Iron (Magnetite) Ore Resources in Southwestern British Columbia: Soft Niche or Steel-Hard Market?

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EXECUTIVE SUMMARY

There are two types of market for iron ore: an international market, where large quantities of ore are used for iron and steel making, and niche markets, where small quantities of ore are custom processed to optimize the properties of the concentrate for a specific industrial mineral application.

The main market for iron ore is iron and steel making. The iron ore industry is truly international because of the availability of large high-grade mines and large ocean-going ore-carrying vessels.

Niche markets represent less than 5% of the total production, but the oxides sold within these markets command higher prices than the international market will tolerate.

Coal beneficiation, coloured pigments, radiation shielding, sand blasting, heavy aggregate, and ballast for pipelines and offshore oil and gas platforms are examples of existing and future potential niche markets for British Columbia magnetite.

The producers supplying iron oxides to niche markets who are able to provide custom processing, and the associated technical services, to meet clients' needs have a competitive edge over suppliers of exclusively raw material.

Before the development of large, high-grade iron deposits in Australia and Brazil, small to mid-size iron skarn deposits were mined successfully along the coast of BC. Several of these past producers closed down during periods of low iron prices. Because of this, magnetite-rich rock, or magnetite in form of tailings, may be available for future recovery. The re-examination of selected past producers, existing prospects, and magnetite-bearing tailings may represent an acceptable risk and low capital requirement if future production is aimed at niche markets.

In the long term, offshore placer deposits also represent a potential source of magnetite. If such deposits could be economically exploited under the current strict environmental regulations, placer magnetite could be potentially recovered as a co-product from the extraction of titanium oxide, garnet, zircon, silica sand and, possibly, gold or platinum.

British Columbia skarns are high-grade deposits able to supply magnetite for niche markets. Worldwide, banded iron formations and their enriched equivalents are, and will remain, the main source of iron ore for steel making, but small iron ore shipments could be extracted from BC's skarn deposits as well.

WORLD IRON ORE RESOURCES AND PRODUCTION LEVELS

World iron ore resources are estimated at over 800 billion tonnes, containing more than 230 billion tonnes of iron (Jorgenson, 2005a). Estimates for the United States alone are 110 billion tonnes of iron ore representing 27 billion tonnes of iron. Most of the known US reserves are low-grade taconite ores that require upgrading and agglomeration (Jorgenson, 2005a). Fifty countries produce iron ore, but 96% of the global total is produced by only 15 of those countries. In 2004, Brazil (220 million tonnes), China (280 million tonnes), Australia (220 million tonnes), India (110 million tonnes), Russia (95 million tonnes), Ukraine (66 million tonnes), United States (54 million tonnes), South Africa (40 million tonnes) and Canada (31 million tonnes) were among the largest iron-ore-producing nations. Seaborne iron ore trade for 2004 is estimated at 593 million tonnes, equivalent to approximately US$25 billion per year (Minesite, 2005).

Magnetite and Hematite Production in British Columbia

British Columbia's iron ore production in 2004 was approximately 87 000 t and, in the first six months of 2005, an estimated 51 000 t (Jorgenson, 2005b). Most, if not all, came from tailings of the Craigmont mine. A large proportion of the material produced by the mine is sold for coal washing. Plans to produce sandblasting media (+70 mesh) were put on hold. Craigmont Mines is also considering the production of specular hematite for surface coatings (Craigmont Mines, 2005).

During the summer of 2005, approximately 4500 t of magnetite in two sizes, ¾" × ¾" and <¼", were barged to an industrial user from Kelsey Bay, North Vancouver Island. The shipment originated from one of the magnetite zones that are located close to the Iron Mike deposit, described by BC Minister of Mines (1961, 1965) and Shearer (2002, 2004). It is currently referred to as Iron Ross. The shipment is likely the bulk sample collected in 2002 and described by Shearer (2002).

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Magnetite began to be recovered as part of routine limestone aggregate processing by Texada Quarrying Ltd. at their Gillies Bay operation on Texada Island. The magnetic material is currently stockpiled for potential use as heavy aggregate but, with additional processing, may also be suitable for a number of other known uses. According to the company, as the quarrying progresses toward the limestone-granodiorite contact, magnetite pockets will be encountered and magnetite will be recovered. The current stockpile is estimated at 3000 t of magnetite-rich rock.

Iron and Steel-Making Market

Most of the world's iron ore production (probably over 95%) is used in iron and steel making. Major iron ore importers are China, Japan and the Republic of South Korea. These three countries account for more than 60% of the world's iron imports (Ericsson, 2004). In 2003, China's imports reached 148.1 million tonnes, relative to Japan's 132.1 million tonnes, and China became the largest iron ore importer in the world. In recent years, an unprecedented increase in iron ore demand from China resulted in corresponding increases in iron ore prices. The price increase of 18.6% for Carajas fines, FOB Europe to US$0.379 per dry metric tonne unit (dmtu) from 2003 to 2004 (Ericsson, 2004), and a more recent 71.5% increase in the price of Mt. Newman high-grade fines to US$0.6172 per dmtu (Anonymous, 2005a; CNN, 2005), are excellent examples of recent market tendencies. Such price increases are attracting the interest of the mining industry. Consequently, BHP Billiton has raised its output from 82 million tonnes in 2003 to 110 million tonnes in 2004 (Xinhua News Agency, 2005), and projects that are expected to come 'on stream' by 2009 represent more than 450 million tonnes of new capacity (Erickson, 2004). A good example of this is a recently announced development of Hope Downs iron ore deposits in Australia by Pilbara Iron, a subsidiary of the Rio Tinto Group. Hopes Downs 1 alone has reserves of 470 million tonnes grading more than 62% iron (Louthean, 2005). Another example is the Cape Lambert magnetite project, also in Australia (Anonymous, 2005b). To what extent this additional capacity will be justified depends largely on the future rate of increase in Chinese iron requirements. Many analysts believe that growth in demand will remain positive but at much lower rates than have been witnessed during recent years.

