REFRACTORY MINERALS AND DERIVED, VALUE-ADDED PRODUCTS, BRITISH COLUMBIA, CANADA

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ABSTRACT

Investment opportunities in refractory industrial minerals and selected energy-intensive, value-added products derived from these minerals exist in British Columbia. The province has magnesite, silica, olivine, kyanite, andalusite, shale, diatomite, pyrophyllite, graphite, dolomite, and brucite deposits or occurrences. Magnesite and silica are of particular interest because they are mined in B.C. and distributed through local and export markets; furthermore, large undeveloped deposits of these two minerals are known in the province. Abundant and relatively inexpensive hydroelectricity is available within B.C. for the development of value-added products. There is a potential to produce "high-tonnage", energy-intensive products such as ferrosilicon, metallurgical- and chemical-grade silicon, and magnesium from local materials. In spite of local lack of bauxite, an aluminum smelter was established by Alcan near Kitimat. Changing technologies, depletion of some raw materials in the American Northwest, rapid escalation of energy costs in some traditional producing areas, and world-scale rationalization within these industries suggest that implantation of energy-intensive industries in the province should be critically reappraised. Niche markets for specialty refractory minerals, advanced ceramics (such as silicon carbide, varieties of fused alumina, fused zirconia, synthetic mullite, synthetic Al-Mg spinel, fused magnesia, fused silica), a wide variety of electronic materials (such as polysilicon and synthetic quartz), and synthetic reinforcing or insulating fibers do offer additional opportunities. Electrofusing plants, capable of producing a variety of products, are a solution to the restrictions caused by limited markets. Plant flexibility increases the relative size of the total market by grouping several small-niche markets. Flexibility results in diversification and provides insurance against premature closure of a plant due to a downturn in demand for a particular product. The high unit-value of electricity-intensive products and the economy of scale available in overseas shipping may contribute to the competitiveness of these products in Europe, Japan and elsewhere.

INTRODUCTION

History and Background

Historically, industrial mineral deposits in British Columbia have received little attention from the mining and manufacturing industries. This is because of B.C.'s small population and limited local markets rather than any

CIM District 6 meeting in Vancouver (1994)

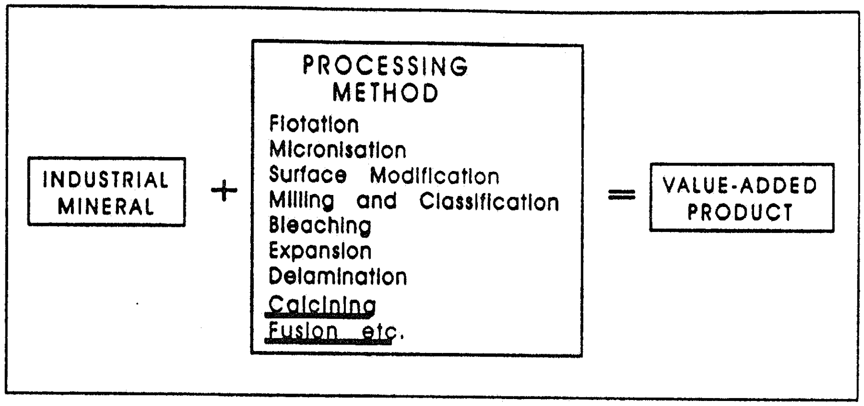

FIG. 1. Value-added concept.

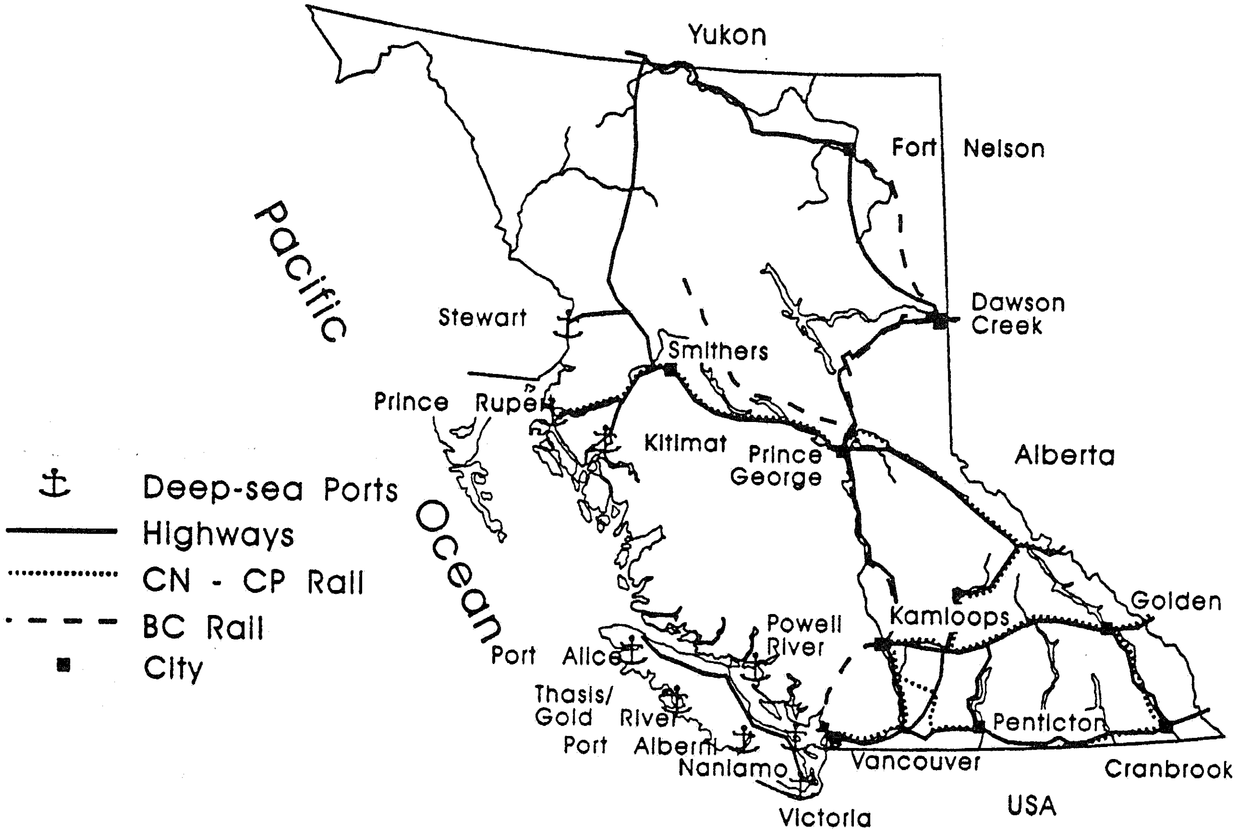

FIG. 2. Selected deep-sea ports, railways, highways, and airports.

lack of industrial mineral potential. Even so, there are 35 active industrial mineral producers in the province, excluding sand, gravel, and construction-aggregate operations. Geological descriptions of selected deposits were summarized by Hora (1992) and Simandl *et al.* (1992).

Because of the limited local market, most new industrial mineral developments in B.C. must be competitive in the global marketplace. One key to success lies in adding value to traditional commodities by further processing and refining. Some of the traditional methods used in processing and upgrading raw industrial mineral commodities are listed in Figure 1. This report focuses on the potential for production of refractory minerals and the electricity-intensive materials derived from them in B.C. Processing of imported raw materials, not available locally, into value-added niche-market products is also considered.

Infrastructure

British Columbia has a modern, efficient infrastructure in the southern third of the province, where most of the population and industry are located. A well-maintained, highway system (Fig. 2) permits efficient trucking within the province and provides connections with interprovincial and U.S. interstate routes. National and provincial rail lines link B.C.'s industrial centres to terminal points across Canada.

B.C. has an efficient system of ports, all ice-free, and offers excellent tidewater sites for heavy industry (Fig. 2). Vancouver is Canada's largest port, and is the second largest on the west coast of the continent in terms of tonnage handled. Prince Rupert is the province's second major deep-water port, mainly handling bulk commodities. There are 22 subsidiary deep-water ports serving coastal communities and resource-processing industries.

Vancouver International Airport is served by 25 international airlines providing passenger and freight service to 40 countries throughout North and South America, Asia, the South Pacific and Europe. There is also regularly scheduled inter-city service throughout the province.

