Brucite — uses, exploration guidelines and selected grass-root exploration targets

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ABSTRACT Brucite is a natural magnesium hydroxide [$Mg(OH)_2$] particularly sought after for its flame-retardant properties, as a raw mineral for the production of caustic or dead-burned magnesia, a variety of other industrial mineral uses, and as a high-grade ore mineral for the production of magnesium metal. Brucite has an advantage over magnesium carbonates, such as magnesite and dolomite, because it does not contain CO_2 in its crystal structure. Consequently, there is no CO_2 released during the calcining or other processing of this mineral except from fuel combustion. This advantage may become even more important in the future as CO_2 is considered the main greenhouse gas contributing to global warming. Carbonate-hosted contact metamorphic/metasomatic (skarn-type) brucite deposits have the best economic potential. The sequence of calcosilicate metamorphic index minerals starting from unmetamorphosed magnesium-bearing carbonate (dolostone or magnesite-bearing rock) to igneous intrusion contact consists of talc, tremolite, forsterite and brucite/periclase. This sequence can be used to focus exploration efforts. The current worldwide brucite market is probably less than 100,000 t/y but it is increasing rapidly. High-grade brucite deposits are expected to become hot exploration targets over the next few years.

KEYWORDS Brucite, Industrial minerals, Fire retardants, Mg-metal, Magnesia, Exploration, Development

INTRODUCTION

Brucite [$Mg(OH)_2$] has a high magnesium content compared to other raw materials commonly used or considered as ore of magnesium metal. It is widely distributed in ultramafic rocks (Hora, 1998; Khan, Ali, & Alam, 1971) and found in a variety of exotic settings (Lee, Fanelli, Cava, & Wyllie, 2000; Malkov, 1974), but nearly all of the brucite deposits of economic interest are hosted by dolomitic marbles or magnesite-bearing rocks affected by contact metamorphism or metasomatism (Simandl, Paradis, & Irvine, 2007). The fibrous variety of brucite (nemalite) is commonly associated with chrysotile in ultramafic rocks (Khan et al., 1971; Ross & Nolan, 2003) and this is the main reason why ultramafic-hosted brucite deposits are not recommended exploration targets. Examples of carbonate-hosted brucite deposits of economic significance are Cross Quarry near Wakefield, Quebec (Hébert and Paré, 1990; Jacob, Cotnoir, Depatie, Goffaux, Dan, & Bergeron, 1991; Perreault, 2003); Kuldur, eastern Russia (Anonymous, 2005); Granåsen, Norway (Øvereng, 2000); Gabbs magnesite-brucite deposit, Nye County, Nevada (Schilling, 1968); and Marble Canyon, Culberson County, Texas (Newman & Hoffman, 1996). A detailed discussion regarding the origin of brucite in contact metamorphic settings is beyond the scope of this paper and is provided by Simandl et al. (2007).

BRUCITE USES

Brucite is one of the minerals classified either as an ore of magnesium metal or as an industrial mineral. Primary magnesium metal production for 2005 is estimated at 667,000 t (Business Research Services Inc., 2006). Many common rock-forming minerals contain magnesium, but brucite, carnallite, dolomite and magnesite are the main ore minerals (Coope 2004; Simandl et al., 2007). Hydrated chlorides other than carnalite (such as bischofite), brines and seawater also represent important Mg resources. In addition, serpentine- and olivine-rich rocks (including asbestos tailings) are possible raw materials for Mg-metal production. The extraction of magnesium from silicates is technologically feasible but economically challenging as proven by the 2003 closure of Noranda's Magnola plant located in Quebec. Magnesium metal and magnesium compounds are also produced from bitterns, seawater and well and lake brines. Figure 1 shows the magnesium content of these raw materials. Because there are no large, high-grade, marble-hosted brucite deposits in production in the western world, natural brucite is not the raw material commonly