As far as steel production in BC goes, there are simply not enough known iron ore resources. Integrated mills are typically designed to produce more than 2 million tonnes of steel products per year, which requires about 4 million tonnes of iron ore in 60% Fe range. This figure is not in line with the currently known conventional iron resources in BC. Mini-mills have smaller capacity, typically on the order of 200 000–400 000 t of steel per year; however, in most cases, their primary feed is scrap steel.

IRON ORE FOR NICHE MARKETS

The use of iron ores in industrial applications (non-iron or steel) represents a small but significant proportion of the total market. These markets are particularly important for small exploration/development companies. In addition to the chemical specifications that are so important in iron making, the industrial mineral use of iron ores is also strongly constrained by physical properties of the final concentrate. The main iron-ore-forming minerals are oxides: hematite (Fe_2O_3) magnetite ($Fe^{2+}Fe_2^{3+}O_4$), goethite ($Fe^{3+}O(OH)$) and limonite (hydrous iron oxides). The use of iron carbonate minerals, including siderite ($Fe^{2+}CO_3$), has been nearly discontinued for iron and steel making, but they are still mined for their industrial mineral applications.

Hematite, or 'red iron ore', varies in colour from shiny black to red; the lamellar variety is highly sought after for its use in surface coatings. Magnetite ore is black and its freshly broken surfaces have a metallic lustre. Magnetite is characterized and easily identified by its magnetic properties. Goethite is highly variable in habit and form. It has a brown streak and is easily recognized when it has a botryoidal texture. Limonite varies in colour from brown or black to yellow. Siderite ranges in colour from grey to yellow, beige or shades of reddish brown, but is most commonly brown. The density of these minerals varies from more than 5 g/cm^3 for magnetite and hematite to as low as 3.3 g/cm^3 for some varieties of goethite. Magnetite is the hardest, while siderite is the softest. Because most of the iron ore deposits along the coast of BC are iron skarns containing mainly magnetite or magnetite placer deposits, this paper will focus largely on magnetite.

Industrial mineral applications of magnetite include coal-washing, production of heavy aggregates, sand-blasting media, ballast in marine structures, counterweights, roofing granules, drilling-fluid media, black pigment, radiation shielding, heat exchangers, water purification and as a source of iron in cement. Selected industrial mineral uses of iron oxides that represent promising niche markets, with emphasis on magnetite, are described below.

Magnetite Use in Coal Beneficiation

Coal beneficiation is a procedure that extracts impurities from raw coal. It improves burning efficiency and reduces unwanted air emissions, homogenizes shipments and reduces transportation costs. Lumps of crushed coal from 1 to 2 cm in size are commonly treated by dense-medium separation. The high-density medium is commonly a suspension of finely ground magnetite or ferrosilicon. Because coal is lighter, it floats and is separated off, while heavier rocks and other impurities sink and are removed as waste. Any magnetite mixed with the coal is separated using water sprays and is then recovered, using magnetic drums, and recycled. Specifications for magnetite concentrate used in the coal industry varies from one coal producer to the next, but data presented below can be considered representative (Kilborn Engineering (BC) Ltd., 1986). No more than 5 wt% of the particles should exceed 45 μm (325 mesh) and no more than 30 wt% should be finer than 10 μm. Density of the magnetite concentrate is expected to be in the range 4.9–5.2 g/cm^3. More than 95 wt% of the particles in the concentrate should be magnetic, and the moisture of the concentrate should be less than 10 wt%. Most of magnetite products currently in use in coal beneficiation exceed 95 wt% of Fe_3O_4.

The 2004 magnetite production in BC totalled 87 000 t and, for the first 6 months of 2005, production reached 51 000 t (Jorgenson, 2005b).

A substantial portion of this material was sold for coal beneficiation. In 1986, magnetite requirements in the combined Alberta and BC coal industries were estimated at 70 000–75 000 t (Kilborn Engineering (BC) Ltd., 1986), and demand is projected to reach 100 000 t by 1990.

An independent approach to constrain the current magnetite requirements for coal washing is by looking at BC's coal production, which was estimated at 27.1 million tonnes in 2004 (Schroeter *et al.*, 2005) and is projected to be 27.5 million tonnes for 2005 (Barry Ryan, pers. comm., 2005).

As a first approximation, magnetite losses from the circuit reported in other jurisdictions vary from 1 to 3.5 kilograms per tonne of coal washed, depending on the engineering design, maintenance level of the plant and quality of the coal. These figures, in combination with a partial user survey in BC, suggest that, if no ferrosilicon was used as the heavy medium, then actual magnetite losses in coal-cleaning circuits of BC's coal producers for 2005 would be between 28 000 and 84 000 t. The most likely range is 50 000–60 000 t of magnetite per year. The coal production of Alberta is traditionally slightly higher than that of BC. For both provinces combined, the magnetite market for coal washing is in the 56 000–168 000 tonne range, with the most likely consumption between 100 000 and 120 000 t per year. This estimate is in agreement with the estimate of 100 000 t of magnetite per year made by Kilborn Engineering (BC) Ltd. for 1990. However, it is necessary to take into consideration the ongoing research into recovery of heavy minerals from Alberta's tar sand operations. Magnetite market conditions for coal washing would change abruptly if one of the by-products from the tar sands was a coal-washing-grade magnetite.

Coloured Pigments

The demand for coloured pigments is closely linked to the economic cycles of the industrialized nations. Iron oxides are an important segment of the overall pigment market. These oxides are found in their natural state and, after fine grinding, they are suitable for use as pigments (Anonymous, 2005c). They are used in a variety of industrial applications; however, building products (masonry cement, ready mix, mortar and roofing granules) and surface coatings account for more than 90% of this market by volume. In most applications, natural iron oxides now compete with their synthetic counterparts that offer a more consistent product in terms of particle shape, particle size and distribution, as well as chemical composition, including lower heavy metal content. Representative chemical analyses are provided in Podolsky and Keller (1994).

