The Metallic and Industrial Minerals of Alberta
Mineral Commodity Profile
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DIMENSION STONE

by

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DIMENSION STONE

INTRODUCTION

Background

Local stone has been used in Alberta for various building and ornamental purposes since the turn of the century. For construction of the Legislature Building and other government buildings, the native Paskapoo sandstone was widely utilized. The local dimension stone industry has since declined and is currently very small. It remains important, however, because of current high interest in the preservation and restoration of historically valuable buildings.

Although the construction industry relies largely on imported stone for new structures, interest in the local materials is evidenced by the number of crown dispositions held for this commodity. The resource is highly varied in character and widespread in distribution. Opportunities for increased usage of Alberta rock as a dimension stone are examined in this report.

Definition of terms, grades, specifications, tests

The term "stone" is applied commercially to all natural rock materials which are quarried or mined for either constructional or industrial uses. In the commodity sense, stone forms two major classes: dimension stone, and crushed (or broken) stone. Dimension stone is trimmed or cut to specified or indicated shapes and sizes, with or without mechanically dressed surfaces.

Scientific and industrial definitions of terms may come into conflict. Industrially, the term "marble" is applied to a wide range of sedimentary and metamorphic stone "capable of taking a polish". To cover the wide commercial usage of the term, the definition of "any calcareous rock capable of taking a polish" has generally been accepted. Igneous rock terminology also suffers abuses. Some of the best-known commercial "granites" are really gabbros, norites or diorites. Dimension stone must meet accepted technical (engineering) standards,but its value depends equally on color, uniformity of texture and the capability of taking a polish. The background color should be fairly uniform. Even-grained textures take the best polish. A contrast in hardness of mineral constituents results in plucking and patchy polishing. Ornamental effect is imparted mainly by textural and structural features such as: sedimentary bedding, metamorphic mineral layering and foliation including ghost stratigraphy, mottling, veins, nodules, fossils, stylolites, mineral blebs, blotches, patches, wisps, etc.

Weathering qualities are of prime importance in selecting a stone. Color, strength, and finish are of little consequence if the stone cannot stand up to minimum wear and tear, whether induced by nature or by man. Weathering does not necessarily denote undesirable changes - it may even enhance some qualities. The term "decay" is used to describe the undesirable effects of weathering. Water is the main agent of natural weathering in the decay of stone, whereas lichens are much less damaging.

Modern practice in the stone industry requires certain laboratory tests for some essential properties which have been agreed upon by suppliers, users, and regulatory authorities. As yet, there is no universally accepted standard testing method. Reputation by usage and performance is no less important than laboratory tests.

Physical tests routinely reported include: thermal expansion tests (flooring over heating systems), toughness or tenacity (floors, curbing or steps), specific gravity, absorption as a quantitative indication of permeability, and rock compressibility.

There is no generally accepted quantitative test or measure of durability. This property depends upon a number of factors including the mode and place of use. Marble, highly satisfactory for use indoors, may be susceptible to weathering by rain (solution), frost, an acidic atmosphere, or the abrasive action of windborne dust and sand. Proper installation may also be a factor in some cases. For example, thin-bedded soft sandstones (e.g. Paskapoo sandstone) are fairly durable if laid with bedding planes horizontal, but may spall and corrode badly if laid vertically. The behaviour of a stone, both in nature and in existing structures or monuments, remains the best guide to durability and actual performance over a number of years.

INDUSTRY SETTING

Size and maturity of the industry, Canada and Alberta

Granite and marble are the principal types of dimension stone produced in Canada. There are at least 30 granite quarry and dressing plants, with activity centred in Quebec and Ontario. Recent establishment of new dressing plants, and the overwhelming value of imported products suggest an immature state of the dimension stone industry in Canada.

Opportunities exist in Canada to compete with the imported granite and marble stones. Not only could Canadian granites and marbles compete directly with the corresponding imported materials, but the well established Canadian granite and limestone industries should compete with the imported marbles.

Historical development

The early European settlers in Alberta sought suitable structural stone for buildings which focusses on sedimentary rocks of the western plains (Parks, 1916; Allan, 1920; Goudge, 1933) and all classes of rocks in the Western Cordillera. Tertiary Paskapoo sandstone became the dominant local building stone and numerous quarries provided stone for many of the major government and commercial structures.