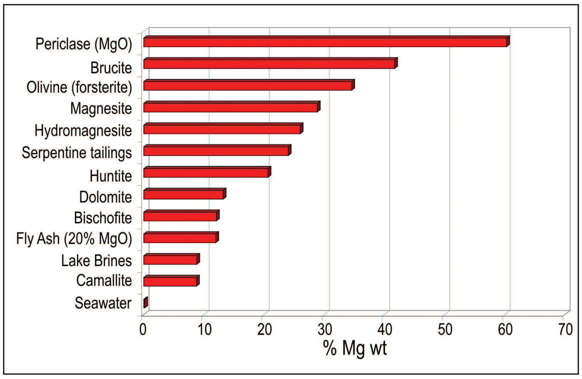

Fig. 1. The main raw materials used or previously considered for use in the production of magnesium metal.

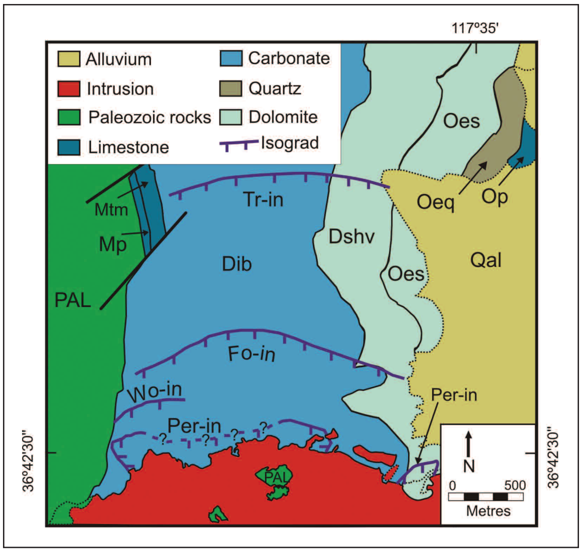

Fig. 2. Mineral zoning in contact metamorphic aureoles could be used to focus exploration efforts. In this example from Ubehebe Peak, California, the first appearance of tremolite (Tr), forsterite (Fo) and periclase (Per) indicates increasing temperature. Periclase formed in the hottest portion of the contact zone, but it was subsequently replaced by brucite. Wollastonite (Wo) is locally developed in layers of calcitic marble. Pognip limestone (Op), Eureka quartzite (Oeq), Ely Springs dolomite (Oes), Hidden Valley dolomite (Dshv), Lost Burro Formation (Dib), Tin Mountain limestone (Mtm), Perdido Formation (Mp), undifferentiated Paleozoic rocks (PAL), alluvium (Qal). From Roselle, Baumgartner, and Valley (1999).

used in magnesium production, as would be expected.

The market for brucite is relatively small, probably less than 100,000 t/y, but expanding rapidly. As an industrial mineral, brucite can be used in caustic and dead-burned magnesia production. It also has a variety of other industrial mineral applications such as a functional filler in plastic compounds, fire and smoke retardant (Hornsby, 2001; O'Driscoll, 2005; Simandl, Simandl, & Debreceni, 2001), electric wire insulation (Bisleri and Fondeur, 2001) and carpet backing. No reliable statistics for the brucite market exist in any of these fields; however, the world market for flame-retardant mineral fillers was estimated at 500,000 t, with magnesium hydroxide accounting for approximately 10% (Rothon, 2004). The magnesium hydroxide estimate includes natural and synthetic brucite. Although natural brucite probably accounts for less than 20,000 t in this market, it is rapidly increasing.

Additionally, brucite is used in wastewater treatment and it was proposed as a key mineral in Britannia mine's (British Columbia) effluent treatment as a neutralizing agent (Kus and Mavis, 2001). Other established uses include agriculture feed, a dietary magnesium supplement, in odour control and in specialty cement preparations as an additive to Portland cement (Godfrey, 2000). Depending on the intended industrial use, natural brucite competes for its share of the market with synthetic brucite, commonly referred to in the manufacturing industry by its chemical formula as magnesium hydroxide, and with other minerals and compounds such as magnesite, dolomite, huntite, hydromagnesite, MgO, CaO and zeolites, and variety of chemical flame retardants.