Iron oxides are typically nonreactive. Oil absorption, surface area, particle size, shape of the particles, optical properties and magnetic properties are important parameters if the concentrate is intended for the pigment market (Podolsky and Keller, 1994). Magnetite is typically used as black pigment. Goethite and limonite (ochre) are traditional yellow pigments and hematite, calcined siderite and calcined pyrite are used as red pigments.

In 2000, the total iron oxide consumption for pigment applications was estimated at 1.5 million tonnes (O'Driscoll, 2004). Although there is no consensus regarding the size of the natural iron oxide pigment market, the United States Geological Survey's estimate for 2002 was 500 000 t.

The main advantage of natural iron oxide pigments over their synthetic equivalents is lower price. The prices for technical-grade natural iron oxide vary from Euro(€)190 to 310 per tonne (ex-works). These prices increased by 15–20% between 2002 and 2004 (O'Driscoll, 2004). Cement-grade natural iron oxide ranges in price from €30 to 40 per tonne (bulk, FOB). Specular hematite (sought after because of its platy nature) was selling in the range €600–800 per tonne (FOB; O'Driscoll, 2004). In North America, prices are expected to have similar ranges for comparable products.

Radiation Shielding

The negative effects of X-rays on humans were recognized in 1895, a few months after Roentgen's discovery, and substantial progress has been achieved in radiation shielding since that time (Shultis and Faw, 2005). The use of magnetite, ilmenite, limonite, goethite, iron ore pellets, barite, steel and iron shot as heavy aggregates in radiation-shielding concrete is relatively common (Cement Association of Canada, 2005a, b). The use of such materials in the construction of nuclear power plants is well documented. Recently, however, the innovative use of heavy aggregates started to expand into construction of facilities such as cancer-care buildings and research laboratories (Finkelstein and Gray, 1995). The radiation-shielding efficiency of construction materials is approximately proportional to their density. Heavy concrete (commonly incorporating magnetite aggregate), with a density of approximately 3.69 g/cm^3, is used in radiation barriers where space is critical. Common concrete has a density around 2.35 g/cm^3. In most situations, magnetite aggregate has a cost advantage over other heavy mineral aggregates (Kase, 2003).

Ballast in Construction of Offshore Oil and Gas Installations

Magnetite is one of the materials that competes with olivine in the ballast market, particularly where the development of offshore oil and gas resources is involved. The best example of the use of magnetite as ballast in Canada relates to the construction of the Hibernia platform. A Newfoundland company called Lodestone Limited obtained a contract to supply 300 000 t of magnetite ballast from the Bishop deposits in western Newfoundland (Boyd, 1997). A total of 411 000 t of magnetite was shipped from St. George's Bay to the Hibernia platform, located off the Grand Banks approximately 300 km southeast of St. John's. The ore was unloaded as slurry consisting of 8% magnetite and 92% water.

Heavy ballast concrete coatings for pipelines represent another important but relatively new market. For example, approximately 620 000 t of magnetite from the famous Kiruna iron mine in Sweden is required for coating the 650 km Nyhamna-Sleipner stretch of Langeled, the pipeline serving the Ormen Lange gas development in the Norwegian and North seas (Lindwall, 2004).

Depending on the type of technology used, if oil and gas drilling starts in BC's offshore, even relatively small magnetite deposits along the coast may become viable sources of magnetite.

Sand Blasting

Before the health and safety regulations regarding 'free silica' were implemented, silica sand had a near monopoly as a sand-blasting medium. Today, besides silica sand, there is a variety of sand-blasting materials in use, including garnet, olivine, slag, staurolite, magnetite and hematite. Both magnetite and hematite are now produced and marketed in Canada for these applications.

GEOLOGY OF IRON ORE DEPOSITS

Banded iron formations (BIFs) provide the bulk of the iron ore currently mined worldwide. They include the Superior and Algoma types (Gross, 1993, 1996), their hypogene or supergene-enriched portions (Morey, 1999; Taylor *et al.*, 2001, 2002) and their metamorphosed equivalents, such as those currently mined in the Wabush area of Quebec and Labrador. Algoma-type deposits are generally smaller than those of Superior type, yet they are commonly 30–100 m thick and extend for several kilometres along strike and average 25% Fe (Gross, 1996). Economic portions of primary (not enriched) BIF consist typically of silica-rich iron ore and are commonly referred to as taconites. Taconites are harder, have lower iron content and require more costly processing than their enriched counterparts. Nevertheless, these primary ores can be upgraded to produce concentrates containing about 65% iron. Taconites are mined mainly in the United States and China but are found throughout the world, including Canada. They currently account for most of the world's known undeveloped iron resources. The iron-oxide facies of BIF is a preferred iron source, since it typically has a lower content of sulphur and other deleterious elements than skarn deposits.

Some geographic areas are known to contain magmatic (Jiang *et al.*, 2004) and/or hydrothermal iron deposits. Iron-oxide breccias (Lefebure, 1995), including the famous Kiruna (Sweden) and Olympic Dam deposits (Australia), and iron-rich skarns (Ray, 1995), represented by BC's Tasu mine on Moresby Island (the last major magnetite producer in BC), Iron Mike and Brynnor (Kennedy Lake), are good examples. At least the last two deposits may still contain economically recoverable iron resources for industrial mineral applications. Skarns were historically important sources of iron ore but, from a worldwide perspective, their importance is continuously declining.

In addition, several other types of iron oxide deposits that supply hematite, goethite, limonite, umber and specular hematite for pigment applications are described by Harben and Kuzvart (1996). In today's global market, these deposits have limited potential as sources of ore for iron and steel making, but they still supply material for a variety of industrial applications. Placer deposits, as summarized by Levson (1995), represent a potential source of magnetite derived as a by-product of gold, platinum, garnet, zircon or ilmenite mining.

