Dolomite in British Columbia: Geology, Current Producers and Possible Development Opportunities along the West Coast

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INTRODUCTION

Dolomite crystals most commonly form rhombohedrons when filling open spaces. They are translucent to transparent, have a pearly lustre and are commonly white, but can be pink, colourless, yellow, grey or brown. Dolomite is characterized by perfect cleavage, and has a white streak, an approximate density of 2.86 g/cm^3 and hardness in the range 3.5 to 4 on the Mohs scale. It does not effervesce when in contact with cold, diluted hydrochloric acid unless it is powdered. Dolomite's theoretical chemical formula is $CaMg(CO_3)_2$, which is equivalent to 54.35% $CaCO_3$ and 45.65% $MgCO_3$. This may also be expressed as 30.4% CaO, 21.7% MgO and 47.9% CO_2.

Specifications of the materials currently marketed as dolomite vary substantially from one producer to the next. This is partly due to the product not being a mineral, but rather crushed dolostone or dolomitic marble with small concentrations of calcite or magnesite, accessory silicates, oxides, barite, and sulphides as impurities. Some of the chemical variation may be due to the incorporation of impurities such as iron or manganese into the dolomite crystal structure. Dolomite is a well-known industrial mineral used for its physical and chemical properties, and is also one of the ore minerals used for production of magnesium metal. Some of the material marketed as dolomite may have been formed by extreme substitution of magnesium into the calcite structure. A high magnesium calcite may contain up to 18 mol% $MgCO_3$ incorporated into the calcite structure by substitution for calcium, depending largely on temperature and the Mg/Ca ratio of ambient water (Stanley *et al.*, 2002). High magnesium calcite is not stable during late diagenesis and metamorphism, and it dissociates into an assemblage of calcite and dolomite.

USES OF DOLOMITE

Dolomite is one of the major ores of magnesium metal (Coope, 2004). It competes with magnesite, brines, carnallite, brucite and a number of other magnesium-rich minerals. British Columbia has large magnesite resources that are concentrated in the southeastern portion of the province (Simandl and Hancock, 1996; Simandl, 2004).

Dolomite is also calcined to produce dead-burned dolomite, dolomite refractory bricks, refractory gunning and ramming mixes, and mortars, as well as flux in steel making (Moore, 2002). Large tonnages of dolomite are sold for soil conditioning, as a compost additive and plant nutrient, as animal feed additive (with some restrictions), and for flue-gas desulphurization. Dolomite is also used as filler in a variety of plastics, paints, coatings and sealants. Other applications include mine-dust suppression, roofing granules, insecticide/fungicide and fertilizer carrier. In the chemical industry and fibreglass and glass manufacturing, dolomite is used as a source of CaO and MgO (Moore, 2002; Crossley, 2003). The use of dolomite in environmental rehabilitation, in its natural or calcined form as 'dolime', is also steadily growing. Dolomite rocks that do not meet industry specifications for the above uses are commonly sold as aggregate for concrete, terrazzo chips or other landscaping applications.

SPECIFICATIONS OF DOLOMITE PRODUCTS ON THE MARKET

Knowledge of products that are currently available on the market is essential in the evaluation of new deposits. Although the CaO and MgO content of dolomite are reported for all applications, there is no published information, in a number of cases, on other major oxides or trace elements. Detailed information is provided to potential buyers upon request. Particle-size distribution, oil absorption, surface area, bulk density (loose and tapped), pH, neutralizing value relative to $CaCO_3$, base metal and free moisture content, and dry brightness are reported for most of the products intended for the filler market.

Table 1 contains information on pulverized natural dolomite products (*i.e.*, products 1 and 3–10). The products that have the widest range of applications tend to approach the stoichiometric composition of dolomite. Product 9 differs from other materials in its high SiO_2 content and above-average Al_2O_3 content. This product is an exceptional functional filler derived from pulverizing rock that consists dominantly of dolomite, with subordinate talc, tremolite, pale mica and antigorite (Goldberg and Wehrung, 1981). In this particular case, the minor constituents, especially talc and tremolite, enhance the properties of dolomite in a number of filler and ceramic applications. Product 2 is a dolomite derivative (dead-burned dolomite). It is characterized by higher overall CaO and MgO content than the other products, which is achieved by a reduction in the CO_2 content during the calcining process. Rock used in the production of dead-burned dolomite is expected to contain more

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TABLE 1. REPRESENTATIVE EXAMPLES OF CHEMICAL COMPOSITIONS OF DOLOMITE AND RELATED VALUE-ADDED PRODUCTS CURRENTLY AVAILABLE ON THE MARKET.

Oxide	Sample									
	1	2	3	4	5	6	7	8	9	10
CaO	30.8	57.2	30.1	>30.0	31.2^	30.8*	30.6*	34.45	25.48	30.9
MgO	21.5	40.1	21.5	>20.0	20.8	20.5	19.8	18.04	19.95	19.3
Al_2O_3	0.02	0.5	0.1	<1.0	0.05	-	-	0.31	0.41	0.26
Fe_2O_3	0.008	0.9	0.2	-	0.14	0.6	-	0.2	0.33	0.13
SiO_2	0.02	1.3	4.7	<1.5	0.7	-	-	0.07	22.95	5.9
TiO_2	0.01	-	-	-	-	-	-	0.01	-	0.02
K_2O	0.01	-	-	-	-	-	-	0.01	-	0.1
Na_2O	0.02	-	-	-	-	-	-	0.01	-	0.02
P_2O_5	0.01	-	-	-	-	-	-	0.01	-	-
LOI	47.7	-	42.8	-	46.9	44	-	46.6	30.3	41

- = not reported * = recalculated from $CaCO_3$ = recalculated from $MgCO_3$ ^ = typical analysis

Sample notes:

1 - Dolomitwerk Jettenberg: natural crushed rock; >99.1% dolomite, 0.8% calcite; used for glass, ceramics and other uses
2 - Jebcoram TL - Usha Martin procurement requirements for refractory monolithic materials; granular calcined magnesia product coated with nontoxic resin binder
3 - Colca processed - micronized, raw dolomite, brightness > 95
4 - The Ocean Command International Trading Co. Ltd: dead-burned dolomite in -120, -100, -200, and -325 mesh
5 - Reade Advanced Materials: 100 Dolowhite
6 - Imasco Minerals Inc: dry-ground dolomite produced in 100, 140, 200, 325, and 400 mesh sizes; used in joint fillers, putties, and caulking, building products and stucco, paints, rubber and adhesives, as well as in glass making; dry brightness (ASTM C110-92) for filler materials varies from 92.5 to 93; cattle feed supplement also available in 100, 250 and 325 mesh
7 - Imasco Minerals Inc: soil conditioners
8 - Ashgrove Cement Company: material currently used in agricultural, environmental and construction applications
9 - Dynatec Canada Talc DOLFIL 50-90, used mainly as functional filler and in ceramics
10 - Mighty White Dolomite - sample quarried in 1987 (Fishl, 1992)

than 18% MgO by volume; the CaO/MgO ratio should be less than 1.6; and the SiO_2 content should be less than 1.5%, preferably less than 1%.