Electricity

The processing of industrial minerals is commonly energy-intensive (Duncan and McCracken 1981; O'Driscoll 1989). This is particularly the case in the production of high-performance refractory, electrofused, and synthetic products. B.C. is fortunate to have an abundance of hydroelectric capacity and good potential for further development. It is a net exporter of electricity. The B.C. Hydro and Power Authority, a Crown corporation, produces approximately 80% of the electricity consumed in the province and serves over 1.3 million customers (Fig. 3). Another major utility, West Kootenay Power, serves more than 63,000 customers in the southern Interior. The remainder of B.C.'s power is produced by industry, mainly pulp and paper mills, and by Alcan's hydro-electric plant near Kitimat and Cominco's facilities in the West Kootenays. Electricity is more competitively priced than in many other major industrialized countries (Fig. 4). BC Hydro rates are less than a third of electrical power costs in Great Britain and Germany, and are well under half the average costs in the U.S.A. and Japan. Privately generated electrical energy, such as Alcan's and Cominco's, has negotiable price rates.

Electricity-intensive Products

Examples of energy-intensive products include silicon, silicon carbide, ferrosilicon, fused silica, synthetic spinel, fused and synthetic mullite, fused magnesia, cultured quartz, optical quality glass, reinforcing and insulating fibres, a wide variety of niche refractories, and traditional and advanced ceramics. Magnesium and aluminum metals should also be considered. Ferrochrome and selected minor ferro-alloys may be of interest, although they are not covered by this study. Silica and magnesite-derived value-added products are of particular interest because mineral sources of both are currently mined in the province for local and export markets.

REFRACTORY MINERALS IN BRITISH COLUMBIA

The term "refractory mineral" is applied to industrial minerals that can withstand high temperatures in specific industrial environments, and also to minerals that can be transformed into materials with similar or improved refractory characteristics. Both natural and synthetic refractories, some of which are advanced ceramics, may have other commercial applications in addition to their traditional uses. For example, silicon carbide, depending on its purity and size classification, is used as a refractory material, in the manufacture of speciality ceramics, in metallurgy or as an abrasive. Magnesite, silica, and refractory clay are currently mined in B.C. The province also

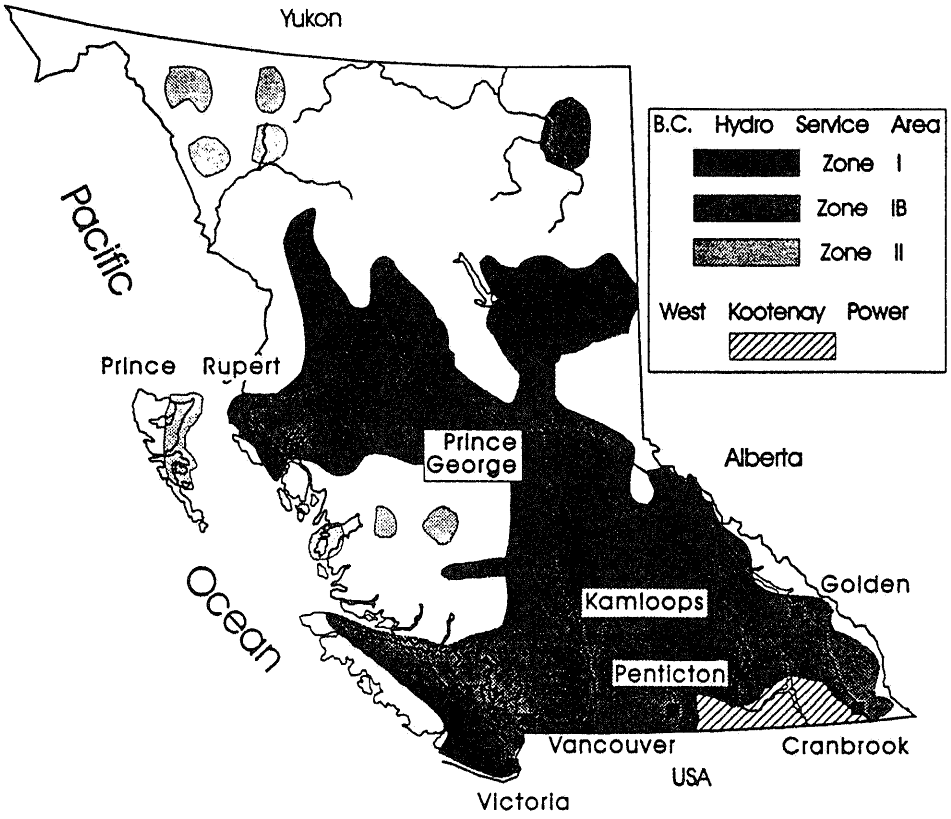

FIG. 3. B.C. Hydro and West Kootenay Power service areas.

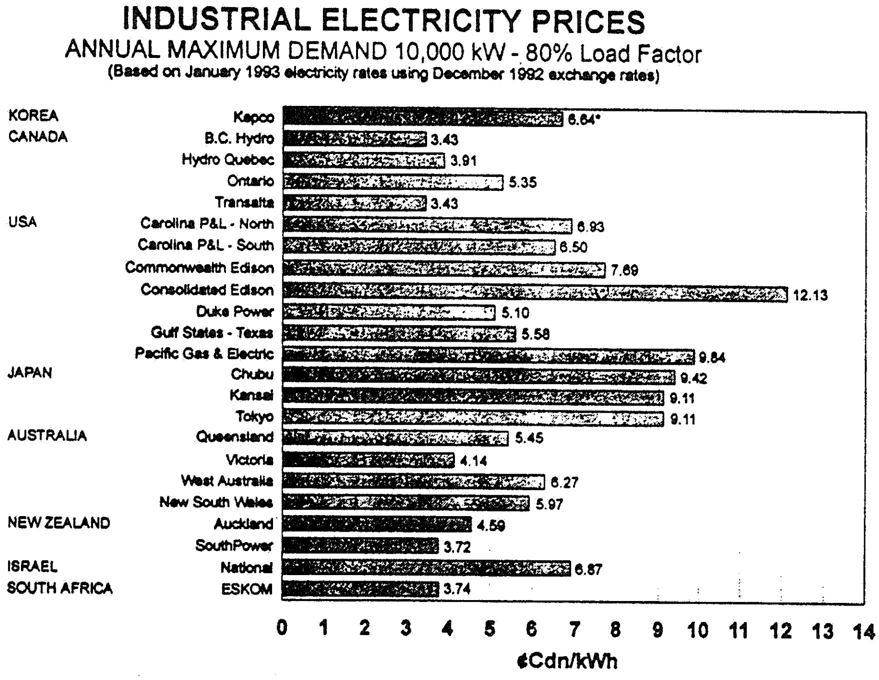

FIG. 4. Electricity prices in various industrialized countries. In several jurisdictions electricity contracts are negotiable. Source: Electric Association, Economic Affairs, London, U.K.

offers possibilities for the production of olivine and has good geological potential for graphite, andalusite, kyanite, refractory clays, and pyrophyllite (Simandl *et al.* 1992).

Magnesite

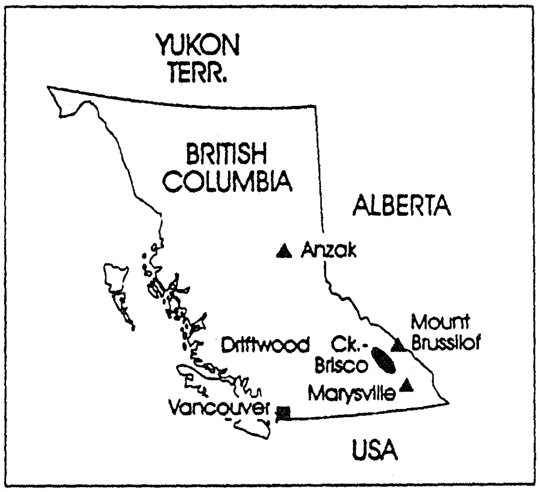

FIG. 5. Selected magnesite occurrences.

There are more than 70 magnesite occurrences known in B.C. (Grant 1987). The most significant are sparry magnesite deposits hosted by sedimentary rocks, but a few are associated with ultramafic rocks. The large, high-grade deposit at Mount Brussilof, northeast of Radium Hot Springs (Fig. 5), accounts for most of Canada's current production.

The Mount Brussilof deposit is hosted by Cambrian dolomites (Simandl and Hancock 1991; Simandl *et al.* 1991). The mine, in production since 1982, is operated by Baymag Mines Co. Limited, a private company owned by Refratechnik GmbH of Germany. Raw magnesite from Mount Brussilof is processed into high-quality calcined and fused magnesia and has also been used as feedstock in the production of magnesium metal by Magcan Ltd. in Alberta. Chemical analyses of some of Baymag's magnesia products are listed in Table 1 and analyses of typical ore are reported in Table 2. Physical properties may be obtained from the company or the B.C. Ministry of Energy, Mines and Petroleum Resources.