CONTACT-METAMORPHIC BRUCITE DEPOSITS

Most of the brucite deposits of economic interest are genetically linked to shallow-level igneous rocks intruded into dolomite and/or magnesite-bearing sedimentary or metasedimentary rocks (Simandl et al., 2007). Examples of well-documented brucite occurrences hosted by contact metamorphosed carbonates are described by Cartwright and Weaver (1993), Ferry (1996a; 1996b; 2000), Ferry and Rumble (1997) and Müller, Baumgartner, Foster and Vennemann (2004). At these, and at the majority of other well-documented localities, brucite-bearing zones are located closest to the igneous intrusion. With decreasing temperature and increasing distance from the intrusive-marble contact, the following succession is observed: periclase/brucite-, forsterite-, tremolite- and talc-bearing zones and finally unmetamorphosed carbonate. Similar patterns are seen at several other well-described brucite-bearing localities. The Ubehebe Peak contact aureole, California (Fig. 2), is an excellent example showing the first appearance of index minerals tremolite (Tr), forsterite (Fo) and periclase (Per) partially retrograded to brucite adjacent to an intrusive contact. The absence of a diopside zone was interpreted as one of the evidences for fluid infiltration (Müller et al., 2004). A similar pattern is also observed at the Beinn an Dubhaich aureole, northwest Scotland, by Holmes (1992) and Ferry and Rumble (1997), where the first appearance of talc separates tremolite from unmetamorphosed carbonates. Mineral zonations, together with the position of the heat source (igneous body) can be used in the exploration for brucite deposits to focus on the most favourable zones; however, brucite may also be present along permeable zones away from the intrusive contact and within the roofpendants entirely surrounded by intrusive rocks. Brucite-bearing zones located within the Ubehebe Peak and Beinn an Dubhaich aureoles are not known to contain economic brucite deposits; however, both of these localities show the partial or complete sequence of first appearances of talc, tremolite, forsterite and periclase (commonly retrograded to brucite) that is expected during the exploration for dolomite-hosted brucite deposits.

The Marble Canyon deposit in Texas (Fig. 3) is an example of an economically important brucite deposit. In the Marble Canyon area, the brucite-bearing halo is developed in all dolomitic rocks (both Heuco and Bone Spring formations) surrounding an elliptically shaped intrusive complex consisting of hornblend-bearing granite, syenodiorite and syenogabbro (Newman and Hoffman, 1996).

The brucite-bearing halo is up to 150 m wide. The protolith of the Hueco Formation was less siliceous than that of the Bone Springs Formation; consequently it contains less calcosilicate minerals (impurities) and has a better potential to host economic brucite deposits (Newman and Hoffman, 1996). Applied Chemical Magnesias Corp. markets the brucite-bearing marble mined from this location.

