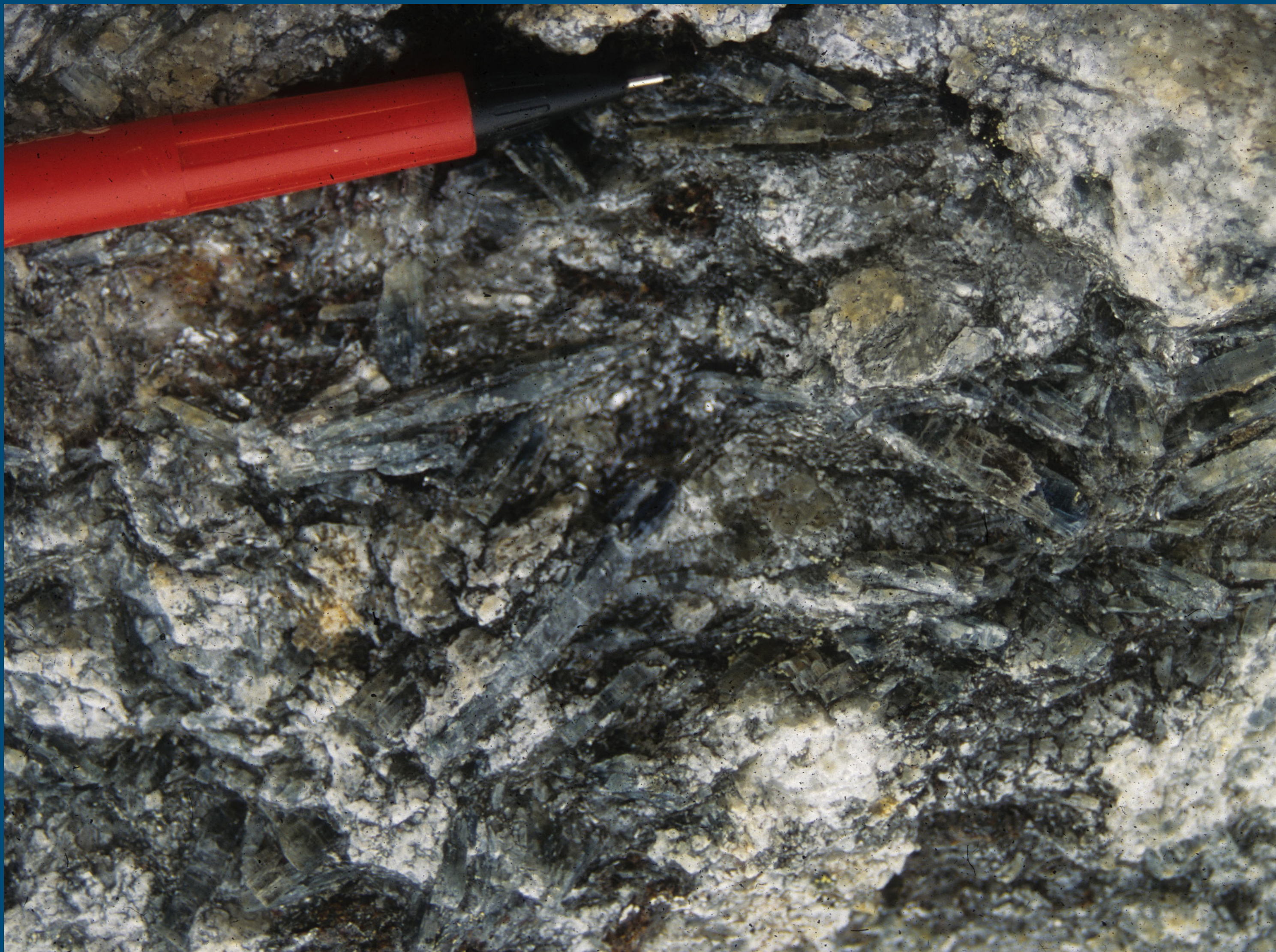

Refractory minerals in British Columbia, Canada, 2014

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Front cover: Blue-grey kyanite crystals, Hawkesbury, northwestern British Columbia.

Back cover: Andalusite crystals in hornfels, Bridge River area, southern British Columbia.

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Refractory minerals in British Columbia, Canada, 2014

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Abstract
Magnesite, silica, olivine, kyanite, andalusite, refractory clays and shale, pyrophyllite, graphite, chromite, and dolomite are some of the traditional refractory minerals known to occur in British Columbia. Besides these, the province also has deposits of lightweight heat insulating materials such as pumice, mineral wool, perlite, and vermiculite. Undeveloped deposits and occurrences of refractory minerals are documented in the BC MINFILE, a free, publically accessible database. Large areas of British Columbia, unexplored for refractory minerals, offer geological potential for the discovery of new deposits. The internal demand of British Columbia for traditional heavy duty refractory raw materials is limited. However, these minerals also have a variety of non-refractory applications, and most of these materials are internationally traded either in raw form, or after value-added processing.

Keywords: Refractory minerals, heat insulation products, magnesite, kyanite, andalusite, graphite, olivine, pyrophyllite

1. Introduction

Refractory minerals are those that can withstand high temperatures in industrial environments and those that can be transformed into materials with refractory properties. Both natural and synthetic refractories, some of which are advanced ceramics, also have non-refractory uses. For example, silicon carbide is a synthetic refractory that can be used as a specialty ceramic, but also has uses in metallurgy or as an abrasive. Representative prices of selected refractory minerals are compiled in Table 1. Updating Simandl et al. (1992a), this paper reviews refractory minerals in British Columbia. It was released at the Industrial Minerals International Congress and Exhibition, held in Vancouver, British Columbia (April 1-3, 2014).

2. Refractory minerals in British Columbia

Currently, magnesite and silica are the only traditional refractory minerals mined in British Columbia. The province has a promising olivine deposit and numerous occurrences of graphite, andalusite, kyanite, pyrophyllite, and other refractory minerals. An inventory of deposits and occurrences containing refractory minerals is part of BC MINFILE, a database that can be accessed at no charge (http://minfile.gov.bc.ca/).

This database contains 45 magnesite, 24 dolomite, 31 graphite, 36 kyanite, 15 sillimanite, 6 andalusite, 79 clay (not necessarily refractory), 54 silica, 12 pyrophyllite, 45 diatomite, 25 perlite, 5 vermiculite, 4 pumice/scoria, and 2 olivine entries corresponding to “primary” occurrences.