Products 6, 7, 8 and 10 are from BC. Product 10 is considered representative of the Mighty White Dolomite operation, which is located near Rock Creek in southern BC (Fig. 1). It is a white, high purity dolomite. Product 8 is mined by the Ashgrove Cement Company on Texada Island. It has lower MgO content than most of the products listed in Table 1, but also an extremely low silica content. The mine is favourably located, permitting low-cost transportation by barging along the west coast of North America. Products 6 and 7 are products from Imasco Minerals, Inc. Product 6 represents a wide range of products varying mainly in particle size and distribution. Soil conditioners (product 7) do not require such tight specifications as products used as mineral fillers or in other industrial applications.

This brief survey of the literature suggests that there is little or no processing of dolomite besides selective mining, crushing, screening, ± hand-picking, milling and blending, as the chemical specifications of products marketed by a given company vary mainly in particle size and particle distribution. The chemical composition of materials from a given deposit varies only slightly from one product to the next or remains the same. In general, the producers try to provide products to supply to a wide range of consumers.

Large unfractured dolomite blocks can be used as dimension stones; smaller blocks are typically sold as riprap and armour stone; and dolomite that is in the 1–20 cm size range is used as aggregate for concrete. Material in the 4–30 mm range is used commonly as roofing granules, stucco, terrazzo chips, etc. In functional filler applications, dolomite competes with limestone, which is better known and more widely used. Filler-grade dolomite products typically sell in the 1 μm to 0.4 mm particle range. Fine-grained material is used mainly in paint, plastics and rubber, while coarser material is used for roofing carpet backing and joint cements. Glass producers commonly use the material in the 20–200 mesh rage. Where there is no market for fines, the dust is commonly pelletized and marketed for horticultural applications. For a global overview, the reader is referred to Carr *et al.* (1994) and Harben and Kuzvart (1996).

GEOLOGY OF DOLOMITE

Worldwide, most dolomite products currently on the market are derived from sedimentary, hydrothermally formed or metamorphic rocks, as described below. In some countries, dolomite is derived from carbonatite, where it is either recovered as a byproduct or mined because there are no conventional local dolomite resources. In BC, most of the carbonatite bodies are located in the same geographic areas as abundant sedimentary dolomite deposits, so this paper will not consider carbonatite but rather concentrate on traditional sedimentary and hydrothermal dolomite sources. The classification of carbonate rocks is described in many textbooks (Folk, 1959, 1962; Dunham, 1962;

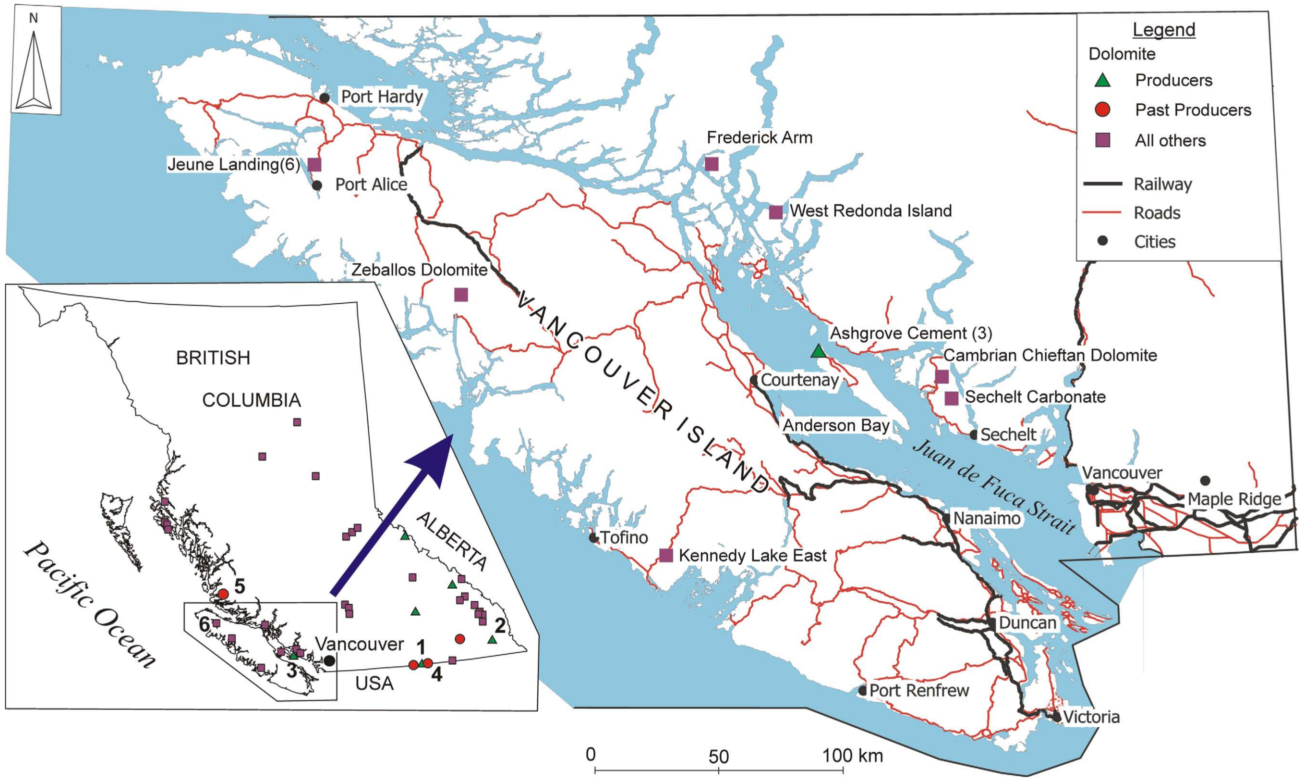

Figure 1. Geographic distribution of dolomite resources in British Columbia. Current dolomite producers: 1, Mighty White Dolomite operation at Rock Creek; 2, Imasco Minerals Ltd. (Crawford Bay); 3, Ashgrove Cement. Other deposits mentioned in the text: 4, Grand Forks Dolomite; 5, Smith Inlet; 6, approximate location of Jeune Landing Dolomite occurrence.