Iron Ore Deposits along the Southwestern Coast of British Columbia

Most of the iron deposits located along the coast of BC are iron-rich skarns (Fe skarns), characterized by the presence of magnetite and hematite as ore minerals and by chalcosilicates as gangue or characteristic rock-forming minerals within the host rock. The most common chalcosilicate gangue minerals are diopside, hedenbergite, garnet, wollastonite, the tremolite-actinolite series of amphiboles, serpentine group minerals, epidote group minerals, scapolite, idocrase, chlorite and, less commonly, prehnite. Calcite, dolomite, quartz and sulphide minerals, including pyrite, chalcopyrite and bornite, are also common accessory minerals. Brucite is present in some of the magnesian (dolomitic) skarns. Magnetite itself is typically distributed within the skarn zone in a manner that is difficult to predict. It may form lenses, pods, veins and stringers (Fig. 1) of massive ore (Fig. 2, 3), or it may be disseminated through carbonates. Figure 4 shows the main excavation at Iron Mike, from which pockets of massive iron ore were mined.

Globally, Fe-skarn deposits range from 3 to more than 250 million tonnes and grade between 40 and 50% iron (Ray, 1995). In BC, Fe-skarn deposits average approximately 4 million tonnes, with the largest deposits being in the 20 million tonne range (Ray, 1995). Table 1 shows the production levels of Fe-skarn mines operating in BC in the early 1960s and provides information on the average iron content and major element composition of ore concentrates that were produced. It also provides information on the size ranges of particles that made up the concentrate. The concentrate from the Empire development was very coarse (<15 cm); the concentrate from Nimpkish Iron Mines Ltd. consisted of particles finer than 0.6 cm; and the concentrate from Texada Mines Ltd. was the finest of the three, with particles finer than 1.91 mm.

Common impurities include SiO_2, CaO, MgO and Al_2O_3. Impurities such as P_2O_3, TiO_2, S, As, Cr, Ni and Cu were highly undesirable in the early 1960s (Gross, 1965), and the same restriction applies today.

There is no good reason to dismiss the possibility that larger Fe-skarn deposits will be discovered along BC's coast in the future, since a large number of known magnetite deposits were discovered during gold and copper exploration. Some of these skarns were mined in part for their copper and gold content. Under current market conditions, these small Fe skarns have a limited iron ore potential, ex-

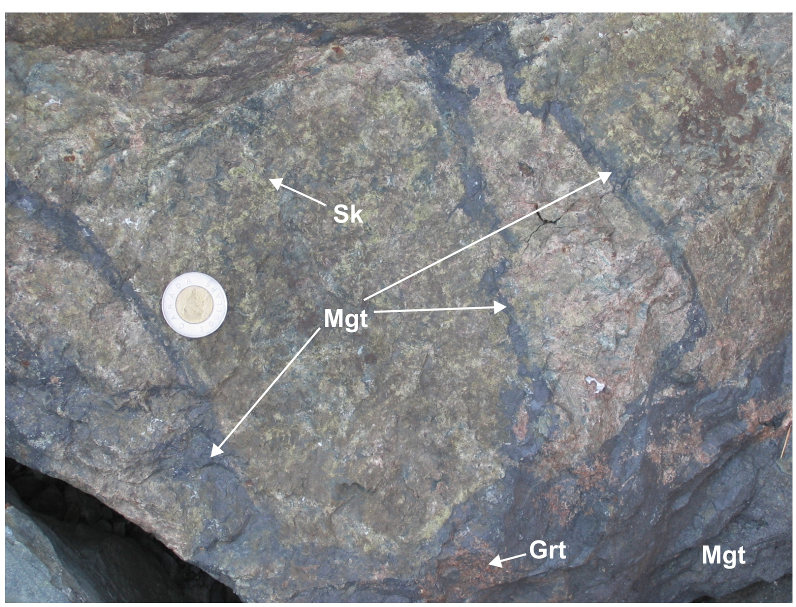

Figure 1. Magnetite stringers cutting clinopyroxene and epidote-rich skarn hostrock, Iron Mike deposit; two-dollar coin for scale. Abbreviations: Mgt, magnetite; Grt, garnet; Sk, skarn.

cept where they are located close to the market or tidewater. Several of these deposits may have industrial mineral potential if they can satisfy specific niche market requirements.

Although the BIFs are the main source of iron ore worldwide, the largest known deposit of this type in BC, Falcon, contains an inferred resource of less than 5.3 million tonnes grading 37.8% Fe (Gross, 1996). These reserve estimates are, however, not compliant with National Instrument 43-101.

In the long term, magnetite could be also derived as a by-product of heavy mineral sand deposits. Such deposits were described by Barrie *et al.* (1988) and Barrie (1991, 1994). Barrie *et al.* (1988) summarized the situation as follows: "Bottom sediments of the northern BC continental shelf contain, on average, 10% of heavy minerals by weight within the dominant sand fraction. Anomalous concentrations occur within selected sand samples from Queen Charlotte Sound (>25%) and Hecate Strait (>18%). The heavy mineral suite here is dominated by amphibole and the titanium minerals ilmenite, sphene and titaniferous magnetite."