British Columbia has a well-developed transportation and industrial infrastructure and a number of deep-water ports. With ready access to Pacific Rim countries and competitive shipping costs to the Atlantic, the province is well situated to serve North American, Asian, and European markets (see http://www.pacificgateway.gov.bc.ca/).

2.1. Heavy- to medium-duty refractory minerals mined in British Columbia

2.1.1. Magnesite

Magnesite ($MgCO_3$) is used in the production of a variety of magnesia compounds (Simandl, 2002) and, to a lesser extent, for magnesium metal (Simandl et al., 2007a, b). World magnesite production for 2012 is estimated at 6.1 million tonnes, mostly from China (Kramer, 2013). More than 50 magnesite occurrences are known in British Columbia (Fig. 1; Grant, 1987). The most significant are sparry magnesite (Fig. 2) deposits hosted by sedimentary rocks (Simandl,

Table 1. Representative prices of selected refractory minerals (Anonymous, 2013).

Material	Specifications	Transportation-Delivery	US$/tonne
Andalusite	57-58% Al_2O_3 (2000 tonne bulk)	[1]FCA Mine South Africa	315-375
	55-59% Al_2O_3	[2]FOB European port	468-569
Graphite	Amorhous powder 80-85% C,	[3]CIF main European port	500-550
	Crystalline flake 85-87% C (+100-80 mesh)	CIF main European port	800-1000
	Crystalline flake 90%C (-100mesh)	CIF main European port	850
	Crystalline flake 94-97%C (+80 mesh)	CIF main European port	1350
Magnesia	Calcined, lump, 90-92% MgO	FOB China	303-343
	Dead-burned, 90% MgO	FOB China	320-350
	Dead-burned, 94-96% MgO	FOB China	450-480
	Dead-burned, 97.5% MgO	FOB China	531-583
	Fused , lump, 96% MgO	FOB China	600-630
	Fused , lump, 98% MgO	FOB China	1023-1100
Olivine	Refractory grade, bulk	[4]US ex-plant/mine	75-150
Refractory clay/mullite	Clay, Mulcoa 47%, coarse, in bulk bags	FOB USA	218
Silicon Carbide	Refractory grade, >95% SiC	CIF UK	1800-1950
	Refractory grade, >98% SiC	CIF UK	2000-2400

[1]FCA: The seller arranges transportation, but at the risk and the expense of the buyer
[2]FOB: Free on board
[3]CIF: Cost, insurance and freight covered
[4]ex plant: Goods are made available for pickup at the production site

2001) but a few are associated with ultramafic rocks (Grant, 1987; Simandl and Ogden, 1999). The large, high-grade deposit at Mount Brussilof, in the Rocky Mountains northeast of Radium Hot Springs (Fig.1), accounts for all of Canada's current production. In 2013 this amounted to 180 000 tonnes (Katay, 2014). The Mount Brussilof deposit is hosted by Cambrian dolostones (Simandl and Hancock, 1991; Simandl et al., 1991). Chemical analyses of magnesite rocks from the Mount Brussilof deposit are shown in Table 2. The mine has been in production since 1982 (Schultes, 1986) and is operated by Baymag Mines Co. Limited, a private company owned by Refratechnik GmbH of Germany. Raw magnesite from Mount Brussilof is currently processed into high-quality caustic magnesia in Exshaw, near the British Columbia-Alberta boundary (Schultes, 1989). Caustic is used in environmental, industrial, and agricultural applications. Fused magnesia and, for a short time, Mg-metal, were also produced from this deposit (Schultes, 1989; Northern Miner 1991). The physical and chemical properties of magnesite rock and host rocks are summarized by Simandl et al. (1992b) and Simandl (2002).

Similar smaller, and less well-exposed sparry magnesite deposits are in the Brisco-Driftwood

Fig. 1. Selected British Columbia sparry magnesite deposits. The Driftwood Creek-Brisco area contains at least seven occurrences.

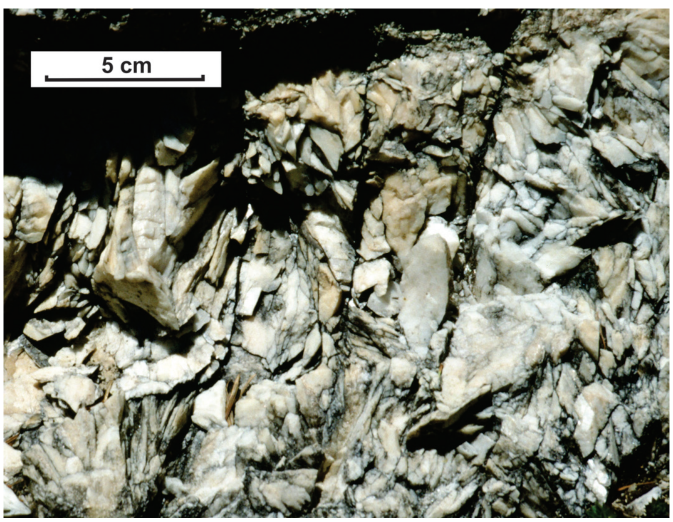

Fig. 2. Coarsely crystalline sparry texture of magnesite ore (weathered surface), Mount Brussilof deposit.

Creek area, west of Radium Hot Springs (Fig. 1). Most are staked, but none have been developed. Canadian Occidental Petroleum Ltd. and its successors drilled the Driftwood Creek deposit. However, most occurrences in British Columbia remain untested by drilling. Chemical analyses of some drill intersections from the Driftwood Creek are comparable to those of Mount Brussilof ore (Table 2). All the deposits in the Driftwood Creek-Brisco area occur along evaporite horizons in the Mount Nelson Formation (Middle Proterozoic; Simandl and Hancock, 1992). In general, they have lower magnesia and higher silica contents than the Mount Brussilof ore, but have similar mineralogy and sparry texture. The most common impurities are quartz and dolomite. Talc, calcite, pyrite, iron oxides, and clay minerals are present in lower concentrations. Chemical analyses of surface samples from seven undeveloped deposits including Driftwood Creek, Topaz Lake, Red Mountain, JAB, Clelland Lake, Dunbar Creek, and Botts Lake (Table 2) have equivalent or higher grades than most magnesite deposits mined in Europe (Simandl, 2002).

Magnesite occurrences are also known in Lower Cambrian sedimentary rocks of the Cranbrook Formation. At Marysville (Fig. 1), magnesite-bearing rocks have been traced for 8 kilometres. They were extensively explored by Cominco Ltd. in the late 1930s. Work included test pitting and driving several adits with bulk sampling and, more recently, diamond drilling. The Marysville magnesite beds are similar to those in the Brisco-Driftwood area, although overall grades are lower. Mineralogy varies across stratigraphy, but the central parts of these beds are the purest (Table 2; Hancock and Simandl, 1992). The principal impurities are dolomite, quartz (1-20%), chlorite (0-2%), sericite (0-1%), and pyrite (trace).