Table 1. Chemical analysis of selected magnesia products of Baymag Mines Co. Limited

PRODUCT	FUSED MgO[1]		BAYMAG 30[2]		BAYMAG 40[3]		BAYMAG 96[4]		BAYMAG 58[5]	
	T	S	T	S	T	S	T	S	T	S
MgO*	97.3	>96.6	97.3	>96.5	97.3	>96.5	97.5	>96.5	97.1	>96.5
CaO*	1.7	<2.0	1.8	<2.3	1.8		1.7	<2.2	2	2.5
Fe_2O_3*	0.5	<0.7	0.6		0.4		0.5		0.5	
Al_2O_3*	0.2	<0.3	0.1		0.2		0.1		0.1	
SiO_2*	0.3	<0.4	0.2		0.3		0.2		0.3	
LOI			2.2		5				0.2	
iodine			30		40					
Mg									58.6	>58.2

Abreviation: T = Typical S = Specified * Reported on loss-free basis

[1] Magnesia-carbon bricks and other high-performance refractory applications where resistance to chemical attack is needed.

[2] Acid neutralizer in manufacturing of MgO compounds, water-treatment agent, gas desulfurization, and fuel additive.

[3] Applications where high reactivity is critical.

[4] Cellulose acetate, specialty refractories, epsom salts, *etc.*

[5] Mainly in animal feed industry.

Table 2. Chemical composition of surface samples from sedimentary-hosted magnesite deposits

DEPOSIT	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL
Anzak	0.44	<0.01	0.21	1.16	0.02	43.79	3.14	0.01	0.01	1.04	50.36	100.19
	0.39	<0.01	0.08	0.76	0.02	34.23	16.70	0.01	0.01	0.82	48.95	101.98
	2.23	<0.01	0.11	0.98	0.02	48.99	0.72	0.01	0.01	0.86	50.01	98.95
Driftwood Creek	7.32	0.09	1.01	0.75	0.01	39.57	0.60	0.27	0.04	<0.01	47.61	97.28
	2.05	<0.01	<0.01	0.86	0.02	37.27	8.08	0.09	0.00	<0.01	50.02	98.42
	15.97	<0.01	0.08	0.52	0.01	38.62	0.10	0.04	0.03	<0.01	43.56	98.95
Topaz Lake	7.11	0.02	0.51	1.37	0.02	42.16	0.61	0.02	0.00	<0.01	46.68	98.51
	7.43	<0.01	0.20	1.34	0.02	41.03	0.31	0.02	0.01	<0.01	48.27	98.65
	4.18	0.03	0.70	1.60	0.02	43.00	0.32	0.02	0.15	<0.01	49.41	99.44
Red Mtn.	10.64	0.01	0.52	1.64	0.03	38.74	0.92	0.10	0.03	<0.01	45.54	98.18
	8.09	0.01	0.33	0.82	0.01	40.14	0.32	0.02	0.03	<0.01	47.91	97.69
JAB	4.67	<0.01	0.13	1.35	0.02	41.99	0.57	0.04	0.00	<0.01	48.66	97.45
	5.56	<0.01	0.13	1.27	0.02	42.55	0.52	0.04	0.01	<0.01	47.37	97.49
	4.43	0.01	0.20	2.02	0.03	41.85	0.35	0.04	0.00	<0.01	48.60	97.54
Clelland Lake	2.80	<0.01	0.12	1.66	0.03	41.12	1.14	0.05	0.01	<0.01	50.36	97.31
Dunbar Creek	2.53	<0.01	0.20	2.11	0.04	41.48	1.36	0.04	0.02	<0.01	50.30	98.10
Botts Lake	3.62	<0.01	0.03	0.27	0.01	38.82	6.68	0.09	0.08	<0.01	48.85	98.47
Marysville	2.59	0.02	0.64	1.71	0.03	46.00	0.92	<0.01	0.01	<0.01	49.50	101.44
	5.90	0.04	0.84	1.12	0.02	43.42	1.09	<0.01	0.03	0.28	47.28	100.03
	3.59	0.05	0.92	0.72	0.01	45.11	1.02	<0.01	0.15	0.02	49.02	100.62
Mt. Brussilof *	<0.01	<0.01	<0.01	0.35	0.01	48.00	0.82	0.01	0.03	<0.02	51.96	101.23
	0.10	<0.01	<0.01	0.38	0.01	47.00	1.41	<0.01	0.02	0.03	51.44	100.42
	<0.01	<0.01	<0.01	0.37	0.01	48.12	1.02	<0.01	0.01	0.01	51.86	101.44
	<0.01	<0.01	<0.01	0.51	<0.0	47.74	0.85	<0.01	0.01	0.02	51.88	101.06
	<0.01	<0.01	<0.01	0.42	0.01	47.89	0.87	0.00	0.00	0.01	52.02	101.31

* Fresh samples from the excavation

Similar sparry magnesite deposits are located in the Brisco – Driftwood Creek area, west of Radium Hot Springs (Fig. 5). Some are staked, but none has been developed. The most recent drilling was by Canadian Occidental Petroleum Ltd. in 1990 on the Driftwood Creek deposit. Chemical analyses of some drill intersections are comparable to those of Mount Brussilof ore. All the deposits in the Brisco – Driftwood Creek area occur along evaporite horizons within the Precambrian Mount Nelson Formation (Simandl and Hancock 1992). In general, the deposits have lower Mg and higher Si contents than Mount Brussilof ore, but have similar mineralogy and sparry texture. The most common impurities are quartz, chert, and dolomite, with traces of talc, calcite, pyrite, iron oxides, and clay minerals. Chemical analyses of surface samples from seven undeveloped deposits are listed in Table 2. These deposits have equivalent or higher grades than magnesite deposits currently mined in Europe.

Magnesite occurrences are also known in Precambrian sedimentary rocks of the Cranbrook Formation. At Marysville (Fig. 5), between Cranbrook and Kimberley, magnesite-bearing rocks have been traced for 8 km. These deposits were extensively explored by Cominco Ltd. in the late thirties. Work then included test pitting and driving several adits, with bulk sampling and diamond drilling done more recently. The company still holds the Crown-granted claims covering most of the showings. The Marysville magnesite beds are similar to those in the Brisco – Driftwood area, but overall grades are lower. Their mineralogy varies considerably across stratigraphy. The central portions of the magnesite beds are purest (Hancock and Simandl 1992). The principal impurities are dolomite, quartz (1-20%), chlorite (0-2%), sericite (0-1%), and pyrite (trace). Analyses from the purest portions are reported in Table 2.

All the deposits mentioned thus far are near a well-developed road and rail network in southeastern B.C. A significant prospect is also known in the northern Rocky Mountains on Chuyazega Creek near Anzac, 120 km northeast of Prince George (Fig. 5). The mineralogy and lithology are similar to the Mount Brussiloff deposit (Hancock and Simandl 1993). Typical analyses from surface samples are reported in Table 2. Initial exploration was undertaken by MineQuest on behalf of Norsk Hydro between 1989 and 1991 (Gourlay 1991).

The economic potential of undeveloped magnesite deposits in B.C. is improving with the increase in nonrefractory uses for magnesite and magnesia, such as environmental applications (Simandl *et al.* 1991), more use of magnesia-based refractories in response to technological changes in steelmaking, and production of magnesium metal. Environmental applications may be particularly significant. An example is the Marysville deposit, which is located a few kilometres from the tailings disposal area of Cominco's Sullivan lead-zinc-silver mine.

Silica

B.C. has large untapped resources of silica classifiable as massive "lump" quartzite, friable quartzite, quartz veins, and pegmatites (Foye 1987). The Mount Wilson Quartzite is the single, largest resource of silica in the province. The quartzite is a Middle to Upper Ordovician unit that extends from Golden, approximately 200 km southwest to Fernie. The thickness decreases from 300 m at Golden to 60 m near Fernie (Norford 1969). The Mount Moberly and Nicholson (Hunt) deposits are currently in production. Other prospects include the Red Cloud and Koot occurrences (Fig. 6). Typical chemical analyses are listed in Table 3.

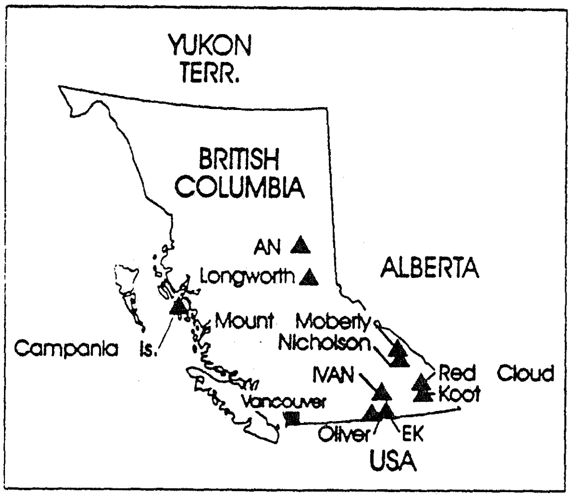

FIG. 6. Selected silica occurrences.

