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GEOLOGY OF THE MOUNT BRUSSILOF MAGNESITE DEPOSIT, SOUTHEASTERN BRITISH COLUMBIA (82J/12, 13)

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KEYWORDS: Industrial minerals, economic geology, magnesite, Cathedral Formation, Middle Cambrian, dolomitization, porosity, base metal association, deposit model.

INTRODUCTION

Magnesite ($MgCO_3$) is an industrial mineral that can be converted into either caustic, fused or dead-burned magnesia. Dead-burned magnesia is used mainly in the manufacture of refractory products; caustic magnesia is used in treatment of water, in animal feedstuffs, fertilizers, magnesia cements, insulating boards and wood-pulp processing, in chemicals and pharmaceuticals and as a curing agent in rubber (Coope, 1987). Magnesium metal is produced either from magnesite or from caustic magnesia.

In the short-term future, production of dead-burned magnesia is expected to remain constant, however, demand for caustic magnesia is increasing (Duncan, 1990). With the increasing trend toward the use of high-performance "magcarbon" refractories, future demand for fused magnesia looks promising.

A number of magnesite deposits are known in British Columbia (Grant, 1987), the most important of these is the Mount Brussilof orebody. It is hosted by dolomites of the Middle Cambrian Cathedral Formation.

HISTORY

The Mount Brussilof deposit was discovered during regional mapping by the Geological Survey of Canada (Leech, 1965). Baykal Minerals Ltd. and Brussilof Resources Ltd. staked and explored the deposit. In 1971, the two companies merged to form Baymag Mines Co. Ltd. In 1979, Refratechnik GmbH. acquired Baymag Mines (MacLean, 1988). In 1980, proven and probable geological reserves were 9.5 million tonnes grading over 95 per cent magnesia in the calcined product and 13.6 million tonnes of 93 to 95 percent magnesia in calcined product. Possible reserves were estimated at 17.6 million tonnes averaging 92.44 per cent magnesia in calcinated product (Schultes, 1986). Previous investigations, including mapping, are described in detail by MacLean (1988).

LOCATION

The Mount Brussilof deposit is located in southeastern British Columbia, approximately 35 kilometres northeast of Radium Hot Springs. It is accessible from Highway 93 by an all-weather unpaved road (Figure 3-2-1). Elevations in the area range from 1250 to 3045 metres above sea level.

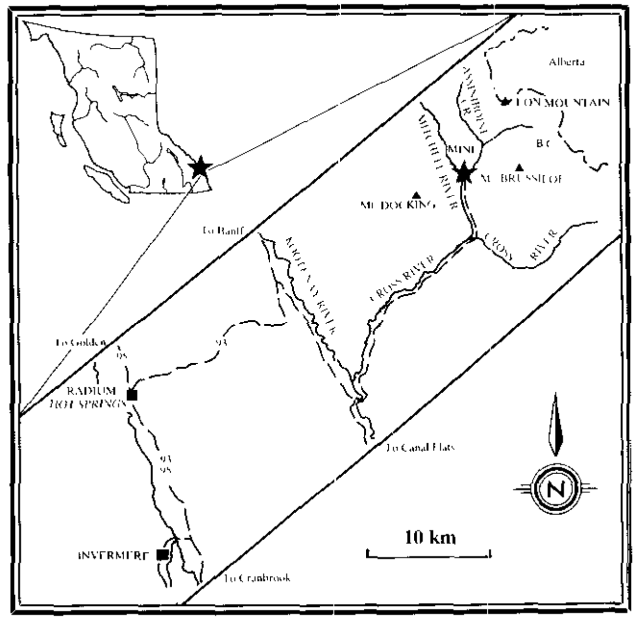

Figure 3-2-1. Location of the Mount Brussilof magnesite mine.

TECTONIC SETTING

The Mount Brussilof deposit is located in the Foreland tectonostratigraphic belt and within the "Kicking Horse Rim", as defined by Aitken (1971, 1989). It is situated east of a Cambrian bathymetric feature commonly referred to as the Cathedral escarpment (Fritz, 1990; Aitken and McIlreath, 1984, 1990). Existence of the escarpment is challenged by Ludwigsen (1989, 1990) who suggests that this feature is a shale-carbonate facies change on a ramp. Leech (1966) described the same feature in the Mount Brussilof mine area (Figure 3-2-2) as a "faulted facies change". In any event, the carbonate rocks east of this feature, which host the magnesite mineralization, were deposited in a shallower marine environment than their stratigraphic equivalents to the west.

STRATIGRAPHY AND LITHOLOGY

The stratigraphic relationship between rocks east of the Cathedral escarpment, and their deeper water equivalents to the west, commonly referred to as the Chancellor Formation, is described by Aitken and McIlreath (1984) and Stewart (1989).