All the above deposits are in southeastern British Columbia, near a well-developed road and rail network. More remote, the Anzac prospect is in the northern Rocky Mountains, at Chuyazega Creek, 120 kilometres northeast of Prince George (Fig 1). The mineralogy and lithology at Anzac are similar to the Mount Brussilof 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 British Columbia is improving with an increase in non-refractory uses for magnesite and magnesia, such as environmental applications, and with tighter restrictions on industrial minerals imports from China.

Table 2. Chemical composition of sparry magnesite rocks in British Columbia. Simplified from Simandl (2002).

Deposit	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
Anzac	0.44	<0.01	0.21	1.16	0.02	43.79	3.14	0.01	0.01	1.04	50.4	100.2
	0.39	<0.01	0.08	0.76	0.02	34.23	16.7	0.01	0.01	0.82	49	102
	2.23	<0.01	0.11	0.98	0.02	48.99	0.72	0.01	0.01	0.86	50	98.95
Driftwood Creek	7.32	0.09	1.01	0.75	0.01	39.57	0.6	0.27	0.04	<0.01	47.6	97.28
	2.05	<0.01	<0.01	0.86	0.02	37.27	8.08	0.09	0	<0.01	50	98.42
	15.97	<0.01	0.08	0.52	0.01	38.62	0.1	0.04	0.03	<0.01	43.6	98.95
Topaz lake	7.11	0.02	0.51	1.37	0.02	42.16	0.61	0.02	0.01	<0.01	46.7	98.51
	7.43	<0.01	0.2	1.34	0.02	41.03	0.31	0.02	0.01	<0.01	48.3	98.65
	4.18	0.03	0.7	1.6	0.02	43	0.32	0.02	0.15	<0.01	49.4	99.44
Red Mtn.	10.64	0.01	0.52	1.64	0.03	38.74	0.92	0.1	0.03	<0.01	45.5	98.18
	8.09	0.01	0.33	0.82	0.01	40.14	0.32	0.02	0.03	<0.01	47.9	97.69
JAB	4.67	<0.01	0.13	1.35	0.02	41.99	0.57	0.04	<0.01	<0.01	48.7	97.45
	5.56	<0.01	0.13	1.27	0.02	42.55	0.52	0.04	0.01	<0.01	47.4	97.49
	4.43	0.01	0.2	2.02	0.03	41.85	0.35	0.04	<0.01	<0.01	48.6	97.54
Clelland lake	2.8	<0.01	0.12	1.66	0.03	41.12	1.14	0.05	0.01	<0.01	50.4	97.31
Dunbar Creek	2.53	<0.01	0.2	2.11	0.04	41.48	1.36	0.04	0.02	<0.01	50.3	98.1
Botts lake	3.62	<0.01	0.03	0.27	0.01	38.82	6.68	0.09	0.08	<0.01	48.9	98.47
Marysville	2.59	0.02	0.64	1.71	0.03	46	0.92	<0.01	0.01	<0.01	49.5	101.4
	5.9	0.04	0.84	1.12	0.02	43.42	1.09	<0.01	0.03	0.28	47.3	100
	3.59	0.05	0.92	0.72	0.01	45.11	1.02	<0.01	0.15	0.02	49	100.6
Mt Brussilof *	<0.01	<0.01	<0.01	0.35	0.01	48	0.82	0.01	0.03	<0.02	52	101.2
	0.1	<0.01	<0.01	0.38	0.01	47	1.41	<0.01	0.02	0.03	51.4	100.4
	<0.01	<0.01	<0.01	0.37	0.01	48.12	1.02	<0.01	0.01	0.01	51.9	101.4
	<0.01	<0.01	<0.01	0.51	<0.01	47.74	0.85	<0.01	0.01	0.02	51.9	101.1
	<0.01	<0.01	<0.01	0.42	0.01	47.89	0.87	<0.01	<0.01	0.01	52	101.3

*Fresh samples from the mine

2.1.2. Silica

The term "silica" includes SiO_2-rich materials with different physical properties and levels of purity. The physical properties determine how the silica is used, which range from high technology applications to construction materials. British Columbia has large untapped resources of silica classifiable as massive quartzite, friable quartzite, quartz veins, and pegmatites (Foye, 1987). The Mount Wilson Formation, a ridge-forming Middle to Upper Ordovician unit (Fig. 3) is the largest resource of silica in the province. It outcrops abundantly for more than 200 kilometres between Golden and Fernie. The thickness of the Mount Wilson quartzite decreases from 300 metres at Golden to 60 metres near Fernie (Norford, 1969). The Nicholson (Hunt) and Mount Moberly deposits and the Red Cloud and Koot occurrences are in this unit.

The Nicholson (Hunt) silica quarry 11 kilometres southeast of Golden (Fig. 4; Table 3), is in massive quartzite. The quarry was owned by Silicon Metaltech of Seattle, Washington and operated by Bert Miller Contracting Ltd. of Golden. Annual production varied from 30 000 (Foye, 1987) to 60 000 tonnes from the 1980s to the 1990s; the ore contained less than 0.15% non-silica material (Table 3). After crushing, washing, and screening on site, lump silica was shipped as feedstock for

Table 3. Composition of samples from selected silica deposits. Adapted from Simandl et al. (1992).

