

PEACE RIVER IRON DEPOSITS

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SUMMARY

The Peace River iron deposits are situated in the Clear Hills district of northern Alberta, about 300 miles northwest of Edmonton. The deposits are easily accessible to all-weather roads and lie within 35 to 45 miles of railway facilities at Hines Creek.

The deposits consist of flat-lying oolitic sandstone 5 to 30 feet thick, exposed about the southeastern slopes of the Clear Hills. The iron content of the bed grades between 32 and 35 per cent Fe, mainly in the form of goethite ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$). Reserves have been estimated at 1,124 million tons of which 227 million tons are considered "proven" ore and 897 million tons are classed as "probable" or "possible" ore. On the basis of grade and volume, the deposits constitute the largest potential source of iron ore in the four western provinces.

The composition of the deposits presents some problems to beneficiation and smelting by conventional techniques. The major impurity is silica (SiO_2), present both as discrete quartz grains and as an intergranular cement (opal). Also, the phosphorus content of the deposits is high, although alumina and sulfur contents are relatively low. Consequently, the ore must be beneficiated to increase the iron and lower the silica contents prior to smelting in a blast furnace or electric-arc furnace.

A number of attempts have been made to upgrade or extract the iron content of the Peace River ore using magnetic separation, flotation, direct reduction, and acid leaching techniques. Large scale direct reduction tests carried out by the R-N Corporation at Birmingham, Alabama, in 1960 resulted in production of metallic briquets grading 90 per

cent Fe, suitable for conversion in an electric furnace, but the economic feasibility of this and similar beneficiation techniques is uncertain.

More recent work indicates that an alternative procedure for upgrading the ore involves mild reductive roasting followed by crushing and grinding to yield a magnetic concentrate. The grade of the concentrate, which ranges between 50 and 60 per cent Fe, depends upon the degree of iron recovery; it appears to be most efficient at a level of about 3.5 parts iron to 1 part gangue.

The value of such a concentrate depends upon a number of factors, including fuel and conversion costs, but available data suggest that it is approximately one-half the cost of a high-grade concentrate grading 10 parts iron to one part gangue. This value is estimated to be \$11.50/ton in Edmonton and compares favorably with the cost of producing pelletized concentrate at the mine site, estimated to be between \$9.95 and \$15.80/ton for large- and small-scale operations, respectively.

The availability of low cost, high quality coke favors direct reduction of the ore concentrate (in the form of self-fluxing sinter or pellets) in an electric furnace, or if a large market is available, smelting in a blast furnace. If coke costs are high compared to the costs of other energy sources (sub-bituminous coal or natural gas), then prereduction of the concentrate followed by conversion in an electric furnace may be the preferred smelting procedure.

Additional research should be carried out to determine the most efficient procedures for beneficiating the Peace River ore, and to characterize the properties of the ore concentrate and the iron produced from the concentrate.

INTRODUCTION

Sedimentary (oolitic) iron deposits of Late Cretaceous age underlie the Clear Hills district in the Peace River area of northwestern Alberta, about 300 air miles north of Edmonton. The deposits were discovered in the 1950's as a result of petroleum exploration activities and were subsequently drilled, sampled, and tested to determine their economic potential. However, it was apparent at the time that development of the deposits was dependent upon the establishment of an integrated steel industry in Alberta, for the deposits are too remote and too low grade to exploit for export markets. This situation still prevails. However, the basis for establishing an integrated steel industry in Alberta is now on much firmer ground than ten to fifteen years ago, and it seems appropriate at this time to review existing knowledge of the Peace River iron deposits and to compare the economic potential of the deposits with that of alternative sources of iron ore in Western Canada.

The report is divided into two parts. The first reviews the geology, composition, and reserves of the Peace River iron deposits, and the second summarizes those aspects dealing with processing and economic evaluation of the deposits. A brief description of other deposits of iron ore found in Western Canada is contained in an appendix.

PART ONE
GEOLOGY, COMPOSITION, AND RESERVES

by
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LOCATION AND ACCESS

The Peace River iron formation is located in the Clear Hills district of northwestern Alberta, about 300 air miles northwest of Edmonton (Fig. 1). The southern margin of the deposits is about 35 miles from a spur line of the Northern Alberta Railway which extends from the town of Peace River to Hines Creek. The deposits are within 5 to 20 miles of an all-weather gravelled road which extends northwestward from Hines Creek along the southern margin of the Clear Hills to Fort St. John, B.C.

A small-scale map showing the precise location of assessed reserves is given in Figure 2.

GEOLOGY AND TERRAIN

The Clear Hills form a gently sloping upland which extends between the Peace River on the south and east and the British Columbia border on the west. The hills rise gradually from the surrounding wooded plains, attaining a maximum elevation of about 3,600 feet near their southwestern margin. Local relief is in the order of 1000 feet along the southern margin of the hills; to the north and east the hills slope gradually into the wide glaciated valleys of the Notikewin and Whitemud Rivers and their tributaries (Fig. 2).

The Clear Hills region is underlain by nearly flat-lying sandstone and shale formations of Cretaceous age, covered in most places by unconsolidated glacial deposits of variable thickness (1, 2). Bedrock exposures are scarce and discontinuous, being confined to some of the small streams which form a radial drainage pattern about the hills. The upper surface of the hills, beneath the glacial deposits, is capped by the Upper Cretaceous Wapiti Formation, which consists of sandstone and shale with thin coal (lignite) and

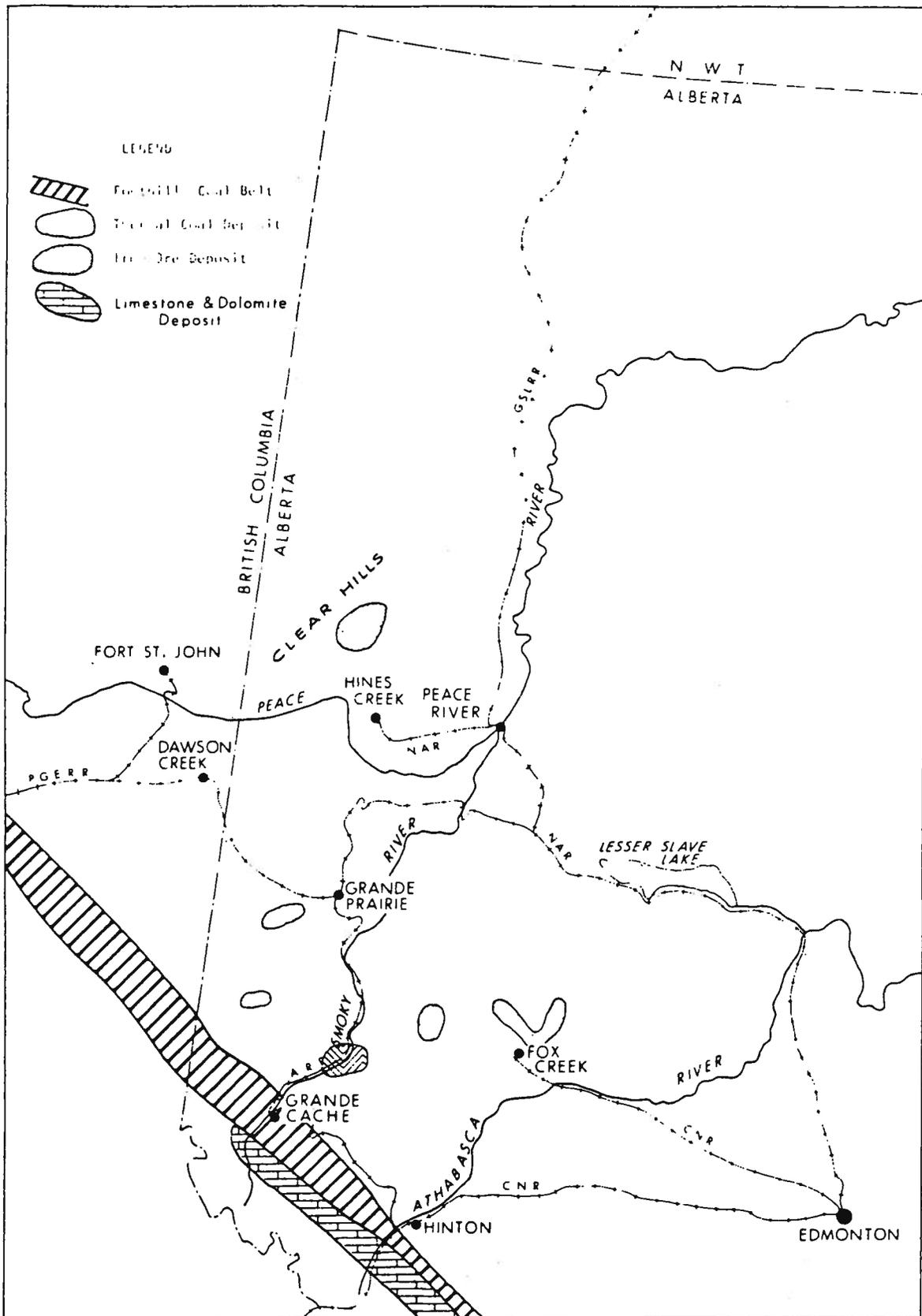


Figure 1. Location of Peace River Iron Deposits and Other Mineral Resources, Northwestern Alberta