The Nicholson (Hunt) silica quarry, 11 km southeast of Golden (Fig. 6), is in massive quartzite of the Ordovician Mount Wilson Formation. The quarry is owned by Silicon Metaltech of Seattle, Washington, and operated by Bert Miller Contracting Ltd. of Golden. Annual production varies between 30,000 and 60,000 tonnes (Foye 1987); the ore contains <0.15% non-silica material (Table 3). After on-site crushing, washing, and screening, lump silica is shipped as feedstock for production of silicon and ferrosilicon at a plant in Wenatchee, Washington.

The nearby Moberly Mountain silica operation is owned and operated by Mountain Minerals Company Ltd. Two ore types, both from the Mount Wilson Formation, are currently mined. The first is a uniform, massive, silica-cemented friable quartz arenite and the second, recently introduced to market, is massive quartzite. Ore-sample analyses are listed in Table 3. In 1985, ore reserves were estimated at 10 million tonnes (Mt) of friable quartz arenite and 50 Mt of quartzite. The bulk of friable quartz arenite production is sold to the glass-manufacturing industry, but the quarry also supplies silica for a variety of other applications including blasting, traction, and foundry sands. The massive quartzite is similar in character to that of the Nicholson deposit a is suitable for silicon metal and ferrosilicon production.

Other high-purity quartz arenite and quartzite occurrences include the Longworth deposit in the Silurian Nonda Formation and the AN and EK showings. Vein deposits include the Oliver, Ivan, and Campania showings (Fig. 6). Typical chemical analyses for these deposits are listed in Table 3.

Quartz veins in the Oliver plutonic complex, near Oliver in the southern Okanagan Valley, have been mined for their gold, base-metal and ilica contents. The veins vary from 0.3 to 4 m in width, with the wider ones invariably cutting the porphyritic quartz monzonite phase of the complex. Production from one vein has been used in the manufacture of ferrosilicon, and quartz from other veins has been used as flux in the Trail smelter. Small-scale production took place at the Ivan deposit, 6 km west of Armstrong. Some of the quartz mined was used for manufacturing synthetic quartz crystals (Foye 1987).

As a group, the silica deposits in B.C. offer excellent potential for the production of a variety of value-added materials, including fibre glass, various glass products, ferrosilicon, silicon carbide, metallurgical-grade

Table 3. Analyses of silica samples (major elements in wt%).

MAJOR ELEMENTS (weight %)

DEPOSIT	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	LOI	S	P	Sample Type
MOBERLY (friable)	99.61	0.07	0.13	0.005	--	--	--	--	--	0.010	--	--	grab
MOBERLY (friable)	99.64	0.06	0.10	0.005	--	--	--	--	--	0.020	--	--	grab
MOBERLY (friable)	99.67	0.02	0.06	0.060	0.020	0.01	0.02	0.01	0.000	0.120	--	--	washed
MOBERLY (lump)	98.0	0.05	0.33	0.0150	<0.001	0.0046	0.07	0.02	<0.001	0.10	--	0.00067	#
MOBERLY (lump)	98.2	0.08	0.16	0.0075	<0.001	0.0038	0.03	0.01	<0.001	0.10	--	0.00048	#
MOBERLY (lump)	98.9	0.04	0.16	0.1040	<0.001	0.0027	0.03	0.01	<0.001	0.20	--	0.00057	#
MOBERLY (lump)	98.4	0.06	0.33	0.0159	<0.001	0.0053	0.05	0.02	<0.001	0.15	--	0.00063	#
HUNT (NICHOLSON)	98.76	--	1.13	nil	--	--	--	--	--	--	--	--	***
HUNT (NICHOLSON)	97.94	--	1.25	nil	--	--	--	--	--	--	--	--	***
HUNT (NICHOLSON)	98.24	--	0.85	nil	--	--	--	--	--	--	--	--	***
HUNT (NICHOLSON)	99.85	0.04	0.10	<0.050	<0.050	<0.10	<0.10	<0.05	<0.010	0.320	--	--	#
HUNT (NICHOLSON)	99.90	0.04	0.10	<0.050	0.050	<0.10	<0.10	<0.05	<0.010	0.310	--	--	#
RED CLOUD	98.56	0.12	0.65	0.050	--	--	--	--	--	0.000	--	--	grab
LONGWORTH	99.40	<0.05	0.18	<0.030	<0.030	<0.04	0.06	<0.04	0.003	1.000	--	--	chip across 10m
LONGWORTH	98.84	0.04	0.20	<0.030	<0.030	<0.03	0.05	<0.04	<0.002	<0.100	--	--	chip across 10m
LONGWORTH	98.76	<0.04	0.16	<0.030	<0.030	<0.04	0.05	<0.04	<0.002	0.300	--	--	chip across 10m
LONGWORTH	98.76	<0.04	0.17	<0.030	<0.030	<0.03	0.05	<0.04	<0.002	0.200	--	--	chip across 10m
LONGWORTH	98.91	<0.04	0.19	<0.030	<0.030	<0.04	0.07	<0.04	<0.002	<0.100	--	--	chip across 10m
LONGWORTH	99.35	<0.04	0.21	<0.030	<0.030	<0.03	0.06	<0.03	<0.002	<0.100	--	--	chip across 10m
LONGWORTH	99.32	<0.04	0.20	<0.030	<0.030	<0.03	0.06	<0.03	<0.002	<0.100	--	--	chip across 10m
LONGWORTH	99.30	<0.04	0.25	<0.030	<0.030	<0.03	0.07	<0.03	<0.002	0.300	--	--	chip across 10m
AN	99.43	0.09	0.08	0.011	0.000	--	--	--	--	0.180	--	--	++
EK	99.00	0.06	0.04	<0.030	<0.020	--	--	--	--	0.100	--	--	chip
EK	99.90	0.11	0.10	0.350	<0.020	--	--	--	--	0.500	--	--	chip
IVAN	99.56	0.08	0.27	0.056	0.000	--	--	--	--	0.000	--	--	loose muck
CAMPANIA	99.73	0.07	0.05	<0.030	<0.020	<0.03	0.02	<0.04	<0.002	0.800	--	--	"clean quartz"
CAMPANIA	99.84	<0.04	0.06	<0.030	<0.020	<0.03	0.01	<0.03	<0.002	0.200	--	--	"clean quartz"
KOOT	99.01	0.25	0.44	0.029	0.022	--	--	--	--	0.260	0.024	0.006	@
KOOT	98.97	0.14	0.42	0.018	0.014	--	--	--	--	0.210	0.096	0.005	@
KOOT	99.22	0.10	0.25	0.010	0.007	--	--	--	--	0.200	0.010	0.006	@
KOOT	99.24	0.27	0.32	0.013	0.008	--	--	--	--	0.260	0.049	0.006	@
KOOT	99.28	0.17	0.36	0.012	0.008	--	--	--	--	0.170	0.032	0.006	@
KOOT	97.48	0.44	0.47	0.320	0.220	--	--	--	--	0.640	0.011	0.007	@
KOOT	97.27	0.28	0.51	0.570	0.430	--	--	--	--	1.060	0.010	0.006	@
KOOT	98.50	0.24	0.64	0.021	0.180	--	--	--	--	0.300	0.017	0.007	@
KOOT	99.06	0.26	0.29	0.008	0.009	--	--	--	--	0.230	0.052	0.006	@
KOOT	98.97	0.17	0.47	0.008	0.013	--	--	--	--	0.240	0.024	0.006	@
KOOT	99.15	0.28	0.30	0.007	0.100	--	--	--	--	0.210	0.040	0.005	@
KOOT	99.07	0.24	0.31	0.007	0.070	--	--	--	--	0.240	0.052	0.005	@
KOOT	99.78	0.28	0.51	0.010	0.012	--	--	--	--	0.330	0.052	0.006	@
KOOT	99.10	0.19	0.38	0.010	0.012	--	--	--	--	0.260	0.032	0.004	@
KOOT	99.07	0.22	0.42	0.014	0.015	--	--	--	--	0.240	0.056	0.005	@
KOOT	98.91	0.23	0.51	0.012	0.014	--	--	--	--	0.250	0.052	0.006	@
KOOT	98.70	0.25	0.69	0.013	0.022	--	--	--	--	0.270	0.054	0.006	@
KOOT	99.27	0.14	0.30	0.014	0.011	--	--	--	--	0.180	0.026	0.003	@
KOOT	99.25	0.11	0.34	0.009	0.010	--	--	--	--	0.180	0.016	0.004	@
KOOT	98.87	0.34	0.42	0.011	0.012	--	--	--	--	0.300	0.056	0.007	@
KOOT	98.93	0.33	0.40	0.011	0.012	--	--	--	--	0.260	0.032	0.006	@
KOOT	99.05	0.24	0.28	0.010	0.011	--	--	--	--	0.230	0.056	0.004	@
KOOT	98.34	0.62	0.33	0.011	0.011	--	--	--	--	0.370	0.096	0.007	@
KOOT	98.67	0.40	0.47	0.010	0.015	--	--	--	--	0.300	0.034	0.006	@
KOOT	99.24	0.14	0.28	0.010	0.012	--	--	--	--	0.170	0.022	0.006	@
KOOT Average	98.90	0.25	0.40	0.05	0.05					0.29	0.04	0.01	
KOOT Std. Dev.(n - 1)	0.54	0.11	0.11	0.13	0.10					0.18	0.02	0.00	