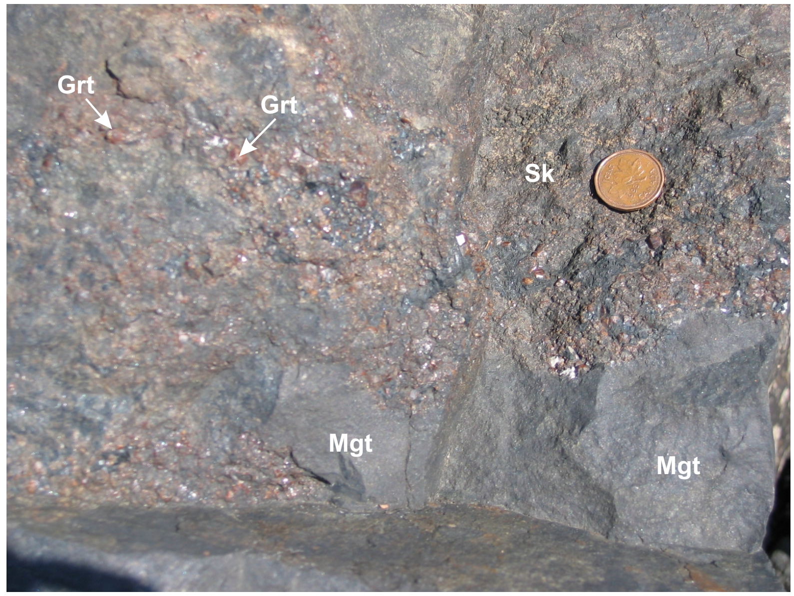

Figure 2. Massive magnetite ore, split along a vein composed mainly of garnet, clinopyroxene, carbonate and epidote, Iron Mike deposit; penny for scale.. Abbreviations: Mgt, magnetite; Grt, garnet; Sk, garnet-clinopyroxene-carbonate skarn.

Current knowledge of these deposits is extremely limited and it remains to be seen if they could be developed in a manner consistent with the strict environmental regulations that apply to any development of BC's offshore resources. In these deposits, magnetite would likely be a co-product of titanium oxide, garnet, gold or platinum, zircon, silica sand and possibly other industrial minerals or gemstones.

The potential of beach sand deposits, mainly around Queen Charlotte Islands, is described by Mandy (1934), Robertson (1956), Russel (1956), Holland and Nasmith (1958), Nickel (1956) and Thompson and Howard (1957). None of these reports is particularly optimistic, but some of these placers are known to contain gold, ilmenite-hematite, magnetite, garnet, staurolite and zircon.

Location and Description of Iron Occurrences in Southwestern British Columbia

According to MINFILE (2005), there are 296 occurrences in BC with magnetite listed as one of the commodities. A compilation by Hancock (1988) covered 90 of these occurrences. Although this compilation is not up to date, it is worthwhile examining, because it contains maps and sketches that are not readily available from MINFILE.

Figure 5 shows iron deposits located along the coast in southwestern BC. From the 157 magnetite occurrences covered by this figure and listed in MINFILE, 129 are of the skarn variety. From the 129 skarn occurrences, 37 are classified as Fe skarns, although they may also contain reported gold and base metal values. The remainder of skarns are identified either as Cu, Pb-Zn or Mo skarns, or simply as skarn. Lady A (A, C and D zones) and Mesabi are tentatively classified as Algoma-type iron formations, although their resources are very limited if compared to tonnages of typical Algoma-type iron deposits.

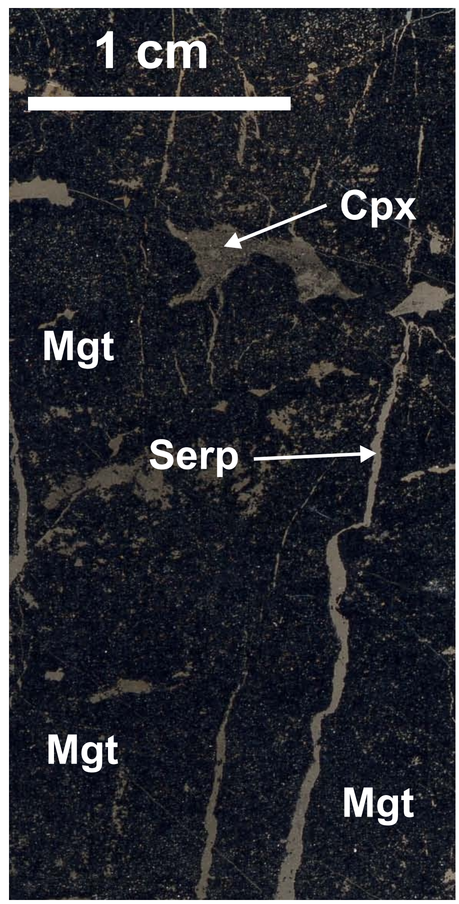

Figure 3. Cut and polished section of massive magnetite ore, Kennedy Lake mine. Gangue minerals are light coloured; the main gangue mineral is clinopyroxene altering to serpentine, with subordinate carbonate. Veinlets consist mainly of serpentine and carbonate, but they also contain amphibole and vestiges of clinopyroxene. Abbreviations: Cpx, clinopyroxene; Mt, magnetite (black); Serp, serpentine.

The skarn zones are typically located near the contact of carbonate and/or volcanic rocks with intrusive bodies. Two of the best known examples are Kennedy Lake, which was documented by Shang and Menzies (1961), and the Iron Mike group of deposits (BC Ministry Mines and Petroleum Resources, 1961, 1965; Hancock, 1988; Shearer, 2004). Both of these deposits are past producers and have some resources left in the ground.

Selected examples of magnetite deposits are listed in Table 2. The MINFILE database indicates that some of the past producers have magnetite resources left in the ground, some of the deposits have partially documented resources, and others are simply occurrences located in favourable geological settings. Follow-up prospecting, modern geophysical surveys or drilling may be justified in a number of these cases.

As with all regional reconnaissance commodity assessments, the uneven quality of available data, the need to produce a compact shortlist, and a large degree of subjectivity involved in the compilation may have resulted in undue omissions from the Table 2. There are also some inconsistencies between inventory reports, MINFILE descriptions and, in some cases, between different sources of primary information. These inconsistencies are most apparent when resource figures are compared. The uncertainty is highest in cases where several deposits are located adjacent to one another and have changed names many times. There is a possibility that resource estimates were assigned to the wrong deposit, especially in the cases of deposits with very long exploration histories. Most of the resource figures that are part of this compilation are not compliant with National Instrument 43-101. This table should not be used to select exploration targets without considering all the information and references provided in MINFILE, Ray and Webster (1997) and Hancock (1988), and from ground verification.