All known occurrences of sparry carbonate, other than veins of calcite or dolomite a few centimetres thick, are located east of the Cathedral escarpment. A composite stratigraphic section of this area is shown on Figure 3-2-3

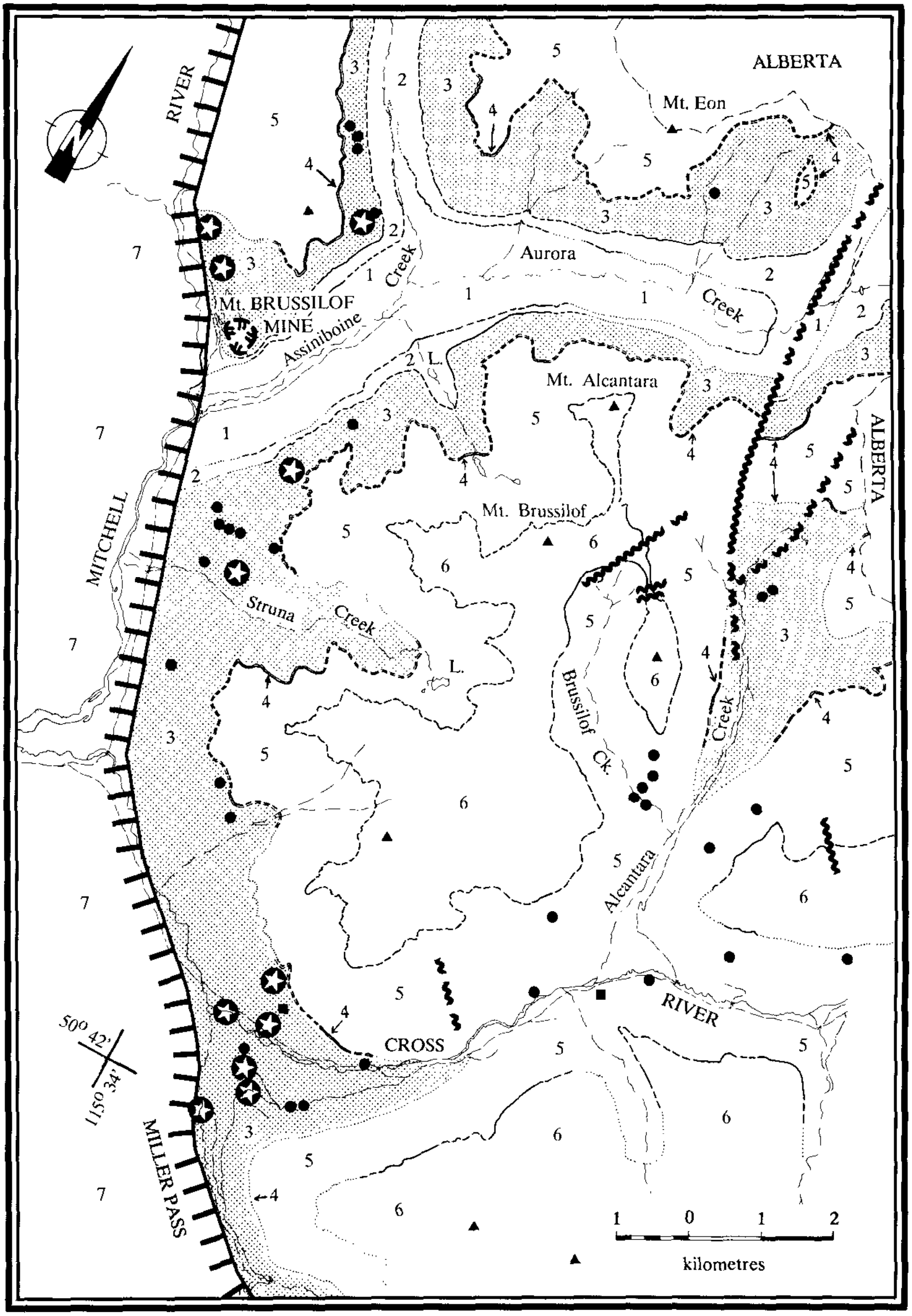

Figure 3-2-2. Geology of the Mount Brussilof area.

LEGEND

Middle Cambrian

7 **Chancellor Formation:** Argillaceous limestone and shales. Basinal equivalent of the Pika, Eldon, Stephen and Cathedral formations

6 **Arctomys Formation:** Purple and red shales with beige dolomite. Overlain by the Waterfowl and Sullivan formations.

5 **Eldon and Pika formations** (undivided): Buff, grey and black massive dolomite, argillaceous dolomite and limestone.

4 **Stephen Formation:** Brown and tan shales. Fossiliferous.

3 **Cathedral Formation:** Buff and grey dolomite and limestone

2 **Naiset Formation:** Thin-bedded, brown and green shale.

Lower Cambrian

1 **Gog Formation:** Massive, tan, quartz sandstone.

SYMBOLS

Open pit

Magnesite

Sparry carbonate

Magnesite (Leech, 1966)

Cathedral Escarpment

Geological contact: defined, approximate, assumed

Fault: defined, approximate

Stratigraphic thicknesses of the formations are approximate. The formations are described below, in order from oldest to youngest.

The Gog Formation is a rusty, grey or buff, medium to coarse-grained, massive to thick-bedded Lower Cambrian sandstone more than 250 metres thick.

The Naiset Formation comprises thinly bedded, brown and green Middle Cambrian shale overlying the Gog Formation. It is 65 to 170 metres thick, characterized by blue-green chlorite spots and by a well-developed cleavage oblique to bedding. Near the Cathedral escarpment this shale may become grey or partially converted to talc and serpentine.