Deposit	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	LOI	S	P	Note
Moberly (friable)	99.61	0.07	0.13	0.005	na	na	na	na	na	na	na	na	*a*
	99.64	0.06	0.1	0.005	na	na	na	na	na	na	na	na	*a*
	99.67	0.02	0.06	0.06	0.02	0.01	0.02	0.01	<0.001	0.12	na	na	*b*
Moberly (lump)	98	0.05	0.33	0.015	<0.001	0.0046	0.07	0.02	<0.001	0.1	na	<0.001	*c*
	98.2	0.08	0.16	0.0075	<0.001	0.0038	0.03	0.01	<0.001	0.1	na	<0.001	*c*
	98.9	0.04	0.16	0.104	<0.001	0.0027	0.03	0.01	<0.001	0.2	na	<0.001	*c*
	98.4	0.06	0.33	0.0159	<0.001	0.0053	0.05	0.02	<0.001	0.15	na	<0.001	*c*
Nicholson	98.76	na	1.13	nil	na	na	na	na	na	na	na	na	*d*
	97.94	na	1.25	nil	na	na	na	na	na	na	na	na	*d*
	98.24	na	0.85	nil	na	na	na	na	na	na	na	na	*d*
	99.85	0.04	0.1	<0.050	<0.050	<0.10	<0.10	<0.05	<0.010	0.32	na	na	*c*
	99.9	0.04	0.1	<0.050	0.05	<0.10	<0.10	<0.05	<0.010	0.31	na	na	*c*
Red Cloud	98.56	0.12	0.65	0.05	na	na	na	na	na	0	na	na	*a*
Longworth	99.4	<0.05	0.18	<0.030	<0.030	<0.04	0.06	<0.04	0.003	1	na	na	*e*
	98.84	0.04	0.2	<0.030	<0.030	<0.03	0.05	<0.04	<0.002	<0.100	na	na	*e*
	98.76	<0.04	0.16	<0.030	<0.030	<0.04	0.05	<0.04	<0.002	0.3	na	na	*e*
	98.76	<0.04	0.17	<0.030	<0.030	<0.03	0.05	<0.04	<0.002	0.2	na	na	*e*
	98.91	<0.04	0.19	<0.030	<0.030	<0.04	0.07	<0.04	<0.002	<0.100	na	na	*e*
	99.35	<0.04	0.21	<0.030	<0.030	<0.03	0.06	<0.03	<0.002	<0.100	na	na	*e*
	99.32	<0.04	0.2	<0.030	<0.030	<0.03	0.06	<0.03	<0.002	<0.100	na	na	*e*
	99.3	<0.04	0.25	<0.030	<0.030	<0.03	0.07	<0.03	<0.002	0.3	na	na	*e*
AN	99.43	0.09	0.08	0.011	0	na	na	na	na	0.18	na	na	*f*
EK	99	0.06	0.04	<0.030	<0.020	na	na	na	na	0.1	na	na	*g*
	99.9	0.11	0.1	0.35	<0.020	na	na	na	na	0.5	na	na	*g*
Ivan	99.56	0.08	0.27	0.056	0	na	na	na	na	0	na	na	*h*
Campania	99.73	0.07	0.05	<0.030	<0.020	<0.03	0.02	<0.04	<0.002	0.8	na	na	*i*
	99.84	<0.04	0.06	<0.030	<0.020	<0.03	0.01	<0.03	<0.002	0.2	na	na	*i*
Koot Average	98.9	0.25	0.4	0.05	0.05	na	na	na	na	0.29	0.04	0.01	*j*

a- grab sample; b-washed sample; c-processed; d-random (several chips); e-chip sample over 10 metres; f- average of 5 drill holes; g-chip sample; h-loose muck; i- "clean" quartz; j - average of 25 drill core sections (20 metres each)

the production of silicon and ferrosilicon at a plant in Wenatchee, Washington. When the plant closed, production gradually ceased; however, ore reserves were not depleted.

The Moberly Mountain silica operation (Fig. 4; Table 3) is owned and operated by Heemskirk Canada Inc. Two ore types, both from the Mount Wilson Formation, have been mined. The first is a uniform, friable quartzite, the second a massive quartzite. Historically, most of the friable quartzite was sold for glass manufacturing, but the quarry also supplied silica for other applications including blasting, traction, and foundry sands. The company maintains silica production for niche markets (eg., silica flour) and is currently looking at the possibility of producing frac sand. The massive quartzite is similar to that of the Nicholson deposit and is suitable for silicon metal, ferrosilicon and, possibly, silicon carbide production.

Other high-purity quartz arenite and quartzite occurrences include the Longworth deposit in the Nonda Formation (Silurian) and the AN and EK showings (Fig. 4; Table 3).

As a group, silica deposits in British Columbia offer potential for the production of material such as fiberglass, various glass products, dinas, ferrosilicon, silicon carbide, metallurgical grade silicon, and sodium silicate.

Fig. 3. The Mount Wilson quartzite is the main silica resource in British Columbia. Resistant to physical and chemical weathering, the unit forms topographic highs.

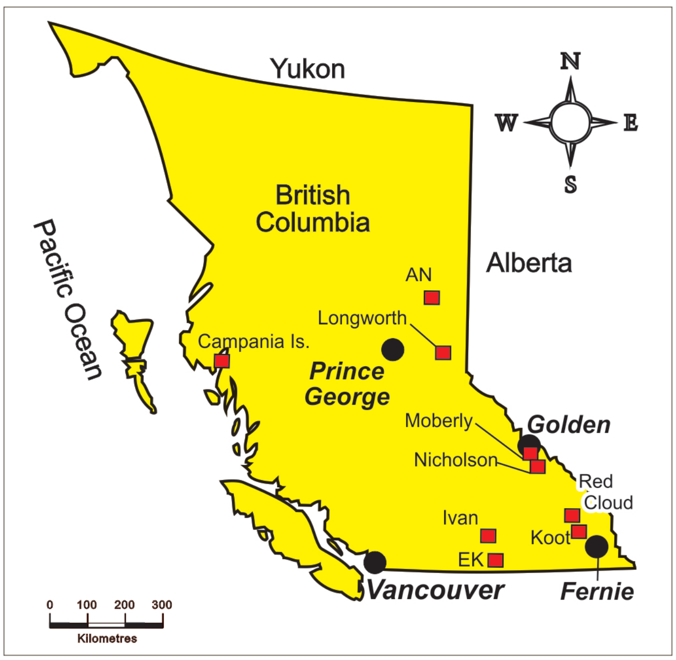

Fig. 4. Selected silica occurrences in British Columbia.

3. Heavy- to medium-duty refractory minerals not mined in British Columbia

3.1. Olivine

Commercial olivine is rich in magnesium (forsterite, approaching Mg_2SiO_4). Currently imported into Canada, olivine is a relatively low-value product (Table 1), sensitive to transportation costs. It is used mainly as a foundry sand in metal casting and as a slag conditioner (non-precalcined material for steel making). Olivine is also used as heat-exchanger filler, an environmentally-friendly blasting sand, heavy aggregate, and marine ballast (Simandl et al., 1992), and in rockwool manufacturing (Syrett, 2013). Olivine is being studied as a raw material for mineral CO_2 sequestration (Voormeij and Simandl, 2004, 2005). Historically, olivine-based panels were used to manufacture silo-type burners for incinerating wood waste. Adding olivine to chromium-bearing waste slags reduces the leachability of chromium by 80% (Kilan and Shah, 1984).