Strohmenger and Wirsing, 1991). This classification is, however, not practical when dealing with finely ground materials, or with recrystallized dolomites where textures are completely destroyed.

Dolostone

Dolostone (also called dolomite) is a sedimentary rock, consisting mainly of the mineral dolomite, which has a chemical composition approaching the theoretical composition of dolomite. Dolomite rocks are commonly divided into penecontemporaneous and replacive dolomites. The penecontemporaneous and replacive dolomite bodies are fine grained and form beds, often interbedded with limestone or dolomitic limestone. Penecontemporaneous dolomite, also called syndepositional dolomite, is relatively rare. Its deposits are restricted in size, and correspond to evaporitic lagoonal or lacustrine settings. The beds and lenses are usually a few centimetres to 20 m in thickness, although they may be substantially thicker and dolomitization within individual bodies in commonly incomplete.

Replacive dolomite forms during burial and is volumetrically the most important. It forms beds or lenses that are commonly more than 100 m thick. This type of deposit offers the best exploration potential for the large-volume, mainstream dolomite markets. The most accepted models for replacive dolomitization are reflux and thermal convection in open half-cell, also referred to as the Kohout convection model (Machel, 2004).

Depending on the level of exposure, availability of regional geological maps and textural information, a definitive distinction between replacive and penecontemporaneous dolomites may not be possible based on rapid field evaluation.

Hydrothermal Dolomite

Hydrothermal dolomite bodies can be formed in most postdepositional and postlithification settings. They are commonly superimposed over earlier replacive dolomite. Hydrothermal dolomite can form sizable bodies. In most cases, the contacts between hydrothermal dolomite and the surrounding rock are at least partially discordant to local stratigraphy, the dolomite zones are highly irregular, and their shape is difficult to predict unless there is a dominant structural control. Individual crystals within bodies of hydrothermal dolomite are typically coarse grained and, in some geological settings, saddle-shaped hydrothermal dolomite is used as an indirect indicator of Mississippi Valley – type Pb-Zn deposits, although, in many districts, it can be found tens or hundreds of kilometres from the nearest Pb-Zn deposit (Leach and Sangster, 1993; Davies, 1996).

Dolomitic Marble

When dolostone is affected by regional or contact metamorphism, it recrystallizes and forms dolomitic marble. The chemical composition of the dolomitic marble does not change significantly from that of its protolith during regional metamorphism; however, the marble formed in the contact metamorphic aureole of an igneous intrusion may have substantially different chemistry than its protolith. This is largely due to the fact that contact metamorphism is most marked in a near-surface environment where the system is open (*i.e.,* fluids and elements may enter or leave the system). Both regional and contact metamorphisms result in major changes in mineralogy, texture and physical properties of the rock. If silica (chert or quartz) or clay impurities are present in the dolomitic protolith, the resulting dolomitic marble, depending on metamorphic conditions, may contain forsterite, diopside, hedenbergite, amphibole of tremolite-actinolite series, garnet or brucite. In most cases, the recrystallization is also accompanied by 'bleaching': a change in colour from grey or beige to white.

DOLOMITE IN BRITISH COLUMBIA

There are 39 known dolomite occurrences (Fig. 1) currently listed in MINFILE (2005). These occurrences are described either as showings, prospects, developed prospects, past producers or producers (*i.e.,* currently operating mines). The distribution of the main carbonate zones in BC was compiled by Fishl (1992, map 1). This map suggests that the best geological potential for dolomite is in the northeastern part of BC. Large quantities of dolomite are also known to occur in the southeastern portion of the province and in the Rocky Mountains between Golden and Canal Flats, where a substantial proportion of the Jubilee, Beaverfoot, Cathedral and Eldon formations is uniformly dolomitized over thicknesses of tens to hundreds of metres. As with most industrial minerals, proximity to the market is essential and the presence of other minerals competing for the same market should be taken into consideration. The southeastern part of the province also holds large sedimentary-hosted magnesite resources and the only magnesite producer in Canada, Mount Brussilof, which is owned by Baymag Inc.

For these reasons, the paper will briefly describe current dolomite producers and then highlight known occurrences along the west coast. In most cases, the descriptions of individual properties are largely based on MINFILE (2005), so the MINFILE numbers are provided in the text. Southwestern BC has a lower geological potential for dolomite than the southeastern part of the province, but its market potential is far better than that of the rest of the province due to its favourable geographic location relative to dolomite users and competitive transportation costs, facilitated by barging.

To put southwestern BC into perspective, it contains, according to MINFILE, two dolomite showings, one prospect, one developed prospect and one past producer. There is also Ash Grove Cement Company, which produces a material with approximately 18% MgO that approaches dolomite in composition and can compete with it in a number of applications. This deposit will be described in the next section.

Dolomite occurrences located in southwestern BC are shown on Figure 1. There is no formal market study, and precise statistics for dolomite are not available because dolomite production is commonly reported together with that of limestone; therefore, any reported dolomite production data are likely underevaluated. Nevertheless, according to United States Geological Survey (USGS) mineral commodity surveys for 2002, Washington State and California produced 537 000 and 316 000 tonnes of crushed dolomite, at average prices of US$4.72 and 7.79 per tonne, respectively. Dolomite production statistics for Oregon were withheld and it is possible that there was no dolomite recently produced in that state. It is not clear what proportion of crushed dolomite went directly to the construction industry versus being milled and otherwise upgraded. Furthermore, the authors' interactions with the American manufacturing industry indicate that the Seattle area of Washington State will need more than 40 000 tonnes of additional high-purity dolomite in the glass and fibreglass industries over the next two years.

