Information Series 75

PEACE RIVER IRON DEPOSITS

E. F. Bertram and G. B. Mellon

Alberta
RESEARCH COUNCIL

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Alberta Research Council
1975

Copies of this report available from:

Alberta Research Council
11315 - 87 Avenue
Edmonton, Alberta
Canada, T6G 2C2

Price $2.00

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ABSTRACT

The Peace River iron deposits are situated in the Clear Hills district of northern Alberta, about 300 miles northwest of Edmonton. The deposits are close 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 along the southeastern slopes of the Clear Hills. The iron content of the bed grades between 32 and 35 percent Fe, mainly in the form of goethite ($Fe_2O_3 \cdot H_2O$). Resources have been estimated at 1,124 million tons of which 227 million tons are considered "proved" and 897 million tons are classed as "probable" or "possible" resources. 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 percent Fe, which is 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 percent 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. (Figures based on 1972 costs).

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 (subbituminous coal or natural gas), then prereduction of the concentrate followed by conversion in an electric furnace may be the preferred smelting procedure.

Additional research is being 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 known to settlers in the area in the 1920's and 1930's, but were "rediscovered" 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 of 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 10 to 15 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 resources of the Peace River iron deposits. The second summarizes aspects dealing with processing and economic evaluation of the deposits.

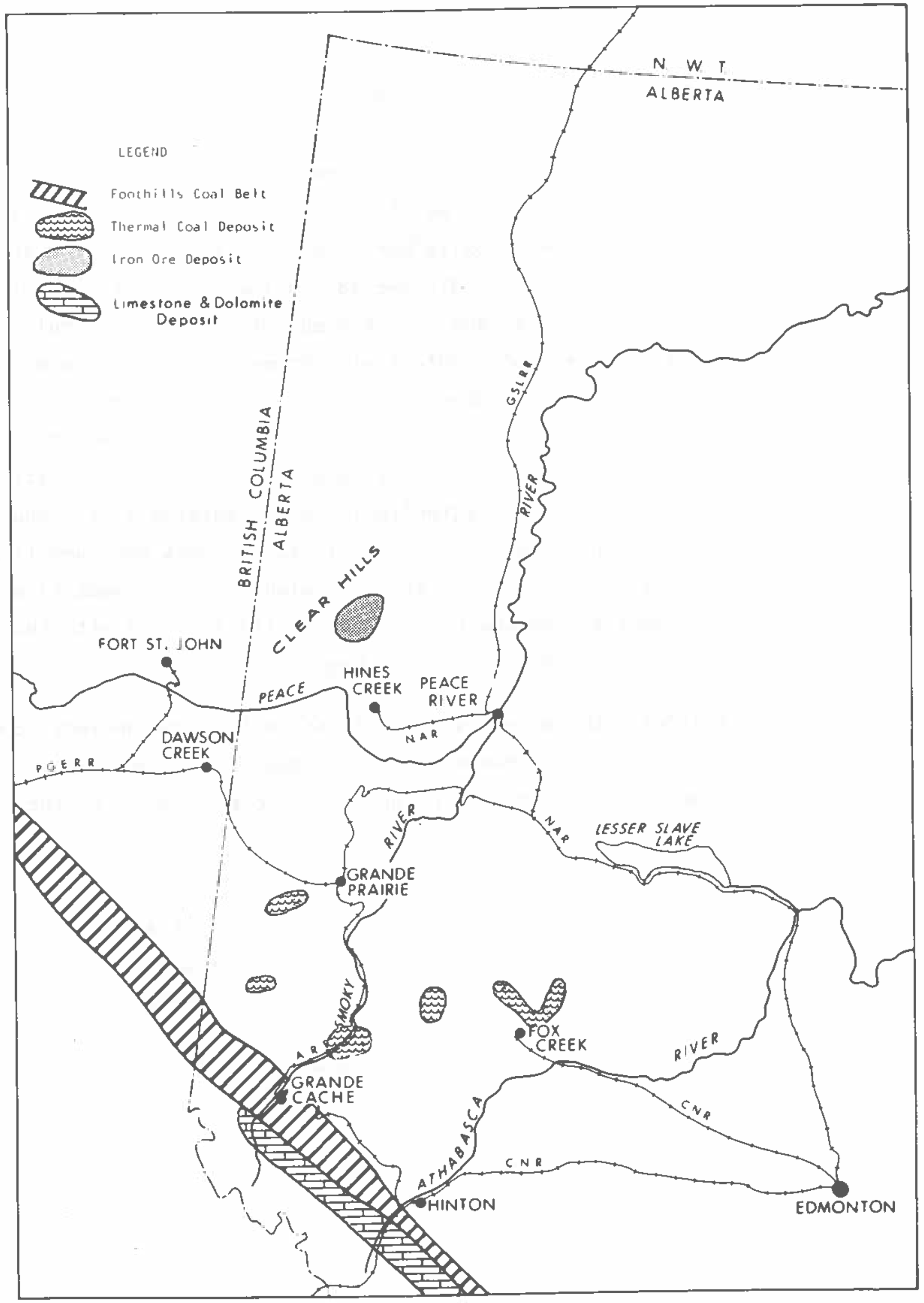

FIGURE 1. Location of Peace River iron deposits and other mineral resources, northwestern Alberta.

PART ONE: GEOLOGY, COMPOSITION, AND RESOURCES

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. These 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, British Columbia.

A small-scale map showing the precise location of assessed areas 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, and attain 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 (Kidd, 1959; Green and Mellon, 1962). 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 bentonite interbeds. The iron bed is intercalated among dark grey marine shales of the Smoky Group which underlie the lower slopes of the hills and the surrounding lowlands (Fig. 3).