The Grasshopper Mountain deposit (Fig. 5) consists of three zones of fresh, olivine-rich rock (Fig. 6) in the Tulameen ultramafic complex (Findlay, 1963, 1969). These rocks were investigated for use in foundries (White, 1987; Hora and White, 1988; Hancock et al., 1991). Contoured loss-on-ignition values of less than 2% outlined a zone of fresh dunite in the core of the complex. Three sites have foundry sand grade olivine. Preliminary tests indicate the olivine sand has casting properties comparable to IMC olivine (Tables 4, 5). The olivine from the Tulameen complex compares favourably with olivine from around the world (Szabo and Kular, 1987; Whiting et al., 1987). As is the case for current olivine producers elsewhere (Syrett, 2013), a potential olivine development in British Columbia could benefit from expanding markets in non-refractory applications.

3.2. Refractory clays, pyrophyllite and diatomite

Several British Columbia clay and shale deposits (Fig. 5) are of potential commercial quality (Ries, 1915; Brady and Dean, 1964). From 1905 to 2012, Clayburn Industries Ltd. mined refractory clays at Sumas Mountain, producing 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 was exported, but their Abbotsford plant is now closed. Most of the material originally used for refractories is now used as a high-alumina “sweetener”, which is blended with material that would otherwise be unsuitable for cement-making, and shipped to plants in the Vancouver area (Lafarge Canada Inc. and Lehigh Hanson

Table 4. Greensand properties of sand from Grasshopper Mountain with repeated use. Results before and after casting indicate that overall performance was satisfactory to good. From Whiting et al. (1987).

Sand Casting Property	**Provenence**	**Casting Trial Number** 1	2	3	4	5	
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	2.2	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	27.1	29	30.2	28.9	
	Grasshopper Mountain	25.7	25.2	28	29.6	28.6	
Clay Additions (%)	IMC Olivine	6	0.1	0.1	0	0	
	Grasshopper Mountain	6	0.3	0.15	0.05	0.02	
Methylene Blue Clay(%)	IMC Olivine	6.1	6.1	6.3	5.8	5.8	
	Grasshopper Mountain	6.1	6.1	6.2	6	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	na	na	na	na	*50.6
	Grasshopper Mountain	44.3	na	na	na	na	*54.5
After Casting Trials							
Moisture (%)	IMC Olivine	0.85	0.82	0.94	0.81	na	
	Grasshopper Mountain	0.93	0.83	0.98	0.85	na	
Methylene Blue Clay (%)	IMC Olivine	5.9	5.9	6.1	6.1	na	
	Grasshopper Mountain	5.7	5.9	5.6	5.8	na	
AFS Clay (%)	IMC Olivine	na	na	na	na	8.96	
	Grasshopper Mountain	na	na	na	na	8.48	
Aditional Tests							
Acid Demand (ml)		at pH 5		at pH 7			
	IMC Olivine	9.6		8.5			
	Grasshopper Mountain	33.6		30.5			
Loss on Ignition (%)		at 500°C		at 700°C		at 975°C	
	IMC Olivine	0.55		1.25		1.51	
	Grasshopper Mountain	0.9		1.82		1.83	

* After fifth trial and washing for AFS clay test

Table 5. Scab Block Casting. Casting trials were rated on scale of 1 to 5 where 1=very good and 5=bad. IMC product was used for comparative purposes. From Whiting et al. (1987).

Casting property	Sand Provenence	Casting Trial Number				
Surface Finish	IMC Olivine	3	3	3	3	2
	Grasshopper Mountain (BC)	3	3	3	3	2
Scabbing	IMC Olivine	1	1	1	1	1
	Grasshopper Mountain (BC)	1	1	1	1	1
Burn On	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain (BC)	2	2	2	2	2
Erosion	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain (BC)	2	2	2	2	2
Penetration	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain (BC)	2	2	2	2	2

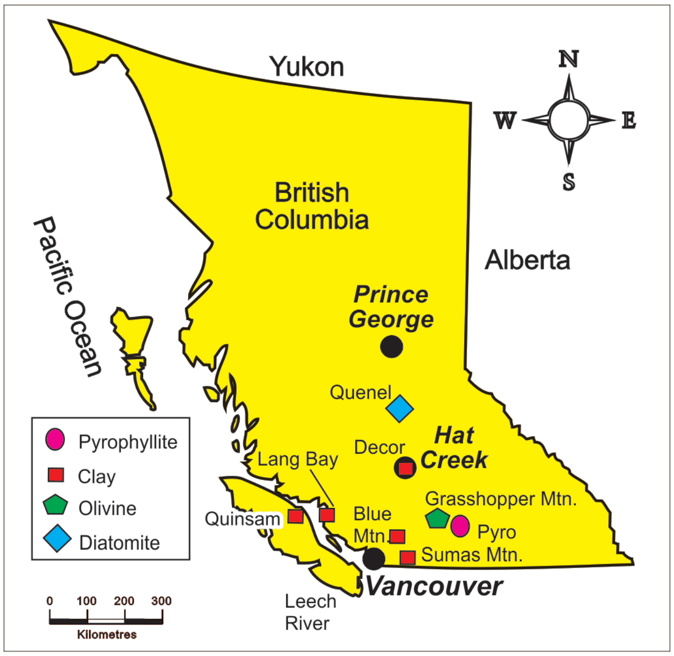

Fig. 5. Selected olivine, clay, pyrophyllite and diatomaceous earth occurrences in British Columbia.

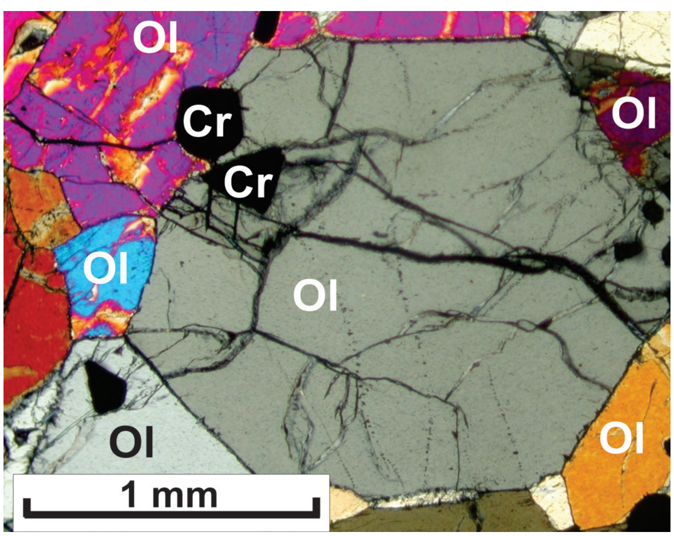

Fig. 6. Unaltered olivine-rich rock (dunite) from Grasshopper Mountain, British Columbia. Cr- chromite, Ol-Olivine. Cross polarized transmitted light.