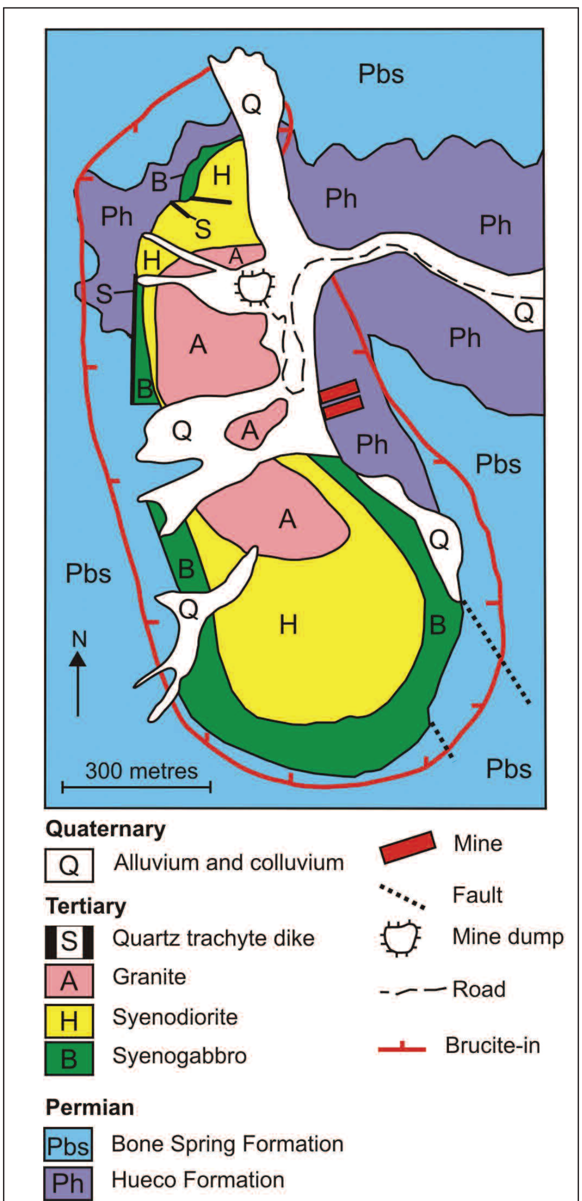

Fig. 3. Marble Canyon, Texas, brucite occurrence represents up to a 150-m wide zone surrounding an intrusive body. All dolomitic rocks overprinted by contact metamorphism contain brucite; however, rocks of the Hueco Formation have better potential to contain economic deposits because they contain less siliceous impurities (Newman and Hoffman, 1996).

BRUCITE IN BRITISH COLUMBIA

Brucite deposits in British Columbia must be considered in light of other potential resources used in the production of magnesium metal and magnesia. The province has a large resource of sedimentary-hosted magnesite deposits as described by Simandl (2002). There is a good exploration potential for the discovery of economic ultramafic-hosted magnesite-talc deposits, as defined by Simandl and Ogden (1999), and magnesite vein deposits (Paradis and Simandl, 1996). Some regions in British Columbia have favourable settings for hydromagnesite ± huntite deposits (Simandl et al., 2001). Olivine deposits and chrysotile-bearing tailings are also available in British Columbia. Consequently, compilation of information on five poorly documented brucite occurrences published by Grant (1987) and summarized below represent grass-root exploration targets. The probability of these occurrences resulting in delineation of large tonnage, high-grade brucite deposits suitable for world-class, magnesium metal or magnesia operation is relatively low; however, with the rapid expansion of brucite's use in specialty filler applications and flame-retardant markets, and with increasing concerns regarding industrial CO_2 emissions (Simandl, 2003), even moderate and small tonnage high-grade brucite deposits may become highly desirable exploration and development targets. As a group, these occurrences (Fig. 4) point to a number of geological settings with promising exploration potential for brucite along the coast within the Insular and Coast Belts. The exact locations of these occurrences are given in the MINFILE <http://www.empr.gov.bc.ca/Mining/Geolsurv/Minfile/> and their descriptions are provided below.

KENNEDY LAKE (MINFILE # 092F 04E)

Carbonates of the Upper Triassic Quatsino Formation are exposed along the south shore of Kennedy Lake and the north slope of Salmonberry Mountain (Eastwood, 1962; 1968). There are at least 12 different mappable units recognized in the area. Carbonate rocks are divided into Upper and

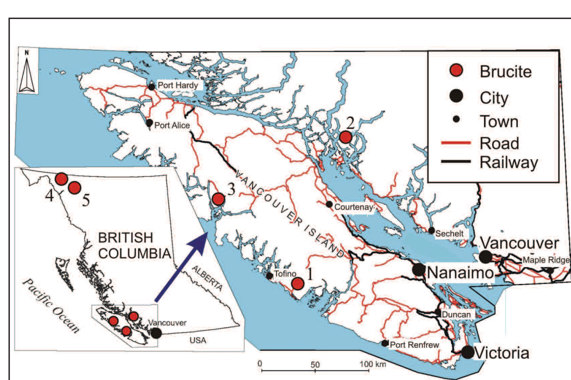

Fig. 4. Location of brucite occurrences in British Columbia. There is only limited information regarding these occurrences; however, their distribution suggests that contacts between dolomitic marbles and plutonic rocks of the Coast Plutonic Belt represent a favourable setting for grass-root mineral exploration. 1) Kennedy Lake, 2) West Redonda Island, 3) Tlupana Arm, 4) Atlin Road and 5) Hurricane Creek.