The Cathedral Formation, which hosts the magnesite deposits, is also Middle Cambrian in age. It is about 340 metres thick and consists of buff, white and grey limestones and dolomites. Laminations, ripple marks, intraformational breccias, *yoholaminites* (McIlreath and Aitken, 1976), algal mats, ooliths, pisolites, fenestrae and burrows are well preserved. Pyrite is common either as disseminations or pods and veins.

The Stephen Formation consists of tan to grey, thinly bedded to laminated shale about 16 metres thick, with a cleavage subparallel to bedding. It is of Middle Cambrian age and contains abundant fossil fragments and locally well-preserved trilobites and inarticulate brachiopods.

The Eldon and Pika formations cannot be subdivided in the map area. The lowermost beds of the Eldon Formation, overlying the Stephen Formation, are black limestones approximately 50 metres thick. This basal unit is very distinctive, containing millimetre to centimetre-scale argillaceous layers that weather to a red, rusty colour; elsewere these formations cannot be readily distinguished from the Cathedral Formation, except by fossil evidence.

The Arctomys Formation, also Middle Cambrian in age, is characterized by green and purple shales and siltstones interbedded with beige, fine-grained dolomites. Mud cracks and halite crystal prints are commonly preserved. The thickness of this formation was not determined, as the base marked the limit of mapping.

All the formations are well exposed over the area, except the recessive Stephen Formation, which was not observed in the southern part of the map area. It is not clear if this lack of exposure is due to lack of outcrops or to nondeposition.

STRUCTURE

Rocks west of the Cathedral escarpment are strongly deformed. The deformation is characterized by numerous small-scale folds with subhorizontal fold axes oriented 160° Minor thrust faults, and a well-developed steeply dipping cleavage striking 160° are other typical features. Along the Cathedral escarpment, cleavage is subvertical, closely spaced and injected by dolomite, calcite and siderite(?) veins.

East of the Cathedral escarpment, cleavage is generally absent in carbonates (Cathedral, Eldon and Pika formations), well developed in the Stephen Formation and strongly developed in the Naiset Formation. The rocks outcropping immediately east of the escarpment strike 170° and dip 20° west.

Farther east the bedding is subhorizontal and characterized, by minor, upright, open folds. Several subvertical faults transect this area (Figure 3-2-2). These faults have vertical displacements of tens to hundreds of metres. In the northeastern corner of the study area, deformation in the Naiset Formation is similar to that of the Chancellor Formation, due to a thrust fault outcropping farther east.