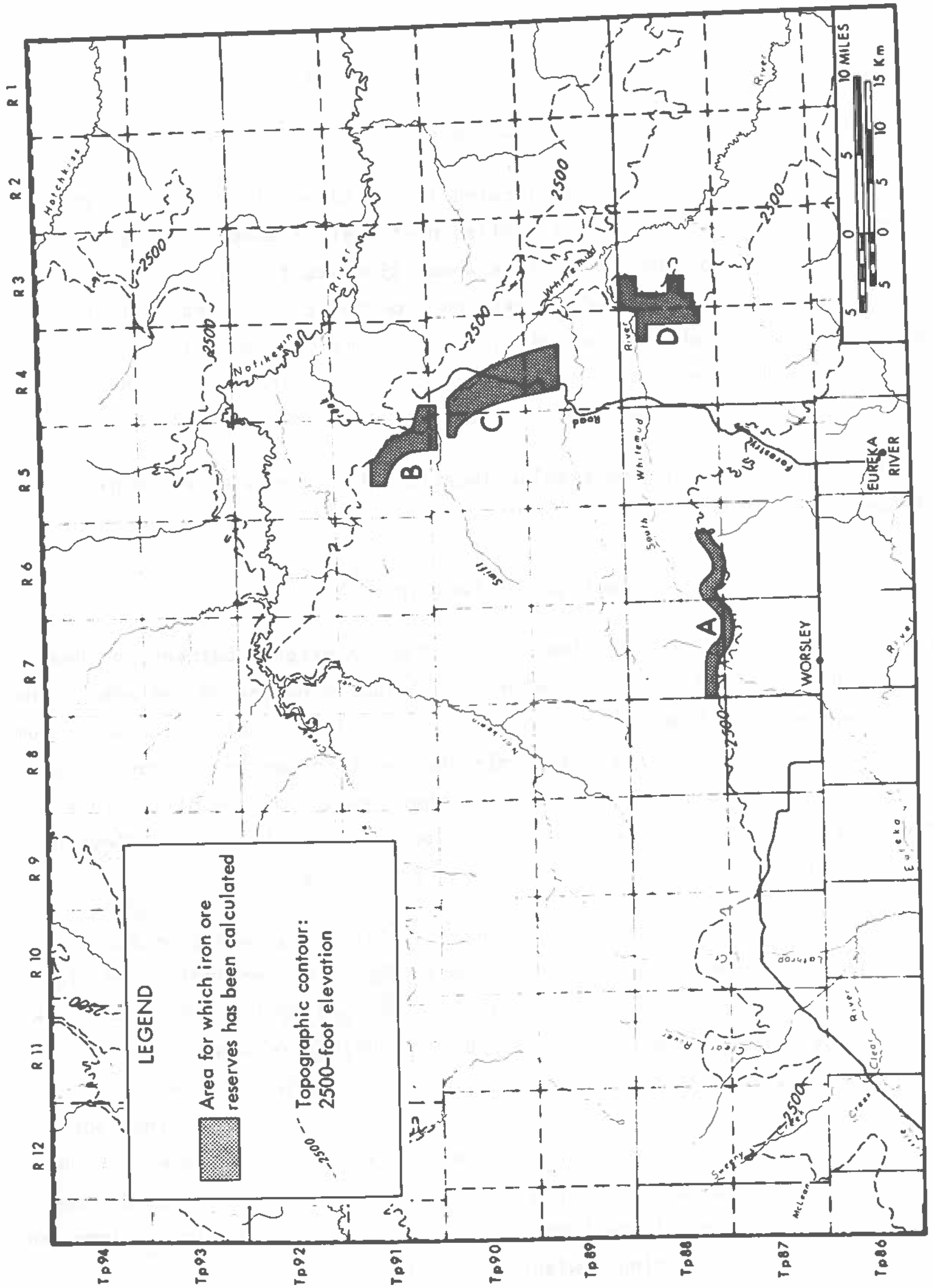

FIGURE 2. Location of assessed iron ore resources, Clear Hills district.

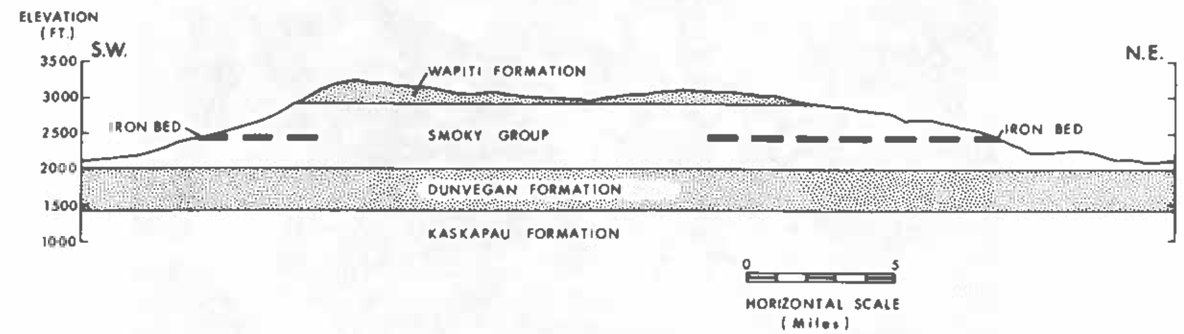

FIGURE 3. Schematic cross section through the Clear Hills showing the stratigraphic position of the oolitic iron formation.

The iron formation consists of dark brown to black oolitic sandstone with thin lenses and interbeds of hard sideritic ($FeCO_3$) "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 up to 30 feet and forms a series of northwest-trending sandstone bodies which are exposed in places along 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 northeast 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 (Green and Mellon, 1962).

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

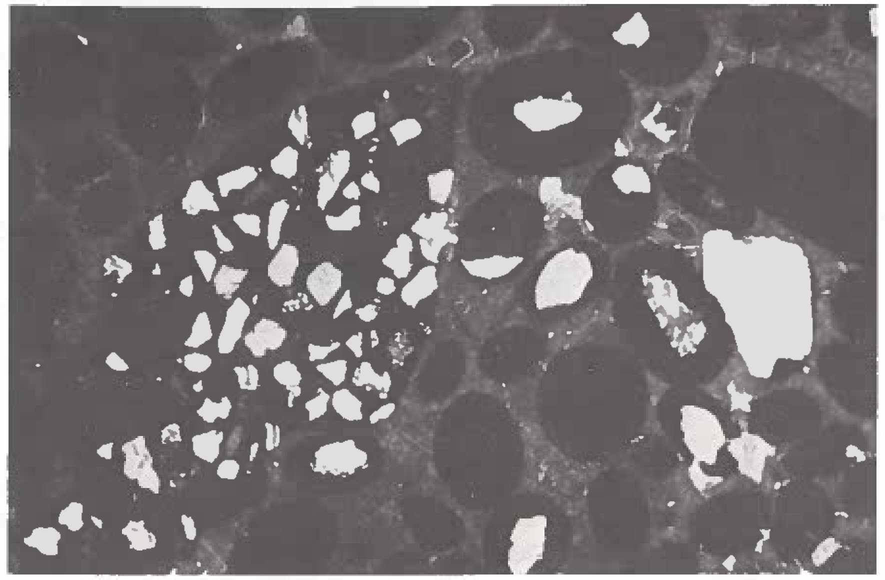

PLATE 1. Peace River iron ore (Swift Creek deposit), transmitted light, magnification approximately 25. Ore consists of dark brown ooliths *and large silty* rock fragments *in a greenish-brown* opaline *(siliceous)* matrix. *Quartz grains (white) are present as nuclei in some of the ooliths and as smaller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