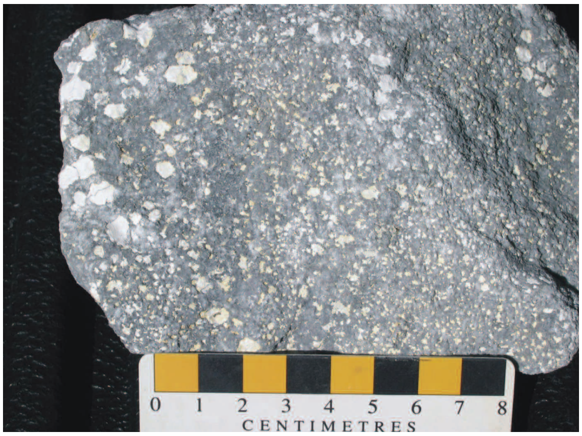

Fig. 5. Natural surface of a brucite–bearing carbonate boulder characterized by mottled texture. White porous, soft patches with negative relief consisting of weathered brucite possibly partially transformed to hydromagnesite. Darker (grey), relatively weathering-resistant matrix consists of calcite. Kennedy Lake area, British Columbia.

Lower Quatsino limestone. Where the fine-grained Upper Quatsino limestone is metamorphosed and recrystallized, it is medium or coarse grained and bleached. This poorly exposed limestone is reported to be at least locally brucite-bearing along its contact with intrusive rocks on the northeast slope of Salmonberry Mountain. Brucite-bearing carbonate blocks can be seen in the proximity of the Kennedy Lake mine. They are also present in the mine dump (Fig. 5), accounting for less than 1% of rock by volume. Carbonates and skarn lithologies consisting of serpentine, garnet, amphiboles, magnetite and sulphides are more abundant than brucite-bearing rocks. Since alteration and metamorphic assemblages are not shown on mine cross-sections produced by Eastwood (1968) and in documents produced by company geologists and consultants, the extent of brucite zones and brucite grade are unknown. Sample KEN 5-9, in Table 1, indicates that the chemical composition of a representative brucite-bearing boulder from the Kennedy Lake area is equivalent of a dolomite.

WEST REDONDA ISLAND (MINFILE # 092K 07W)

The granitic intrusions of the Coast Plutonic Complex contain numerous carbonate roofpendants. Along the Strait of Georgia, these roofpendants belong to the Permian Marble Canyon Formation and/or the Upper Triassic Quatsino Formation (Grant, 1987). A deposit of carbonate (mainly limestone) is reported about 1.2 km west of George Point and was quarried from 1920 to 1926 for use in the paper industry; however, it was not known to contain brucite before 1929 (Goudge, 1944). The carbonate exposure is approximately 40 m wide and at least 135 m high. The limestone is medium to coarse grained, white and grey. Locally it has a mottled texture. Brucite occurs as granules one to three millimetres in diameter and accounts for up to 30% of the rock. Brucite grains have a concentric structure and most are surrounded by white dolomite within a calcite matrix. Serpentine grains appear as the main silicate impurity.

Sample 1 in Table 1 represents the entire width of the quarry including the brucitic and non-brucitic limestone. Sample 2 represents a 6 m width of brucite-bearing carbonate. The MgO/CaO ratio indicates that the composition of brucite-bearing carbonate is equivalent to dolomite (Table 1). Parks (1917) indicates that limestone may extend to higher elevations.