Figure 4. Main excavation at Iron Mike group of deposits. Massive magnetite ore is still visible in the walls of the excavation. Geologist for scale. Abbreviation: Mgt, magnetite.

In a number of occurrences listed in the Table 2, the main exploration driver may be the presence of copper, gold or molybdenum rather than the magnetite content. Magnetite may still be an important by-product.

CONCLUSION

Most of the iron occurrences and deposits in the study area are skarns. Virtually all of these skarns contain some

TABLE 1. CHARACTERISTICS OF CONCENTRATES PRODUCED FROM SKARN DEPOSITS IN BRITISH COLUMBIA AND SHIPMENT LEVELS FROM 1960 TO 1962 (GROSS, 1965)

Company and Property Location	Ore Mineral / Grade	Year	Concentrate Shipped				
			Shipment ($x10^3$ tonnes)	Average Analyses (%)			
				Fe	SiO_2	P	Mn
Kennedy Lake, Vancouver Island	Magnetite / >50% Fe	1960	-	-	-	-	-
		1961	-	-	-	-	-
		1962	417	61.4	5.0	0.05	-
Empire Development Company, Ltd., Benson R., 40 km southwest of Port McNeill, Vancouver Island	Magnetite / 48.4% Fe	1960	421	58	6.38	0.025	-
		1961	269	57.84	6.81	0.039	-
		1962	22	56.49	4.27	0.025	-
Jedway Iron Ore Ltd., Moresby Island, Queen Charlotte Islands	Magnetite / 51 52% Fe	1960	-	-	-	-	-
		1961	-	-	-	-	-
		1962	49	58.97	0.57	0.02	0.17
Nimpkish Iron Mines Ltd.	Magnetite / 41.6% Fe	1960	257	59.3	5.22	0.013	0.016
		1961	384	59.1	5.1	0.014	-
		1962	329	58.6	5.4	0.013	0.15
Texada Mines Ltd., Texada Island	Magnetite / 41.20% Fe	1960	381	61.39	3.93	0.014	0.13
		1961	449	61.42	3.93	0.11	0.13
		1962	547	61.81	3.92	0.011	0.13
Zeballos Iron Mines Limited, Vancouver Island	Magnetite / 48% Fe	1960	-	-	-	-	-
		1961	-	-	-	-	-
		1962	230	62.6	5.45	0.01	-

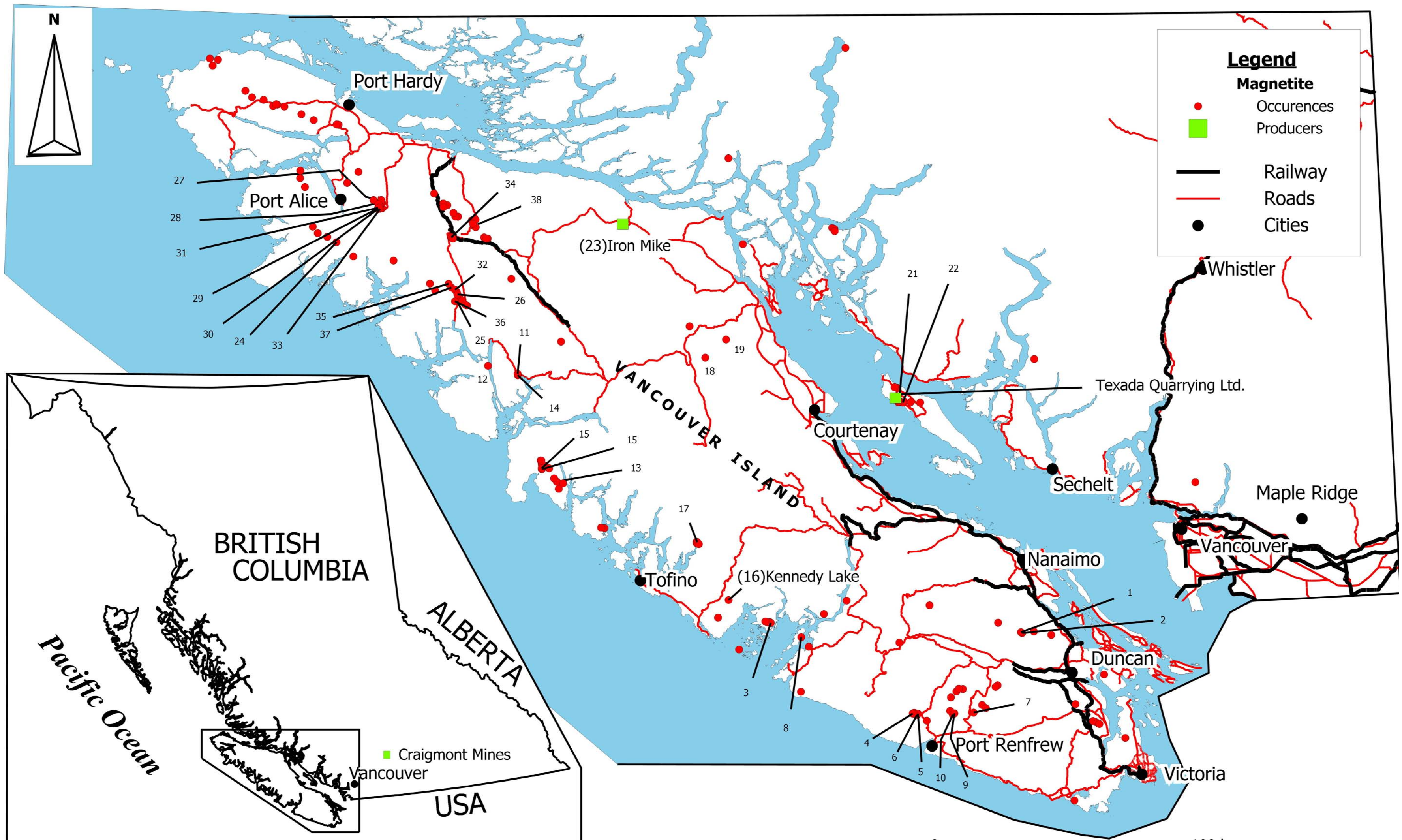

Figure 5. Location of selected magnetite producers, deposits and occurrences in southwestern British Columbia. The deposits that are identified by numbers are listed and characterized in Table 2.