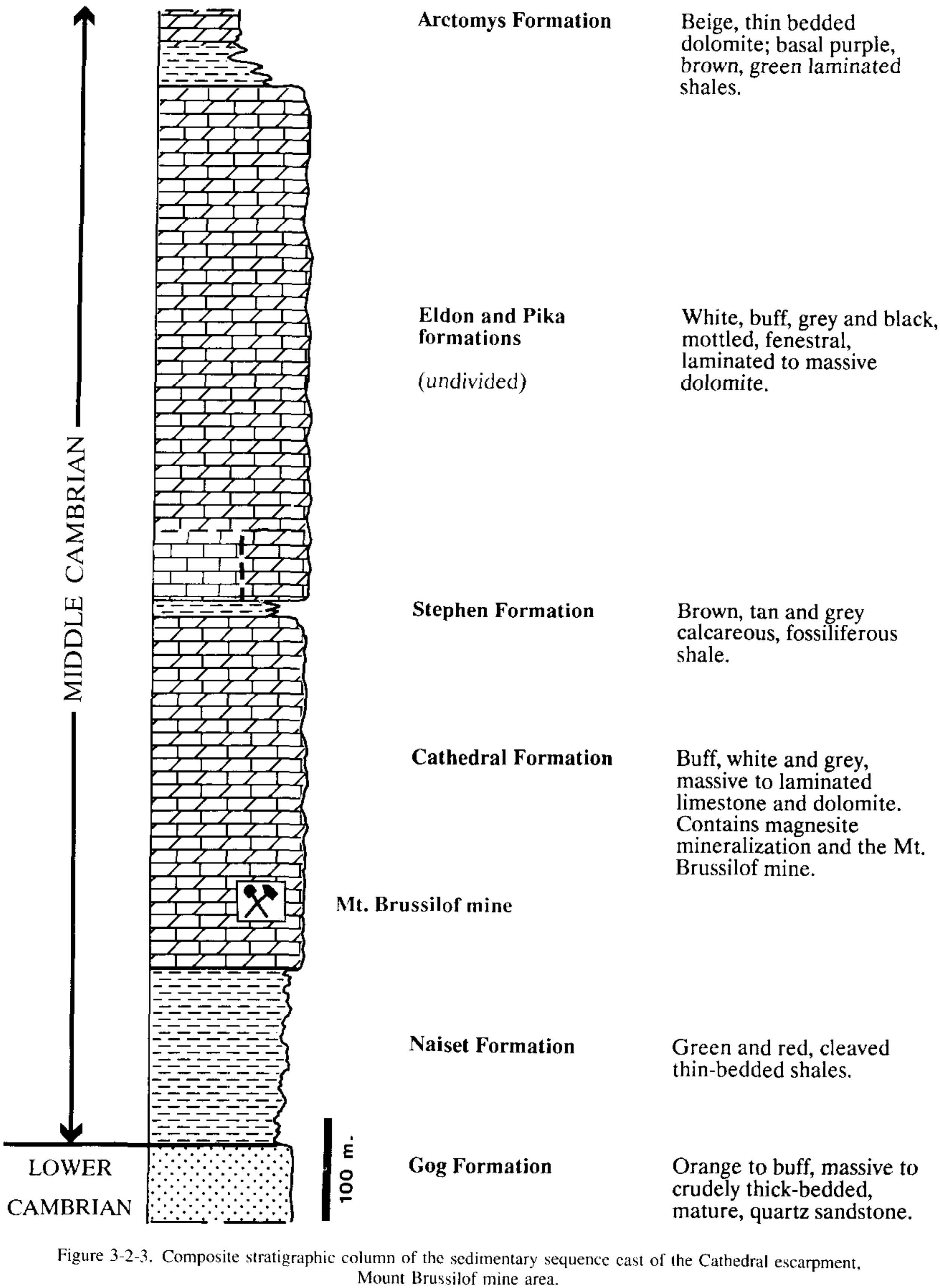

Figure 3-2-3. Composite stratigraphic column of the sedimentary sequence east of the Cathedral escarpment, Mount Brussilof mine area.

MAGNESITE DEPOSITS

Sparry carbonate rocks occur within the Cathedral, Eldon and Pika formations (Figure 3-2-2). They consist mainly of coarse dolomite and magnesite crystals in varying proportions. Magnesite-rich sparry carbonates are restricted to the Cathedral Formation, where they form lenses, pods and irregular masses.

Barren Cathedral Formation consists mainly of fine-grained, massive or laminated dolomites interbedded with limestones. It contains well-preserved sedimentary and diagenetic features. These fine-grained carbonates are locally brecciated and cemented by coarse white dolomite, indicating a strong secondary porosity (Plate 3-2-1).

Parts of the Cathedral Formation are entirely altered to sparry magnesite, forming deposits of economic interest.

Sparry carbonates are separated from limestone by light grey, massive dolomite, which may contain needle-shaped quartz crystals (Plate 3-2-2). The contacts between sparry carbonate masses and the fine-grained dolomite are sharp and may be concordant or discordant (Plates 3-2-3 and 4).

Magnesitic sparry carbonate is usually white or light grey in colour and buff when weathered. It consists of regularly spaced, alternating white and grey magnesite layers (Plate 3-2-5), randomly oriented centimetre-scale white magnesite crystals (Plate 3-2-6) or a mixture of light grey and white magnesite crystals. Common impurities in magnesite ore are isolated rhombohedral dolomite crystals, calcite veins, pyrite veins (Plate 3-2-7), subvertical fractures filled by a mixture of beige ankerite, calcite and chlorite, coarse radiat-

Plate 3-2-1. Dark grey dolomite fragments cemented by coarser white dolomite: Cathedral Formation, outcrop adjacent to Cathedral escarpment.

Plate 3-2-2. Fine-grained dolomite containing acicular quartz crystals (QZ). These crystals are commonly present near the contact of sparry carbonates with dolomite.

Plate 3-2-3. Concordant contacts between sparry carbonate (SC) and fine-grained dolomite (DO).

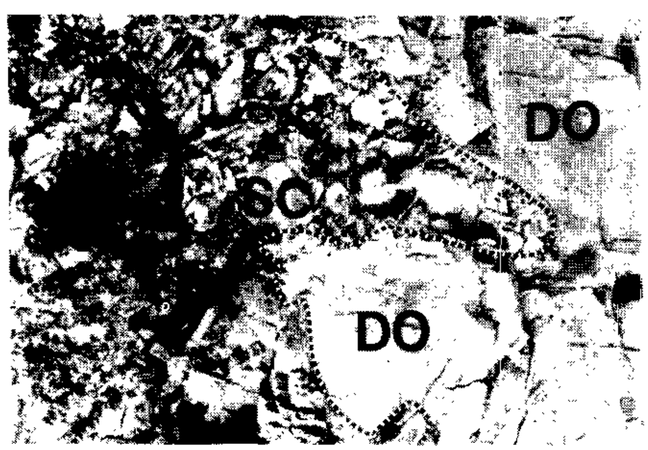

Plate 3-2-4. Discordant, sharp and irregular contact between sparry carbonate (SC) and fine-grained dolomite (DO).