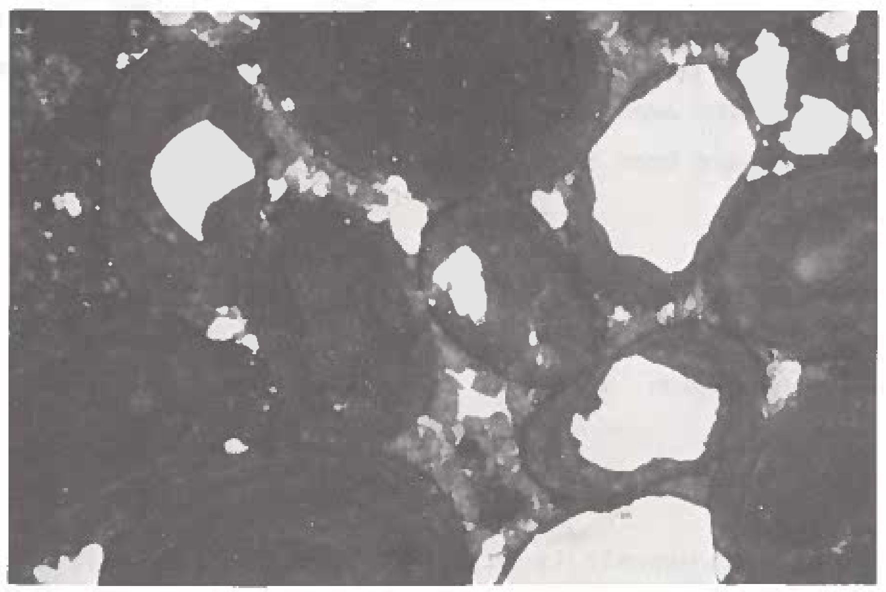

PLATE 2. Peace River iron ore (Swift Creek deposit), reflected light, magnification approximately 50. Ooliths consist of a nucleus (whitish quartz grains or dark brown to black rock fragments) about which concentric layers or shells of goethite *($Fe_2O_3 \cdot H_2O$) and* opal *(hydrous silica) have 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 ooliths.*

(opal), siderite (iron carbonate), and "clay" (Mellon, 1962). 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* ($Fe_2O_3 \cdot H_2O$) and *siderite* ($FeCO_3$); 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 opaline substance which forms part of the intergranular "matrix". This opaline 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:

(1) Total iron (Fe) content averages between 32 and 36 percent. 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 ($Fe_2O_3 \cdot H_2O$) and calcite ($CaCO_3$).

(5) The water content is unusually high due to abundant opaline "cement".

Table 1. Chemical analyses of Peace River iron deposits

Constituent		Deposit		
		Worsley[1]	Swift Creek[2]	Swift Creek-Whitemud River[3]
Iron	Fe	32.65	35.44	32.98
Silica	SiO_2	25.67	26.49	29.26
Alumina	Al_2O_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_2O CO_2	14.36	13.78	11.91

N.A. = not available.

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

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

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

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.

Resources

Estimated resources 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 N. S. Edgar, consulting mining engineer, whose reports subsequently were submitted to the Alberta Energy

and Natural Resources. Copies of the reports are now kept in the industrial Minerals Files, Alberta Research Council (Edgar, 1961, 1962, 1964, 1965).

The distribution of areas for which resources 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 resource estimates varies substantially among the four areas: the resources 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 resource estimates in table 2 are classified as "proven", "probable", and "possible" according to the data available for each area.

The total resources of iron ore inferred to be present in the four blocks are in excess of 1.1 billion tons grading between 32 and 36 percent total iron (Fe). About 227 million tons of this are considered "proven" and underlie blocks A (Worsley) and B (Swift Creek). The remaining 897 million tons are classed as "probable-possible" and underlie blocks C and D. 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.

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				

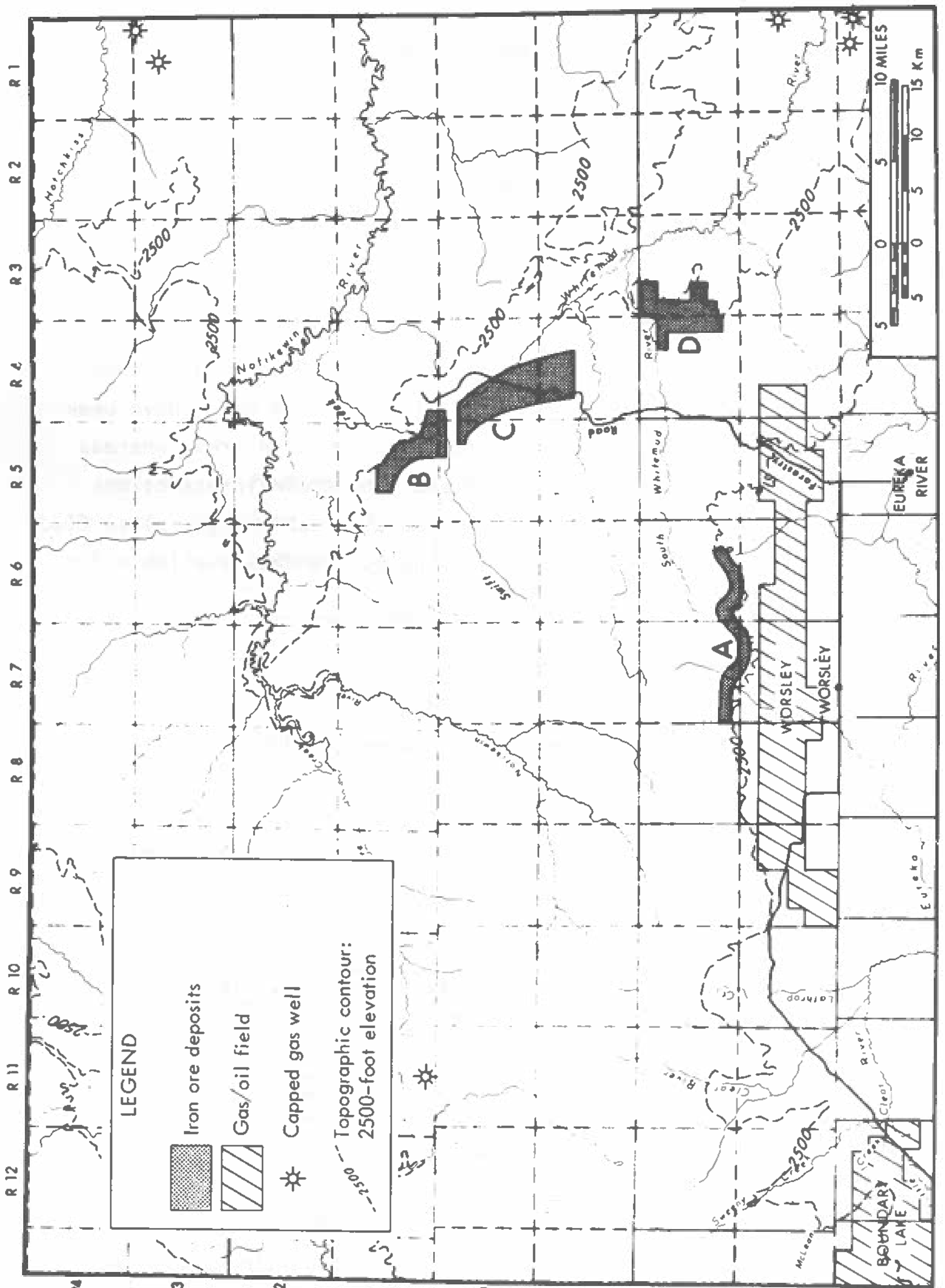

FIGURE 4. Location of iron ore deposits and oil and gas fields, Clear Hills district.