Heilderberg Cement Group), and near Seattle (Ash Grove Cement Company).

Other potential refractory clay deposits in the Lower Mainland include a mudstone deposit, 15 to 30 metres thick, exposed on Blue Mountain (Fig. 5), and a number of brown and dark grey mudstone and claystone beds intersected by drill holes during exploration for residual kaolin deposits in the Lang Bay area of the Sechelt Peninsula northwest of Vancouver (Fig. 5). 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 the beds are 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 adjacent to the No. 1 coal seam at the Quinsam colliery near Campbell River (Hora, 1988).

High-alumina clays of the Hat Creek area were pyrometamorhosed by burning underground coal seams. They are mined from the Decor pit (Fig. 5) and marketed for landscaping applications (such as golf courses) by Pacific Bentonite Ltd. and used in cement making by the Lafarge plant in Kamloops. Their potential for refractory applications remains undetermined. The Burnt Shale deposit in Quesnel (Fig. 5), probably formed under the same geological conditions as material mined from the Decor Pit. The material from the Burnt Shale deposit is marketed under the trademark Pozzolite and, similar to the Decor pit, it has high alumina content.

Clayburn Industries Ltd. mined diatomaceous earth from Quesnel (Fig. 5). The most promising diatomite occurrences in the province are between Kamloops and Quesnel (Hora, 1984). Diatomite is not limited to refractory uses; its main applications include filter aids, specialty fillers, anti-blocking agents, and mild abrasives.

Clayburn Industries Ltd. also historically used small quantities (140 tonnes/year) of pyrophyllite from the Pyro claims (Fig. 5) in its refractory and thermal insulation products. Small or poorly known pyrophyllite occurrences described by MacLean (1988) require additional investigation to determine if they can be used in refractories.

3.3. Kyanite, andalusite and sillimanite

World production in 2012 of these Al_2SiO_5 polymorphs is estimated at 450 000 tonnes (Tanner, 2013). Although used mainly in refractories, attempts are being made to find new applications in the manufacturing of paper, paint, brake linings, welding rods, catalytics, and filters. Andalusite (Fig. 7) is preferred in Europe and Japan as it requires no pre-firing before use (reducing energy costs and CO_2 emissions). Most world andalusite production comes from South Africa. Kyanite (Fig. 8) is the main Al_2SiO_5 polymorph produced in the United States. Standard mullite is a value-added product made by calcining naturally occurring aluminosilicates, usually kyanite.

Anhydrous high-alumina minerals in British Columbia are hosted by high-grade metamorphic rocks (Hancock and Simandl, 1996). They include 50 kyanite, 23 sillimanite and 8 andalusite localities (Pell, 1988; Fig. 9; Table 6). Most are in pelitic schists of the Coast and Omineca crystalline belts, but significant potential for contact metamorphic andalusite deposits exists (Simandl et al., 1995a).

The crystal size of the aluminosilicates varies from a few millimetres to several centimetres. Sillimanite commonly occurs in the form of fibrolite (Fig. 10), which is difficult to extract, but the prismatic variety is also reported in British Columbia (Pell, 1988). Unfortunately, with few exceptions in the Bridge River area, andalusite is at least partly retrograded into muscovite.

Fig. 7. Andalusite crystals in hornfels, Bridge River area, southern British Columbia.

Fig. 9. Selected occurrences of kyanite, andalusite, and sillimanite in British Columbia.

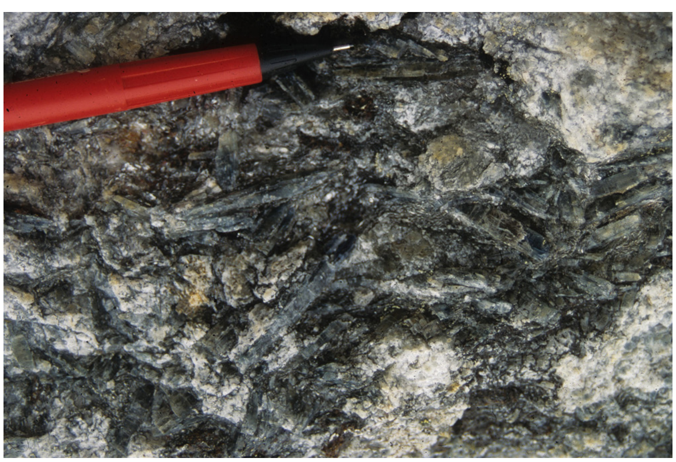

Fig. 8. Blue-grey kyanite crystals, Hawkesbury, northwestern British Columbia.

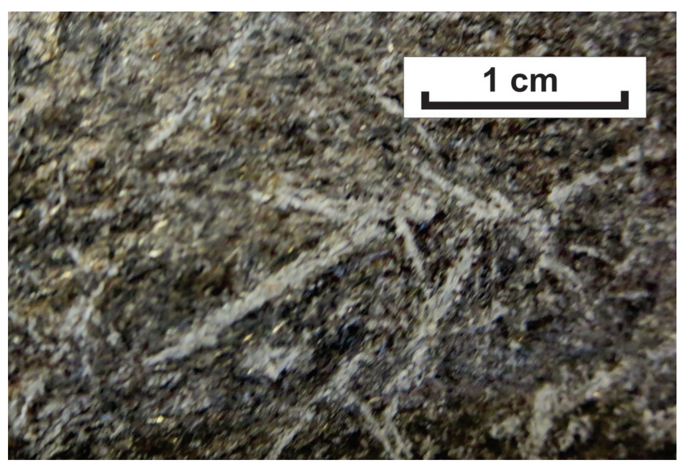

Fig. 10. White acicular crystals of sillimanite (fibrolite variety), Eagle Pass, British Columbia.

Table 6. Selected kyanite family mineral occurrences in British Columbia. Garnet (Ga), mica (Mi) and Staurolite (St) are potential byproducts (modified from Pell, 1988). Other abreviations: L = local, Av. = average, P=prismatic, R= moderately to strongly retrograded into mica.