Current Producers and Advanced Projects

There are currently only three active operations in BC that produce dolomitic material (Fig. 1). Mighty White Dolomite Ltd., near Rock Creek, and Imasco Minerals Ltd., at its Crawford Bay underground operation on Kootenay Lake, produce high-quality dolomite. Ashgrove Cement Company's operation on Texada Island is renowned as a limestone producer, and the same property also produces material with a high MgO content that can best be described as limy dolomite. Such material has lower MgO content than typical dolomite and, depending on the application, this may be to its advantage, as long as the product is consistent. For example, in flat glass industry, the ideal ratio of CaO/MgO is 3:2 (Moore, 2002). This ratio is commonly achieved by mixing limestone and dolomite; therefore, the Ashgrove Cement deposit should not be disqualified from many potential uses based strictly on higher than normal CaO content.

Pan Pacific Aggregates Ltd. proposes to construct and operate a quarry on the Sechelt Peninsula, approximately 15 km northwest of Sechelt (Fig. 1). Dolomite is one of the many rock types reported from this property, which is described in more detail in the occurrences section under 'Sechelt Carbonate' (MINFILE 092GNW031). Based on currently available data, it is difficult to predict if the dolomite produced from this property could be used for applications other than soil conditioner or aggregate. The project proposal includes processing plant, conveyor system and loading facility.

Albrit Minerals and Materials Corp. owns a quarry (MINFILE 082ESE036) located 250 m north of Highway 3, just east of Morrissey Creek and approximately 4 km due east of Grand Forks, which in the past supplied dolomite for rock wool. It is referred to in this publication as Grand Forks Dolomite.

A newly discovered dolomite deposit near Port Alice, referred to as 'Jeune Landing Dolomite' (Village of Port Alice, 2005), is also discussed in this section.

MIGHTY WHITE DOLOMITE LTD.

Mighty White Dolomite Ltd. operates a dolomite quarry near Rock Creek (MINFILE 082ESE200). The deposit consists of a dolomite lens in altered metasedimentary and volcanic rocks of the Carboniferous or Permian Knob Hill Group that outcrops over a 100 m by 100 m area along the top of a knoll, 4.5 km south-southeast of the community of Rock Creek (Fig. 1). The lens is largely embedded in hornblende gneiss (amphibolite). An irregular band of talc-chlorite schist lies along the hangingwall contact. Bedding strikes 157–180° and dips 40–80°E. A schistosity strikes 150° and dips 30–50°W (Fishl, 1992).

The lens contains massive, white, fine to very fine grained dolomite. Scattered grains, patches and veinlets of quartz and a trace of talc were reported in Fishl (1992). During a property visit, however, yellowish serpentine appeared to be the main impurity (<0.5%). Two samples of crushed dolomite taken from a stockpile averaged 30.73% CaO, 18.16% MgO, 6.55% insoluble material, 0.32% R_2O_3, 0.135% Fe_2O_3, 0.01% MnO, 0.0025% P_2O_5, 0.015% SO_3 and 44.04% loss-on-ignition (McCammon, 1972).

A chemical analysis of a sample of dolomite quarried in 1987 is listed in Table 1 (product 10). In 1972, the deposit was estimated to contain 15.4 million tonnes of proven (measured geological) reserves and 9.0 million tonnes of probable (indicated) reserves (Anonymous, 1972; Melville *et al.*, 1992). These reserve estimates are not compliant with National Instrument 43-101, and they were reduced by active mining.

Figure 2. Mighty White Dolomite Ltd. processing plant, Rock Creek, southern British Columbia.

Mighty White Dolomite Ltd. currently produces crushed dolomite for agricultural, landscaping and decorative uses, and for a variety of other markets (Boulton *et al.*, 2001) at its plant, which is located near Rock Creek (Fig. 2).

IMASCO MINERALS LTD.

The Crawford Creek Dolomite (MINFILE 082FNE113) underground mine (Fig. 1, 3) is located in the Kootenay Lake area, 600 m south of Crawford Creek, and is operated by Imasco Minerals Ltd. The orebody is hosted by a band of limestone and dolomite of the Lower Cambrian Badshot Formation, which extends north-northeast from the head of Crawford Bay for at least 12 km. The bed outcrops along the east flank of the Preacher Creek antiform: a tight, overturned, eastward-closing fold cored by overlying gneiss, schist and amphibolite of the Lower Cambrian and younger Lardeau Group. Underlying quartzite and schist of the Hadrynian – Lower Cambrian Hamill Group outcrops along the flanks of the fold.

The deposit consists of white medium-grained dolomite containing scattered crystals of metamorphic minerals, especially tremolite. The dolomite develops a brown staining on weathered surfaces. Numerous randomly oriented fractures occur with spacings of 10–15 cm. A sample of chips collected from the quarry contained 30.26% CaO, 20.17% MgO, 2.14% insoluble materials, 0.77% R_2O_3, 0.92% Fe_2O_3, 0.021% MnO, 0.012% P_2O_5, 0.01% S and 46.37% LOI (BC Ministry of Mines and Petroleum Resources, 1965). The chemical analyses of two of the products (6 and 7) are shown in Table 1.

Imasco initially quarried dolomite on the south side of Crawford Creek, 600 m north of the current mine site, during 1962 and 1963. Quarrying began at the current site in 1964, and underground mining began in 1969. Between 1962 and 1988, 734 500 tonnes of dolomite were mined. The dolomite is trucked to the company's plant in Sirdar, where it is crushed and screened for a variety of products: agricultural soil conditioner, a component in stucco and roofing materials, and white ornamental aggregate rock.

ASHGROVE CEMENT

Ashgrove Cement Company has opened a new quarry on Texada Island. This quarry, named Pit #7 (Fig. 4), is located adjacent to the main pit, commonly referred to as Pit #6. The deposit is only partially delimited. The drilling

Figure 3. Crawford Creek Dolomite mine, operated by Imasco Minerals Ltd.

done in 2003 suggested that rocks with the highest MgO content are probably located outside the current limit of the Pit #7. Further drilling is planned in early 2006 to define this new area. The rock is pale grey or white on fresh surfaces and pale buff on a weathered surfaces. A representative sample taken from this pit by the senior author assayed 16.93% MgO, 35.63% CaO, 1.7% SiO_2, 0.44% Al_2O_3, 0.7% Fe_2O_3, 0.03% Na_2O, 0.07% K_2O, 0.02% TiO_2, 0.03% P_2O_5, 0.04% MnO, 0.001% Cr_2O_3, 5 ppm Ni, 1 ppm Sc and 44.4% LOI. Based on this chemical analysis, the rock can best be described as calcitic dolomite. Pyrite, present in trace amounts, appears to be the main source of Fe_2O_3. The company uses this product to satisfy its in-house needs and is marketing this stone on the open market for a variety of applications. Most recent data point to higher MgO content and lower Fe_2O_3 content than previously reported. An analysis of a composite sample, consisting of 50 subsamples taken with an auto sampler on a 12 500 tonne barge load, assayed 18.04% MgO, 34.45% CaO, 0.07% SiO_2, 0.01% TiO_2, 0.31% Al_2O_3, 0.20% Fe_2O_3, 0.01% MnO, 0.01% Na_2O, 0.01% K_2O, 0.01% P_2O_5, 0.01% Ba and 46.59% LOI. According to the company, this sample also contained a dirty surface muck-pile, which may have contaminated the load. The material satisfies or exceeds requirements for a number of agricultural and environmental applications.