The most accessible resources 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" resources 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 Mines 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 subbituminous 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 are limestone ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$] 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 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 ($CaO{\cdot}MgO$). 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 has been developed for industrial mineral use.

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.

PART TWO: PRELIMINARY REPORT: PROCESSING AND EVALUATION

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 per 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 Beneficiation 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 Samis and Gregory (1962) and the geology of the deposits is described in Green and Mellon (1962).

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 percent iron concentrate (Samis and Gregory, 1962). 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 (Wyman *et al.*, 1962). A fine grind yielded 70 percent iron recovery, and the separation upgraded the ore from 32.6 percent to an average of 40 percent 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 (Funk and Lawver, 1970) and high intensity wet magnetic separation (Lawver and Carpenter, 1965) 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 (Samis and Gregory, 1962). This method was followed to make an iron briquet of 90 percent iron metal which could then be used in electric-arc furnace steelmaking.

Table 3. Composition of product resulting from R-N processing and magnetic separation of Peace River ore

Constituent	Percent
Total iron	90.00
Metallic iron	84.69
SiO_2	3.56
Al_2O_3	2.31
CaO	0.76
P	0.29
S	0.026
C	0.25

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 again put through a series of magnetic separators and finally yielded a product which, on filtration, had the analysis given in table 3. The iron recovery was actually 74.32 percent 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 percent of the initial iron.

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, filter, 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 Btu per ton of iron concentrate. Fifty-three percent of the fuel was from gas sources and 47 percent from coke or nonvolatile coal sources. The commercial projection was for 25.486 million Btu per ton of iron concentrate, with approximately 53 percent from gas and 47 percent 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 per ton in Edmonton, at the 300,000 tons per year production level. The estimated cost of steel ingots via the electric-arc process was $55 per ton. A more recent evaluation of the R-N process at the 1,000,000 tons per year level estimates $27 per 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 Alberta Research Council (Gravenor *et al.*, 1964, Rigg, 1968, Rigg and Rahaman, 1971), 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 opaline 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 percent concentrations, dissolved from 85 to 95 percent of the iron present in the ore, depending on the reduction technique used. The filtration step recovered 85 to 95 percent of the iron as crystalline compounds; therefore, the overall efficiency of recovery of iron would be in the 80 percent range (0.90 x 0.87 x 100% = 78.3%). However, the iron product produced from the chloride salts is in the order of 99 percent 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 (Puddington and Farnand, 1968). 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 siliceous material remains suspended in the water fraction. The concentration of the iron increases from 63 percent Fe_2O_3 in the original ore to 75 percent in the concentrate. The silica concentration decreases from 20 percent in the original ore to 10 percent in the concentrate, whereas the CaO concentration increases from 4 percent in the original to 10 percent 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 Alberta Research Council. 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 material used in these experiments is similar to the weathered (oxidized) ore extracted from the Worsley area for use in the R-N tests.

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 4). 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.

Table 4. Results of reductive roasting of sized fractions of ore

Sample	Percent Iron in Concentrate	Reduction	Percent Iron Recovered	Percent Iron in Concentrate/ Percent 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 percent iron and up to 6 percent 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 (Conners and Butcher, 1971), 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 steel-making 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 whether an adequate separation can be obtained. The reducibility, agglomeration characteristics, and iron-making qualities of the various concentrates should also be tested in order to evaluate totally 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 per day scale (Rogers, 1962, Konig, 1970). In addition, to save on coking and other requirements, the blast furnace should be set up in units of at least two. Thus, an economically sized blast furnace operation could attain production in the order of 1.5 million tons per 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 (United Nations, 1966). 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 (Miller, 1966). Also, if high Btu-value gas (such as coke-oven gas or natural gas) is available for firing the stoves, economies 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 (Konig, 1970, MacManus, 1972).

Direct Reduction Methods

Direct reduction methods now available produce a metal product which is about 90 to 95 percent 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 (Rogers, 1962, United Nations, 1966). 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 (MacKenzie, 1969, Miller, 1970, Lounie, 1971, Litton and Muller, 1971).

The common rotary kiln processes currently in use 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 counter-flow 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 countercurrent flow of hot reducing gases and iron ore occurs in a stack. The ore must be sized and of 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 percent iron and 15 percent 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 steelmaking furnace. Most of the originally designed units have been abandoned, and straight feeding of cold ore and coke to the electric furnace is preferred (B. R. Nijhawan, pers. comm.).

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, British Columbia. The ore used is sinter from pyrite or iron sulfide roasts. The raw ore is about 50 percent 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 reduced 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 (Cuke and Wagner, 1962). 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 have high iron and silica contents. Mud grading from 30 to 60 percent Fe, composed of waste material and slag resulting from the aluminum refining process, is pelletized, preheated, and prereduced 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 (United Nations, 1966). 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% SiO_2, 0.3% P, and 2% CaO,

(C) crude Peace River iron material, 35% Fe, 30% SiO_2, 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 5 gives the relative values of several ores produced in Russia; these may be compared to the selected ores, A, B and C.

Table 5. Relative values of several ores produced in Russia

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 per 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 (1970) 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 to 40 percent 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 percent prereduced, the power load is 1,800 kwh per ton and 1,500 kwh per 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 per ton of metal. These estimates show that large savings in power consumption can be obtained by prereduction of the ore charge (Konig, 1970).

The United States price of ore is determined by the "standard price" method, especially when applied to Lake Superior prices (Strossburger, 1969). 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 or 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 6 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 6. Relative values of A, B, and C ores in different countries

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 6, 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 per ton (unpublished economic survey, 1973), then a medium grade concentrate should be worth between $11.50 and $17 per ton. A 5 percent reduction in the silica content - from 20 percent to 15 percent - would increase the ore value by greater than 10 percent. It has been suggested in a previous section of this report that a concentrate of 60 percent iron and 15 to 20 percent 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 Steel-making

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

(1) selective mining; that is, 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 (Fraser and Mecklin, 1970) has estimated the costs of beneficiating and pelletizing a 45 percent magnetite ore to be $13.80 per M ton and $7.95 per M ton for small- and large-scale operations, respectively. If $2 per M ton is added for a magnetizing roast, the costs become $15.80 per M ton and $9.95 per M ton for pellets grading 67 percent Fe and 64 percent Fe, respectively. These estimates include operating, capital, and overhead costs but do not include capital costs for a magnetizing roast.