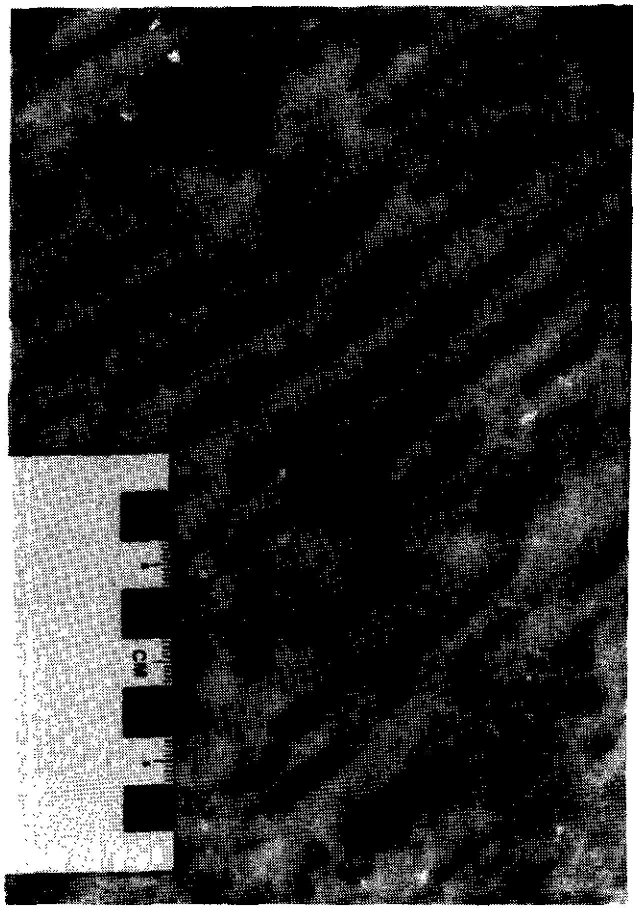

Plate 3-2-5. White and grey, layered sparry magnesite ore from the Mount Brussilof mine.

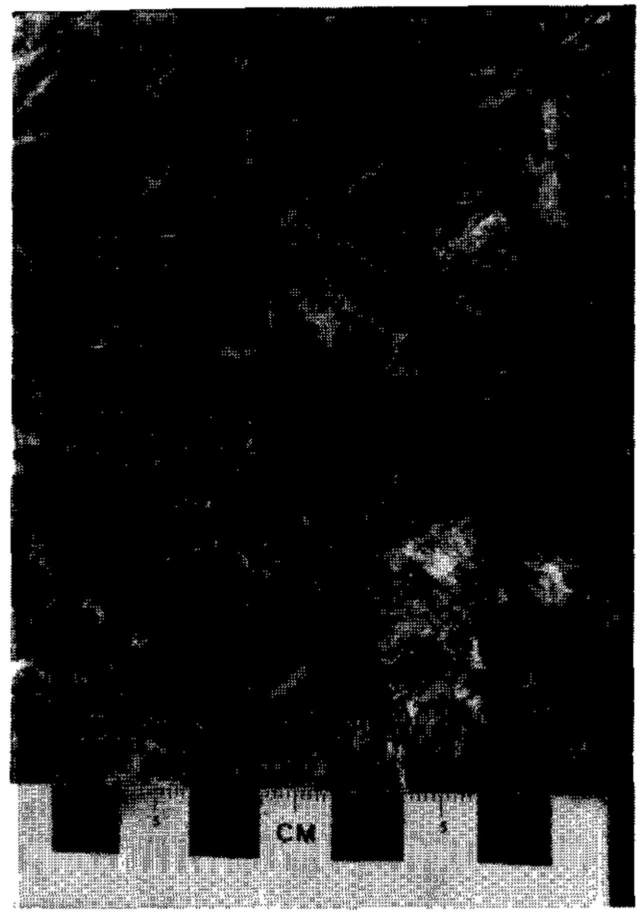

Plate 3-2-6. Randomly oriented sparry magnesite crystals, Cathedral Formation, 100 metres east of the Mount Brussilof mine.

ing or single quartz crystals and coarse pyrite pyritohedrons and octahedrons disseminated within sparry magnesite. Chalcocite, fersmite, phlogopite, talc and coarse, white, acicular palygorskite were also observed in the mine. Boulangerite, huntite and brucite were reported from laboratory analysis by White (1972).

Where fine-grained dolomite is not entirely converted to magnesite, replacement features such as coarse, white carbonate crystals growing perpendicular to fracture planes (Plate 3-2-8) or partings (Plate 3-2-9) and lenses of fine-grained dolomite enclosed by sparry carbonates are common. Bipolar growths of zoned magnesite crystals (Plate 3-2-10), magnesite pinolite (Plate 3-2-11), rosettes and coarse carbonate crystals having lozenge-shaped cross-sections (Plate 3-2-12). All these features are interpreted as replacement textures. Some long magnesite crystals are deformed, suggesting that at least some magnesite predates or is penecontemporaneous with the last period of deformation.

Sparry dolomite rock consists mainly of dolomite rhombs. It forms lenses, veins or irregular masses in fine-grained dolomite and is believed to occur at the same stratigraphic horizons and to contain the same impurities as coarse sparry magnesite.

Dolomite veins cutting magnesite ore occur at the mine, however, magnesite veins were never observed to cut sparry dolomite.

CHEMISTRY OF CARBONATE ROCKS

Analyses of 19 samples of magnesite and dolomite-bearing rocks were available in time for this publication. These samples were analyzed for MgO, CaO, FeO, SiO_2 and Al_2O_3. The major constituents are MgO and CaO, which are negatively correlated (Figure 3-2-4).

The magnesium content of the carbonate rocks varies continuously from dolomite to magnesite. Stoichiometric dolomite and magnesite are given for reference. Fine-grained massive or laminated carbonates are dolomitic in composition. Coarse and sparry carbonates have higher magnesia contents than fine-grained carbonates.

ELEMENTS OF THE GENETIC MODEL

Several elements of a genetic model explaining the origin of the Mount Brussilof deposit are indicated by the tectonic, stratigraphic and structural setting, secondary porosity features, replacement textures, paragenesis and absence of fine-grained magnesite, protodolomite or hydromagnesite, The presence of huntite (White, 1972) remains to be explained.