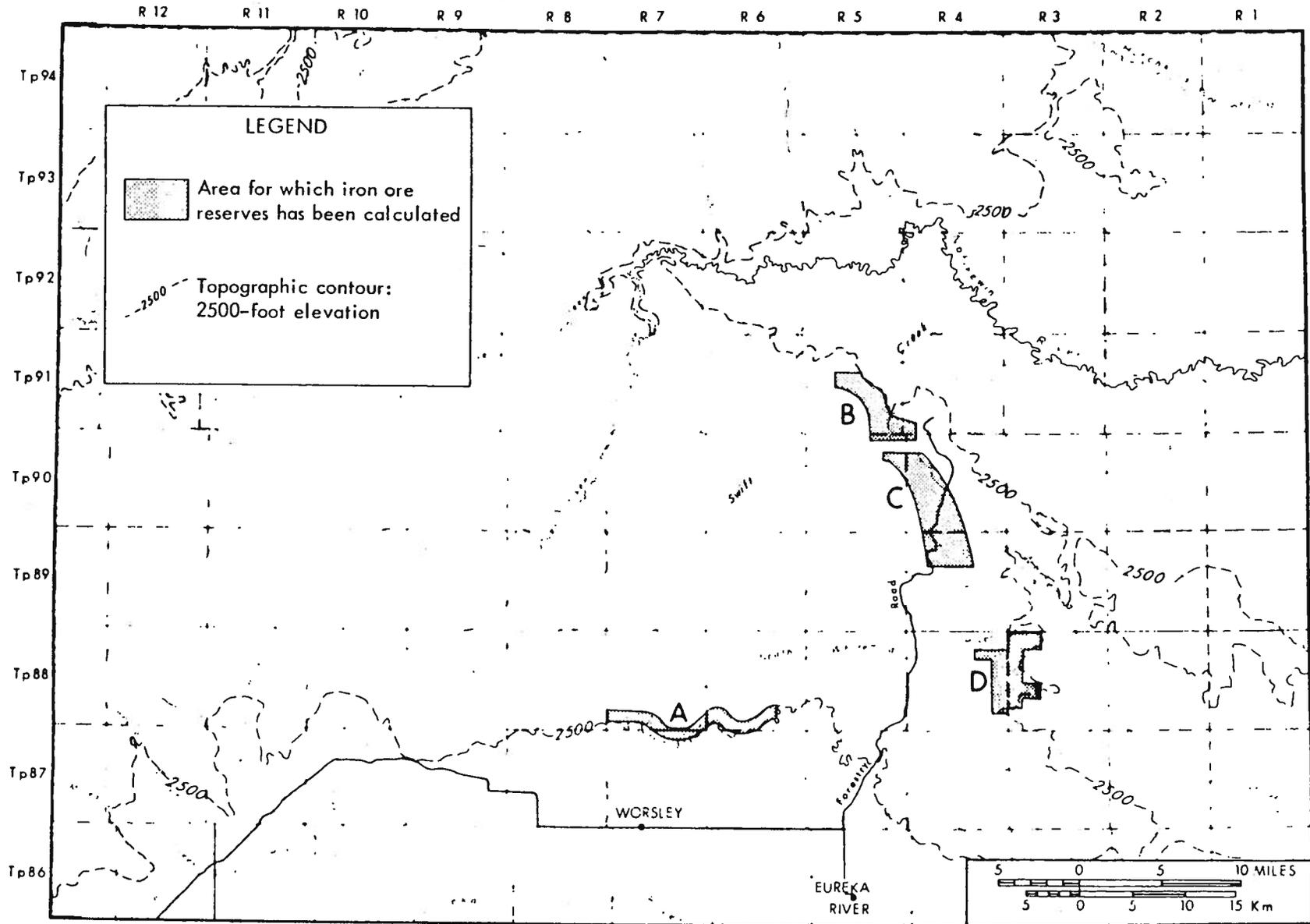


Figure 2. Location of Assessed Iron Ore Reserves, Clear Hills District

bentonite interbeds. The iron bed is intercalated among dark grey marine shales of the Smoky River Group which underlie the lower slopes of the hills and the surrounding lowlands (Fig. 3).

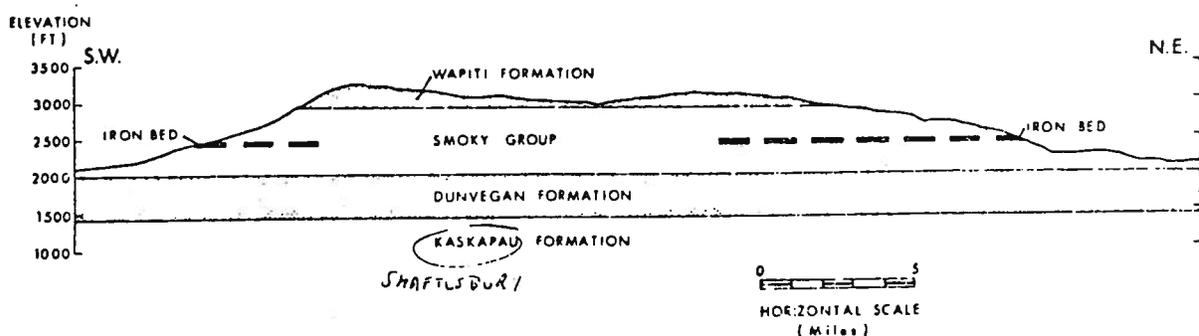


Figure 3. Schematic Cross Section Through the Clear Hills Showing the Stratigraphic Position of the Oolitic Iron Formation.

The iron formation consists of dark brown to black oolitic sandstone with thin lenses and interbeds of hard sideritic (iron carbonate, FeCO_3) "ironstone" and greenish-grey mudstone. Near the outcrop margin the sandstone has been oxidized to form a soft, compact, reddish-brown aggregate with harder carbonate-cemented lenses. Where present, the formation ranges in thickness from 5 to 30 feet, forming a series of northwest-trending sandstone bodies which are exposed in places about the flanks of the hills at elevations between 2500 and 2700 feet. The mineable deposits are restricted to those areas near the

outcrop margin where overburden is thinnest; the thickest and most widespread deposits underlie the southeast slopes of the hills, and thinner less extensive deposits have been found along the southern slopes north of Worsley (Fig. 2).

Scattered showings of oolitic sandstone also have been found in the northern, less accessible part of the Clear Hills, but these have not been explored in detail (2).

COMPOSITION

The Peace River iron deposit is an oolitic sandstone grossly comparable in mineral composition and texture to certain sedimentary iron formations in other parts of the world. The sandstone consists of densely packed oolites 0.5 to 1 mm in diameter, large nodular rock fragments, and angular quartz grains in a finely crystalline "matrix" composed of hydrated silica (opal), siderite (iron carbonate), and "clay" (3). The oolite content (and hence the iron content) is highest in the upper part of the bed, decreasing progressively towards the base of the sandstone which grades into underlying dark grey shale.

The major iron-bearing minerals are goethite ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) and siderite (FeCO_3), and small amounts of pyrite (FeS_2) and glauconite (Fe silicate) are found in some samples. Silica (SiO_2) is present as discrete quartz grains and as an amorphous opalline substance which forms part of the intergranular "matrix". This opalline substance (or "cement") is also a constituent of the iron-bearing oolites, having been co-deposited with goethite to form the outer concentric shells of the oolites (Plates 1 and 2).

Chemical analyses show that the various deposits are relatively uniform in average composition (Table 1). The salient features revealed by the analytical data are:

Table 1. Chemical Analyses of Peace River Iron Deposits.

Constituent		Deposit		
		Worsley ¹	Swift Creek ²	Swift Creek- ³ Whitemud River
Iron	Fe	32.65	35.44	32.98
Silica	SiO ₂	25.67	26.49	29.26
Alumina	Al ₂ O ₃	5.53	4.95	5.47
Manganese	MnO	0.16	0.16	N.A.
Magnesia	MgO	1.25	1.02	1.60
Lime	CaO	3.25	1.90	N.A.
Phosphorus	P	0.69	0.67	0.45
Sulfur	S	0.11	0.07	N.A.
Ignition loss	H ₂ O CO ₂	14.36	13.78	11.91

N.A. = not available.

¹Weighted averages of borehole samples (block "A", Fig. 2). Unpublished report by N.S. Edgar on Iron Prospecting Permit No. 17.

²Weighted averages of borehole samples (block "B", Fig. 2). Unpublished report by N.S. Edgar on Iron Prospecting Permit No. 16.

³Weighted averages of borehole samples (blocks "B" and "C", Fig. 2). Given in Kidd, 1959 (Res. Coun. Alberta Prelim. Rept. 59-3).