TRACE ELEMENTS (ppm) - analyses by ICP; K and Na by AAS

DEPOSIT	Ag	Al	Ba	Ca	Cd	Co	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P	Sr	Ti	Zn	Zr
MOBERLY	2	370	3	130	<0.3	<0.3	<0.5	100	180	4	51	2	<1	32	<2	12	2	56	2	6
MOBERLY	3	370	3	140	<0.3	<0.3	<0.5	93	180	4	55	2	<1	31	<2	12	2	56	2	6

from General Electric Corporate Research and Development: GEL-Quartz Products Department, 1993.

*** Random samples of equal-size chips

++ Average based on 5 drillholes; no road or rail access to site

Stockpile of processed material

@ composite drill sample over 20-m interval

-- Not analyzed

silicon, and sodium silicate. A continuing trend towards the use of chemical-thermal-mechanical pulp processes in North America may substantially increase the use of silica sand to produce sodium silicate. Currently the sodium silicate used in B.C.'s pulp mills is imported from the U.S.A. as briquettes and is liquified at the National Silicates Ltd. plant at Parksville on Vancouver Island. Some of the many secondary and tertiary silica products are fused silica, silicon nitride, single and poly-silicon crystals, silanes, silicones, microsilica, as well as aluminum, calcium, and potassium silicates, precipitated silica, and fused silica.

Olivine

Olivine is another industrial mineral currently imported into Canada that is benefiting from expanding markets in new applications. It is traditionally used as a foundry sand in metal casting, and as a non-precalcined material for steel making. Olivine is also finding new uses as a heat-exchanger filler, an environmentally friendly blasting sand, and as heavy aggregate and marine ballast (Simandl *et al.* 1992). A relatively new market is production of olivine-based panels used to manufacture silo-type burners for incinerating woodwaste. These burners are more environmentally sound than the traditional beehive waste burners. Silo-type, olivine-panel burners can also be equipped to generate electrical power which can partly offset the cost of waste disposal. The olivine-based panels used in B.C. were imported from the United States. The market within B.C. is uncertain due to proposed new environmental regulations on wood burners. However, there is potential for sales to developing countries such as Brazil where no burners are used. Recent studies by the U.S. Bureau of Mines indicate that addition of olivine to chromium-bearing waste slags reduces leachability of chromium by 80% (Kilan and Shah 1984). Olivine may be used in the future for disposal of chrome-based slags.

Thirty kilometres northwest of Princeton (Fig. 7), three zones of fresh, olivine-rich rock (dunite) have been investigated on Grasshopper Mountain (Hancock *et al.* 1991; Hora and White 1988; White 1987). Findlay (1963 1969) mapped and sampled the Tulameen ultramafic complex. Contoured loss-on-ignition values of <2% outlined a zone of fresh dunite within the core of the complex. Three locations have been found that have olivine of foundry-sand grade. Preliminary tests indicate the olivine sand has casting properties comparable to IMC olivine (Table 4). The olivine from the Tulameen complex (Table 5) is high magnesia and compares favourably with other olivine from around the world (Szabo and Kular 1987; Whiting *et al.* 1987). Ideally, a potential developer could attempt to supply all segments of the olivine market and develop new applications for this versatile mineral in order to maximize the utility of the market.

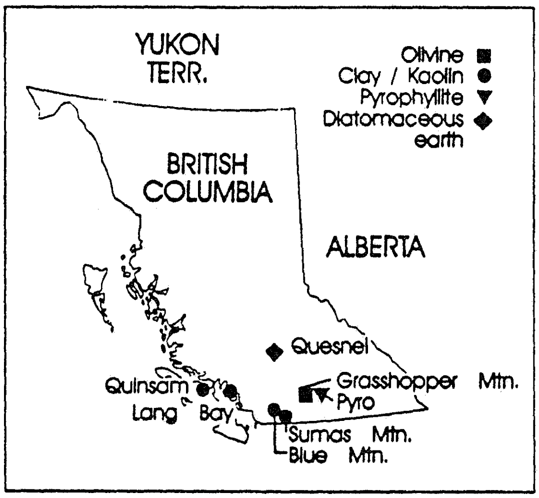

FIG. 7. Selected olivine, clay, pyrophyllite, and diatomaceous earth occurrences.

Refractory Clays, Pyrophyllite, and Diatomite

There are a number of clay and shale deposits (Fig. 7) of potential commercial quality in B.C. (Brady and Dean 1964; Ries 1915). At present the only production of clay for refractory brick is by Clayburn Industries Ltd., at Sumas Mountain in the Fraser Valley, solely for its own use.

Clayburn Industries Ltd. also uses small quantities (140 tonnes in 1990) of pyrophyllite from the Pyro claims near Princeton, and diatomaceous earth from Quesnel. Other raw materials, such as bauxite and ball clay used in the refractories, are imported. The raw materials are used to manufacture high-alumina (50-85 % Al_2O_3) brick, fireclay brick, light-weight, machine-ground insulating brick, castables, plastic insulation, brick, and mortars.

Table 4. Greensand properties before and after each trial (after Whiting *et al.* 1987).

Casting Property	Sand Type	1	2	3	4	5	
Sand Properties Before Each Casting Trial:							
Compactability, %	IMC Olivine	44	45	48	44	49	
	Grasshopper Mountain	49	47	45	45	49	
Moisture, %	IMC Olivine	2.15	2.15	2.24	2.20	2.15	
	Grasshopper Mountain	2.16	2.21	2.14	2.13	2.23	
Density, grams	IMC Olivine	195	195	193	192	190	
	Grasshopper Mountain	186	185	185	185	183	
Permeability, AFS units	IMC Olivine	200	195	210	215	228	
	Grasshopper Mountain	249	240	240	243	253	
Green Compressive Strength, psi	IMC Olivine	30.0	27.1	29.0	30.2	28.9	
	Grasshopper Mountain	25.7	25.2	28.0	29.6	28.6	
Clay Additions, %	IMC Olivine	6.0	0.1	0.1	0.0	0.0	
	Grasshopper Mountain	6.0	0.3	0.15	0.05	0.2	
Methylene Blue Clay, %	IMC Olivine	6.1	6.1	6.3	5.8	5.8	
	Grasshopper Mountain	6.1	6.1	6.2	6.0	5.8	
Mold Hardness, B scale	IMC Olivine	88	88	88	90	88	
	Grasshopper Mountain	88	88	90	90	88	
AFS Grain Fineness Number	IMC Olivine	42.7					*50.6
	Grasshopper Mountain	44.3					*54.5
After Casting Trials							
Moisture, %	IMC Olivine	0.85	0.82	0.94	0.81	N/D	
	Grasshopper Mountain	0.93	0.83	0.98	0.85	N/D	
Methylene Blue Clay, %	IMC Olivine	5.9	5.9	6.1	6.1	N/D	
	Grasshopper Mountain	5.7	5.9	5.6	5.8	N/D	
AFS Clay, %	IMC Olivine	N/D	N/D	N/D	N/D	8.96	
	Grasshopper Mountain	N/D	N/D	N/D	N/D	8.48	

Additional Tests				
Acid Demand	at	pH 5	pH 7	
IMC Olivine	mL	9.6	8.5	
Grasshopper Mtn.	mL	33.6	30.5	
Loss On Ignition	at	500 °C	700 °C	975 °C
IMC Olivine	%	0.55	1.51	1.51
Grasshopper Mtn.	%	0.90	1.82	1.83

* After fifth trial and after washing for AFS Clay test.