Figure 4. Quarry (Pit #7) on Texada Island, operated by the Ashgrove Cement Company.

GRAND FORKS DOLOMITE

Albrit Minerals and Materials Corp. owns a quarry (MINFILE 082ESE036) located 250 m north of Highway 3, just east of Morrissey Creek and approximately 4 km due east of Grand Forks, which in the past supplied dolomite for rock wool. A 30–60 m thick bed of biotite schist (mica gneiss) containing several 10–30 m thick lenses of dolomite extends eastward from Morrissey Creek along the base of a bluff for at least 488 m. The bed lies within high-grade metamorphic rocks of the Proterozoic and possibly Paleozoic Grand Forks gneiss. The bedding in a quarry just east of Morrissey Creek strikes 110° and dips 75°S. Across the creek to the west, a 30 m thick band of dolomitic limestone and overlying biotite-hornblende migmatite strike north and dip 30°W (Fishl, 1992).

The deposit comprises medium to coarse-grained (2–6 mm), brownish weathering white dolomite that contains scattered streaks and spots of light green to yellowish green serpentine, flakes of yellow to light brown phlogopite and vein-like bodies of feldspar. Other minor constituents include calcite, forsterite, diopside, spinel, anthophyllite, tremolite, biotite and apatite. A sample of randomly collected chips from the quarry east of Morrissey Creek contained 30.86% CaO, 20.69% MgO, 1.19% insoluble material, 0.98% R_2O_3, 0.49% Fe_2O_3, 0.039% MnO, 0.03% P_2O_5, 0.004% S and 46.20% LOI (McCammon, 1971). Dolomite reserves are estimated at 1 million tonnes (Gunter, 1984). These reserve estimates, however, are not compliant with National Instrument 43-101.

The dolomitic limestone west of Morrissey Creek is medium grained and white in colour. Chert beds are prominent within this unit. The limestone contains minor diopside, mica and serpentine. Dolomite and limestone were initially quarried here for building stone and lime as early as 1916. Ramshead Quarries Ltd. quarried the dolomite for building stone from 1968 to 1971. V.T.S. Quarry Ltd. performed some minor exploration work for agricultural lime in 1984. More recently, in the 1990s, the material was extracted by Roxul West International's predecessor for use in the Grand Forks insulation plant. The last assessment report from this property was produced by Caron (1998).

JEUNE LANDING DOLOMITE

A 30 m thick dolomite bed was reported near the village of Port Alice, in the same geological setting as the well-known limestone deposit called Jeune Landing (MINFILE 092L 151). No other geological data were available at the time of writing.

The project has the support of the Village of Port Alice Council. During its regular meeting of September 14, 2005, the council approved a motion to support Sechelt Industrial Minerals Corporation in establishing a dolomite quarry near Jeune Landing and request that the permit be expedited (Village of Port Alice, 2005).

Dolostone Occurrences on Vancouver Island and the Sunshine Coast

At first glance, dolomite resources along the west coast may appear to be limited. This is largely due to a regional geological setting that is not as favourable for dolomite exploration as that of eastern BC. An overwhelming focus on high-calcium carbonate during past exploration may also be a factor. For example, Mathews and McCammon (1957) highlighted at least two zones on Texada Island that they labelled as “chiefly magnesian limestone”. Interestingly, their definition of ‘magnesian limestone’ included carbonate with MgO content of 4.79–19.15%. They also defined ‘dolomitic limestone’ as carbonate with MgO content in the range 19.15–21.86%. These definitions are not in line with modern terminology or even with the terminology of their era, because 21.86% MgO corresponds to the stoichiometric composition of pure dolomite. It is therefore possible that a number of zones, other than those on Texada Island, with high exploration potential for dolomite may have been overlooked.

ANDERSON BAY (MINFILE 092F 088)

The Anderson Bay occurrence consists largely of a limestone-marble deposit. It is located just west of Anderson Bay on the southeast coast of Texada Island (Fig. 1). Marble was produced from several quarries until 1917.

A 37–60 m thick limestone bed of the Mississippian–Permian Buttle Lake Group extends northward for 1.7 km and is unconformably overlain by amygdaloidal basaltic flows of the Upper Triassic Karmutsen Formation (Vancouver Group), and underlain by mafic volcanic breccia, grey argillite and aphanitic volcanic rocks of the Paleozoic Sicker Group. Bedding strikes north to northwest and dips 30–60°W. The limestone bed pinches out to the south and is truncated to the north by a fault extending northwest from Anderson Bay (Fishl, 1992).

The deposit consists of coarse to fine-grained, white to reddish brown crinoidal limestone. The lower 12–15 m consists of white to pink crinoidal limestone that grades upward into 9–15 m of banded, pink to red crinoidal limestone containing some jasper. This is overlain by red and green tuffaceous limestone (Fishl, 1992).

Magnesian and high-calcium beds are found in the upper portion of the deposit. Lenticular masses of fine-grained pink dolomite veined with white calcite occur near the north end of the deposit. A sample from one of these lenses assayed 33.02% CaO, 16.20% MgO, 4.94% SiO_2, 0.85% Al_2O_3 and 1.56% Fe_2O_3 (Goudge, 1944). Four chip samples taken in succession across a total stratigraphic thickness of 53 m averaged 48.4% CaO, 2.8% MgO, 2.9% insoluble material, 1.7% R_2O_3, 0.92% Fe_2O_3, 0.065% MnO, 0.13% P_2O_5, 0.004% S and 42.95% LOI (Mathews and McCammon, 1957).

Two small quarries were opened in the early 1900s in this area. Nootka Quarries operated one quarry, 380 m northwest of the head of Anderson Bay. Continental Marble operated a second quarry about 540 m to the south. Until 1916, 96.7 tonnes (1265 cu. ft.) of marble were produced from this quarry for ornamental stone (Goudge, 1944).