Self-fluxing pellets[2] produced from Peace River iron ore (roasted and upgraded to produce a concentrate containing 60 percent Fe) presumably would cost similar amounts except that the Peace River pellets would contain 50 to 55 percent Fe. However, the costs of such pellets ($9.95 per ton to $15.80 per ton) compare favorably to values estimated for medium grade Peace River ore concentrates in the preceding section of the report ($11.50 per ton to $17 per ton).

A number of factors affect the cost of converting iron ore (lump ore or pellets) to iron metal. Two recent estimates (Fraser and Mecklin, 1970, Reed, 1971) suggest that fuel and operating costs required to convert high grade iron ore pellets are in the order of $9 to $10 per net ton. These costs would increase from 20 to 30 percent if a lower grade pellet were used.

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

In addition to operating costs, capital outlay in the order of $24 to $40 per annual ton of iron metal is required. Capital outlay could increase to $50 per annual ton iron metal, if the SL/RN prereduction-electric furnace technique were used.

The Japanese estimate for iron production is $38 per ton hot metal (Lounie, 1971). 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 per annual ton pig iron (6,000 ton per day plant) to $60 per annual ton pig iron (2,000 ton per day plant) (Konig, 1970).

These estimates can be applied to the Peace River iron ore as shown in table 7, if one assumes the ore to be available in the form of a self-fluxing pellet grading 52 percent Fe.

Table 7. Estimate of costs to process Peace River iron ore

Item	Costs/ton of iron: Large-scale plant	Small-scale plant
(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.

Other estimates are available for comparison of costs for various processes of converting iron ore to steel. For example, Cartwright (1971) 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 per ton and at a capacity of about 1.5 million tons per year. The cost per 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 per 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, that is, the material which normally would be mined for beneficiation and smelting.

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Appendix

Peace River Iron Deposits: History

In the 1950s, Alberta was in the grip of oil fever, but for a brief period during that decade, oil was not the only resource in the limelight.

In 1953, petroleum exploration activities in the Clear Hills area of Alberta, about 300 miles northwest of Edmonton, turned up traces of iron ore and news of the find sparked a wave of excitement that has periodically rippled through the province ever since.

It appeared that the interest and enthusiasm which greeted word of the discovery was well-founded, particularly when subsequent drilling, sampling and testing revealed several major deposits in the Peace River area containing millions of tons of low-grade iron ore.

For a province forced to rely on scrap iron to feed its modest steel industry, the prospect of a vast source of raw material within its borders was enough to produce heady visions of massive mining and smelting operations and speculation that a significant integrated steel industry could eventually emerge in Alberta.

Perhaps nowhere was the news more favourably received than in northwestern Alberta communities such as Peace River, Hines Creek and Fairview -- centers that stood to profit from any major iron mining and processing developments in the area. But to some residents of Fairview, it came as no surprise to hear that vast deposits of iron ore lay beneath the tree-covered slopes of the Clear Hills and along the banks of the winding creeks that emptied into the Peace River. They had been part of a similar discovery some 30 years earlier.

The early discoverers were Cliff Chalmers, a farmer from the Waterhole District, about 10 miles south of Fairview; Rod Redfern, a pioneer horse rancher in the Hines Creek area; and John Lundstrom (better known as John the Swede), a trapper who also homesteaded near Eureka River.

Like others in this remote area (often there were only two or three people to a township), the three turned their hand to a variety of jobs in order to make a living. In addition to farming, Chalmers worked in his father's sawmill, trapped and prospected. The same applied to Redfern and Lundstrom, both of whom combined the more prosaic life of ranching and farming with the adventure of trapping and prospecting.

Like the drilling crews of the '50s, they too had come across the iron deposits. Although their discovery created little or no excitement beyond their circle of family and friends, there is little doubt the three were responsible for first attempts to identify the Peace River iron ore deposits.

In 1924, while returning from a spring trap for beaver along the Chinchaga River, the men discovered an outcropping of the iron-bearing material near the Notikewin River, then known as the Third Battle, about 55 miles west of the town of Manning. The iron ore, covered by thick overburden in most places, was exposed at that spot as a dark green rusty outcropping on a cliffside above Swift Creek. The men later described it as "a mountain of iron."

Excited by their find, the men carefully noted the location of their discovery, gathered samples and resolved to return the following year to stake claims.

Upon returning home, they sent samples of the rock to Edmonton to be assayed. Official records of the assay have long since disappeared (likely lost in the transfer of mining records from federal to provincial jurisdiction in the early '30s), but the Chalmers family remembers that the eagerly awaited report showed that the material contained 32 percent iron.

Rod Chalmers, Cliff's older son and still a resident of Fairview explains: "When they first brought out those samples, maybe they weren't quite sure what they had -- but they knew they had something."

Whatever hopes they had for their find, the men spent the winter planning the next year's expedition. On July 10, 1925, Chalmers and his 22-year-old wife, Redfern and his wife, and John the Swede began the trek north to the Notikewin from Hines Creek.

PLATE 3. Cliff and Bea Chalmers and Rod Redfern on their way to stake claims, July 1925.

PLATE 4. Mrs. Chalmers and Mrs. Redfern relaxing in camp.