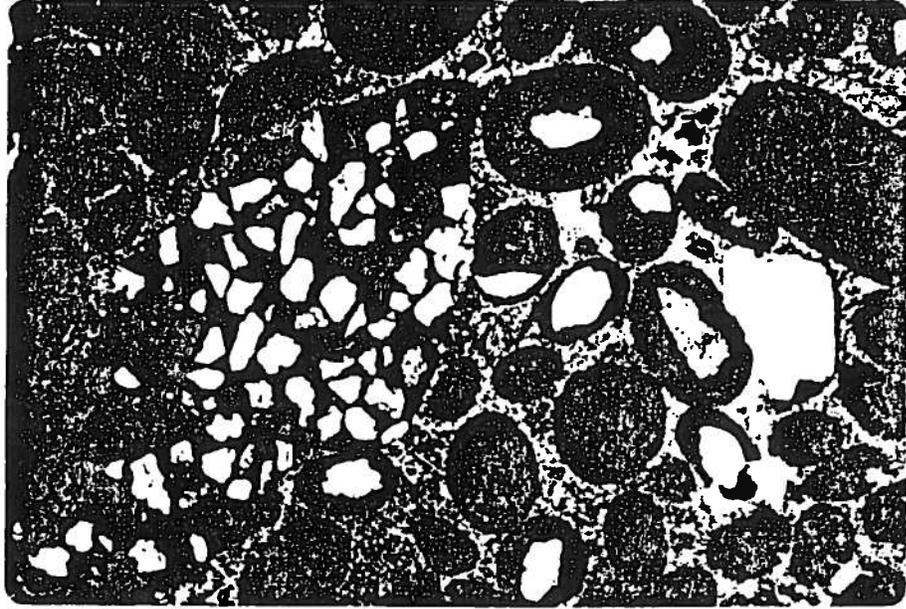


PLATE 1. Peace River iron ore (Swift Creek deposit), transmitted light, magnification approximately 25x. Ore consists of dark brown *oolites* and large silty *rock fragments* in a greenish-brown *opalline* (siliceous) *matrix*. Quartz grains (white) are present as nuclei in some of the oolites and as smaller silt grains in rock fragments.

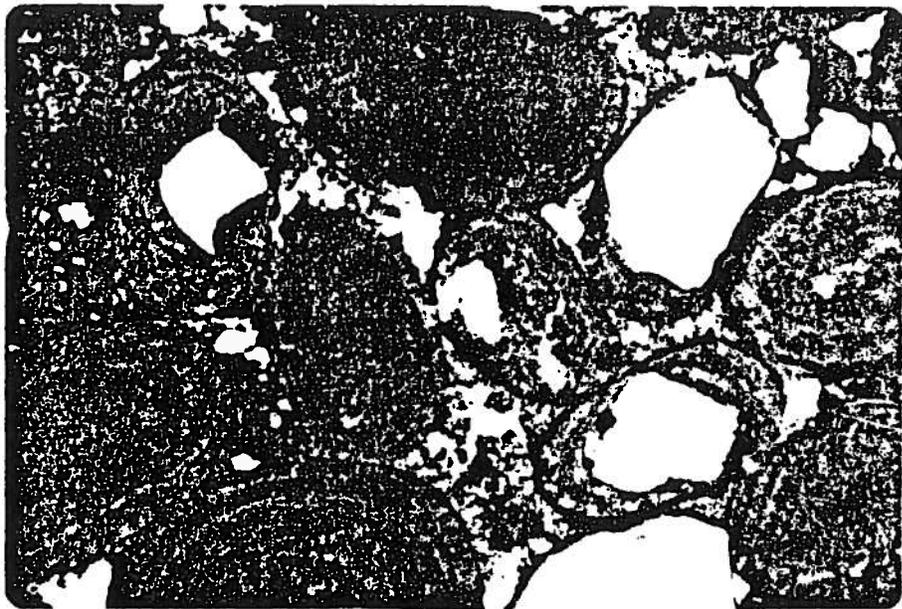


PLATE 2. Peace River iron ore (Swift Creek deposit), reflected light, magnification approximately 50x. Oolites consist of a nucleus (whitish quartz grains or dark brown to black rock fragments) about which concentric layers or shells of *goethite* ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) and *opal* (hydrous silica) have been deposited. The greenish intergranular matrix is mainly *opal* admixed with patches of "clay." Most of the iron is in the concentric outer shells of the oolites.

- (1) Total iron (Fe) content averages between 32 and 36 per cent. The Worsley deposits contain lower iron contents than the thicker deposits to the northeast (Swift Creek, Whitemud River - see Fig. 2).
- (2) The silica content is relatively high, and the alumina content is correspondingly low.
- (3) The phosphorus content is higher than desirable for a conventional iron ore. However, the sulfur content appears to be consistently low.
- (4) The lime (CaO) content of the Swift Creek deposit is lower than that of the Worsley deposits. This may be caused by partial oxidation of the Worsley deposits in which siderite (FeCO_3) has reacted with groundwater solutions to form goethite ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) and calcite (CaCO_3).
- (5) The water content is unusually high due to abundant opalline "cement".

In summary, the Peace River oolitic deposits can be described as a low grade, highly siliceous iron ore with complex mineral composition and texture. Because of the complex intergrowth relationships of the different mineral constituents, the deposits are difficult to upgrade by conventional beneficiation procedures.

RESERVES

Estimated reserves and grades for the Peace River deposits are summarized in Table 2. The estimates are based on the results of drilling programs carried out between 1959 and 1965 on four areas explored under iron prospecting permits held by Peace River Mining and Smelting Ltd., Edmonton, Alberta. The programs were supervised by

Table 2. Reserves and Grades of Sedimentary Iron Ore, Clear Hills District, Northwestern Alberta

Block	Reserves (tons)			No. of Drillholes	Average Thickness Iron Bed (ft)	Grade (% Fe)	Maximum Overburden Thickness (ft)
	Proven	Probable	Possible				
A	25,750,000	8,225,000	-	120	8	33	65
B	201,000,000	-	-	115	22	34	130
C	-	684,000,000	-	8	17	-	200
D	-	-	205,000,000	2	11	-	200
Total	226,750,000	692,225,000	205,000,000				

N.S. Edgar, consulting mining engineer, whose reports subsequently were submitted to the Department of Mines and Minerals. Copies of the reports are now kept in the Industrial Minerals Files, Research Council of Alberta (4).

The distribution of areas for which reserves have been calculated is shown in Figures 2 and 4. The areas are situated along the southern flank of the Clear Hills 5 to 6 miles north of Worsley (block A), and along the southeast margin adjacent to the Notikewin-Eureka River forestry access road (blocks B, C, D).

The degree of precision associated with the reserve estimates varies substantially among the four areas: the reserves for blocks A and B have been calculated from more than 100 borehole intersections in each area, whereas those for blocks C and D are based on only 8 and 2 borehole intersections, respectively. Consequently, the reserve estimates in Table 2 are classified as "proven", "probable", and "possible" in accordance with the data available for each area.

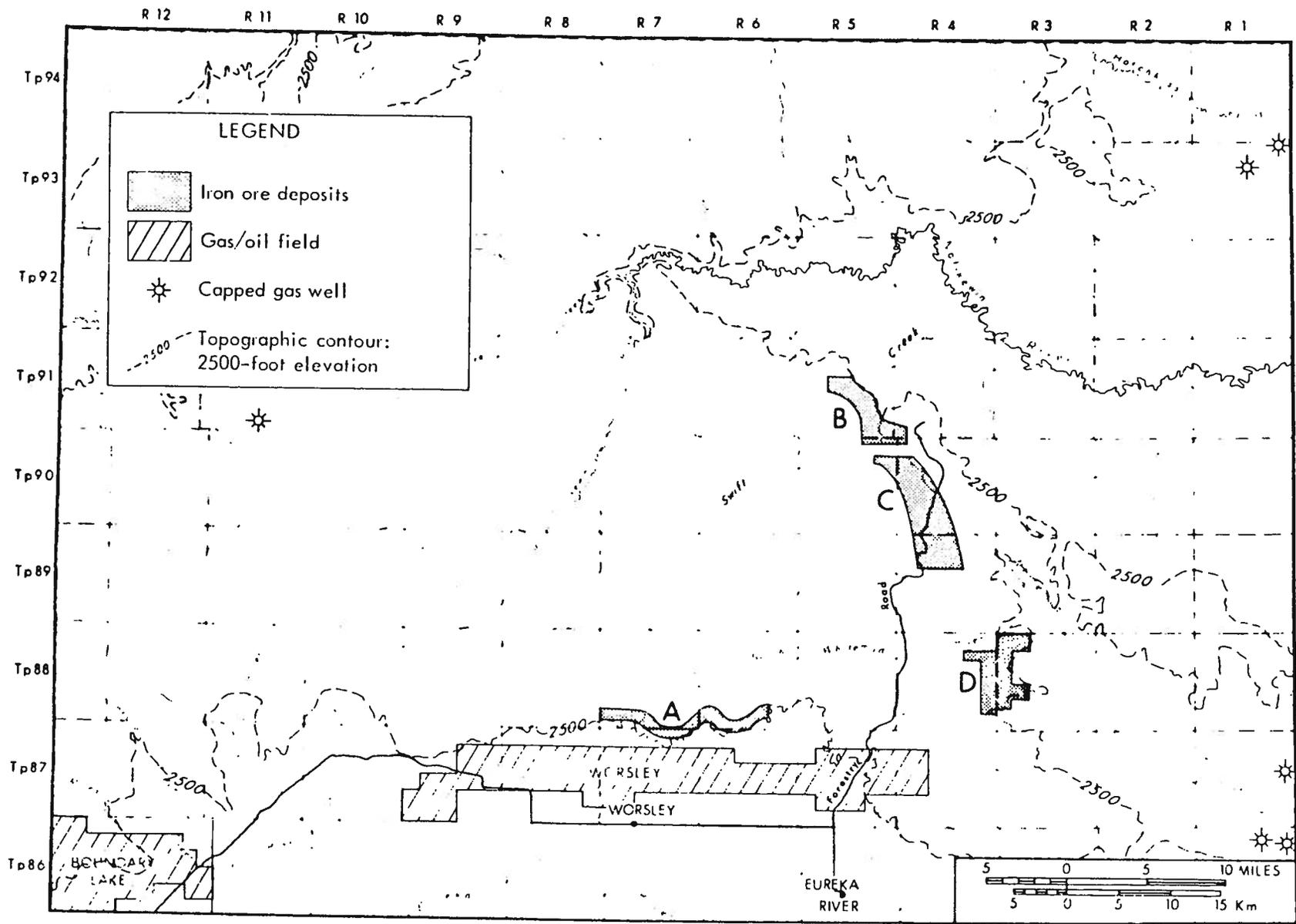


Figure 4. Location of Iron Ore Deposits and Oil and Gas Fields, Clear Hills District