Table 5. Scab block casting tests (source: Whiting *et al.* 1987).

Casting Property	Sand Type	1	2	3	4	5
Surface Finish	IMC Olivine	3	3	3	3	2
	Grasshopper Mountain	3	3	3	3	2
Scabbing	IMC Olivine	1	1	1	1	1
	Grasshopper Mountain	1	1	1	1	1
Burn On	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain	2	2	2	2	2
Erosion	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain	2	2	2	2	2
Penetration	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain	2	2	2	2	2

Note: Each casting was rated on a scale of 1 to 5 where:
1 = good and 5 = bad.

The major products marketed by Clayburn Industries are acid refractories used in aluminum and base-metal smelting, oil refining, incinerators, lime kilns and other industrial furnaces, and in the pulp and paper industry. Much of Clayburn's production is exported.

Other potential refractory clay deposits in the Lower Mainland area include a mudstone 15 to 30 m thick, exposed on Blue Mountain, 20 km northwest of Mission (Fig. 7), and a number of brown and dark grey mudstone and claystone beds intersected in drillholes during exploration for residual kaolin deposits in the Lang Bay area of the Sechelt Peninsula northwest of Vancouver. The Lang Bay claystone beds are classified as medium to high-duty fireclay (Hora 1989). Tests on samples of the Blue Mountain mudstone indicate that it is less refractory than the material mined at Sumas Mountain (Ries 1915).

On Vancouver Island, a claystone bed with good refractory properties (pyrometric cone equivalent of 31.5) is associated with the No. 1 coal seam at the Quinsam colliery near Campbell River (Hora 1989). Several small or poorly known pyrophyllite occurrences were described or listed by MacLean (1988). The most promising of these require additional investigation to determine if they have economic potential. One of the deposits conveniently located on the west coast of Vancouver island is being investigated by New Global Resources Ltd.

There are several documented diatomite occurrences in the province. The most economically interesting are located between Kamloops and Quesnel (Hora 1984). Recent experiments indicate that diatomite can be used to manufacture synthetic mullite. This may improve the economic assessment and value of some diatomite occurrences. Diatomite is not limited to refractory uses. Major applications include filtration/filter aids, specialty fillers, anti-blocking agents, and mild abrasives.

Kyanite, Andalusite, Sillimanite, and Mullite

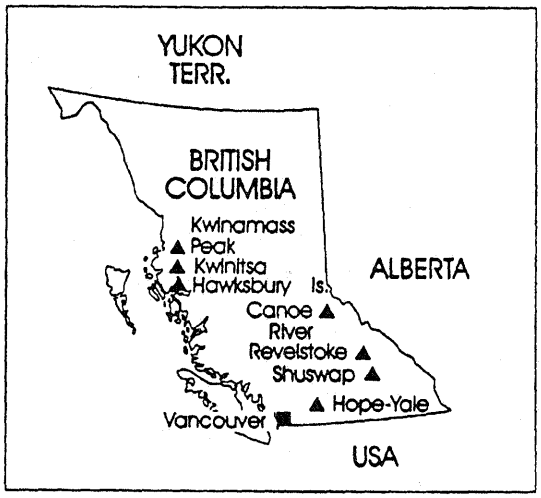

FIG. 8. Selected kyanite and related mineral occurrences.

Occurrences of anhydrous aluminosilicates commonly developed in amphibolite-facies metamorphic rocks are widespread in B.C. They include 50 kyanite, 23 sillimanite, and 8 andalusite localities (Pell 1988). Some of these occurrences also contain garnet and mica. The majority of the occurrences is in metapelitic schists of the Coast and Omineca crystalline belts (Fig. 8). There is also a significant potential for contact-metamophic andalusite deposits locally associated with porphyry copper systems. The mineralogy and grades of a few selected occurrences are summarized in Table 6. The crystal size of the aluminosilicates varies from a few millimetres to several centimetres. Sillimanite commonly occurs in the form of fibrolite, which is difficult to extract, but prismatic sillimanite is also reported (Pell 1988).

The most important industrial use of aluminosilicates is in refractories, but new applications are being developed in the manufacture of paper, paint, brake linings, welding rods, catalytics, and filters. Andalusite is preferred in Europe and Japan as it requires no pre-firing before use. The greatest portion of world andalusite production comes from South Africa. Political uncertainties in South Africa could force major trading companies to investigate alternate deposits, including those in B.C. Standard mullite is a value-added product made by calcining naturally occurring aluminosilicates, usually kyanite. High-quality synthetic mullite is produced by fusing Bayer process alumina with pure silica sand.

Kyanite prospects, where kyanite coexists with garnet and mica, may be also worthwhile exploration targets.Typical garnet abrasive currently sells for US$160 to $220 per tonne. Sketchy geological descriptions rarely specify the variety of mica associated with garnet and aluminosilicates; however, light mica concentrates are currently valued at US$200 to $1000 per tonne, depending on the level of processing.

Table 6. Summary of published information on kyanite, andalusite, and sillimanite (after Pell 1988).

Area	Aluminosilicate			Possible Byproducts %
	Ky %	Sill %	And %	
Southern Shuswap		20 - 25		<30 Gr, (Mi?)
Revelstoke - Big Bend	20 - 30			(Mi?)
Canoe River	20 - 25			15 - 20 Gr, (Mi?)
Hope-Yale Settler Schist	23 (L)	24 (L) 15 (P)		<30% Gr, (Mi?)
Hope-Yale (Breakenridge Fm.)	<40		Minor	<50 Gr
Hope-Yale (Cairn Needle)	15 (av.)			20 (av.) Gr, (Mi?)
Kwinamass Peek		<50		15 - 20 Gr, (Mi?)
1 km east of Kwinitsa		5 - 30		5 - 30 Gr
Hawksbury Island	<20			<20 Gr
Valentine Mountain			?	Gr, St

Abbreviations: And - andalusite, Gr - garnet, Ky - kyanite, P - prismatic, Sill - sillimanite, St - Staurolite, L - Locally, av. - average, (Mi?) - type of mica is not specified

Graphite

More than 30 occurrences of graphite are reported in B.C. Few have ever been investigated or described in the literature. The most promising areas for crystalline, flake-graphite showings are located within the Coast plutonic complex and the Omineca crystalline belt. Several reported showings are suggested for preliminary field examination, based on published descriptions (Fig. 9).

The AA graphite prospect, located on tidewater at the head of South Bentinck Arm, occurs in a retrograde, granulite facies, metasedimentary roof pendant within granitic rocks of the Coast plutonic complex. Assays indicate C_{total} contents in the range 2.98 – 17.9%. The size and shape of the graphitic zone are not known (Marchildon *et al.* 1993). This or other amphibolite- or granulite-facies metasedimentary roof pendants have excellent potential to host economic graphite deposits.

The Skeena showing, hosted by amphibolite and biotite-hornblende gneisses of the Coast plutonic complex, is reported to contain 3% graphite across a width of 120 m (Clothier 1922). A few grab samples of vein material with gold values up to 3 g/t were reported in 1922 but have not been confirmed. The Payroll showing, in amphibolitic rocks of the Coast complex, is an apparently concordant graphitic unit 3 to 4.5 m thick (Clothier 1921). The Mon occurrence reportedly contains flakes of crystalline graphite disseminated in marbles, calcsilicates, and biotite schists of the Wolverine metamorphic complex in north-central B.C. Sillimanite was observed in metapelitic rocks (P. Ferri 1994, personal comm.). Assays reported by Halleran (1985) suggest grades in excess of 4% graphitic carbon.

These and other graphite showings indicate geological environments in which economic concentrations of crystalline, flake graphite may occur and warrant further investigation. Microcrystalline graphite in metamorphosed coal seams has not been reported in B.C., but meta-anthracite seams are known. Systematic exploration for microcrystalline graphite in metamorphosed coal beds has not been done in B.C.

FIG. 9. Selected graphite occurrences.

Quinto Mining Corporation is attempting to develop a gold, graphite, and sericite deposit, 37 km east of Vernon. The microcrystalline graphite is intergrown with mica and cannot be upgraded to a marketable graphite concentrate. Therefore, the company is examining the possibility of marketing a muscovite-graphite product derived as a byproduct of the processing of gold ore (Schiller 1993).

Other Minerals

Dolomite is another mineral with known refractory applications, but it is not produced for this purpose in B.C. (Fischl 1992). Although several tidewater dolomite occurrences are known, no systematic study of the possible use of this material for refractories has been done. Occurrences of zircon, chromite (Hancock 1991), and brucite (Grant 1987) have also been reported in the province. Magnesia-bearing tailings are located at the site of former Cassiar asbestos mine. Zircon, an accessory mineral in many igneous rocks, is commonly recovered from beach placer deposits, raising the possibility of byproduct recovery from placer gold mining.