SECHELT CARBONATE (MINFILE 092GNW031)

Dolomite and limestone are reported over a distance of 3 km in a northwest-trending pendant of metavolcanic and metasedimentary rocks of the Upper Triassic Karmutsen Formation (Roddick *et al.*, 1979) just northwest of Carlson Lake, 13 km east of Pender Harbour on the Sechelt Peninsula (Fig. 1). This pendant lies in diorite and quartz diorite of the Jurassic–Tertiary Coast Plutonic Complex. The beds within the pendant strike north and dip moderately to steeply east. The beds comprise mostly carbonate outcropping over widths in excess of 150 m with several amphibolite, skarn-altered metavolcanic rocks. They are cut by north-trending, steeply dipping andesitic to basaltic dikes.

The carbonate consists of fine to coarse-grained, white to medium grey, banded limestone and fine to medium-grained, massive to mottled dolomite. Minor to trace amounts of quartz, muscovite, serpentinite, diopside, olivine, talc, graphite and pyrite are present in the limestone. The dolomite contains minor chlorite and quartz, and is commonly cut by veins of dolomite and calcite. Ten composite samples collected from various limestone outcrops averaged 55.3% CaO, 0.5% MgO, 0.7% SiO_2, 0.2% R_2O_3 and 43.3% LOI (Wright Engineering Ltd., 1983; Candol Development Ltd., 1984). Assays of dolomite samples ranged from 16.8 to 20.0% MgO (Ditson, 1987).

Candol Development Ltd. carried out an extensive program of mapping, sampling and diamond drilling (1423 m) between 1983 and 1987. Drilling indicated a 30–80 m wide zone of dolomite at least 500 m long that is bounded to the west by limestone and to the east by an andesitic dike. The deposit is estimated to contain geological reserves of 3.5 million tonnes of dolomite averaging 19.2% MgO over an average width of 55 m, a strike length of 500 m and down to 50 m in depth (Ditson, 1988; Melville *et al.*, 1992). These reserve estimates, however, predate National Instrument 43-101.

Additional investigations are described by Murphy (2003). Chemical analyses done independently by Ashgrove Cement Company confirmed the presence of dolomite but did not provide information about SiO_2, Al_2O_3, Fe_2O_3 or other potential impurities in the dolomite. The project is currently under environmental assessment and more information can be found at http://www.eao.gov.bc.ca/epic/output/html/deploy/epic_project_home_271.html. Results of the drilling in 2005 are not yet available.

CAMBRIAN CHIEFTAN DOLOMITE (MINFILE 092GNW054)

This occurrence is located 8.3 km northeast of the community of Garden Bay, near the old Cambrian Chieftan Mine (MINFILE 092GNW011) on the Sechelt Peninsula.

A dolomite lens lies in a northwest-trending roof pendant of volcanic and sedimentary rocks of the Upper Triassic Vancouver Group (probably Karmutsen and/or Quatsino formations) within diorite and quartz diorite of the Jurassic–Tertiary Coast Plutonic Complex. The sedimentary rocks strike due north and dip vertically to steeply east. They are cut by a few vertically dipping andesitic and dioritic porphyritic dikes that commonly strike 140°.

The dolomite lens is at least 311 m long and up to 37 m wide on the surface, averaging 30 m in exposed thickness. The lens is composed of white to grey, mottled crystalline dolomite containing epidote and calcite veinlets and sparse pyrite grains. Nine 4.5 kg samples randomly collected over the dolomite lens assayed 18.8–21.1% MgO, with an average MgO content of 19.8% (Bacon, 1957). Assays of six of these samples are found in Table 2 (Bacon, 1957), and show consistent CaO, MgO and SiO_2 contents.

TABLE 2. ANALYSES OF DOLOMITIC ROCKS FROM THE CAMBRIAN CHIEFTAN DEPOSIT (BACON, 1957

	Sample					
	1	2	3	4	5	6
CaO	32.3	31.5	33.1	31.7	30.6	30.9
MgO	19.3	20	18.8	20.1	21.1	20.7
SiO_2	3.3	5.1	3.4	3.4	2.1	2.9
R_2O_3	0.5	0.9	0.6	0.6	0.4	0.8
Fe_2O_3	0.6	0.6	0.4	0.4	0.4	0.5
H_2O at 105 C	0.1	0.1	0.1	0.1	0.2	0.1
Loss-on-ignition	44	41.9	43.5	43.6	45.1	44.2
Totals	**100.1**	**100.1**	**99.9**	**99.9**	**99.9**	**100.1**

A mass of thinly bedded, white to grey crystalline limestone outcrops just west of the dolomite lens. The north end hosts magnetite-chalcopyrite skarn zones that were sporadically mined as part of the Cambrian Chieftan deposit.

FREDERICK ARM (MINFILE 092K 136)

A 300 m wide band of limestone and dolomite enclosed in granitic rocks of the Jurassic–Tertiary Coastal Plutonic Complex extends northwestward from the west shore of Frederick Arm up the side of Treble Mountain (Fig. 1) for at least 800 m. The carbonate rocks strike 125° and dip vertically. The band is cut by fine-grained diabase dikes.

The carbonate is composed of bluish grey fine-grained limestone containing a few beds of white to yellowish white dolomite. In places, dolomite and pyrite grains are disseminated in the limestone. A chip sample across a 30 m section of limestone contained 48.52% CaO, 2.77% MgO, 5.92% SiO_2, 1.16% Al_2O_3, 0.50% Fe_2O_3 and 0.46% S (Goudge, 1944). A chip sample across a 3.7 m thick dolomitic bed on the west side of the carbonate deposit contained 32.78% CaO, 17.94% MgO, 2.60% SiO_2, 0.55% Al_2O_3, 0.46% Fe_2O_3 and 0.38% S (Goudge, 1944).

SMITH INLET (MINFILE 092M 008; 2005)

A band of limestone, hosted in granitic rocks of the Jurassic–Tertiary Coast Plutonic Complex, outcrops on both sides of Smith Inlet in the vicinity of Nalos Landing (Fig. 1). The limestone strikes 110° and dips nearly vertically to the northeast.