The total reserves of iron ore inferred to be present in the four blocks are in excess of 1.1 billion tons grading between 32 and 36 per cent total iron (Fe). About 227 million tons of this are considered "proven", underlying blocks A (Worsley) and B (Swift Creek). The remaining 897 million tons are classed as "probable - possible", underlying blocks C and D. Undoubtedly, additional drilling is necessary to confirm the extent and grade of the iron bed in blocks C and D and to determine the exact thicknesses and composition of overburden deposits.

The most accessible reserves are contained in block A, which extends as a narrow strip along the southern slope of the Clear Hills for a distance of approximately 10 miles. Although shown as a continuous band on Figures 2 and 4, block A is actually a series of discontinuous sub-blocks, separated by erosional channels filled with glacial deposits. Overburden is thinner than in the other three areas, but the iron bed also tends to be thinner (5 to 10 feet) on the average. Block B, which straddles Swift Creek along the southern slopes of the Notikewin River valley, is less accessible than the deposits north of Worsley. However, it contains much larger "proven" reserves of ore, owing to the fact that the iron bed is thicker (17 to 25 feet) and more continuous in areal extent.

AVAILABILITY OF FUEL AND OTHER RAW MATERIALS

Fuel accounts for a significant part of the total cost in producing pig iron or steel from iron ore. Fortunately, adequate supplies of coking coal and natural gas are available in Alberta, although fuel costs will depend to some extent on where the ore is beneficiated and smelted.

Coal

Good quality coking coal is mined at several localities in the Alberta Foothills. The nearest deposits to the Clear Hills district are at Grande Cache, approximately 160 air miles southwest of Hines Creek (Fig. 1), where McIntyre Coal Limited currently mines 1 to 2 million tons of coking coal annually for export to Japan. Alternatively, if the raw ore were shipped to Edmonton for beneficiation and smelting, coking coal is available from the Luscar area, about 160 miles west of Edmonton in the central Alberta Foothills.

Locally, some thin coal seams have been observed in the Wapiti Formation which caps the upper part of the Clear Hills (Fig. 3), about 300 to 500 feet above the iron formation. However, the coal is lignitic or sub-bituminous in quality, and the extent and mineability of the seams are unknown.

Natural Gas

Natural gas fields of moderate size are present along the southern margin of the Clear Hills, in close proximity to the iron deposits (Fig. 4). As of December 31, 1971, the reserves of these fields are calculated to be:

Field	Initial Reserves (BCF)	Current Reserves (BCF)
Worsley	136	35
Boundary Lake	143	102

In addition, the Worsley field contains 147,000 barrels of recoverable crude oil (light and medium gravity), and the Boundary Lake field 7,905,000 barrels of recoverable crude oil (light and medium gravity) as of December 31, 1971.

Several capped gas wells are present along the eastern and northwestern flanks of the Clear Hills (Fig. 4), but their production capacity and reserves have not been assessed.

Limestone, Dolomite, and Refractories

Raw materials essential to the smelting of iron ores include limestone (CaCO_3) and dolomite ($\text{CaMg}[\text{CO}_3]_2$) - used for fluxing stone - and fireclay - used in the manufacture of refractories for lining various types of furnaces (electric, open hearth, or blast furnaces).

Limestone (or dolomite) is used as a flux in smelting iron ore to remove siliceous and other impurities from the molten iron in the form of a slag.¹ As much as 1000 pounds of fluxing stone per ton of pig iron is used in blast furnaces; lesser amounts are used in other types of furnaces, depending on the grade and composition of the iron ore.

High quality limestone is mined at several localities in the Front Ranges of the Rocky Mountains: near Crowsnest Lake in southwestern Alberta, at Exshaw west of Calgary, and at Cadomin 160 miles southwest of Edmonton. The Cadomin quarry is operated by Inland Cement Industries Limited, which ships substantial tonnages of raw limestone to Edmonton for cement manufacture. The nearest source of limestone to the Clear Hills is

¹The Peace River ore contains a small amount of lime (CaO), presumably in the form of calcite (CaCO_3). A 5000-ton shipment of ore from the Worsley deposit (block A, Fig. 4) sent to Birmingham, Alabama, for reduction by the R-N process contained approximately 4.0 per cent lime, sufficient to remove the sulfur content from the metallized ore (5). However, the ore consisted of highly weathered material from the outcrop and may not be representative of the bulk of the deposit.

found in the Rocky Mountains west of Grande Cache, about 160 miles southwest of Hines Creek (Fig. 1). However, the quality and extent of the deposits are unknown.

Dolomite is used both as a fluxing stone (like limestone) and as a refractory in the form of "dead-burned" dolomite ($\text{CaO} \cdot \text{MgO}$). The latter is calcined dolomite prepared in granular form for lining the bottoms of open hearth and certain other types of furnaces. Dolomite-bearing formations are extensively exposed in the Rocky Mountains of Alberta, but none have been developed for industrial mineral use (6).

Fireclay is the raw material for firebrick, the most common type of refractory used in iron smelting. Requirements are for high and super heat-duty firebrick in the hottest parts of the furnace, and lesser rated firebrick in the cooler parts. The installation and maintenance of refractory linings is a major cost factor in smelter operations.

Fireclay is found interbedded with coal seams presently being mined at Wabamun, 40 miles west of Edmonton and appears to be economically recoverable in amounts of 200,000 tons annually. The clay has been found suitable for the manufacture of moderate heat-duty firebrick and could be upgraded by blending with imported clays for use in higher rated refractories. It holds considerable promise as a source of raw material for manufacture of refractory clay products in Alberta (7).

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PART TWO
PRELIMINARY REPORT:
PROCESSING AND EVALUATION

by
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INTRODUCTION

This report deals with some of the problems involved in utilizing the Peace River iron ore. No attempt has been made to estimate the available market for steel, except that it is probably below the 1 million tons/year range; therefore, methods contemplated for using the ore involve both blast furnace possibilities and other smaller-scale procedures.

A history of the beneficiation attempts performed on the ore is given, followed by a tentative evaluation of the beneficiated products. However, in order to evaluate the products, some attempt must be made to understand the available iron-making processes. Therefore, a brief summary of those processes which might be used to beneficiate and smelt the Peace River ore is contained in the second part of the report.

The final section of the report attempts to evaluate the ore and its beneficiated products. A procedure for utilizing the ore is outlined, and estimates of conversion costs are discussed. Those aspects of beneficiation and iron-making requiring additional research are listed.

HISTORY OF BENEFICATION OF PEACE RIVER ORE

The Peace River iron deposit is complex both in structure and mineral content. The mineral content also varies with depth of the bed so that obtaining representative samples for experimental purposes is a problem. The composition and results of initial beneficiation tests on the ore are summarized in Research Council of Alberta Information Series No. 40 (1), and the geology of the deposits is described in Research Council of Alberta Preliminary Report 62-8 (2).

Magnetic Separation

First attempts at beneficiating the ore include work done by the Ontario Research Foundation. The ore was flash-roasted and partially reduced; the partially-reduced magnetic iron ore was then separated by a magnetic technique to yield a 54 to 56 per cent iron concentrate (1). No report is given for the gangue content or its composition. The feed is recommended only for a blast furnace. Other than stating that a magnetic separation was tried, the report does not describe the actual procedure (wet or dry, high or low intensity, fineness of the grind). Neither the roasting conditions nor other details are available.

In 1962, the Mines Branch, Department of Energy, Mines and Resources, Ottawa, carried out a high-intensity magnetic separation using the Jones-type apparatus on a oolitic ore (3). A fine grind yielded 70 per cent iron recovery, and the separation upgraded the ore from 32.6 per cent to an average of 40 per cent iron. This ore may or may not have been Peace River ore, but the oolitic nature and complex mineral composition certainly are similar.

Recent advances in electrostatic separation (4) and high intensity wet magnetic separation (5) of fully-oxidized iron oxides show great promise in that a nonreductive roast on a dried ore may yield a concentrate equivalent to that from a reductive roast-wet low intensity magnetic separation.