VALUE-ADDED, ELECTRICITY-INTENSIVE MINERAL PRODUCTS

British Columbia's Potential

History indicates that successful plants producing large tonnages of energy-intensive products have most often been established in areas with low energy costs. B.C. has attractive energy prices and deep-sea ports. In addition, it is strategically located to serve Asian and western North American markets. Through economies of scale in offshore shipping, as described by Crouch (1993), B.C. may also be competitive in Europe. Because of the abundance of locally generated and competitively priced electricity, and relatively small population, B.C. is expected to maintain competitive energy prices. It is expected that more densely populated countries will face greater pressures to reduce the proportion of electrical energy available for industrial use in favour of residential and commercial purposes. As well, countries with existing plants based on obsolete or polluting technology will increasingly be at a competitive disadvantage (Horst 1993) and, as a consequence, will probably experience declining sales or close down.

Currently, there is a worldwide rationalization of production of energy-intensive products. This restructuring is mainly due to rapid increasing acceptance of high-performance refractories, instability in light-metal markets which is largely a result of major political changes in Central and Eastern Europe, the recent global economic slowdown, and lastly, the emergence of China as a competitive supplier.

The above-described rationalization, changes in market conditions, development of new technologies, depletion of raw materials in some traditional producing areas, rapid escalation of industrial energy costs in some European countries (Anonymous 1994b), unreliable power supplies in parts of northwestern U.S.A. (Anonymous 1993a), and political instability in other countries suggest that it is time to evaluate the feasibility of producing these materials in B.C.

An important consideration that has not been previously addressed in the province is the development of selected energy-intensive niche products. Electrofusing facilities can be designed to produce a variety of products for refractory niche markets, is demonstrated by a plant under construction at Kalamassery, Kerala, by Carborundum Universal Ltd. It will have an annual capacity of 12,000 t white fused alumina or 8,000 t of brown fused alumina. The key feature is that its design is flexible and allows the plant to also produce fused magnesia and fused zirconia products (Anonymous 1993b).

B.C. is well-positioned to serve such niche markets as it can utilize both locally produced mineral resources and widely available low-cost imported materials. High unit-value electrofused materials produced in the province could be traded internationally. Targetting of multiple niche markets allows increased diversity in product lines and higher plant capacity. This is the key to long life in quickly evolving markets such as high-performance refractories for the steel industry. Similar rapid changes are taking place in the advanced-ceramics field.

A variety of electricity-intensive products could be produced in B.C. Those derived from silica and magnesite are of particular interest. Both minerals are currently mined and sold in the province, or are exported for further processing into energy-intensive products. Furthermore, large undeveloped deposits of these minerals are locally available.

Worldwide available low-cost raw materials, that are not locally produced, can be imported from overseas, upgraded, and subsequently exported. The low-cost and availability of imported raw materials, such as bauxite or alumina, may play a key role in the decision-making concerning the installation of a modern electrofusing plant in B.C. Such imports may be recquired to allow specialized electrofusing plants to serve multiple niche markets.

Table 7. Selected electricity-intensive minerals and products.

Group I - High tonnage	Group II - Small tonnage	Group III - Limited tonnage	Group IV - Other Products***
Typical production capacity: 30,000 to 50,000 tpa Typical power consumption: 8,000 to 13,500 kWh/t	Typical production capacity: 5,000 to 30,000 tpa Typical power consumption: <5,000 kWh/t	Typical production capacity: ≤ 5,000 tpa Typical power consumption: highly variable	Tonnage and power consumption are product-specific.
- Ferrosilicon - Silicon metal a) chemical grade b) metallurgical grade - Silicon carbide - Mg metal * - Al metal *	- Fused magnesia -abrasive grades -refractory grades -electrical grades - Fused silica: -optical & electronic grades -refractory grade - Fused alumina * -brown -white -pink	- Al-Mg spinel - Synthetic mullite - Zirconia-mullite - Fused zirconia - Magnesia-spinel brick - AZS fused shapes - AZS brick - Zirconium metal	- Polysilicon # - Single silicon crystals # - Synthetic diamonds # - Synthetic quartz # - Sinterable silicon carbide # - Silicon nitride # - Sialons # - Composites # - Ceramic fibres and whiskers # - Boron nitride # - Titanium diborite # - Rock wool ** - Glass** - Fibreglass ** - Sodium silicate ** - Precipitated silica **

*	Some aluminum and magnesium plants have significantly higher capacities than those listed above.
**	High- or small-tonnage production capacity, moderately energy-intensive products.
#	"Lab-scale" or less than several thousand tonnes/year production capacity.
***	Steel derived from mini-mills using electric arc furnace technology, and plasma-coating advanced ceramics are covered by previous studies.

Categorizing Electricity-intensive Materials

For the purpose of this paper, electricity-intensive, value-added industrial products can be divided into four basic categories (Table 7), based on the production capacity of a typical plant and to some extent on energy consumption per tonne. The Table is not complete and its main objectives are to channel the discussion and better focus the concepts covered in this paper.

Group I: high tonnage (silicon, ferrosilicon, silicon carbide, aluminum, and magnesium)

This group consists of materials that are typically produced on large scale (Table 7). The capacity of a typical plant that produces these materials is in the range of 30,000–50,000 tonnes per year (tpa). That size of production requires the input of electrical energy in the range of 8,000–13,500 kilowatt-hours per tonne (kWh/t). The group includes silicon metal, ferrosilicon, and silicon carbide. Substantial quantities of coke are used in the manufacure of these products. Also included in this group are aluminum and magnesium metals, although the annual capacity of plants producing aluminum and magnesium commonly exceed 50,000 t. The Alcan aluminum-refining plant near Kitimat imports its raw materials. With the exception of aluminum metal, there is no production of Group I electricity-intensive materials in B.C. A large portion of the silica and magnesite mined in the province is exported with little or no upgrading.

Group II: small-tonnage fused products (fused silica, alumina, and magnesia)

This group consists of silica and magnesite-based products which involve production capacities of 5,000 to 25,000 tpa, with an average of 10,000 to 15,000 tpa. Their production requires a less intensive input of electrical energy, in general less than 5000 kWh/t. Examples of this group include refractory-grade fused silica and fused magnesia. Fused magnesia is currently produced in Alberta from magnesite mined in B.C. by Baymag Mines Co. Limited. Various grades of fused alumina belong to Group II, but raw materials for fused alumina production would have to be imported into B.C.

Group III: limited-tonnage products (electrofused products and zirconium metal)

This group includes a variety of products based on magnesite, alumina, chrome, zirconia, and zirconium metal that are produced in limited tonnages of 2,000 to 5,000 tpa. Production requires a highly variable input of electrical energy ranging from 2,500 to 62,000 kWh/t. The group includes fused alumina-magnesia (spinel), fused alumina-zirconia-silica (AZS), synthetic mullite, fused zirconia, fused chrome-magnesia, zirconium metal, and other products. In spite of limited markets, these high-priced products are used in in modern, high-performance ceramics and refractory products.

Group IV: other products

This group contains specialty products that, for various reasons, do not fit into categories I through III. Polysilicon, single silicon crystals, synthetic quartz, sodium silicate, precipitated silica, mineral wool, fibre glass, and synthetic diamond are well-known examples. Polysilicon and single silicon crystals are both extremely energy-intensive products, consuming approximately 160 kWh/kg and 110 kWh/kg respectively. The impact of power costs on competiveness in the manufacturing of these materials is extreme even if an annual capacity of a typical plant is <1,000 tpa. Other members of this group are some advanced ceramics and synthetic minerals that are produced at a "nearly laboratory scale" or have restricted markets. Boron carbide, boron nitride, silicon nitride, titanium diborite, zirconium diborite, and sialons are a few examples described by Haries-Rees (1993). Specialty fibres and whiskers are described by Bray (1993) and by Ault and Yeckley (1993).

Patterns of Consumption and Use

Group I: high tonnage (silicon, ferrosilicon, silicon carbide, aluminum, and magnesium)

Silicon metal is divided into two major categories: chemical and metallurgical. The purer chemical-grade silicon is a starting material for production of silicon tetrachloride (tetrachlorosilane), silanes, silicones, semiconductor-grade silicon, high-purity fused silica, and other products (Coope 1989). The consumption of chemical-grade silicon is expected to grow rapidly because of the variety of uses of its derivatives, their limited cost, and the relative immaturity of their markets. The metallurgical-grade silicon market is more competitive because of low-cost exports from Argentina, Brazil, China, and other countries.