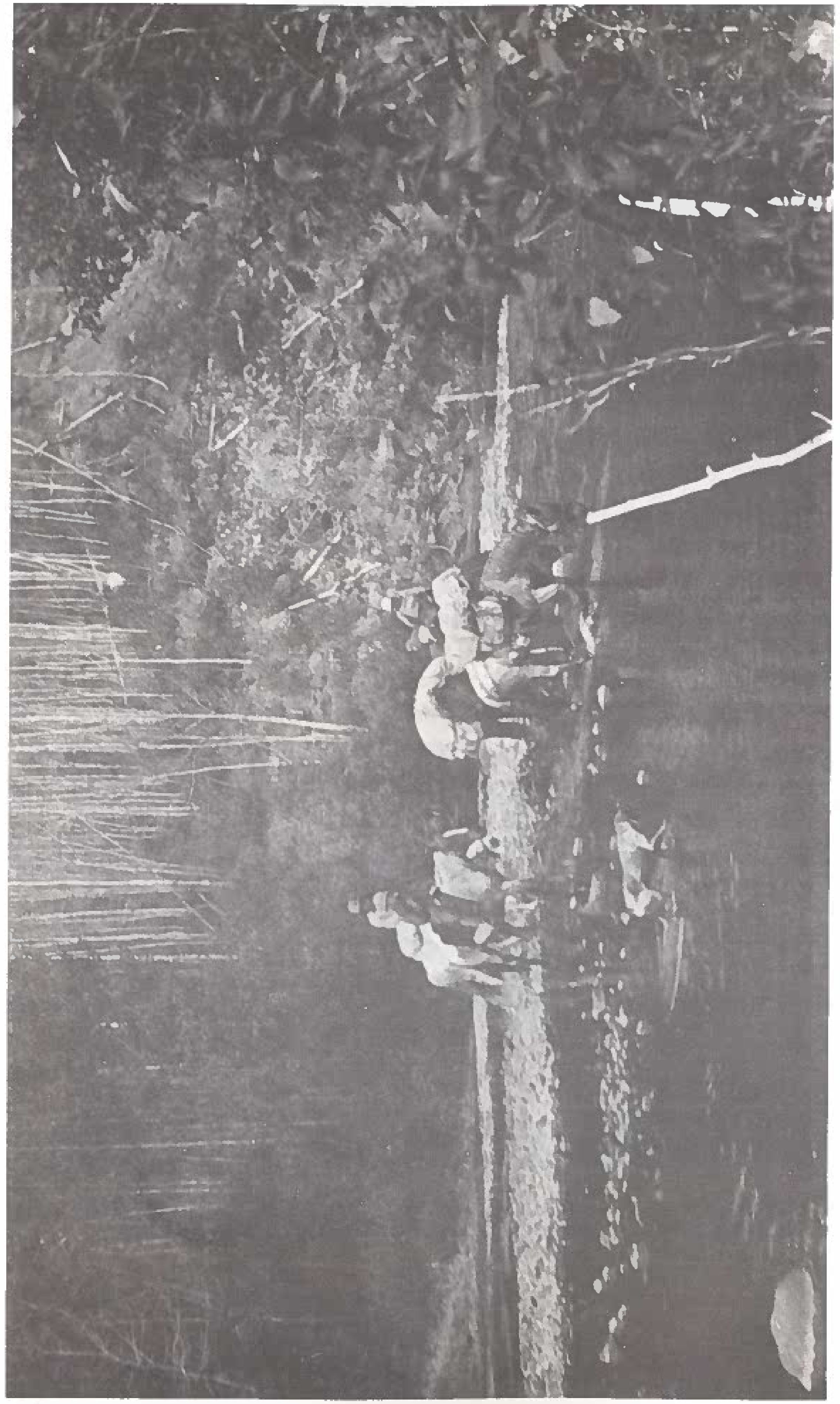

PLATE 5. *The pack train returning from the deposit, 1925.*

As well as five riding horses, the tiny procession included 15 packhorses loaded with supplies for their own expedition and for Lundstrom's traplines. Bringing up the rear was Peggy, a small spotted dog belonging to Mrs. Redfern.

Bea Chalmers, the only member of the group still living, recalls that they were away from home for about 60 days -- a period in which they saw no one but the members of their own party. Despite the fact that they had to cover miles of burnt-over muskeg, follow narrow trappers' trails through heavy bush, negotiate a variety of streams, rivers and hills, and put up with the constant onslaughts of hungry mosquitoes, she recalls the trip as primarily a pleasant experience.

She explains that she and Mrs. Redfern were simply "along for the ride".

"We didn't make a meal or wash a dish. John the Swede made breakfast, Rod wrangled the horses and Cliff helped with the packing and made the supper."

She admits that, before the trip, friends warned her that she would likely regret her decision to go along. "Once or twice I wanted to get away by myself and have a cry. The worst part was the heat. But then I'd get over it. I remember we had a lot of laughs. I wouldn't want to go through it again, but when you're young, that sort of thing can be fun."

Once at the deposit, the women fished or read and played cards at camp while the men were busy staking their claims. John the Swede went on to cache his supplies along his trapline.

The men were careful to stake their claims according to regulations, Bea recalls. Pine posts were squared and pointed, then set in rock at the prescribed intervals.

"Great thought went into the choice of names for the claim markers," she says. "I chose 'Elk Horn' for the name of the town in Wisconsin where I was born. Mrs. Redfern chose 'Onyx' meaning 'unexpected'." No record was kept of the names chosen by the men but Bob Bieraugle, a farmer at Notikewin who trapped in the Swift Creek area during the '20s, recalls seeing the stakes in 1926, one of which bore the name "Coyote".

Bea remembers that one of the few frightening moments of the trip came the day the group broke camp and started for home. The women made one last tour of the claim to check the markers, then decided to ride on ahead. "It was pouring rain and somehow we must have made a wrong turn. We were heading north and away from home. By late afternoon we were just beginning to realize we were lost when we heard a 'clip clop' behind us and Rod Redfern appeared, demanding to know where we thought we were going."

Hungry and soaked through, the women made their way back to camp. After a hot supper and a good night's sleep, they were ready to take to the trail again, this time heading the right direction and staying close to the rest of the party.

Once home, the men sent more samples to Edmonton and the report again showed the material to be low-grade iron ore which tested about 30 to 35 percent.

The men sought no publicity but they were happy to show samples to anyone who showed an interest. One of these was Gib Oliver, a pioneer resident of the area and principal of Fairview School at that time.

Now retired and living in Fairview, Mr. Oliver recalls the men putting a blowtorch to the samples to show the existence of iron. "You could see the iron run like water when they did that."

Despite their knowledge that they had probably stumbled on a significant find, the three men decided to do nothing further for the moment. The remoteness of the region, the lack of transportation (the railroad didn't reach Hines Creek until 1930), a lack of strong demand at the time for new sources of iron ore and perhaps most of all, a shortage of money, meant there was little hope of them doing anything in the way of development or promotion themselves.

There were no newspapers in the area at that time to report the discovery and few people even knew about the men's "mountain of iron". But occasionally the samples would be brought out and examined and plans made for the day when the claims would be registered and the men would be part of an exciting new resource development in the province.

But that day became more remote as the men became involved in other pursuits and no move was made to register the claims for almost three decades.

Eventually Rod Redfern and his wife left the area. He worked as a brand reader in Calgary; then they moved to Saskatchewan, where Mrs. Redfern died. Redfern continued to be interested in the iron ore, however. In 1939, he wrote from Moose Jaw to Alberta's Minister of Mines to inquire about the analysis of samples shipped to Edmonton by Chalmers about 1925. Although the department queried the provincial analyst on the matter, no reply was kept on file and it appears the matter was dropped. In his letter to the provincial analyst, the Deputy Minister of Mines asked for a copy of the analysis, adding: "it would mean a great deal to the Province if an iron deposit were to be discovered in Alberta."

It's not known if Redfern ever received a reply to his letter. He returned to Alberta and took up residence at Longview. According to the Chalmers family, it's unlikely that he ever lost his prospector's interest in the iron ore "find", but he died before events of the '50s focussed attention on the resource.

In the late '20s, Cliff and Bea Chalmers, along with other residents of Waterhole, moved north to form a new settlement at Fairview, on the route of the Northern Alberta Railway. Cliff farmed there until his death in 1970 and his wife continues to live there. The couple had three children -- Rod and Jack who both farm at Fairview, and Glee, a daughter who is married and lives at Crystal Springs, Alberta.