Grant (1987) reports a second limestone occurrence nearby. Although the mining of brucite-bearing rocks along the shore in this area may involve permitting difficulties, ongoing logging activity and new logging roads are apparent on satellite images of West Redonda Island. They may facilitate exploration farther from the shore. It would not be surprising if brucite-bearing rocks were present elsewhere on this island.

TLUPANA ARM (MINFILE # 092E 16W)

Metamorphosed equivalents of northwest-trending Upper Triassic Quatsino limestone and dolomite were reported along Deserted Creek where the Quatsino Formation is intruded by granitic plugs and stocks of Jurassic-Cretaceous Coast intrusions (Grant, 1987). The chemical composition of carbonates provided by Goudge (1944) corresponds to limestone. About one kilometre southeast of the limestone quarry on Deserted Creek, hard dolomitic bands are reported to contain numerous scattered spots up to 5 mm in diameter. The spots contain crystals or crystalline aggregates that appear dark on the fresh surface. The material is more soluble than the host rock and weathers to a white fibrous residue left in cavities or pits on the dolomite surface (Parks, 1917). This description does not positively identify brucite, but the texture fits the description of virtually all known brucite occurrences in Canada. We were unable to locate this brucite outcrop. Samples of carbonates, BRU 5-1 and BRU 5-2, were collected in this area; however, their magnesium content is too low to be a favourable protolith for formation of economic brucite deposits. Additional ground follow-up is needed.

Table 1. Chemical composition of brucite-bearing rocks and related carbonates

ELEMENT	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	LOI	CO_2	H_2O+105°C	SUM
Sample No.	%	%	%	%	%	%	%	%	%	%
1*	1.28	0.22	0.32	9.22	46.27			39.94	2.94	
2*	0.48	0.05	0.18	20.5	37.21			34.6	6.48	
BRU 5-1	0.15	0.03	0.36	5.18	50.48	0.01	43.7			99.93
BRU 5-2	1.02	0.03	0.18	5.31	50.26	0.01	43.1			99.92
KEN 5-9	0.23	0.13	0.39	21.73	36.12	0.01	41.3			99.92

*From Parks (1917). Na_2O, K_2O, TiO_2 P_2O_5, Mn and Cr_2O_3 contents of these rocks is near the detection limit of the analytical method and are not reported.

ATLIN ROAD (MINFILE # 104N 13W)

Brucite is reported immediately south of the Yukon border and east of the Atlin Road. It occurs in high-magnesian limestones of the Cache Creek Group that have been thermally metamorphosed at their contact with the Black Mountain granite (Grant, 1987). Aitken (1959) provided a similar description, but he also reports that brucite coexists with serpentine. The extent of mineralization and brucite concentration in carbonates are not reported. No chemical analyses are available.

HURRICANE CREEK (MINFILE # 104N 06W)

Brucite is reported in the area east of Hurricane Creek and south of Hayes Peak. The host rocks are contact-metamorphosed limestones and limestone breccias of the Cache Creek Group at the contact with Jurassic Mount McMaster granitic intrusions (Grant, 1987). Brucite is believed to coexist with serpentine (Aitken, 1959). As is the case of the Atlin Road showing, the extent of mineralization and brucite content of carbonate host rock are not reported. No chemical analyses are available.

GUIDELINES FOR MINERAL EXPLORATION AND DEVELOPMENT

Brucite currently has a relatively small market, largely due to the rarity of high-grade world-class deposits in comparison to more common magnesium-bearing minerals such as dolomite and magnesite. If medium- to high-grade brucite deposit(s) with acceptable tonnage are discovered in British Columbia, either along the coast or close to major industrial or population centres, there should be no problem finding a market. Such brucite deposits could be a source of material for a variety of industrial mineral applications in the manufacturing of caustic or dead-burned magnesia or for the production of magnesium metal. One of the most important advantages of brucite over carbonates is that it does not contain CO_2 that would be released during its calcination or processing. The future use of brucite may involve CO_2 credits.