Demand for silicon carbide in metallurgical applications (*e.g.*, as a deoxidant in steel-making) is forecast to increase in Southeast Asia as steel production expands in that region. Applications of silicon carbide in refractories (*e.g.*, silicon-bonded silica-carbide shapes), as an abrasive, and in advanced ceramics are relatively stable but are expected to grow. Besides the steel industry, silicon-carbide refractories are used in electrical generating plants, waste incinerators, and other applications (Skillen 1993). World consumption of silicon carbide is expected to grow slightly or remain relatively level. However, the location of production facilities will change in response to rising energy costs and as more stringent environmental controls are applied. New plants are designed with environmental restrictions in mind and they are more energy efficient. Plants that use obsolete technology must address new environmental requirements through costly retrofitting, or risk closure.

As in the case of silicon, location of ferrosilicon production facilities is moving to areas of low energy costs with available raw materials. Ferrosilicon supply currently outstrips demand. The rationalization of production capacity, as described by Robinson (1993), especially in plants with high production costs, will continue. However, these unfavorable market conditions may not deter the entry of plants with new technology into the marketplace.

The magnesium and aluminum markets are very competitive (Krammer 1993; Ridgway 1993; Humprey 1993). Within industry, opinions vary greatly as to the timing of expected improvements in market conditions. Worldwide rationalization in the aluminum industry is taking place (Anonymous 1993c,d), and numerous new projects are in various stages of planning or construction in anticipation of market improvements (Chevalier 1993). The Guangxi Pingguo Aluminum Corporation's project, which may indicate the importance of future Chinese involvement, is expected to have an annual capacity of 300,000 t of alumina and 100,000 t of aluminum metal in its stage one (Anonymous 1993e). The outcome of negotiations concerning aluminum-production cutbacks that took place in Brussells, and the degree to which signatory countries will adhere to the agreement, will reflect on the aluminum market in the near future. The automotive market for aluminum is expected to expand dramatically. Currently there are about 86 kg of aluminum per car and there will be about 258 kg in the next decade, according to General Motors (Anonymous 1994c).

Trade disputes dominate the magnesium market. Production cutbacks were widespread in 1992 (Ridgway 1993), but research and development, new expansions, and construction of new plants is underway. Noteworthy developments include the construction of a magnesium metal and alloy plant in Israel by Dead Sea Works Limited. In Quebec, further research was carried out on the Magnola technology that is claimed to be the lowest operating cost primary magnesium-producing process using asbestos tailings as feed. Magcan's 10,000 tpa smelter, located in Alberta, which was supplied by magnesite from B.C., is for sale. The Magmetal, Australian and Japanese joint-venture project is focusing on magnesium-metal production. The raw material source for the project will be a large magnesite deposit located at Kunwarara, central Queensland. State-of-the-art electrolytic technology will be provided to the joint venture by Alcan (Anonymous 1994d).

Magnesium demand is expected to improve in the mid to long term, and largest demand is expected to come from the automotive industry. Currently, the amount of magnesium alloys in car production is almost 50% higher than industry predicted 10 years ago. North American cars currently have the highest magnesium-alloy content and Japanese and Korean cars have the lowest. This is expected to change before the year 2000 (Ridgway 1993). Recent developments of magnesium technology in the automotive industry (Clow and Barber 1994) and the introduction of the export license system by China for all grades of magnesia (Anonymous 1994a) may strongly favor manufacturing of magnesite-derived energy-intensive products in the province.

Group II: small-tonnage fused products (fused silica, alumina, and magnesia)

Fused silica has a wide variety of uses, from refractories to crucibles, optical elements, fibre optics, electronics, tubing in infrared radiant heating systems, and in chemical applications. B.C. may have the low-grade raw materials used in refractories, and natural raw materials for nonrefractory applications would have to be imported. Synthetic silica or silicon tetrachlorite (derived from chemical-grade silicon) are the main starting materials in production of high-quality optics and optical wave guides for fibre-optic systems. Demand for high-purity, nonrefractory fused silica is forecast to increase fastest in semiconductor processing and in fibre-optics segments. The 1992 world demand for nonrefractory-grade fused silica was estimated at 20,000 t (Roskill 1992). No published production statistics are available for the refractory-grade fused silica, but it is expected to exceed those of non-refractory fused silica.

The magnesia market is large, but very competitive (Coope 1993). In B.C., excellent-quality magnesite is mined near Mount Brussilof by Baymag Mines, and is shipped to Alberta where it is processed into calcined and fused magnesia. The latter is produced exclusively for the refractory market. Chemical analyses of Baymag's products are listed in Table 1. Baymag's parent company, Refratechnik GmbH, has other plants at Göttingen and Kraichtal-Gochsheim in Germany and Gornal in Spain. Refratechnik produces a range of products including magnesia-spinel bricks, fired magnesia bricks, magnesia graphite bricks, fireclay, high-alumina bricks, and a whole range of so-called unshaped refractories.

Group III: limited-tonnage products (electrofused products and zirconium metal)

Fused Al-Mg spinel, fused zirconia, AZS fused shapes, AZS bricks, and synthetic mullite are good examples of niche products that represent recently established growth markets. Products related mainly to steel manufacture are forecast to show strongest growth in China and, to a lesser extent, other Southeast Asian countries and worldwide. Products used in the aluminum, glass, and specialty-cement industries are expected to show more uniform growth worldwide. The use of chrome-magnesia refractories is decreasing in North America, Europe, and Japan. Some of the developing countries, where environmental problems are a less sensitive issue, such as India, are expected to continue using mag-chrome products for some time to come. This is supported by a recent transfer of mag-chrome brick technology from Refratechnik GmbH of Germany to Associated Cement Co. of Bombay, India (Anonymous 1994e). Alumina-magnesia spinel is the main substitute for mag-chrome refractories in industrialized countries. All materials in this group III are traded worldwide.

Group IV: other products

The key considerations in evaluating production potential for group IV in B.C. are: energy consumption per unit of product, the fraction of the sale price that the energy cost represents, growth in demand for that commodity, and proportion of the total market that the output of the new plant would represent. The examples that follow illustrate the concept. In Canada, there are no plants producing sodium silicate west of Toronto (Boucher 1993). The main sodium silicate uses are in detergents and synthetic zeolite production, pulp and paper manufacture, newsprint de-inking, ore flotation, textile bleaching and water treatment, catalysts and abrasives industries, and precipitated silica manufacturing. Sodium silicate is available in liquid or briquette form (sodium silicate glass) which is easy to transport and can be liquified near industrial centres. Several pulp mills in the province are large consumers of sodium silicate. It's manufacture is discussed by Coope (1989).

Precipitated silica is commonly produced by reaction of sodium silicate with sulfuric acid. It has applications in the rubber and paint industries, and also in manufacturing thickening and polishing agents.

The only synthetic quartz plant in Canada is near Trois Rivières, Québec, and has a 40-tpa capacity (Boucher 1993). Total consumption of cultured quartz was estimated at 1,500 to 2,000 t worldwide. According to Roskill (1992), consumption is expected to grow 5% annually. The price of cultured quartz is in the $US 25 – 30/kg range as grown, and over $US 100/kg in lumbered form. In the past, one deposit in B.C. supplied raw material for synthetic quartz production (Foye 1987). However, raw material imports may be required for future developments. Demand for polysilicon and single silicon crystals is expected to continue to grow and new production facilities will be located in the areas of low electricity cost, such as B.C.

Fibre glass is used mainly as insulation or a reinforcing material. Stringent insulation standards that are being established in B.C. and elsewhere are expanding the current market. The reinforcing glass-fibre market is closely linked to the automotive industry (Russell 1991). If the recent gradual opening of Japanese markets to glass exports is not disrupted, Japan may represent a previously inaccessible market.

SUMMARY AND CONCLUSIONS

B.C. has magnesite, silica, olivine, kyanite, andalusite, shale, diatomite, pyrophyllite, graphite, dolomite, and brucite deposits or occurrences. Magnesite and silica are of particular interest because they are mined in B.C. and are distributed through local and export markets; furthermore, large undeveloped mineral sources are known in the province.

A large variety of energy-intensive, value-added materials is marketed world-wide. Considering world-scale markets, technology, and regional energy costs, B.C. is one of the favorable locations for future plants. Energy-intensive, value-added materials include light metals, such as magnesium and aluminum, metallurgical- and chemical-grade silicon, ferrosilicon and ferrochrome, silicon carbide, sintered or electrofused refractories, synthetic abrasives, reinforcing or insulating fibres, traditional or advanced ceramics, glass, and intermediate products used in the electronic and chemical industries. Niche markets within the field of electrofused minerals, advanced ceramics, and electronic products should not be overlooked.

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