TABLE 2. PARTIAL LIST OF MAGNETITE DEPOSITS IN THE COASTAL AREA OF SOUTHWESTERN BRITISH COLUMBIA. RESOURCE ESTIMATES ARE COMPILED FROM OLD REPORTS OF UNEQUAL QUALITY, LARGELY NOT COMPLIANT WITH NATIONAL INSTRUMENT 43-101. MINFILE NUMBERS ARE PROVIDED IN THE SECOND COLUMN OF THE TABLE FOR SO THAT INTERESTED PARTIES CAN CONSULT MINFILE (2005). LOCATION NUMBERS FOR THE DEPOSITS CORRESPOND TO THOSE ON FIGURE 5

Location Number	MINFILE Number	Name	Deposit Code[1]	Status[2]	Resources[3]	Grade	Selected Sample	Mineralization[4]	Reference
1	092B 029	Lady A (A Zone)	G01	DP	estimated: 366 000 t	25% Fe	-	Mgt	BC Minister of Mines (1956a)
2	092B 033	Lady A (C Zone)	G01	DP	estimated: 2 150 000 t	18% Fe	-	Mgt	Buckham (1953)
3	092C 002	Crown Prince	K03	DP	inferred: 67 500 t possible: 180 000 t	50% Fe	-	Mgt	BC Minister of Mines (1916a)
4	092C 022	Bugaboo	K03	DP	possible and probable: 4 400 000 t	55.67% Fe, 3.61% S (Daniel) 54.31% Fe, 2.21% S (Conqueror)	-	Mgt	Menzie and Nichols (1960); Gilmour and McKinley (2003)
5	092C 025	Sirdar	K03	DP	proven: 9000 t probable: 8900 t possible: 69 000 t	-	56.57% Fe, 8.52% insolubles, 2.75% S, 0.121% P (ore)	Mgt	Young and Uglow (1926); Gilmour and McKinley (2003)
6	092C 027	Baden Powell	K03	DP	proven: 33 800 t probable: 56 000 t	-	59.34% Fe, 5.93% insolubles, 2.57% S, 0.012% P, 1.14% MnO (high grade)	Mgt	Gilmour and McKinley (2003)
7	092C 031	Tally	K	SH	-	-	<1.5% Cu, <0.5% Co, <17.14 g/t Ag (grab) <3.5% Cu (from the pit)	Mgt, Cu, Co, Ag	092C 031 Property File Mineral Deposit Inventory Card
8	092C 033	Mountain	K03	DP	-	-	50.4% Fe (representative)	Mg	BC Minister of Mines (1902)
9	092C 090	Reko 3	K	PR	zone 8 estimated: 33 000 t	-	-	Cu, Mgt	Eastwood (1975); Gilmour and McKinley (2003); Roscoe (1973)
10	092C 110	Reko 38	K	PR	zone 5 estimate: 35 000 t, zone 4 & 6 also substantial	-	-	Mgt, Cu	Eastwood (1975), Roscoe (1973); Gilmour and McKinley (2003)
11	092E 001	Glengarry	K03	PP	possibly 270 300 t remaining	42.7% Fe	-	Mgt, Cu	BC Minister of Mines (1956b); MINFILE Production Report, 092E 001
12	092E 010	Geo	K01, K03	PR	-	-	13.71 g/t Ag, 6.17 g/t Au, 5.2% Cu (680 t bulk sample), minor mgt	Au, Ag, Cu, Mgt, Gms, Pb, Zn, Mo	BC Minister of Mines and Petroleum Resources (1962a); Coombes (1992)
13	092E 011	Indian Chief	K01, K03	PP	possible and potential: 1 900 000 tonnes	23.2 g/t Ag, 0.31 g/t Au, 1.5% Cu, mgt may be in tailings (mgt. grade unavailable)	-	Cu, Ag, Au, Mgt	Agnew (1962)
14	092E 015	Rob Roy	K03	PR	probable reserves: 45 359 t	56.8% Fe	-	Mgt	BC Minister of Mines (1916b)
15	092E 016, 031	Brown Jug, Thelma	K03	DP	potential: 500 000 t 1.5 million t	40% Fe 30% Fe	-	Mgt, Au, Ag, Zn, Cu, Pb	Agnew (1962); Chaplin (1962)
16	092F 001	Brynnor (Kennedy Lake)	K03	PP	some remaining	56% Fe	-	Mgt, Agg	Hancock (1988)
17	092F 015	Hetty Green	K01, K07	PP	-	0.5110% Mo	0.5110% Mo (chip - 20 m)	Cu, Mgt, Mo, W, Ag, Au	Ostler (1979); BC Minister of Mines and Petroleum Resources (1963); Hancock (1988)
18	092F 075	Iron Hill (Argonaut)	K03	PP	possibly some remaining resources	60% Fe	-	Grt, Mgt	Hancock (1988)
19	092F 076	Iron River	K03, K01	DP	east: indicated: 1 450 000 t west: indicated: 3 175 000 t varies widely depending on source of information	1.4 1.7 g/t Au, 2.4 3.4 g/t Ag	Cu concentrate Cu concentrate	Mgt, Cu, Ag, Au	Durek and Nordin (1972); McCullough (1974); http://www.info-mine.com/mining/

TABLE 2 (CONTNUED)