John Lundstrom worked on his homestead at Eureka River -- but his first love remained trapping and he was considered one of the most successful trappers in the area. Jack Chalmers recalls making visits to several of John the Swede's "spotless" cabins strung along his traplines north of Eureka River. Lundstrom died in 1958.

Iron ore was probably the last thing on the mind of drilling crews working for Phillips Petroleum Company in the Swift Creek area in 1953; but traces of "oolitic hematite" were noted in Phil C No. 1 well that year, and

Albertans were soon to learn of the potential mineral wealth of the Swift Creek deposits.

About the same time, outcroppings of rusty material on the southern side of the Clear Hills were seen by Jack Guthrie of General Geophysical Company, who was working in an area about five miles north of the village of Worsley.

Men who understood the possible significance of the finds began to take an interest. One of these, D. B. McDougall, who was associated with a Calgary exploration company, began drilling test holes in the Clear Hills and Swift Creek areas. Two reports compiled by McDougall in 1954 and 1956 attracted the attention of the Research Council of Alberta and Premier Steel Mills Limited, an Edmonton steel manufacturing concern.

When these discoveries were reported in the press, some of Chalmers' friends began to encourage him to revisit the site of the 1924 discovery. Two men who showed particular interest in relocating the deposit were George Olstad, a garage operator and farmer from Hines Creek and his son-in-law Fred Lambert, who worked with Olstad in the garage. A number of geophysical crews were stationed at Hines Creek and the oilmen's speculation about the significance of the recent iron ore finds fanned the two men's interest in the discovery made by their friends some 30 years earlier.

"There was a real flurry of excitement," recalls Bea Chalmers. "The men thought there was a chance they might still get on the bandwagon somehow, at least get some credit for having been first to note the deposit and have samples analyzed."

Between 1953 and 1955 at least five trips into the Swift Creek area were organized by Chalmers and his friends. In all, about a dozen men were involved, including Chalmers and his two sons, Lundstrom, Olstad and Lambert, plus a handful of prospectors and trappers familiar with the narrow trails crisscrossing the Clear Hills area.

One of these was Emil Ducharme, a trapper from Eureka River. Now retired and living in Fairview, Ducharme was one of the first to try to reach the

deposit in the '50s. Travelling on horseback, he was accompanied by Harris Davis, a prospector from Hines Creek -- a man always intrigued by word of a "strike". Although the two were apparently unsuccessful in locating the iron deposit, Harris was later involved in trying to help Chalmers find financial backing for development. Later still, he was to find his own fortune in the form of a rich copper deposit in northwestern B.C. Now the owner of Davis Keeys Mine, Harris spends much of his time in Fort Nelson.

Lambert, now a parks official in the Yukon, was involved in four of the trips. He recalls attempts to relocate the site were made by parties on foot, on horseback, on snowshoes and with the help of snow vehicles. The various expeditions approached the site from different directions -- some travelling north from Eureka River and others heading west from the Mackenzie Highway. The aim was to make a definite location of the site, restake the claim and bring out samples.

Conrad Rudd, a farmer and trapper now retired to his cabin north of Worsley, was a member of a party which was successful in reaching the site, probably in 1954. "Lambert, Chalmers and I drove to Hotchkiss, north of Manning, in the truck, then we rode west on horseback for two days to reach the spot," he says. "I saw the old stakes all rotted down -- squared old jackpines that had been used to stake claims." According to Rudd, about 15 pounds of ore were brought out and sent to Edmonton. He claims the samples graded about 37 percent iron.

Jack Chalmers recalls accompanying his father to the site in 1954. Also on this expedition were Lambert and Jack Cheshire, a trapper from Eureka River. For the young Chalmers, then 20, the trip was "a real adventure". The party hired a bombardier at Manning and headed almost straight west toward "the iron ore mountain". When the snow got too deep for the machine, they took to snowshoes. The men reached the Third Battle (Notikewin), followed the river for a short distance, then turned south and west.

"We had to snowshoe for 25 miles or so. I had never been on snowshoes before and I spent quite a bit of the time flat on my face."

He recalls that during the trip he was regaled by Cheshire with colorful stories of life on the traplines. "Everyone knew him as Oregon Jack," comments Chalmers, adding that he was well-known throughout the area for his southern drawl and the fact that, at one point, he tended his traplines with an "all-wolf" dog team. Cheshire, who spent his last years at Berwyn, died there about 1973.

The group eventually found the packtrail which had lead Chalmers and his friends to their original discovery and soon the men were standing on the site of the early claim.

The men restaked the claim and cut a boundary around the area of the deposit to serve as a guideline. Jack recalls that since the ore was exposed on the surface of the ground, it was not difficult to gather samples with the aid of dynamite.

Back in Manning, the group was met by Olstad and Harris Davis. Lambert joined them with the samples and the men set out immediately for Edmonton. Encouraged by the assay report, the three began to look for a backer. They were soon joined by Chalmers and his sons and the party spent several weeks in the city, contacting mining officials and steel company representatives in an attempt to interest them in financing development.

Before leaving home the men involved had signed a paper saying they would share any benefits that might come of their discovery. As it turned out, there was nothing to share. Prospecting and mining regulations had changed in the 30 years since the area was first staked and the men soon learned they had no legal claim to the deposit.

Says Rod: "We all went down to the place where you register claims. But we found it was too late. We learned it would have cost thousands of dollars to have registered the claim and to have done the required amount of work each year. You had to put up a bond and do a certain amount of diamond drilling each year or the bond would be forfeited. It seemed it would have cost something in the neighborhood of $130,000. None of us had 130 thousand cents, let alone that amount."

The men didn't give up, however. There was still a remote chance a mining company might be persuaded to finance further work on the claims, and perhaps even put up the money for a full scale development of the ore. By this time, Chalmers, a diabetic, was in failing health, and it was Lambert and Olstad who continued to try to generate some interest in the deposit. In 1955 Lambert guided a geologist from Premier Steel to the site, but by this time it was apparent the discoverers of the iron were not likely to benefit from its development.

In 1956 the Research Council of Alberta assigned Dr. Donald Kidd, a geologist, to study the iron ore deposits of the Clear Hills and Swift Creek areas. He spent two summers in the area and later reported that the deposit north of Worsley along the southern slopes of the Clear Hills contained well over 25 million tons of ore while the Swift Creek deposit contained more than 200 million tons.

Dr. Robert Green of the Research Council accompanied Kidd on a trip to the Swift Creek deposit. He notes that in their contacts with several area residents, no mention of the earlier find was made and it was believed by Research Council personnel that the discoveries made by the seismic crews in the '50s were the first in the area.

Although pioneer residents claim they were always vaguely aware of the presence of iron in the rocky outcropping and had noticed the rusty color of water in the bogs and muskeg patches, no one appears to have realized either the extent or the significance of the deposits until the late '50s.