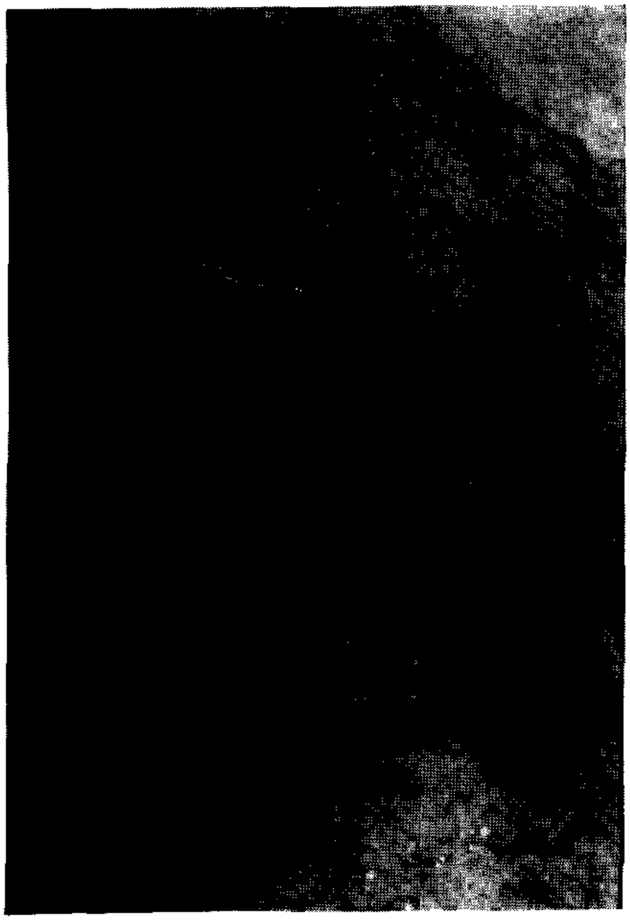

Plate 3-2-7. Pyrite veinlets cutting magnesite rock: Mount Brussilof mine.

Plate 3-2-8. Bipolar growth of sparry carbonates from a fracture plane in fine-grained dolomite that hosts the Mount Brussilof deposit.

It is suggested that the magnesite postdates early diagenesis of the Cathedral Formation and probably of the Stephen, Eldon and Pika formations as well. Widespread dolomitization and subsequent fracturing and brecciation contributed significantly to an increase in porosity. Some of the fracturing may be due to reactivation of a pre-Cathedral escarpment fault or to a difference in competence of deep and shallow-water sediments during the post-Middle Cambrian tectonic activity. However, most of the breccias were probably produced by a partial dissolution and collapse of the carbonate hostrock, caused by incursion of meteoric water or hydrothermal solutions in the manner described by Sangster (1988).

Fluids responsible for crystallization of coarse sparry carbonates reacted with dolomitized, permeable and fractured reef facies along the Cathedral escarpment and moved up-dip along the permeable zones. The fluid cooled and evolved chemically along its path due to interaction with dolomitic hostrock. The most important parameters determining the ability of the fluid to increase the magnesium content of carbonate rock are temperature, the mole Ca^{2+}/mole Mg^{2+} ratio of the solution, the fluid/rock ratio and the salinity of the fluid as well as the permeability, porosity and physical and chemical characteristics of the protolith. The relationship between temperature and mole Ca^{2+}/mole Mg^{2+} ratio is illustrated in Figure 3-2-5, high temperature and low mole Ca^{2+}/mole Mg^{2+} ratio increases the potential of the fluid to convert carbonates to magnesite.

Predictions based on this model suggest that the highest grade magnesite deposits should be located along the edge of the Cathedral escarpment, within the reef facies. Lower grade magnesite deposits and sparry dolomites would be located at a greater distance up-dip from the Cathedral escarpment along the same permeable zones, or adjacent to the escarpment but in the zones of lesser permeability.

This model conforms well to the field observations. It requires confirmation and integration with the results of future petrographic work, geochemical (isotopic, REE, minor and major element) analysis, fluid inclusion and crystallinity studies, mass balance determinations and further thermodynamic considerations. Future studies will focus on constraints on the origin, temperature and composition of the mineralizing fluid, geochemical gradients, paragenetic relationships and fluid/rock ratios.

ECONOMIC CONSIDERATIONS

Several new magnesite showings that are part of a continuous sparry carbonate belt parallel to the Cathedral escarp-