Area (Locality)	Kyanite family minerals			Possible byproducts	References
	Kyanite	Sillimanite	Andalusite		
Southern Shuswap		20 - 25%		<30% Gr, (Mi?)	Pell (1988)
Revelstoke - Big Bend	20 - 30%			Mi?	Pell (1988)
Canoe River	20 - 25%			15 - 20% Gr, (Mi?)	Pell (1988)
Hope-Yale Settler Schist	23%(L)	24% (L) 15 (P)		<30% Gr, (Mi?)	Pell (1988)
Hope-Yale (Breakenridge Fm.)	<40%		Minor	<50% Gr	Pell (1988)
Hope-Yale (Cairn Needle)	15% (Av.)			20% (av.) Gr, (Mi!)	Pell (1988)
Kwinamass Peek		<50%		15 - 20% Gr, (Mi?)	Pell (1988)
1 km east of Kwinitsa		5 - 30%		5-30%Gr	
Trail Bay	20-40%				Hancock and Simandl (1996)
Dudevoir Passage	<25%			<7% Gr	Hancock and Simandl (1996)
Hawksbury Island showings	typically <20%			<20% Gr, St (L)	Hancock and Simandl (1996)
Bridge River area showings			<12%		Simandl et al. (1995)
Leach River area showings			<10% (R)	Gr, St	Simandl et al. (1995)

3.4. Natural graphite

World graphite production for 2012 is estimated at 1.1 million tonnes, mostly from China (Olson, 2013). Graphite deposits are subdivided into those that produce amorphous, lump and chip (vein), and crystalline flake graphite (Taylor, 1994; Simandl et al, 1995b, Simandl and Keenan,1998 a,b,c). Depending on the physical and chemical properties (purity), natural graphite finds use in refractories (bricks and linings used in metal production, ceramics, petrochemicals, and cement industries), in batteries as the main anode material, in steel-making (as a recarburizer), pencil manufacturing and, to a lesser extent, as brake-linings for vehicles. China accounts for more than 65% of graphite production and is the main supplier of crystalline flake graphite used mainly in refractories. High-technology graphite niche products represent a small part of the total graphite market in terms of tonnage; however, they have high unit value ($/kg) and are essential for the electronic, automotive, and aeronautical industries.

More than 30 occurrences of graphite are reported in British Columbia. The most promising areas for crystalline, flake graphite showings are in the Coast Plutonic complex and the Omineca Crystalline belt (Simandl and Keanan, 1998c).

The AA graphite prospect (Fig.11) is hosted by a granulite facies metasedimentary roof pendant in Coast Plutonic complex granitic rocks. It is located on tidewater at the head of South Bentinck Arm. Assays indicate total carbon contents in the range of 2.98 to 17.9 %. The size and shape of the graphitic zone is unknown because of sparse surface exposure (Marchildon et al., 1993). The Skeena showing is hosted by amphibolite and biotite-hornblende gneisses of the Coast Plutonic complex and is reported to contain 3% graphite across a width of 120 metres (Clothier, 1922). The Payroll showing is in a 3- 4.5 m thick graphitic unit in amphibolite rocks of the Coast complex (Clothier, 1921). The Mon occurrence reportedly contains flakes of crystalline graphite disseminated in marbles, calcsilicates, and biotite schists of the Wolverine Metamorphic

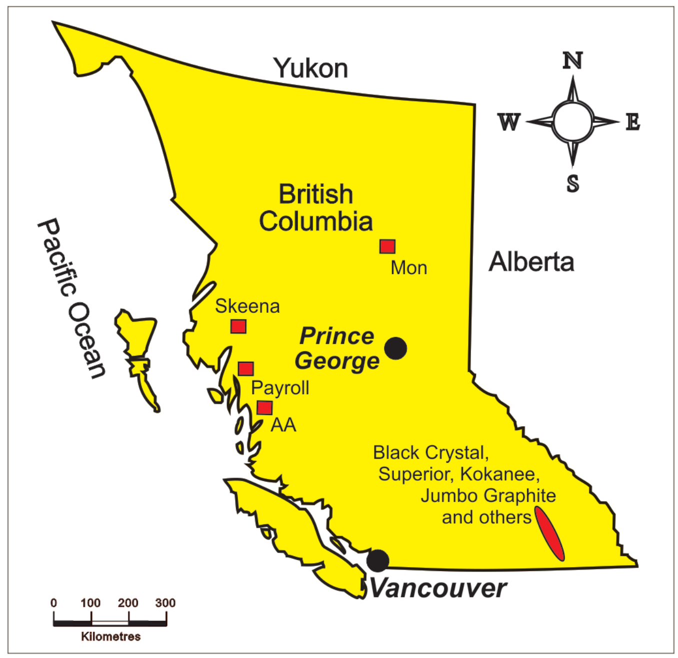

Fig. 11. Selected graphite occurrences in British Columbia.

complex in north-central British Columbia. Assays reported by Halleran (1985) suggest grades in excess of 4% graphitic carbon. Several attempts to produce crystalline flake graphite on a commercial scale in southern British Columbia were unsuccessful (eg. Black Crystal project, Fig. 11). Eagle Graphite Corp. is the current owner; no commercial scale production took place in 2013. The Superior, Kokanee and Jumbo Graphite properties, in southeastern British Columbia, are currently being investigated as sources of flake graphite (Kerr, 2013).

Microcrystalline graphite in metamorphosed coal seams have not been reported in the province, but meta-anthracite seams are known. Systematic exploration for microcrystalline graphite in metamorphosed coal beds has not been done in British Columbia.

3.5. Dolomite

Dolostone consists mainly of the mineral dolomite (Ca,Mg $(CO_3)_2$). It is used: in refractory and glass making applications; for soil conditioning (as dolime) and effluent treatment; as plastic and paint filler; to produce white ornamental aggregate and roofing granules; as fine aggregate; and in synthetic marble products (Simandl et al., 2006a). Worldwide, dolomite remains the main ore for production of magnesium metal (Simandl et al., 2007c). Dolostone is widespread in the Canadian Rocky Mountains. It is less abundant along the coast of British Columbia (Fishl, 1992), where operations would be able to target export markets (Simandl et al, 2006a). Since the 1960s, dolostone has been quarried by Imasco Minerals Ltd at its underground Crawford Bay mine on Kootenay Lake; in 2013, the quarry was not in production. Mighty White Dolomite Ltd. has its plant and quarry near Rock Creek (Simandl et al., 2006); however, the operation is inactive. In 2003, Ashgrove Cement started mining limy dolostone from an area adjacent to their limestone quarry on Texada Island. It produced approximately 24 000 tonnes/year (Simandl et al., 2006a) for the American market. This operation is now also dormant.

3.6. Chromite

Chromite is a spinel-group mineral characterized by high chrome content. Chromite concentrates are commonly subdivided into metallurgical, chemical and foundry, and refractory grades. In recent years, metallurgical uses accounted for more than 90% of the chromite market. Most of the exploration for chromite in British Columbia took place before and during the Second World War. The main occurrences were described by Hancock (1991).