Location Number	MINFILE Number	Name	Deposit Code[1]	Status[2]	Resources[3]	Grade	Selected Sample	Mineralization[4]	Reference
20	092F 130	Iron Mountain	K03	DP	possible resource: 250 000 t, reserves: 18 000 t	50% Fe	-	Mgt	BC Minister of Mines (1916c)
21	092F 258	Yellow Kid-Texada Mines	K03, K01	PP	possibly a small resource left underground	-	-	Cu, Ag, Au, Mgt, Zn	BC Minister of Mines (1952)
22	092F 259	Lake-Texada Mines	K03, K01	PP	possibly a small resource left underground	-	-	Ag, Au, Cu, Mgt, Zn, Co	British Columbia Minister of Mines (1952)
23	092K 043	Iron Mike	K03	PP	possible resource: 786 530 t	43.5% Fe	-	Mgt, Cu	H.L. Hill and Associates (1965); MINFILE Production Report, 092K 043
24	092L 003	Little Lake	K03	DP	inferred: 2 846 000 t	0.0270% Cu, 47.82% Fe, 1.113% S	-	Mgt, Cu	Deleen and Durek (1974)
25	092L 028	Ford	K03	PP	-	-	-	Mgt	MINFILE Production Report, 092L 028; Hancock (1988)
26	092L 031	Churchill Magnetite	K03	DP	726 000 t	35 40% Fe	-	Mgt	Saukko (1967)
27	092L 035	Old Sport	K01	PP	some mgt in tailings	-	4.41 g/t Ag, 1.45 g/t Au, 8.65% Cu, 38.6 g/t Ag, 0.03% Co (grab)	Mgt, Cu, Ag, Au, Co	Hancock (1988); BC Minister of Mines and Petroleum Resources (1960)
28	092L 040	Shamrock	K03	DP	resource: 180 000 t	26.0% Fe	-	Mgt	Lamb (1961)
29	092L 044	Merry Widow 5	K03, I05	PP	-	17% Cu, 2.9% Zn, 0.2% As, 0.16% Co, 200 g/t Ag, 32 g/t Au	17% Cu, 2.9% Zn, 0.2% As, 0.16% Co, 200 g/t Ag, 32 g/t Au (sulphide-rich)	Mgt, Cu, Au, Zn, Co, As, Ag	Ettlinger and Ray (1989)
30	092L 045	Kingfisher	K03	PP	-	-	-	Mgt	Hancock (1988)
31	092L 046	Raven	K03	PP	-	-	-	Mgt, Cu, Au, Ag, Zn	Ettlinger and Ray (1989)
32	092L 068	Artlish	K03	DP	inferred: 635 000 t	0.08% Cu, 44.1% Fe, 3.16% S	-	Mgt, Cu	Saukko (1965)
33	092L 091	Benson Lake	K01	PP	possibly 272 154 t	1.0 g/t Au, 1.6% Cu, 30.0% Fe	-	Cu, Mgt, Au, Ag	Carter (1991)
34	092L 123	Klaanch	K	SH	-	-	-	Mgt, Cu, Zn	Tipper (1959); Hoadley (1953)
35	092L 127	Hiller 4-5	K03	DP	3 357 000 t	35.9% Fe, 0.66% S, <0.02% Cu	-	Mgt	Saukko (1967)
36	092L 128	Ridge	K03	DP	45 359 t	-	68.84% Fe	Mgt	BC Minister of Mines and Petroleum Resources (1962b); Stevenson, 1950
37	092L 301	Hiller 8-12	K03	DP	180 000 t	30% Fe	-	Mgt	McDougall (1965)
38	092L 337	Bob 17	K01, K03	PR	inferred: 12 608 t	3.0% Cu, 30% Mgt	-	Cu, Mgt, Au, Ag	McDougall (1961)

[1] Deposit code key:
- K - skarn (unclassified)
- K01 - copper skarn
- K03 - iron skarn
- G01 - algoma-type iron formation

[2] Status key:
- SH = showing
- PR = prospect
- DP = developed prospect
- PP = past producer

[3] Resource estimates are from a variety of technical reports, most of them not compliant with National Instrument 43-101.

[4] Mineralization key:
- As = Arsenic
- Co = Cobalt
- Cu = Copper
- Grt = Garnet
- Gms = Gemstones
- Au = Gold
- Fe = Iron
- Pb = Lead
- Mgt = Magnetite
- Mo = Molybdenite
- Ag = Silver
- W = Tungsten
- Zn = Zinc

magnetite, but a large number were discovered during the exploration for copper and gold. Some of the past-producing iron mines in southwestern BC still contain magnetite-rich rocks in the ground and others contain magnetite in tailings. Such resources are expected to have limited tonnage, but they require minimal capital investment and offer relatively low risk as short term sources of magnetite, especially if the contract to deliver the magnetite can be obtained prior to mining. The most recent example of such activity is the extraction of a bulk sample from the Iron Ross deposit, which is covered in this document as one of Iron Mike group of deposits. In a number of cases, the remaining reserves may be too deep or so small that they could be entirely extracted under the bulk-sampling permit.

Although the prices of iron ore increased drastically over the last two years, banded iron-formation-type deposits and their enriched equivalents will remain the main worldwide source of iron ore for steel making. Small shipments from BC skarn deposits could be sold as a direct shipping ore, but will more likely be used as a concentrate for industrial mineral niche markets.

As exploration in BC is on the rise, exploration for base and precious-metal-bearing skarn deposits along the coast may result in the discovery of new magnetite deposits.

The lack of detailed information regarding BC's offshore placer resources makes it impossible to predict if magnetite could be recovered from them as a by-product. If the offshore oil and gas developments go ahead, magnetite-bearing skarns located near the coast may become suppliers of heavy mineral aggregate.

With the expansion of coal production in British Columbia and worldwide, there may be potential for a new magnetite producer along the northwestern coast, who could take advantage of the Prince Rupert terminal and railway to supply magnetite to the future coal mines of northern BC and Alberta.

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