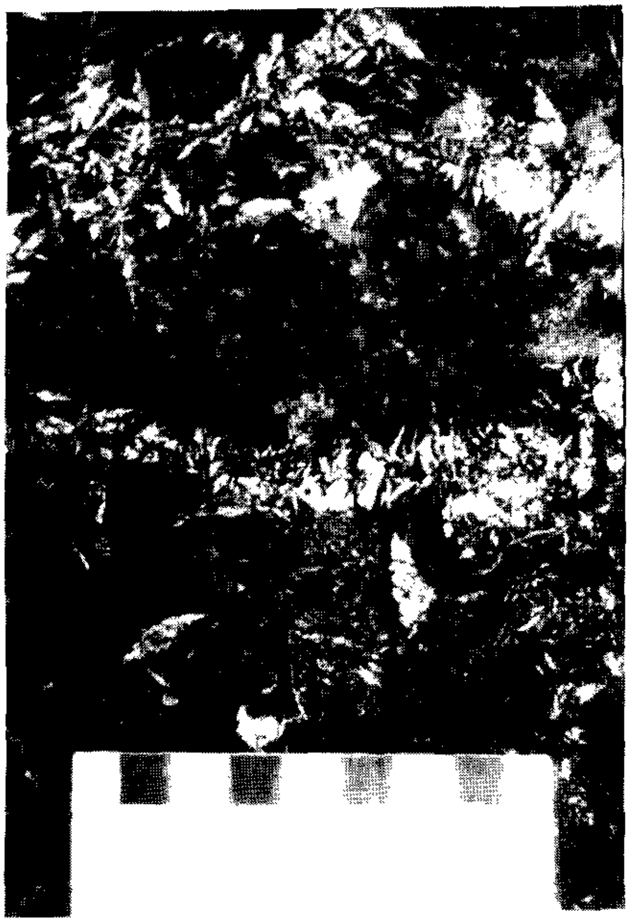

Plate 3-2-9. Subparallel layers of sparry carbonates (white) growing along original parting within fine-grained dolomite; 150 metres east of the Mount Brussilof mine.

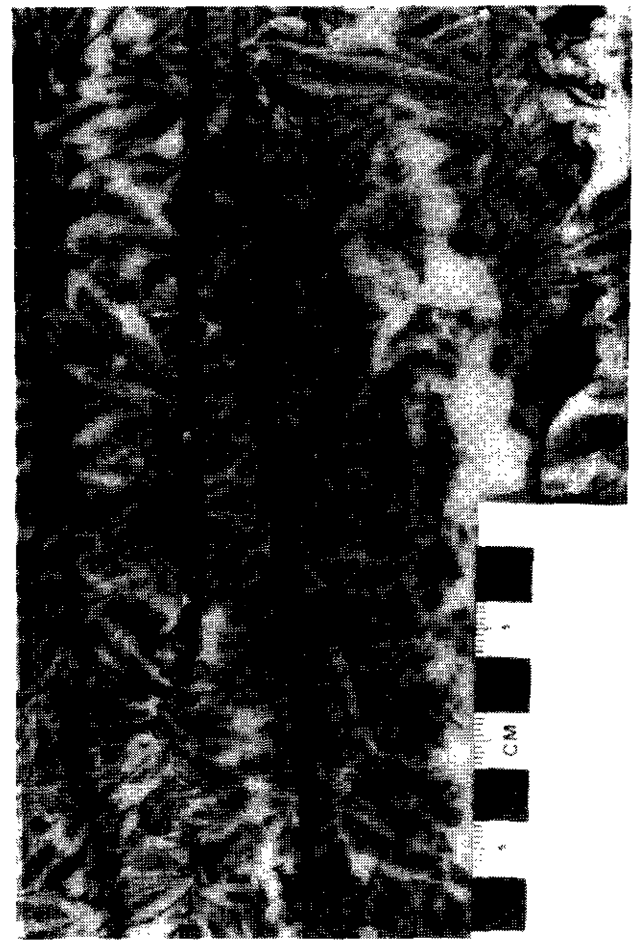

Plate 3-2-10. Bipolar magnesite pinolite; vestigial silty dolomitic protolith (black), zoned magnesite crystals (white and light grey); Mount Brussilof mine.

ment were identified in the course of fieldwork. Magnesia content varies considerably within this belt. About 1 kilometre north of the mine the favorable horizon of the Cathedral Formation is covered by barren Eldon Formation. However the continuity of the mineralization beneath this cover is proved by sparry carbonate showings along the Assiniboine Creek valley. The belt may extend south of the known Miller Pass showings (Figure 3-2-2). Very little is known about the grade of these occurrences and further exploration is justified.

Mapping confirmed that magnesite is not confined to a single stratigraphic horizon within the Cathedral Formation. Sparry dolomite is widespread throughout the formation, and also occurs within the Eldon Formation. The possibility that the Cathedral escarpment is not the only permeable zone that was open to magnesite-forming fluids should be considered by prospectors.

The known association of base metal deposits with the Cathedral escarpment (Aitken and McIlreath,1984), similarities between the dolomitization styles in the Kicking Horse mine (Rasetti, 1951) and in the Mount Brussilof area indicate that exploration should not be restricted to magnesite.

Discovery of a fluorapatite float on Mount Brussilof, the identification of fersmite (a niobium-bearing mineral) and chalcocite, the previously reported occurrence of boulangerite (White, 1972) and abundant pyrite in the Mount Brussilof mine further encourage exploration programs in the Mount Brussilof area.

ACKNOWLEDGMENTS

Baymag Mines Co. Ltd. kindly provided access to company documents and a field office during the lengthy rainy periods of the 1990 field season. Twenty major element analyses were performed by Baymag free of charge. Special thanks are extended to H. Fergen, Mine Manager, and I. Knuckey, Mine Geologist, for their cooperation and assistance. R. Matthew, Consulting Engineer, directed our attention to the mineralogical particularities of the Mount Brussilof mine. Dr. S. Paradis of the Geological Survey of Canada in Quebec, performed most of the density studies used to determine the proportions of magnesite and dolomite. Z.D. Hora of the British Columbia Ministry of Energy, Mines and Petroleum Resources proposed the project and kindly proof-read an earlier version of this manuscript. Enriching discussions with Dr. J.M. Aitken, Dr. I. Jonasson and Dr. D. Sangster from the Geological Survey of Canada are acknowledged.