4. Low-duty refractory materials in British Columbia

4.1. Rockwool

Thermal insulation materials, similar to rockwool produced at Grand Forks by Roxul Inc., which can withstand temperatures in excess of 600°C, are commonly considered as the low-temperature fringe of refractory products. The Roxul West Inc. plant is one of the largest employers in the Grand Forks area (Fig. 12). The plant's main source of raw material is the Winner diorite quarry in the Greenwood mining camp. Dolomite and other ingredients are used in smaller quantities to control batch chemistry.

4.2. Pumice

The Garibaldi Pumice deposit operated by Garibaldi Pumice Ltd., and Mount Meager deposit, formerly operated by Great Pacific Pumice Ltd.

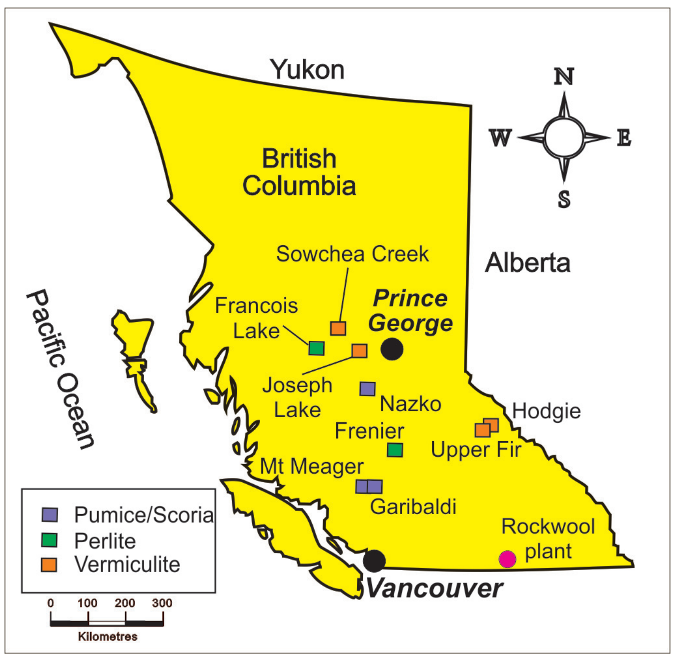

Fig. 12. Selected occurrences of lightweight heat insulating raw materials and rockwool plants in British Columbia.

(currently inactive) are 150 km north of Vancouver (Fig. 12). Pumice is widely used as a lightweight aggregate, abrasive, landscaping material, and loose-fill insulation. More specialized uses are in pet litter and other absorbents, and as plastic and rubber fillers. Pumice-based fire bricks are considered as refractories. The Nazko scoria deposit described by Hora and Hancock (1995) is approximately 100 km west of Quesnel (Fig 12). It was successively exploited by number of small companies but has remained inactive since 2012.

4.3. Perlite

Perlite is a rhyolitic volcanic glass that expands to form a white, low density, porous material, known largely for its use in heat and acoustic insulation, and as a lightweight aggregate, soil conditioner, filter aid, and chemical carrier. Perlite occurrences in British Columbia are described by White (1990, 2002). The Frenier and Francois Lake deposits (Fig. 12) are past producers. The Terrace Mountain and Marilla perlite/volcanic glass occurrences were described by Simandl et al. (1996) and Simandl and Rotella (2004), but many others have not been investigated in detail. Some of the occurrences on Haida Gwaii/ Queen Charlotte Islands are near tidewater and contain perlite that expands when heated with a propane torch (White, 2002).

4.4. Vermiculite

Vermiculite is a mica group mineral. Economic deposits are typically hosted by ultramafic rocks or associated with carbonatites. Five vermiculite occurrences are reported in BC MINFILE. The Joseph Lake and Sowchea Creek (Fig. 12) occur in fresh and weathered zones of Jurrassic granite, granodiorite, and quartz diorite intrusions (White, 1990). The Hodgie zone (Figs. 12, 13), in the Blue River area, is a promising carbonatite-related deposit (Simandl et al., 2010). Coarse bronze-coloured mica, probably vermiculite, outcrops adjacent to the Upper Fir carbonatite, which is being explored for tantalum and niobium by Commerce Resources Corp. The extent of this zone is only partly delimited. All of these occurrences are reported to contain expandable mica (vermiculite).

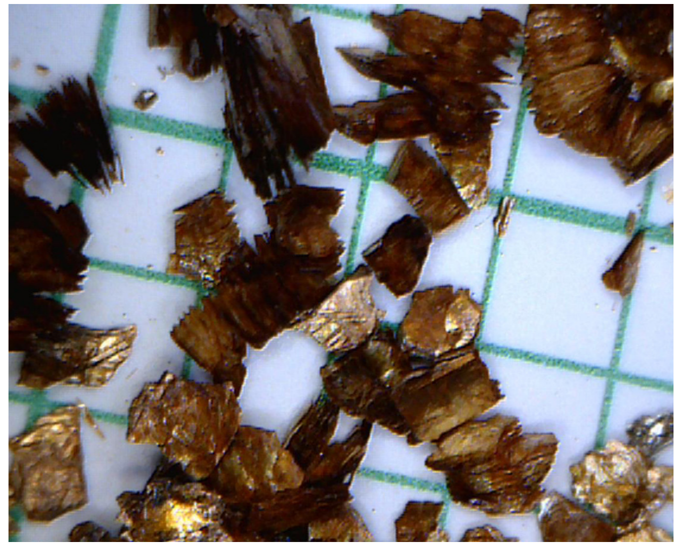

Fig. 13. Fine-grained, expanded vermiculite from the Hodgie Zone, Blue River area; (2mm grid).

Summary

British Columbia has exceptional magnesite deposits, including Mount Brussilof, the only currently producing magnesite mine in Canada. Large resources of high-grade silica are hosted in the Mount Wilson and Nonda formations. High-alumina and refractory clays have been historically extracted from Sumas Mountain. Olivine, kyanite, andalusite, pyrophyllite, graphite, chromite, and dolomite are other refractory minerals in British Columbia. The province also has deposits of lightweight heat insulating materials such as pumice, perlite, and vermiculite. Rockwool is produced in southeastern British Columbia. The internal demand for traditional heavy-duty refractory raw materials in British Columbia is limited, and potential new producers should look for a combination of export opportunities, value-added processing, and non-refractory markets. Assuming desirable technical characteristics of the raw material, deposits close to low-cost transportation corridors will have the best development potential.

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