Improved transportation, particularly by the introduction of railways, allowed the better stones to be moved across Canada. Consequently, the Tyndall Limestone from central Manitoba is very prominent in major structures built in Alberta during the past 60 years.

In recent years there has been a conscious effort to preserve the heritage of Alberta, and especially as represented by its early major stone buildings. Preservation and restoration of buildings are emphasised in the Historical Resources Act (January 31, 1985) and 192 Designated Historical Resources sites have been identified in Alberta (Alberta Culture, 1985).

The Paskapoo sandstone has not entirely withstood the rigorous weather conditions of the western plains and a great deal of effort is now required to restore and maintain these historic structures. The search is on for quarries and new sources capable of producing matching stones, as it is no longer feasible to reactivate many of the original quarries. If suitable new sources of Paskapoo sandstone are developed, perhaps there will be sufficient encouragement for new structures to be contemplated in addition to the present restoration activity.

Uses, trends and markets of stone

The recent trend is to revert to stone for interior and exterior building facing wherever economically feasible (Mattar, et al., 1985). In the past 20 years there has been a tendency to use undressed or rustic stone. However, new dressed stone-clad buildings continue to be built. Several factors have contributed to the revival of interest. Reduced maintenance and improvements in quarry block extraction, processing, and overlay insulation and protection techniques, all tend to encourage the use of stone.

The architect designing stonework is no longer confined to the softer stones which were in vogue at the turn of the century. Modern cutting techniques combined with advanced fixing methods permit almost any architectural design (Campbell, 1986).

Architects play a major role in decisions on the use of stone in buildings. Many are attracted by the color, quality and finish of dressed granite, as well as new economical application techniques. Canadian granite is competitive with sheet, glass, concrete and other facing materials, both domestically and abroad. Demand should continue to increase as the construction industry becomes more aware of the quality and variety of Canadian stones available.

The main uses of stone include: structural (building construction, jetties, retention walls, fences, sea walls, road and river embankments - i.e. - Paleozoic limestone, Cretaceous sandstone or glacial erratics as rip rap along Alberta's rivers); ornamental (cladding, curtain walling, panels or wall facing - i.e. glacial boulders (granite, gneiss or Athabasca sandstone) and Triassic siltstone (Rundlestone) for interior and exterior walls and buildings especially in Banff or Waterton and Lower Cambrian white and pink quartzite blocks for building construction in Jasper); monumental (carved or sculptured stone); flooring (exterior flagging, paving, blocks and cobbles - i.e. Rundlestone at the Provincial Museum in Edmonton); roofing; curbs and sidewalk slabs.

The various types of stone commonly in use are listed in table 1, showing the status of Alberta as a source of these stones.

Production and consumption in Canada

In 1982, shipments of all granite from Canadian quarries were 6.3 million tonnes, with a value of $49.8 Million ($57.1 million in 1983). Of this, dimensional stone accounted for 70 thousand tonnes, with a value of $7 million. Most Canadian granite was shipped from Quebec ($20.4 million) and Ontario ($17.8 million).

DRIE statistics (Canada, 1985, 1986) show that granite and marble imports (shaped, dressed and rough) amounted to $20.7 million, and other dimension stone import classes (table 2) amounted to $8.2 million for a total of $28.9 million in 1984.

Table 1. Commonly Used Commercial Stones and the Status of Alberta Sources.

Commercial Dimension Stones	Alberta Status
Marble	
Recrystallized limestone/dolostone	X
Onyx	X
Travertine	P
Serpentine	X
Limestone	P
Dolomite (dolostone)	P
Sandstone*	+
Quartzite	+
Granite*	
Granite	P
Syenite	P
Diorite	P
Labradorite	P
Gabbro	X
Tuff	X
Basalt	P
Diabase	X
Gneiss	P
Slate	X

No Alberta source X

Possible Alberta source P

Production in Alberta +

* Found as glacial boulders and used as fieldstone

Table 2. Canadian Stone Imports for 1984 and 1985 (Department of Regional Industrial Expansion)

CITC No.	1984 metric tonnes	1984 $x(000)	1985 metric tonnes	1985 $x(000)
47149-10 Natural stone basic products		7,017		9,996
27649-20 Sandstone, building rough	4,025	768	4,842	836
27649-30 Limestone, building rough	1,523	163	2,367	233
27649-90 Building stone rough (N.E.S.)	1,921	272	2,539	309

Dollars are Canadian and do not include import duty.
N.E.S. - not elsewhere specified.