Plate 3-2-11. Magnesite pinolites (light grey) growing *within a fine-grained dolomite matrix; Mount Brussilof* mine.

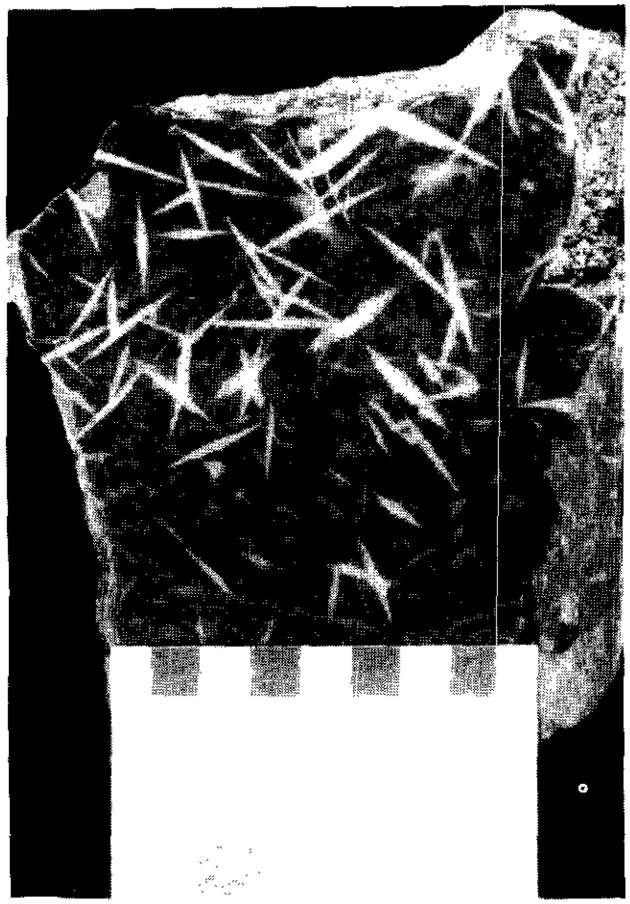

Plate 3-2-12. Lozenge-shaped cross-sections of dolomite crystals (white) growing within fine-grained dolomite: less than 15 metres from the contact between sparry dolomite and sparry magnesite; Miller Pass Road showing.

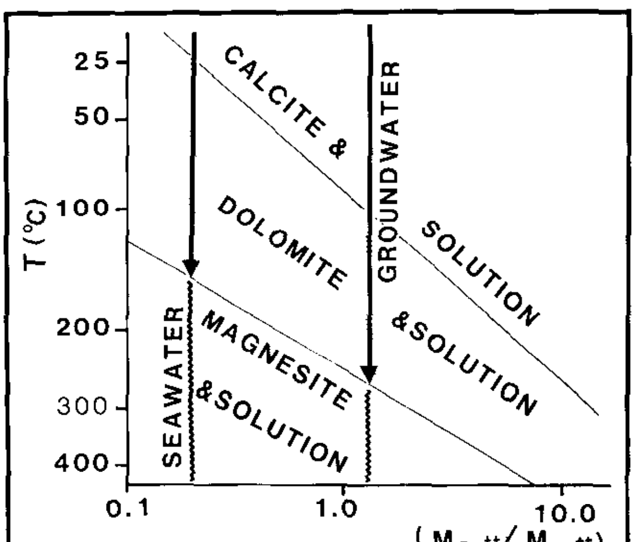

Figure 3-2-5. Potential of a solution to convert carbonate to magnesite as a function of temperature and M Ca^{2+}/M Mg^{2+} ratios. Compositions of ideal seawater and groundwater are shown for refererence. 1 mole chloride solution assumed. After Wilson *et al.* (1990), data extrapolated from Rosenberg, Burt and Holland (1967).

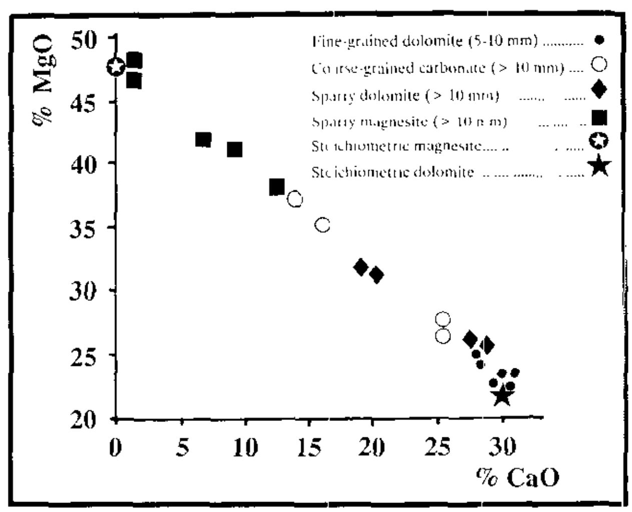

Figure 3-2-4. Negative correlation between Cao and MgO in carbonate rocks, Mount Brussilof area. The distribution of the data suggests a continuum in composition. Coarse-grained and sparry dolomites have higher MgO content than fine-grained carbonate rocks.

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