R-N Process

The second and most thoroughly investigated conventional approach to processing the Peace River ore involved the R-N reduction process followed by magnetic separation (1). This method was followed to make an iron briquette of 90 per cent iron metal which could then be used in electric-arc furnace steelmaking.

The R-N tests used coke as the reducing agent and natural gas as the heating source. The coke and ore were mixed and fed into a rotary kiln. Temperature of the kiln was kept below slagging temperature - about 900 to 1000° C - and closely controlled and measured by an array of multiple gas inlets and thermocouples placed along the length of the rotary kiln. The reduced ore was then put through a series of wet crushers and wet magnetic separators until a fairly enriched metallic iron fraction was obtained. The enriched and crushed ore was further upgraded by use of a cyclone separator. The concentrated portion was again put through a series of magnetic separators and finally yielded a product which, on filtration, had the analysis given below. The iron recovery was actually 74.32 per cent of the iron present in the ore, but due to spillage (which could have been prevented) the recovery was estimated to have been 83.17 per cent of the initial iron.

Constituent	Per cent
Total iron	90.00
Metallic iron	84.69
SiO ₂	3.56
Al ₂ O ₃	2.31
CaO	0.76
P	0.29
S	0.026
C	0.25

The number of operational steps in the separation procedure is quite large, with 11 magnetic separators, 7 cyclones, and 6 ball mills involved in processing either all or part of the ore. In addition to these steps, there are settling ponds, filters, pumps, coolers, tabling and screening equipment, and drying and briquetting steps in the separation procedure. The fuel requirement - excluding that required for briquetting, mining, and initial crushing - was 28.250 million Btus/ton of iron concentrate. This fuel was 53 per cent from gas sources and 47 per cent from coke or nonvolatile coal sources. The commercial projection was for 25.486 million Btus/ton of iron concentrate, with approximately 53 per cent from gas and 47 per cent from solid fuels. A nonvolatile coal, coke, or coke breeze is suggested as a source of solid fuel, since the volatile components of ordinary coal may be lost as a heat source.

The estimated cost for the iron produced by the R-N process in 1960 was \$25/ton in Edmonton, at the 300,000-ton/year production level. The estimated cost of steel ingots via the electric-arc process was \$55/ton. A more recent evaluation of the R-N process at the 1,000,000-ton/year level estimates \$27/ton, but the return on investment is low.

Acid Leaching

Another of the techniques investigated for extracting iron from the low grade Peace River ore involves recovering a mineral acid salt of the iron, purification of the iron salt, and production of a high grade iron product. This procedure was investigated at the Research Council of Alberta (6) and developed to a partial pilot plant stage by Peace River Mining and Smelting Ltd.

The initial procedure is to leach the ore in a mineral acid such as H_2SO_4 or HCl , then purify the iron by precipitation of a crystalline iron compound. The ferrous state (Fe^{++}) is more easily crystallized than the ferric state (Fe^{+++}); thus the ore must be partially reduced to ensure that as much of the iron as possible is in the ferrous state before leaching. Various methods were devised for obtaining the ferrous state, including reduction of the ore before dissolution and reduction of the leachate after dissolution. The latter procedure involves the use of organic reducing agents, scrap metal, or partially metallized ore. The pure crystalline ferrous compound can then be directly reduced to pure metallic iron powder if ferrous chloride is produced, or to a very high purity iron oxide if either ferric sulfate or ferric chloride salts are produced. The iron oxide can then be used to produce high purity sponge iron by conventional techniques.

One of the major drawbacks to the process is the loss of acid. Repeated washings were required to remove the residual acid retained by the gangue components or the undissolved pulp, and the residual acid is not recoverable. In addition to iron, Ca, Mg, Al, and Mn were dissolved by the acid to form various salts, and this acid is not economically recoverable. Phosphorus and sulfur, both of which are detrimental to high quality iron, also were dissolved during the solution trials.

The crystallization phase of the process did yield a pure iron salt in good quantities, with only minor silica and alumina impurities, but filtration presented some problems if large amounts of the opalline matrix of the ore (alumina-silicates) were dissolved during leaching. Therefore, steps were taken to reduce the amount of alumino-silicates dissolved and thereby alleviate the flocculent-type crystallization of the silica which caused filtration problems.

The leaching step, using HCl in 20 to 30 per cent concentrations, dissolved from 85 to 95 per cent of the iron present in the ore, depending on the reduction technique used. The filtration step recovered 85 to 90 per cent of the iron as crystalline compounds; therefore, the overall efficiency of recovery of iron would be in the 80 per cent range ($0.90 \times 0.87 \times 100\% = 78.3\%$). However, the iron product produced from the chloride salts is in the order of 99 per cent Fe and therefore would demand a premium price for low-carbon steelmaking processes and for powder metallurgical applications.

Flotation Processes

An agglomeration or flotation process for upgrading the Peace River ore has been developed by the National Research Council (7). The process uses a ball mill with hydrophilic surfaces, an oil fraction, and an aqueous fraction. The iron-bearing mineral (goethite) is concentrated in the oil phase (tall oil or acid petroleum oil), and the silicious material remains suspended in the water fraction. The concentration of the iron increases from 63 per cent Fe_2O_3 in the original ore to 75 per cent in the concentrate. The silica concentration decreases from 20 per cent in the original ore to 10 per cent in the concentrate, whereas the CaO concentration increases from 4 per cent in the original to 10 per cent in the concentrate. No mention is made of the yield of iron concentrate or the

efficiency of iron recovery. The oil:iron oxide ratio used is about 1:1 on a volume basis; on a weight basis this is about 10:1 for an ore:oil ratio.

Recent Work

Additional work has recently been carried out on the Peace River iron ore at the Research Council of Alberta. The preliminary experiments involve drying, crushing, magnetizing roasting, oxidative roasting, magnetic separation (wet and dry), high-intensity dry magnetic separation, electrostatic separation, and solution-type recovery processes. The origin of the material used in these experiments is uncertain; it appears to be similar to the weathered (oxidized) ore extracted from the Worsley area for use in the R-N tests.¹

The iron concentration in the ore appears to decrease in the finer-sized fractions of the crude ore and continues this trend after mild crushing. This is shown by the chemical analyses of dried and classified crude ore and mildly-crushed ore. The difference is not significant enough for the technique to be used as a primary beneficiation technique.

Extensive tests on fluidized bed reductive roasting of sized fractions of ore show that the depth of reduction is not an important factor in the ability to magnetically concentrate the ore. A more important feature is the fineness of the ore and the percentage of total iron recovered in the concentrate (Table 1). Concentrates 1 and 2 show variations in the percentage of iron recovered and grade of concentrate, whereas a comparison of concentrates 2 and 3 shows that the depth of reduction has little effect upon the iron-to-gangue ratio at comparable iron recovery levels.

¹G.B. Mellon, personal communication.

Table 1

Sample	Per cent Iron in Concentrate	Reduction	Per cent Iron Recovered	Per cent Iron in Concentrate/ Per cent Acid Insolubles in Concentrate
1	64.7	Strong	66	4.3
2	60	Strong	90	2.8
3	50.7	Mild	85	3.3

The use of high intensity magnetic separation on ore roasted under oxidative conditions yields a high recovery of iron but a low grade of product as compared to the reductive-roast experiments. A high intensity separation on straight ore, dried in air at ambient temperatures, yields little to no upgrading of the iron content.

Preliminary tests using an electrostatic separator give insignificant separation. The separations were attempted on ore from both an oxidative roast and a reductive roast. Also, ore dried at ambient temperature yields little or no separation. Highly classified ore fractions give slightly better beneficiations than do nonclassified material.

Leaching-type experiments using various mineral acids yield relatively high grade iron oxides. The technique is to leach the ore, or partially-reduced ore, at high temperatures to yield as concentrated a solution of iron salts as possible. This concentrated solution is then separated from the gangue components by filtration or centrifugation and then evaporated to dryness. The dry salts are next roasted in air to yield iron oxides; a concentrate containing better than 60 per cent iron and up to 6 per cent alumina is obtained with sulfuric acid leaches. The possibilities of using this method should increase as the technology of steel mill pickle-liquor utilization develops (8), although the high alumina

content of the Peace River concentrates may present some problems during smelting.

In the light of existing knowledge, the best procedure for treating the Peace River ore appears to be either

- (1) a mild reductive roast followed by crushing and grinding to yield a magnetic concentrate, or
- (2) intensive reduction of the ore to an iron-metal product followed by magnetic beneficiation of this product to remove the gangue constituents.

Either procedure will be relatively expensive when one considers the value of the products. The mild reductive roast procedure may be better in that a wider range of iron- and steel-making procedures can be used on the upgraded product. The selected procedure will have to reflect the iron- and steelmaking procedures to be used, and the location of beneficiation and smelting facilities.

Additional research on the ore should be carried out in the areas of beneficiation. More specifically, the mildest reductive roast conditions and methods required to yield optimum iron concentrations and recovery should be determined. Also, other beneficiation techniques should be tested to determine if an adequate separation can be obtained. The reducibility, agglomeration characteristics, and iron-making qualities of the various concentrates also should be tested in order to totally evaluate the various beneficiation procedures.