On the north side of the inlet, the limestone band is 700 m wide, continues inland for 800 m and is intruded by mafic dikes (Fishl, 1992). Medium to coarse-grained carbonate rocks consist of high-calcium limestone interbedded with dolomite that contains traces of disseminated pyrite (Fishl, 1992). Dolomite forms irregular masses, up to 7.6 m in diameter, within the limestone, which becomes more siliceous and dolomitic along the edges of the deposit (Fishl, 1992).

A sample taken across a 15 m width in the centre of the deposit on the north shore of the inlet contained 53.39% CaO, 1.14% MgO, 1.08% SiO_2, 0.02% Al_2O_3, 0.08% Fe_2O_3 and no S (Goudge, 1944). A sample of white dolomitic rock contained 32.48% CaO, 19.61% MgO, 0.058% SiO_2, 0.19% Al_2O_3, 0.09% Fe_2O_3 and no S (Goudge, 1944).

In 1929, two quarries were opened along the north shore of Smith Inlet by Coast Calcite Co. Ltd. Operations were suspended a short time afterward and no production figures are available.

ZEBALLOS DOLOMITE (MINFILE 092L 214) AND NOMASH RIVER

Limestone and dolomite are reported in the 900 crosscut of the Central Zeballos mine (MINFILE 092L 212), located 7 km northeast of the community of Zeballos and 110 km due west of the town of Campbell River (Fig. 1). The deposit lies within a discontinuous belt of limestone of the Upper Triassic Quatsino Formation that extends for 120 km from Quatsino Sound in a southeasterly direction to Tlupana Inlet. The belt is locally intruded along its southwestern flank by quartz diorite and granodiorite of the Jurassic Island Intrusions to the northeast. Underlying basaltic flows of the Upper Triassic Karmutsen Formation (Vancouver Group) outcrop to the northeast. The limestone strikes northwest and dips moderately southwest. The 900 crosscut is situated near the west end of a mass of medium to coarse-grained recrystallized limestone that extends westward from the Nomash River for 2000 m along the northern margin of a stock of granodiorite. The crosscut exposes grey calcium limestone intermingled with white dolomite and magnesian limestone. Most of the white carbonate is confined to a zone between 46 and 122 m from the portal. Laboratory studies indicate that the white carbonate comprises mostly dolomite with interstitial calcite (Stevenson, 1950). The dolomite and magnesian limestone occur as white streaks commonly ranging from a few centimetres to 10 m in thickness, the thickest being 21 m. These lenses may be the result of hydrothermal dolomitization. Stevenson (1950) reported that a white crystalline dolomitic limestone in the crosscut assayed 32.70% CaO, 19.6% MgO, 0.05 R_2O_3 and 1.1% insoluble material. Samples taken along a section of white carbonate between 57.9 and 85.3 m from the portal averaged 36.2% CaO, 17.0% MgO, 0.93% insoluble material and 0.28% R_2O_3 (Stevenson, 1950). Samples from a section of grey limestone between 182.9 and 201.2 m from the portal averaged 47.3% CaO, 7.26% MgO, 1.8% insoluble material and 0.25% R_2O_3 (Stevenson, 1950). Various grab samples were collected by Impact Resources Inc., the analyses of which are found in Table 3 (Econotech Services Ltd., 1981, 1982; Kent, 1989).

Dolomite reserves were estimated at several million tonnes (Econotech Services Ltd., 1981, 1982; Kent, 1989), but are not compliant with National Instrument 43-101.

Zones of garnet-diopside skarn, sometimes containing magnetite and sulphide minerals, are frequently formed along the intrusive contacts. The deposit was sampled in 1981 and diamond drilled in 1982 by Impact Resources, Inc.

When the property was visited in 2005, the adit was open and appeared to be in good condition (Fig. 5). The road that leads to the adit is overgrown but well preserved.

Stevenson (1950) also indicated that cream-coloured carbonate in a bed of the Nomash River, approximately 1.3 km upstream from the north fork of the Zeballos River, contains 35.00% CaO, 17.1% MgO, 0.76% R_2O_3 and 0.94 % insoluble material.

Two carbonate samples collected in 2005 from the mountain face, within 10 m of the portal, contain 0.75 and

TABLE 3. ANALYSES AND RESULTS OF BRIGHTNESS TESTS ON CARBONATE ROCKS COLLECTED BY IMPACT RESOURCES INC. FROM THE ZEBALLOS DOLOMITE (ECONOTECH SERVICES LTD., 1981, 1982)

	Sample			
	A	B	C	D
$CaCO_3$	87.9	61.95	61.2	93
$MgCO_3$	9.5	37.35	38.5	1.76
SiO_2	-	-	-	0.5
Insoluble material	2.6	0.78	-	-
H_2O	-	-	0.13	-
Brightness:				
Blue light	90.4	90.8	84.6	-
Green light	91.25	92.1	-	-
Unspecified	-	-	-	89.6

0.72% SiO_2, 0.03 and 0.08 Al_2O_3, 0.20 and 0.13% Fe_2O_3, 1.05 and 1.38% MgO, 1.05 and 1.38% MgO, 55.44 and 54.67% CaO, 0.02 and 0.02% Na_2O, 0.04 and 0.04% K_2O, 0.01 and 0.01% TiO_2, 0.02 and 0.08% P_2O_5, 0.001 and 0.001% Cr_2O_3, and 42.4 and 42.8% LOI, indicating that they are limestone in composition.

Figure 5. Adit at Zeballos Dolomite was open during the visit in 2005.

Other Dolomite Occurrences Along the Coast

A number of dolomite occurrences were also described along the north coast of BC. All other factors being equal, however, these deposits become less economically viable with increasing distance from the market. The descriptions provided below indicate that at least some of these occurrences are worth following up. Refer to Roddick (1970a, b) for local and regional geology.

CLAXTON (MINFILE 103J 033)

The area is underlain by Permian–Triassic feldspathic schist with a northerly trend and 80°W dip. A large dolomitic deposit is reported to occur 300 m from the water at Claxton, 24.0 km south of Prince Rupert. A sample contained 41.9% $MgCO_3$ (Fishl, 1992).

BANKS ISLAND (L.797, MINFILE 103H 062)

A 180 m wide band of white coarse-grained limestone and dolomite outcrops on Lot 797 on the east coast of Banks Island, 2.5 km south of Gale Point. The bed is contained in a roof pendant of gneissic diorite and migmatite within granodiorite of the Coast Plutonic Complex. The deposit strikes 125° and dips steeply to the northeast. Numerous inclusions of country rock are present along the northeastern edge of the band. Sinuous quartzite fragments are sometimes found floating in the limestone. The dolomite commonly contains veins of white quartz (Goudge, 1944).