Production and consumption in Alberta

Dimension stone production in Alberta is carried out on a very limited scale today. The primary sources of local stone in active production are:

1. "Rundlestone" (Triassic siltstone) from the Canmore region;
2. Quartzite (Lower Cambrian); blocks are recovered from the avalanche at Poboktan-Jonas Creeks, Jasper National Park; and
3. Fieldstone (Pleistocene); glacial boulders in till are recovered from fields and gravel pits.

Major commercial buildings continue to be faced with Tyndall Limestone (Manitoba) and imported marble, although foreign granites are gaining favor. The traditional use of granites (from eastern Canada and offshore) for ornamental and monument purposes remains unchanged.

The value of building stone produced in Alberta during 1984 amounted to about $50,000. Data are not available for the consumption of dimension stone in Alberta.

GEOLOGY AND RESOURCES

Geologic setting

The simplified bedrock map of Alberta (figure 1) shows that the province has a good representation of rock types of the geologic column. Sedimentary rocks dominate the geology of Alberta. Subordinate amounts of low-grade metasediments crop out in the mountain belt, and plutonic igneous-metamorphic complexes characterize the small area of Precambrian Shield exposed in northeastern Alberta.

Rocks suitable for dimension stone are found in a number of geologic systems in Alberta (table 3). Exploration for building stone materials in Alberta was particularly active in the early part of this century and various geological aspects have been well summarized by Parks (1916), Allan (1920) and Goudge (1933).

Exploration, development and distribution of deposits

The only area of Alberta where granites and gneisses are abundant is the remote northest corner. Geological mapping and building stone exploration by the Alberta Research Council (Godfrey, 1979) and more recently Alberta Native Affairs, have shown the Chipewyan Red Granite to be a high quality stone, with prospects for another 10 to 15 other distinctive granite stone types in the region.

Field stone boulders, collected from the plains Laurentide glacial deposits, feature plutonic igneous-metamorphic lithologies derived from the Shield area, plus a dominant proportion of Athabasca sandstone in pink to mauve shades. Outcrops of the Athabasca sandstone are scarce but the subcrop of the Athabasca Group in northeastern Alberta is substantial (Wilson, 1985). Any improvement of surface transporation in this region, which relies on barge and winter roads for movement of large freight volumes, could make this prospective area more attractive.