IRON METAL PRODUCTION

Blast Furnace Method

The blast furnace becomes an economically feasible method for smelting iron ore only

if large-scale continuous production is contemplated. The average blast furnace in North America is tending toward the 2,000 - 4,000 tons/day scale (9, 10). In addition, to save on coking and other requirements, the blast furnace should be set up in units of at least 2. Thus, an economically-sized blast furnace operation could attain production in the order of 1.5 million tons/year.

The blast furnace uses high grade coke to ensure smooth flow of the burden through the stack. Usually, the ore is uniformly high grade and sized to approximately 1/2 to 1 inch; this ensures a smooth flow of materials and economical furnace-charging procedures. It has been found that removing gangue by mechanical means - such as heavy-media separation, magnetic separation, electrostatic separation, or flotation - is less expensive than removing it as slag in a blast furnace. One estimate is that the cost of simple mechanized removal of gangue is usually about 1/3 that of removing it as slag (11). However, to take advantage of this cost differential, a crushing-beneficiation-sintering procedure must be added to the front end of the blast furnace operation to regain proper ore size.

The blast furnace is probably the least expensive method of processing medium grade and high grade ores. Self-fluxing agglomerates (sinter and pellets), properly sized, along with well-sized coke result in high production rates. Use of fuel injection with high-temperature blasts has aided in reducing the quantity of high grade coking coal required per ton of hot metal produced. If capital is a problem, but a cheap source of coking coal is available, non-byproduct-recovery coke ovens could save on capital requirements (12). Also, if high Btu-value gas (such as coke-oven gas, natural gas)

is available for firing the stoves, economics in the size and number of stoves required may aid in reducing the overall capital cost of a blast furnace and its ancillary equipment. Single smaller-size blast furnaces are in operation for producing iron from medium grade ore, especially where the ore and coal are readily available (10, 13).

Direct Reduction Methods

Direct reduction methods now available produce a metal product which is about 90 to 95 per cent iron. This iron is usually produced in the solid form so that subsequent melting is required for steel production. The several methods available for direct reduction can be put into various classes: rotary kiln processes, static and fluidized bed processes, moving bed processes, and electric furnace type processes (9, 11). All of the processes overlap in the type of energy used or the type of equipment used. These processes are thoroughly reviewed in several recent reports (14).

The common rotary kiln processes in use today are the R-N (SL/RN) and the Krupp-Renn. The R-N process uses coke or coal as the reducing agent and gas as the heat source. The burden is kept below slagging temperature. The process can be used for either high grade or low grade ores. With the low grade ores, the reduced product is magnetically beneficiated. The Krupp-Renn process is very similar, except that the temperature is increased so that "lumpen" or iron nodules, produced from softening the metal, are the main product. In the case of low-grade ores, the nodules are then crushed and beneficiated. In both processes the fuel consumption is relatively high, especially if low grade ores are used.

Among fixed bed processes, the HyL process is the most common. Preheated cracked natural gas is the source of energy for reduction. High grade lump ore or concentrates

are necessary, and the process creates successive, overlapping batches of "sponge" iron for conversion in an electric furnace. The H-iron process uses hydrogen as a reducing gas and three fluidized beds. The ore is reduced step by step as it flows from one bed to the next. The product is ore reduced to a steady state. A careful sizing is required, but the process is continuous.

The Wiberg process overlaps the gaseous bed-reduction process and electric processes. The method involves a burden in a stack. Raw ore is fed into the top and the sponge iron product is removed from the bottom. A counterflow of preheated carbon monoxide provides the reducing agent and the heat requirement. Carbon monoxide is produced from electrically-heated coke and recycled carbon dioxide from the top of the stack. This combination of reducing agent and heating arrangement has provided the basis for several commercial operations.

The Midland-Ross (Midrex) process is similar to the Wiberg process, in that a counter-current flow of hot reducing gases and iron ore occurs in a stack. The ore must be sized and high grade to yield good quality sponge iron. The Midland-Ross process also is in commercial production.

Electric furnace reduction of ores produces a molten product of iron and slag. Ore and the coke used for reduction can be charged directly to the furnace, either cold or preheated and prereduced. Electrical energy requirements for cold-charging are in the order of 2,000 to 3,000 kwh; hot and prereduced-charging reduces the energy requirements to slightly more than 1,000 kwh. For melting of additional slag, it is estimated that 40 kwh of extra electrical energy are required for each 100 pounds of slag formed;

thus, an ore of 50 per cent iron and 15 per cent SiO_2 requires a minimum of 500 kwh just to melt the slag components. If high grade reactive coke is not used, electrical consumption can increase greatly. The coke requirement changes only if prereduced ore is fed to the furnace, and then only if no coke is used in the prereduction step. The burden must have physical characteristics about equal to those required for the blast furnace, since the basic reduction and smelting operations are the same. Many problems have arisen from trying to feed preheated and prereduced ore directly to the electric steel-making furnace. Most of the originally designed units have been abandoned, and straight feeding of cold ore and coke to the electric furnace is preferred (14e, 15).

The electric furnace produces molten slag and iron which can be tapped occasionally to allow for continuous processing. The molten iron can be formed into cold pig iron or directly charged to a steelmaking furnace, thus saving on remelting costs. The off-gases from the electric furnace should be used to take advantage of their high carbon monoxide content. A logical place to use off-gases is in the prereduction step. Experimental and commercial processes which incorporate the prereduction and preheating steps in electric smelting of iron ore are the Strategic-Udy, McDowell DLM, and Elektrokemisk processes. The Lubatti and Tysland-Hole electric furnace procedures do not incorporate these steps.

An electric-furnace procedure is used to make pig iron from iron sulfide tailings in the Cominco Ltd. plant at Trail, B.C. (16). The ore used is sinter from pyrite or iron sulfide roasts. The raw ore is about 50 per cent iron but is beneficiated to a high grade low-silica ore before the smelting process. When cast, the pig iron is ideal for remelting furnaces because of its compact nature, which facilitates charging and reduces the number of charges required to fill the steelmaking furnace. A sponge iron, which is less dense

than an ingot pig iron, may require repeated charging for a single furnace melt.

Other advantages of pig iron are that it melts at a lower temperature, and the dissolved carbon and silicon become a source of heat during steelmaking (17). The additional heat supply can be used to superheat the steel melt or to supply heat for melting additional pig iron or scrap; in fact, a pig iron process can be almost self-sustaining as far as melting is concerned, especially if the pig iron is preheated prior to charging to the melting zone. High-carbon sponge iron has a disadvantage for preheating in that it is readily reoxidized.

Another recent advance in steelmaking, which involves smelting of low grade ores, is the utilization of red muds associated with aluminum ores, which contain high iron and silica contents (18). Mud grading from 30 to 60 per cent Fe, composed of waste material and slag resulting from the aluminum refining process, are pelletized, preheated, and pre-reduced before charging to an electric furnace for smelting. The pellets are made from red mud and coal.

ORE EVALUATION

Relative Values of Iron Ores

An absolute value for an ore is hard to obtain except through actual test runs, but several organizations from different countries have produced formulas which assist in estimating a relative value for an ore (20). These formulas were used to estimate the following relative values for three different ores:

- (A) a high grade hematite, 67% Fe,
- (B) a medium grade concentrate obtainable from the Peace River iron deposit, 60% Fe, 20% SiO₂, 0.3% P, and 2% CaO,

(c) crude Peace River iron ore, 35% Fe, 30% SiO₂, 0.3% P, and 4% CaO.

The relative values using the Polish formula for C, B and A are 1:5.0:8.5, respectively, and the ratios using the Czechoslovakian formula are 1:6.0:9.2, respectively. A formula developed by Swedish interests is available, but sufficient production data to calculate the relative values are not. Russia did not supply a base formula, but did supply the relative values of various ores produced in Russia, together with mineral analyses. Table 2 gives the relative values of several ores produced in Russia; these may be compared to the selected ores, A, B and C.

Table 2

Ore	% Fe	% SiO ₂	% CaO+MgO	Relative Value
(1)	47	30	0.2	0.126
(2)	56	18	0.2	1.042
(3)	58	17	1.0	1.183
(4)	68	3	0.16	2.039
Ratio of relative Fe values = 1 : 8.26 : 9.39 : 16.2				

Another method of estimating the value of iron ore involves the coking consumption. French and British formulas for such estimates are available; they yield the following consumptions in kg of coke/ton of iron produced:

French: C, 1,038 kg/ton; B, 662 kg/ton; A, 540 kg/ton
 British: C, 1,094 kg/ton; B, 654 kg/ton; A, 507 kg/ton

The following values for coke consumption taken from a graph produced by Konig (10) show a similar trend in coke requirements for the three ores:

German: C, 900 kg/ton; B, 650 kg/ton; A, 600 kg/ton.

Recent improvements in blast furnace technology may be the cause of the major variations in the estimates above, in that there is an almost 8-year difference in the citations. The German coke consumption may not reflect a true picture either - no account is taken for actual gangue content of the ore, only the iron content is considered. Since 25 per cent to 40 per cent of the cost of iron production is due to coke costs, the coke consumption has a direct bearing on the value of the ore.

