless, pale to deep orange to pale red.

Walkerite
$Ca_{16}MgB_{52}O_{68}(OH)_{48}Cl_6\bullet 28H_2O$
Orthorhombic

First described from the Penobsquis deposit by Grice *et al.* (2002), which remains the only known locality. Although rare it was found in several parts of this deposit. It is found in halite associated with hilgardite, hydroboracite, volkovskite, boracite, szaibelyite, a mica group mineral, a clay group mineral and anhydrite. It occurs as white bundles of fibres to 7 mm and more rarely as colorless single, acicular crystals elongated parallel to the **c** axis. It is translucent to transparent with a vitreous luster. It is brittle with no apparent cleavage and a splintery fracture. It has some crystal-structure similarities to pringleite, ruitenbergite and penobsquisite (Grice *et al.* 2001)

References

Burns, P.C., Hawthorne, F.C. and Stirling, J.A.R. 1992. Trembathite, $(Mg,Fe)_3B_7O_{13}Cl$, a new borate mineral from the Salt Springs potash deposit, Sussex, New Brunswick. *Canadian Mineralogist*, 30, 445-448.

Burns, P.C., Grice, J.D. and Hawthorne, F.C. 1995. Borate minerals I: Polyhedral clusters and fundamental building blocks. *Canadian Mineralogist*, 33, 1131-1152.

Grice, J.D., Burns, P.C. and Hawthorne, F.C. 1994. Determination of the megastructures of the borate polymorphs, pringleite and ruitenbergite. *Canadian Mineralogist*, 32, 1-14.

Grice, J.D., Burns, P.C. and Hawthorne, F.C. 1999. Borate minerals II. A hierarchy of structures based upon the borate fundamental building block. *Canadian Mineralogist*, 37, 731-762.

Grice, J.D., Gault, R.A. and Van Velthuizen, J. 1996. Penobsquisite: a new borate mineral with a complex framework crystal structure. *Canadian Mineralogist*, 34, 657-665.

Grice, J.D., Gault, R.A. and Van Velthuizen, J. 1997. Brianroulstonite: a new borate mineral with a sheet structure. *Canadian Mineralogist*, 35, 751-758.

Grice, J.D., Gault, R.A. and Van Velthuizen, J. 2002. Walkerite: a new borate mineral from Sussex, New Brunswick. *Canadian Mineralogist*, 40, (in press).

Roulston, B.V. and Waugh, D.C.E. 1981. A borate mineral assemblage from the Penobsquis and Salt Springs evaporite deposits of southern New Brunswick. *Canadian Mineralogist*, 31, 795-800.

Webb, T.C. and Roulston, B.V. 1994. Geology and development of New Brunswick's Potash Deposits: Field Trip #1. *30th Forum on the Geology of Industrial Minerals.*

MOST COMMON BORATE MINERALS FROM SUSSEX, NEW BRUNSWICK, CANADA

MINERAL	FORMULA	CONNECTIVITY	CLASS
Brianroulstonite*	$Ca_3B_5O_6(OH)_7Cl_2 \bullet 8H_2O$	6Δ6□ : ⟨Δ□•⟩	Sheet
Penobsquisite*	$Ca_2FeB_9O_{13}(OH)_6Cl \bullet 4H_2O$	10Δ11□ : ⟨Δ□•⟩–3⟨2Δ□⟩–	Framework
Pringleite*	$Ca_9B_{26}O_{34}(OH)_{24}Cl_4 \bullet 13H_2O$	8Δ7□ : ⟨Δ□•⟩–⟨Δ2□⟩Δ–	Framework
Ruitenbergite*	$Ca_9B_{26}O_{34}(OH)_{24}Cl_4 \bullet 13H_2O$	8Δ7□ : ⟨Δ□•⟩ –⟨Δ2□⟩Δ–	Framework
Trembathite*	$(Mg,Fe)_3B_7O_{13}Cl$	1Δ6□ : [ϕ]⟨3□ ⟩| ⟨3□ ⟩| ⟨3□⟩| Δ	Framework
Walkerite*	$Ca_8MgB_{26}O_{34}(OH)_{24}Cl_3 \bullet 14H_2O$	10Δ10□ : ⟨Δ□•⟩–2⟨Δ2□⟩	Sheet
Boracite	$Mg_3B_7O_{13}Cl$	1Δ6□ : [ϕ]⟨3□⟩| ⟨3□ ⟩| ⟨3□⟩| Δ	Framework
Congolite	$Fe_3B_7O_{13}Cl$	1Δ6□ : [ϕ]⟨3□ ⟩| ⟨3□ ⟩| ⟨3□⟩| Δ	Framework
Colemanite	$CaB_3O_4(OH)_3 \bullet H_2O$	1Δ2□ : ⟨Δ2□⟩	Chain
Hilgardite	$Ca_2B_5O_9Cl \bullet H_2O$	2Δ3□ : ⟨Δ2□⟩–⟨Δ2□⟩	Framework
Hydroboracite	$CaMgB_3O_4(OH)_3 \bullet 3H_2O$	1Δ2□ : ⟨Δ2□⟩	Chain
Szaibelyite	$MgBO_2(OH)$	2Δ : 2Δ	Cluster
Veatchite	$Sr_2B_{11}O_{16}(OH)_5 \bullet H_2O$	3Δ2□,1Δ : ⟨Δ2□⟩–⟨2Δ□⟩,Δ	Sheet
Volkovskite	$KCa_4B_{22}O_{32}(OH)_{10}Cl \bullet 4H_2O$	3Δ2□,1Δ : ⟨Δ2□⟩–⟨2Δ□⟩,Δ	Sheet

*type locality