Table 3 emphasises the sedimentary formations which hold some potential

Figure 1. Bedrock geology of Alberta

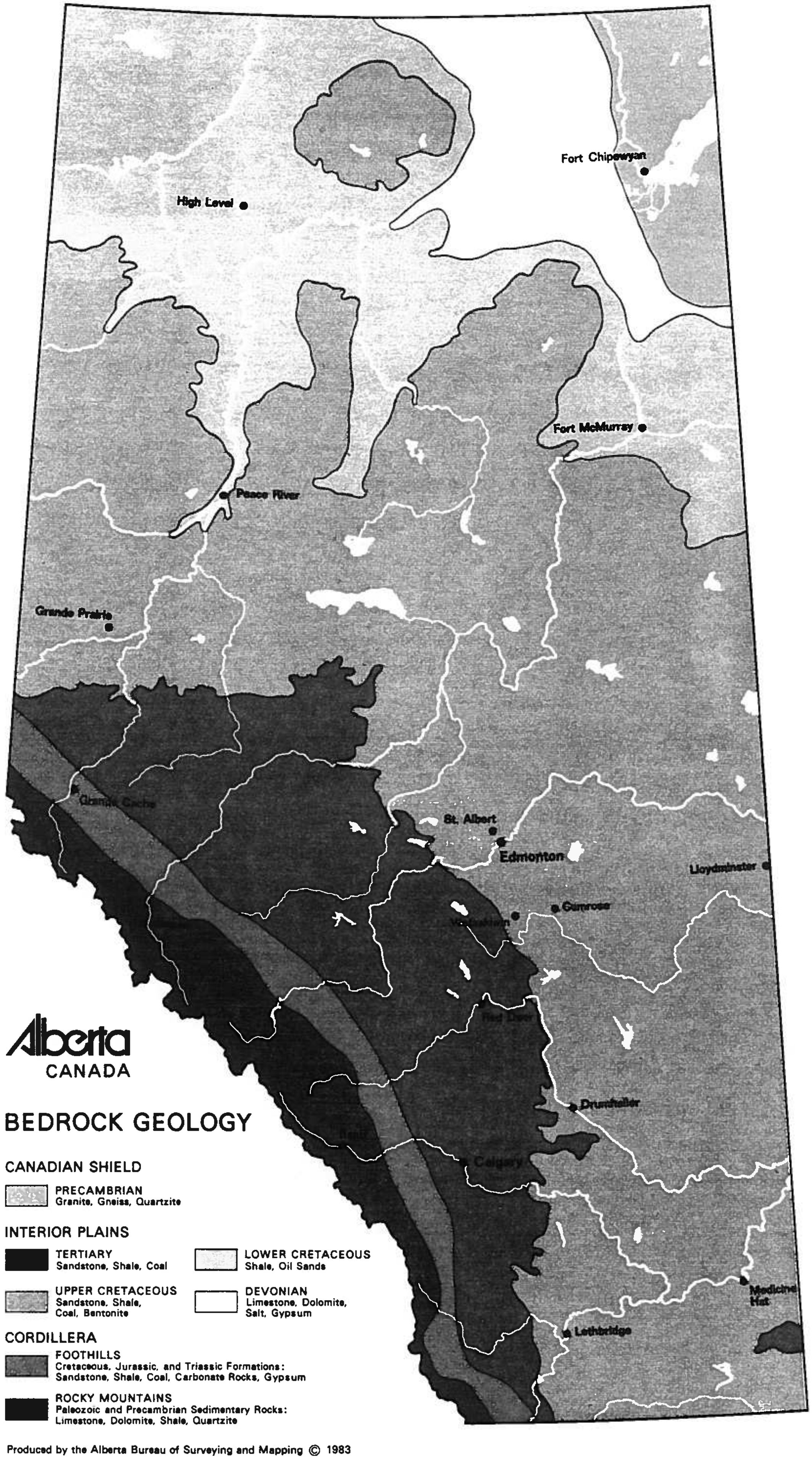

Table 3. Alberta Building Stone Potential

Age	Formation-Lithology	Stone Quality	Accessibility	Production
Pleistocene	Glacial boulders	X	X	X
Tertiary	Paskapoo sandstone	/	X	X
Cretaceous	Edmonton Gp. sandstone	-	X	/
Triassic	Spray River siltstone	X	X	X
Permian	Rocky Mountain quartzite	/	X	/
Mississippian	Rundle limestone	/	X	-
Devonian	Palliser limestone	-	X	-
Cambrian	Cathedral limestone	/	X	-
Cambrian	St. Piran quartzite	X	X	-
Proterozoic	Athabasca sandstone	X	-	-
Proterozoic	Corral Creek sandstone	X	X	/
Archean	Granite, gneiss	X	/	-

Legend

Stone quality and accessibility:

Stone quality and accessibility:	Poor	-
	Moderate	/
	Good	X
Production history:	None	-
	Inactive	/
	Active	X

as a dimension stone. Minor production was achieved from several of these formations in the past. Although many of the accessible propects lie within the mountain national parks, some can also be found outside. Despite Goudge's (1933) statement that the Rocky Mountains have not yielded material suitable for the cut-stone industry (the limestones being shattered, hard and brittle), it is not apparent that there has been a comprehensive survey for limestone or sandstone/quartzite dimension stones.

Significant production of building stone has been achieved from only two formations in Alberta: the Triassic Spray River Formation ("Rundlestone"), a carbonate-cemented siltstone; and the Tertiary Paskapoo Formation sandstone, a carbonate-cemented soft sandstone.