If coke consumption is related to the cost of metal production, then for electric furnace smelting the electrical energy consumption also should vary with ore grade and composition. For ores A and B, assuming B is 30 per cent prereduced, the power load is 1,800 kwh/ton and 1500 kwh/ton for cold-charging. If ore B is oxidized before charging, as it will be if pelletized, then the energy consumption increases to 2,200 kwh. An estimate for the power consumption for ore C is greater than 3,000 kwh/ton of metal. These estimates show that large savings in power consumption can be obtained by prereduction of the ore charge (10).

The United States price of ore is determined by the "standard price" method, especially when applied to Lake Superior prices (21). If the price of the ore is computed using the "standard price" formula, then the relative values of iron ores can be determined on the iron content basis as 3.5:3.0:1 for A, B, and C, respectively. These relative values do not take into account the silica or phosphorus contents of the ore, for price adjustments for impurities have not been standardized. Thus, relative values based only on the iron content of ores are approximate.

The prices of German iron ores are available, and relative values for ores A and B are calculated to be 3 and 2, respectively. The same limitations apply here as for the

estimated relative values of U.S. ores.

Table 3 summarizes the relative values of iron ores according to different formulas used by various countries. The U.S. values are not really comparable to the other estimates, but they are included nevertheless. Relative values obtained from coke and electrical power consumption estimates are omitted.

Table 3

Ore	Polish	Czechoslovakian	U. S. S. R.	U. S. A.	German
C	1	1	1	1	N.A.*
B	6.0	5.1	9.4	3.0	2
A	9.2	8.5	16.2	3.5	3

*Not available.

From the series of relative values in Table 3, the medium grade concentrate (B) is worth roughly 1/2 to 2/3 the value of the high grade concentrate (A) for smelting under blast furnace conditions. These relative values also should apply to some degree to electric smelting and direct reduction processes. The above calculations are only rough estimates and ignore other values such as reduceability, texture and physical properties of the ore, undesirable impurities, moisture content, and varying energy costs.

If an offshore or domestic high grade iron ore concentrate were available in Edmonton at \$23/ton (22), then a medium grade concentrate should be worth between \$11.50 and \$17/ton. A 5 per cent reduction in the silica content - from 20 per cent to 15 per cent - would increase the ore value by greater than 10 per cent. It has been suggested in a preceding section of this report that a concentrate of 60 per cent iron and 15 to 20 per cent

silica conceivably could be obtained by beneficiating raw Peace River ore.

It must be emphasized that the actual value of an iron ore can be determined only by use. The value of the ore also will vary with the process used. The cost of removing molten slag is usually less on a high-tonnage basis in a blast furnace than it is in direct reduction and electric smelting processes, especially if coking coal is readily available.

Cost Estimates for Iron- and Steelmaking

A suggested procedure for utilizing the Peace River iron deposits involves the following steps:

- (1) selective mining; i.e. mine only the upper, richer part of the iron formation;
- (2) beneficiation by reductive roast and magnetic separation;
- (3) pelletization (self-fluxing pellets);
- (4) pig iron production by
 - (a) prereduction and electric smelting, or
 - (b) blast furnace;
- (5) steelmaking.

The mining, beneficiation, and pelletizing (agglomeration) costs vary with the size of the operation. For example, the Marcona Corporation (23) has estimated the costs of beneficiating and pelletizing a 45 per cent magnetite ore to be \$13.80/M ton and \$7.95/M ton for small- and large-scale operations, respectively. If \$2/M ton is added for a magnetizing roast, the costs become \$15.80/M ton and \$9.95/M ton for pellets grading 67 per cent Fe and 64 per cent Fe, respectively. These costs include operating, capital, and overhead costs but do not include capital costs for a magnetizing roast.

Self-fluxing pellets¹ produced from Peace River iron ore (roasted and upgraded to produce a concentrate containing 60 per cent Fe) presumably would cost similar amounts except that the Peace River pellets would contain 50 to 55 per cent Fe. However, the costs of such pellets (\$9.95/ton to \$15.80/ton) compare favorably to values estimated for medium grade Peace River ore concentrates in the preceding section of the report (\$11.50/ton to \$17/ton).

A number of factors affect the cost of converting iron ore (lump ore or pellets) to iron metal. Two recent estimates (23, 25) suggest that fuel and operating costs required to convert high grade iron ore pellets are in the order of \$9 to \$10/net ton. These costs would increase from 20 to 30 per cent if a lower grade pellet were used. In addition to operating costs, capital outlay in the order of \$24 to \$40/annual ton of iron metal is required. Capital outlay could increase to \$50/annual ton iron metal, if the SL/RN prerduction-electric furnace technique were used.

The Japanese estimate for iron production is \$38/ton hot metal (14a). Raw materials (ore and fuel) are \$28, labor \$2, and fixed charges \$7. Capital costs for a blast furnace are estimated to range from \$20/annual ton pig iron (6,000 ton/day plant) to \$60/annual ton pig iron (2,000 ton/day plant) (10).

These estimates can be applied to the Peace River iron ore in the following manner, if one assumes the ore to be available in the form of a self-fluxing pellet grading 52 per cent Fe.

¹ Pellets composed of iron ore concentrate and lime (CaO). The latter acts both as a bonding agent and as a flux.

<u>Item</u>	<u>Costs/ton of iron</u>	
	<u>Large-scale plant</u>	<u>Small-scale plant</u>
(1) Iron pellets (52% Fe)*.....	\$17	\$27
(2) Fuel (coke, average value)	\$20	\$20
(3) Labor and fixed charges**	\$12	\$18
TOTAL	\$49	\$65

*Costs are based on estimated pellet values of \$9.95/ton and \$15.80/ton, respectively, converted to costs/ton of iron metal.

**Based on one-third the cost of pellets and fuel.

These estimates do not include capital costs which vary from \$20 to \$60/annual ton pig iron.

Other estimates are available for comparison of costs for various processes of converting iron ore to steel. For example, Cartwright (24) shows a graph in which, at prevailing rates of energy, the estimated costs for the SL/RN/arc furnace and B.F./BOS processes "cross" at \$52/ton and at a capacity of about 1.5 million tons/year. The cost/ton increases less rapidly for the SL/RN/arc furnace as the annual capacity decreases. The minimum capacity of the blast furnace is estimated at about 1 million tons/year. As the price of electricity decreases with respect to coking coal, the cost of steelmaking by the SL/RN/arc furnace is again favored.

From the estimates and calculations presented above, it can be seen that a slight change in costs for any item can lead to large changes in the costs of converting iron ore to iron metal. In addition, the scale of the process has a large bearing on determining the ultimate costs of conversion.

To determine more precisely the value of the Peace River iron ore, the following aspects

of ore beneficiation and smelting are recommended for further research:

- (1) grindability of the ore;
- (2) reducibility of the ore;
- (3) minimum level of reduction for efficient magnetic separation;
- (4) agglomeration (pelletizing) characteristics of the ore;
- (5) reducibility of the agglomerated ore;
- (6) smelting qualities and conditions;
- (7) quality of the steel produced from the iron.

Needless to say, should additional research be carried out on these or other aspects of the Peace River iron deposits, some care should be exercised in obtaining samples which are representative of the bulk of the ore, i.e. the material which normally would be mined for beneficiating and smelting.

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APPENDIX:
OTHER IRON DEPOSITS IN WESTERN CANADA

by
G. B. Mellon

A number of iron-bearing deposits have been discovered in Western Canada, the locations of which are shown in Figure 5. The geology, size, and grade of these deposits vary widely, but the dominant factor governing their development has been the proximity to export markets, i.e. Japan.

The only iron deposits in Western Canada currently being exploited are situated along the coastal islands of British Columbia. Although widely scattered, the deposits are similar in geology and composition: they consist of irregular veins and lenses of magnetite (Fe_3O_4) in metamorphosed limestones, associated in some cases with copper sulphide ores. The ore grade ranges from 30 to 55 per cent iron (Fe); the raw ore is crushed and beneficiated to produce magnetic concentrates grading between 60 and 65 per cent iron (Fe). The ore bodies tend to be small and irregularly distributed in comparison with the huge deposits in the Precambrian iron formations of Eastern Canada, and, consequently, "proven" reserves are relatively low in most areas (one million tons or less).

In 1968 six mines along the West Coast produced 1,771,000 tons of magnetite concentrate for shipment to Japan.¹ Two of the mines ceased operations in 1968, having run out of ore at that time. The only other source of iron ore utilized in British Columbia during the 1960's is the iron sulphide tailings from the Sullivan lead-zinc mine at Kimberley, from which Cominco Ltd. produced approximately 100,000 tons of pig iron per year until recently. However, the Kimberley furnace is presently shut down and may be converted to smelting copper concentrates.²

¹ In addition, Craigmont Mines near Merritt, B.C., produces about 20,000 tons of magnetite concentrates annually as a byproduct of milling copper ore.

² Personal communication: Dr. S.S. Holland, Dept. of Mines and Petroleum Resources, Victoria, B.C.