Although brucite is relatively widespread as an accessory mineral in a variety of lithologies, Mg-rich carbonate horizons within contact metamorphic aureoles have the best exploration potential. Dolostone or magnesite-bearing protoliths are most favourable as they provide in situ sources of magnesia. A succession of talc, tremolite, (diopside) and forsterite-bearing zones is expected to separate unaffected carbonates from brucite/periclase-bearing marbles. Brucite-bearing zones are typically located directly along the carbonate-intrusive rock contact as illustrated in Figures 2 and 3; however, brucite-bearing marble may also form roofpendants within plutons.

Under favourable circumstances, remote sensing methods could identify brucite-rich rocks because of their visible and near infrared spectra properties (Kozak and Duke, 1999). The recessive nature of brucite deposits makes boulder tracing one of the most effective prospecting methods. Brucite-bearing carbonate boulders are mostly white or grey. They are characterized by mottled texture formed by porous, soft, pale-coloured patches within grey carbonate matrix (Fig. 5). The contrast between fresh and weathered brucite is shown on Figure 6. Depending on the degree of weathering and ore grade, brucite can be altered to hydromagnesite or atinite to depth greater than five metres and weathered surfaces of outcrops may have a characteristic pitted appearance. While magnesite-hosted, high-grade deposits analogous to the Kuldur brucite deposit (Anonymous, 2005) are the most attractive targets because they require little upgrading, lower-grade deposits should not be overlooked because, for some applications, a natural blend of brucite and calcite may represent a good functional filler.

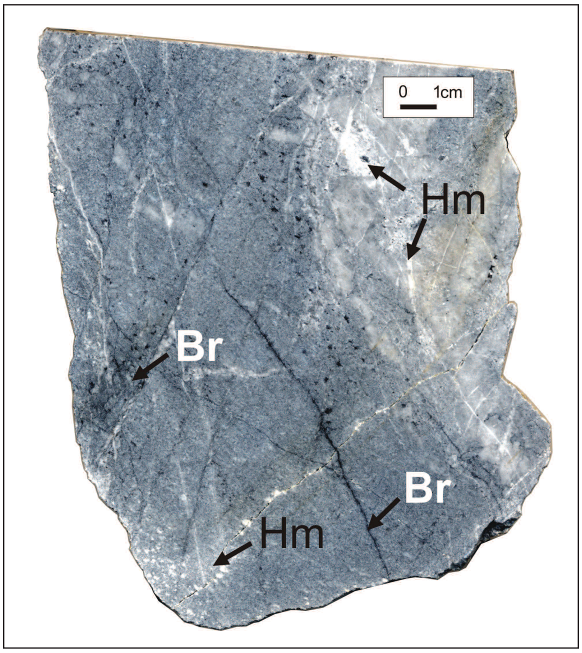

Fig. 6. Cut surface of brucite-bearing marble from the Kennedy Lake area, British Columbia. Fresh brucite (Br) in very dark blue-grey is either disseminated through a matrix or controlled by fractures, suggesting that the fluid infiltration played a significant role in the formation of brucite. The brucite along natural edges of the boulder and along open fractures is weathered to a white, soft, chalky material that may consist of hydromagnesite (Hm) or atinite. Matrix consists predominantly of calcite.

CONCLUSION

Brucite is a mineral with an excellent market growth potential. It is an ore of magnesium metal and exceptional raw material for magnesia production. It is also used in a variety of niche markets such as a functional filler and flame retardant in plastic and construction materials and in environmental rehabilitation. There are several brucite occurrences in British Columbia where the extent of the brucite-bearing zone and its brucite content are unknown. These localities merit further geological assessment. They also mark regions and geological settings favourable for grass-root brucite exploration.

ACKNOWLEDGMENTS

Laura Simandl from St. Margaret's School in Victoria, British Columbia, is credited for collecting the most spectacular brucite specimen at the Kennedy Lake mine. She also provided most of the photographic documentation and participated in rock sampling. Brian Grant and David Lefebure helped to improve an early version of this manuscript.

Paper reviewed and approved for publication by the Industrial Minerals Society of CIM.

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