BANKS ISLAND (L.2224, MINFILE 103H 039)

A 180 m thick, bed of limestone that strikes 130–140° and dips steeply outcrops on Lot 2224 on the north coast of Banks Island, 12 km northwest of Keecha Point. The limestone lies within quartz diorite of the Coast Plutonic Complex. It contains interbeds of schist that become numerous toward the edges of the deposit. The bed consists of erratically intermingled, white high-calcium limestone and dolomite. The dolomite occurs as thin beds to large lenses that become more frequent near the margins of the bed. A chip sample taken across 30 m of high-calcium limestone contained 54.56% CaO, 0.72% MgO, 0.24% SiO_2, 0.18% Al_2O_3, 0.07% Fe_2O_3 and no S, while a sample across a 9 m thick dolomite lens contained 31.84% CaO, 20.77% MgO, 0.24% SiO_2, 0.08% Al_2O_3, 0.23% Fe_2O_3 and trace S (Goudge, 1944).

LIMESTONE BAY (MINFILE 103H 038)

A 240–300 m wide band of limestone outcrops on Despair Point on the northeast coast of Banks Island and continues in a southeasterly direction for 1.2 km. The band is in contact with gneissic diorite and migmatite to the northwest and quartz diorite to the west. The limestone strikes 100° and dips vertically. It is occasionally split into two bands by quartzite mineralized with pyrrhotite and banded silicified schist.

The deposit comprises mostly white coarse-grained limestone and minor grey medium-grained limestone with irregular interbeds and masses of dolomite. A 15.2 m chip sample taken across light grey limestone on the northeast side of the deposit contained 52.80% CaO, 0.85% MgO, 1.66% SiO_2, 0.53% Al_2O_3, 0.20% Fe_2O_3 and 0.03% S, while a sample taken across a 4.6 m thick bed of coarse-grained white dolomite near the southwest edge of the deposit contained 31.72% CaO, 20.62% MgO, 0.78% SiO_2, 0.15% Al_2O_3, 0.08% Fe_2O_3 and no S (Goudge, 1944).

EXPLORATION GUIDELINES

In general, exploration programs for industrial minerals that have relatively low unit value ($/tonne) are not justified, unless they are backed by conceptual and market studies. In certain circumstances, large established companies incorporate extra properties into their portfolios for strategic reasons. Such properties are important in strategic planning and typically offer material of exceptional grade and are located near low-cost transportation corridors. The motivation to hold such properties is to ensure the long-term supplies of raw materials for established or captive markets, or to tie up the deposit to limit potential competition. Long-term holding of such undeveloped resources is, however, not an option for junior companies or individual prospectors, who cannot afford to cover the cost of maintaining the property in good standing for several decades.

Knowledge of the specifications of dolomite currently on the market is necessary for the design of new exploration programs. Material from the new deposits should match or exceed current consumer specifications. In most applications, dolomite is considered a low-cost material; therefore, deposits that do not require processing other than crushing and milling are preferred. Mineralogy and physical properties of the final product are extremely important, especially where dolomite is expected to be used as a filler or extender.

The proximity of the deposit to the market is essential, unless it is adjacent to low-cost transportation corridors, such as the one provided by barging along the west coast of British Columbia.

The distinction between sedimentary-diagenetic and hydrothermal origins of dolomite formation provides important clues to the geological potential of any given area on the conceptual or grassroots exploration level, when looking for world-class dolomite deposits. In the areas where dolomitization appears erratic or limited to a specific, narrow stratigraphic horizon and where detailed geological maps are not available, the best starting points for exploration are the investigation of known dolomite occurrences, followed by tracing or projecting dolomitic rocks along stratigraphic or structural controls into geographic areas with the best possible existing infrastructure.

The acid test, in conjunction with the use of non-toxic heavy liquid or staining, provides fast reconnaissance-level information in exploration for magnesite (Simandl *et al.*, 1993). It can also be applied to other carbonate minerals, such as dolomite. Shortwave infrared spectroscopy was successfully used to distinguish dolomite from magnesite-rich rocks (Thompson and Simandl, 2004), and the same method may reflect variations in magnesium content within the calcite-dolomite range of carbonate rocks. Beyond the reconnaissance stage, there is still no substitute for chemical analyses, especially if material is required for its magnesia content rather than its physical properties.

If the carbonate rock was metamorphosed, the presence of diagnostic metamorphic minerals, such as forsterite, tremolite, diopside and talc, can indicate the presence of a magnesium component in marble, but the concentration of these minerals is not directly proportional to magnesium content because it also depends on other parameters.

Methods used in advanced stages of exploration must match the needs dictated by field conditions and other factors. They are best handled by a specialist and are outside the scope of this paper.

CONCLUSION

The best geological potential for dolomite appears to be in southeastern British Columbia, where thick uniform beds of dolomitic rocks are common. Since dolomite competes with magnesite in a number of markets, it is important to recognize that southeastern BC is also known for important magnesite resources, including the world-class Mount Brussilof magnesite mine, the only magnesite producer in Canada.

There are only three active operations in BC producing dolomitic rock. Coastal areas of southern BC have moderate geological potential to host a world-class, high-grade dolomite deposit, but their potential to host mid-sized dolomite deposits that can sustain a production level in the 50 000 to 100 000 tonnes of dolomite per year is excellent. There is no formal market study regarding dolomite in BC, but the development of deposits located along the coast is economically favourable because of low-cost transportation to potential markets in the Pacific Northwest of the United States. Recent requests from potential American dolomite consumers suggest that the market in Washington State alone is large enough to accommodate a new mid-size BC-based coastal dolomite producer. New glass and fibreglass plants are expected to begin production in the Seattle area within a year.

One of the known dolomite occurrences in southwestern BC (such as those listed in this paper) or another favourably located dolomite occurrence may become a new dolomite supplier on west coast of BC. Texada Island is well known for its high-calcium limestone resources; however, its potential in terms of 'dolomite-type' resources is probably underestimated.

If no new potential producer is identified in southwestern BC, areas further north along the coast (*e.g.*, Banks Island) should be further explored for dolomite. Unfortunately, transportation costs from northwestern BC to the west coast of United States will be higher than from the southwestern part of the province, resulting in a higher delivered price, and consequently lower number of potential industrial users in the US Pacific Northwest.

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