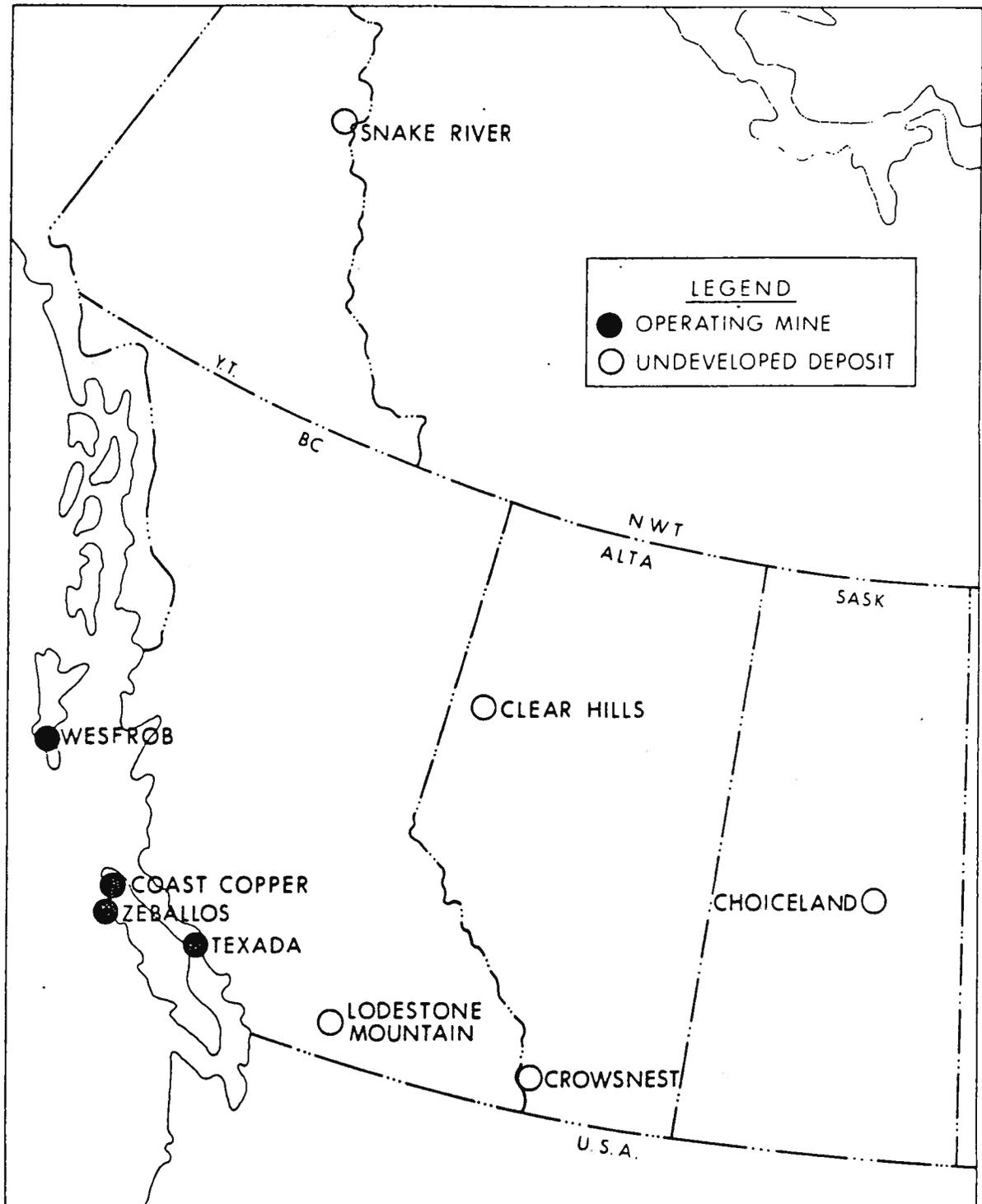


Figure 5. Location of Major Iron Ore Deposits, Western Canada

Among the undeveloped iron ore deposits in Western Canada (excepting the Peace River deposits), only the Lodestone Mountain deposit in south-central B.C. appears to have much potential for exploitation in the near future. Although the grade is low and the ore has a significant titanium content,¹ the deposit may lend itself to beneficiation and upgrading. Moreover, it is close to rail facilities and could be shipped eastward as far as the Alberta Foothills in empty coal cars.

A summary of the salient features for each of the iron deposits listed in Figure 5 is given below.

<u>Deposit:</u>	WESFROB MINES LIMITED
<u>Location:</u>	Moresby Island (Queen Charlotte Islands).
<u>Type of deposit:</u>	Magnetite (Fe ₃ O ₄); contact metamorphic iron-copper deposit.
<u>Reserves and grade:</u>	Crude ore grades 35 per cent Fe and 0.38 per cent copper (Cu).
<u>Production:</u>	780,000 tons of concentrate grading 62.3 per cent Fe were shipped to Japan in 1968.
<u>Deposit:</u>	COAST COPPER COMPANY, LIMITED (COMINCO LTD.)
<u>Location:</u>	Benson Lake, Vancouver Island.
<u>Type of deposit:</u>	Magnetite (Fe ₃ O ₄); contact metamorphic iron-copper deposit.
<u>Reserves and grade:</u>	Crude ore grades 30.5 per cent Fe and 1.22 per cent copper (Cu).
<u>Production:</u>	67,000 tons of concentrate grading 64.9 per cent Fe were produced in 1968.

¹Titanium presents some problems in conventional smelting (blast furnace) techniques. It forms a viscous slag difficult to handle at normal furnace temperatures.

- Deposit: ZEBALLOS IRON MINES LIMITED
- Location: Zeballos, Vancouver Island.
- Type of deposit: Magnetite (Fe_3O_4); contact metamorphic deposit.
- Reserves and grade: Not available.
- Production: 133,000 tons of concentrate grading 62.2 per cent Fe were shipped to Japan in 1968.
-
- Deposit: TEXADA MINES LIMITED
- Location: Texada Island, B.C.
- Type of deposit: Magnetite (Fe_3O_4); contact metamorphic iron-copper deposit.
- Reserves and grade: Crude ore grades 36.5 per cent Fe; copper content not available.
- Production: 530,000 tons of concentrate grading 61.6 per cent Fe were shipped to Japan in 1968.
-
- Deposit: SNAKE RIVER
- Location and access: MacKenzie Mountains, Yukon and Northwest Territories, about 130 miles northeast of Mayo, Y.T.
- Type of deposit: Sedimentary deposit of Precambrian age. Consists of bedded hematite (Fe_2O_3) and jasper (SiO_2) similar to certain Precambrian iron formations in Eastern Canada.
- Reserves and grade: 20 billion tons of which 5 billion tons can be recovered by open-pit mining. The grade averages 46 per cent Fe, but the phosphorus content is high (0.35 per cent).
- Economic potential: The deposit is too remote to be developed in the foreseeable future.
- Reference: L.H. Green and C.I. Godwin, Geol. Survey Canada Papers 63-33 and 64-36, 1963 and 1964.

Deposit: CHOICELAND

Location and access: Central Saskatchewan, about 50 miles east of Prince Albert.

Type of deposit: Metamorphosed sedimentary deposit of Precambrian age. Consists of banded magnetite (Fe_3O_4) and quartz (SiO_2) with some hematite (Fe_2O_3). Deposit is in the crystalline "basement" beneath 2000 feet of younger sedimentary strata (Devonian and Cretaceous beds).

Reserves and grade: 150 million tons averaging 30 per cent Fe.

Economic potential: None in the foreseeable future; the deposit is buried beneath 2000 feet of hard bedrock overburden.

Reference: R.L. Cheesman, Can. Mining Metall. Bulletin, Vol. 67, 1964.

Deposit: CROWSNEST

Location and access: Widely scattered localities in the Crowsnest Pass - Waterton areas of southwestern Alberta.

Type of deposit: Titaniferous magnetite (Fe_3O_4) present as thin discontinuous beds or lenses in the basal sandstone of the Belly River Formation (Upper Cretaceous). Similar and more extensive deposits are found in the State of Montana.

Reserves and grade: Reserves are estimated at less than 10 million tons scattered over several localities. The grade is highly variable, averaging approximately 30 per cent Fe and 3.5 per cent titanium (TiO_2).

Economic potential: Very low as iron ore. The deposits are too widely scattered and too structurally complex to mine economically. Moreover, the titanium content cannot be lowered sufficiently by magnetic separation techniques.

Reference: G.B. Mellon, Res. Council Alberta Bulletin 9, 1961.

Deposit: LODESTONE MOUNTAIN

Location and access: South-central B.C. about 15 miles west of Princeton. Deposit can be reached by logging road from Coalmont, a distance of 8 miles.

Type of deposit: Titaniferous magnetite (Fe_3O_4) present as lenses and veins in a pyroxenite intrusive (igneous) body.

Reserves and grade: 99 million tons of "proven" ore grading 15.5 per cent iron, and 1,175 million tons of "probable" ore grading 13.9 per cent iron.

Economic potential: Uncertain, although the deposit has several factors in its favor. It is close to rail facilities (C.P. line), and concentrates could be shipped eastward to Alberta in empty coal cars. The iron content is low, but magnetite ores normally are relatively easy to upgrade and concentrate. However, the titanium content of the ore could prove troublesome depending on the amount present and to what extent it can be separated from the magnetite during beneficiation.

Reference: Dr. S.S. Holland, Department of Mines and Petroleum Resources, Victoria, B.C. (personal communication).