One oldtimer comments: "We always knew there was iron there but we just didn't get very excited about it."

Further studies of the iron ore were undertaken by Premier Steel Mills Limited. Overburden was stripped from the Worsley deposit and in 1957 Premier Steel took a 50-ton sample out of the pit. Kidd was believed to have brought the first large sample out of the Swift Creek deposit in 1956 -- a 120-pound load which was carried out by packhorses.

Interest was high in finding an economic means of upgrading the ore which was found to be complex in makeup. Premier Steel, in co-operation with the Alberta Research Council, sponsored a pilot-plant test at the R-N Corporation in Birmingham, Alabama. About 5,000 tons of ore, shipped from the Clear Hills deposit, were treated at Birmingham and briquets containing 90 percent iron were produced with 83 percent recovery. The briquets were found suitable for electric furnaces.

At the same time, the Research Council initiated a program to produce iron powder by chemical methods. The powders that resulted were of high purity -- 99 percent iron -- and hopes were raised that with low-cost ore and low-cost fuel available in Alberta, iron powders could be produced that would compare in cost with those of conventional iron-making processes.

When Premier Steel was bought out by Stelco during the '60s, Premier's president, G. R. Heffernan, continued to be associated with the company's successor -- Peace River Mining and Smelting Ltd. The new firm continued its interest in the iron ore deposits and proved up reserves in the Peace River area. The company also took part in a joint venture with the Research Council for developing a process to produce iron powder. Obvious applications included stamping out brake drums, clutch pedals and other auto parts. The company set up a pilot plant at the Alberta Research Council facilities at Clover Bar and began what it hoped would be a successful business venture.

However, the advantage of cheaper natural gas was not enough to offset the cost of shipping products east and the firm soon moved its operations to Windsor to be closer to the Detroit auto manufacturers, relying on scrap for feedstock. Once again, interest in developing the local iron ore began to fade. When a number of firms began to produce processes for iron powder using other sources of iron ore, market prices dropped and Peace River Mining and Smelting was forced into receivership.

Although Research Council personnel at Clover Bar intermittently continued the search for a means to economically beneficiate the ore, little was heard about large-scale development of the deposits for a number of years.

Then came the '70s -- and worldwide shortages of steel. Once more attention focussed on the desirability of a western Canadian steel industry fed by iron ore from the province's healthy deposits. In addition to the Peace River ore, deposits were known to exist in the Crowsnest area. According to R. Green of the Alberta Research Council, the Peace River iron offered the more attractive alternative because ore from the Crowsnest area lay in deposits which were unpredictable, faulted and potentially difficult to develop.

In 1973, Fred Peacock, then Minister of Industry and Commerce, announced that development of the Peace River iron ore deposits was now considered economically viable. He promised that the province would have "either a sponge (pig) iron or steel plant within the next five years."

Renewed interest in the iron, he said, was the result of continuously increasing demand for steel and a U.S. embargo on scrap metal. He noted that a Japanese firm was interested in establishing a steel plant in Alberta with a capacity of 350,000 to 400,000 tons a year and the Peace River deposits represented the logical feedstock.

A brief item in the Edmonton Journal, noting Peacock's announcement, stated that the iron ore had been discovered two decades earlier by seismic crews working in the area. That comment brought an immediate response from Fairview's Gib Oliver. Then he was 88 but alert and in good health. He vividly recalled events surrounding the earlier find -- and wasted no time in giving the government the details. Gib pointed out that he, personally, had seen samples of iron ore from the Swift Creek area some three decades earlier.

"I felt that the men who made the discovery back in the '20s should at least receive some credit for their part in this."

A two-year federal-provincial study by the Alberta Research Council and Canmet in Ottawa is currently under way to determine the economic feasibility of developing the deposits. If a decision is reached to proceed with development, the implications for residents of the area will have to be determined.

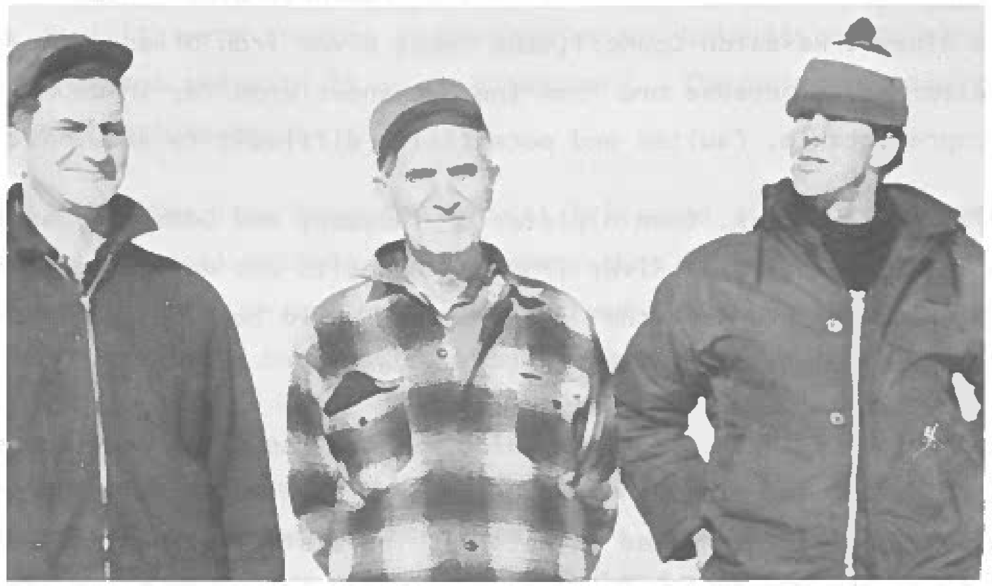

PLATE 7. Cliff Chalmers and sons, Rod and Jack, 1963.

PLATE 6. Bea Chalmers, 1975. *PLATE 8. John the Swede Lundstrom, 1958.*

There is a possibility that a processing plant could be located in the Peace country; ore of the Swift Creek deposit would be most easily accessible from the east, by a rail spur from the Slave Lake Railway.

However, answers to the questions surrounding the possible development of this abundant and long undisturbed resource will have to await the outcome of the current study and others that will likely follow.

Meanwhile, in the Fairview area, a small group of people associated with the original discovery watches with more than casual interest as the story of Alberta's iron ore unfolds.

For Chalmers, Redfern and Lundstrom, their discovery brought nothing in the way of fame or riches -- but perhaps it should ensure them a place in Alberta's history.

Bea Chalmers sums it up this way: "I think some day there will be a big development. I feel Cliff and the others should have some recognition -- but I certainly don't feel bitter that I won't get rich over it. The years passed so quickly. We were all keyed up again in the '50s, but by then it was too late. We'd just like our grandchildren to know about it."