Rundlestone, a medium to dark blue gray color, has been extracted from several locations in the vicinity of Banff, Canmore, and Kananaskis. It has been used extensively as a facing stone on walls in Banff townsite. Because of its ability to split along fairly even, thin bedding surfaces, this stone has also been used as a patio random-patterned floor cover, e.g., Provincial Museum, Edmonton.

The Paskapoo sandstone, used widely as a building stone in Alberta during the early 1900's, became the most important stone produced in the Province. At least 20 quarries were identified by Parks (1916), shown in figure 2 to occur in eight regions. The colors and general characteristics of sandstone from each of these regions are tabulated in tables 4 and 5. The different colors are a function of alteration and oxidation.

Allan (1920) points out that the workable zone is a superficial part of an exposure and depends on the depth of oxidation. This depth varies between localities for the Paskapoo sandstone and is "never very great"; consequently quarries were never deep or extensive. This workable zone limitation affected quarry production capabilities and detracted from wider acceptance and use of the stone by the industry. The unoxidized blue stone would be an exception to the rule. The fresh rock has a high calcite cement, which provides the hardness of the rock. Solution of the calcite cement produces a softer and more porous altered rock.

Figure 2. Former quarries in Paskapoo sandstone (Parks 1916).

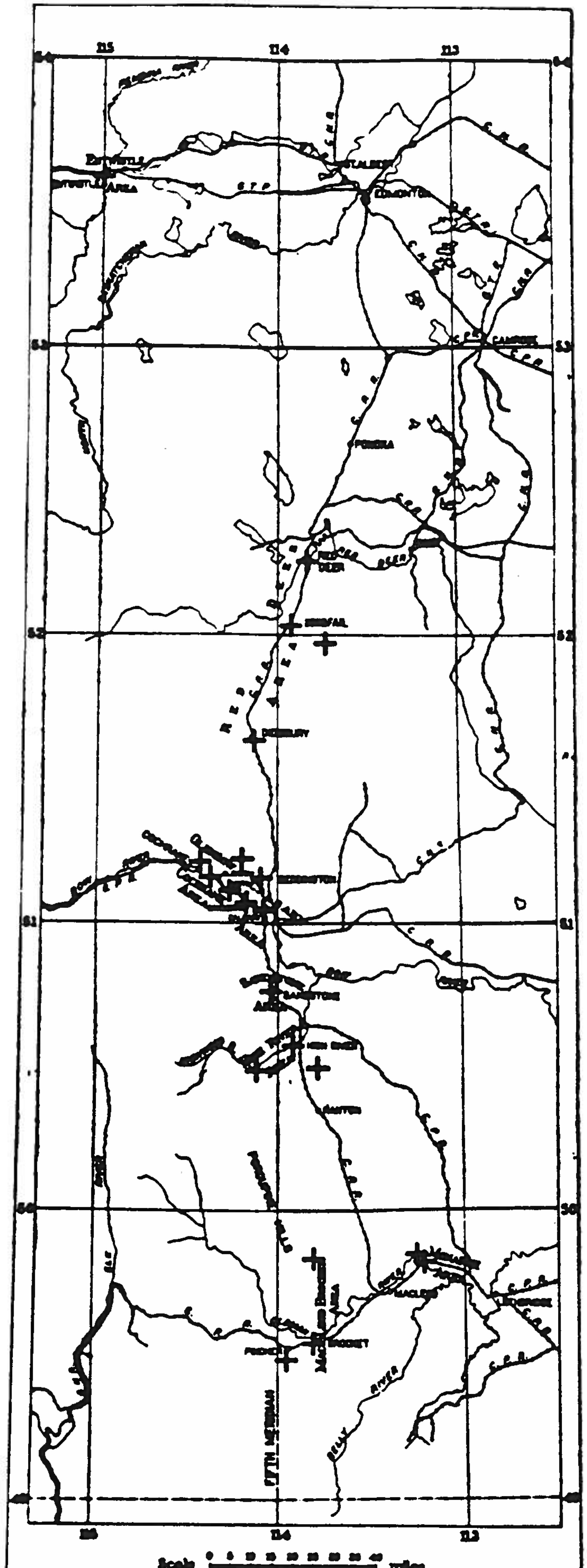

Table 4. Distribution of Paskapoo sandstone by color from former quarry regions (based on Allan, 1920).

Paskapoo sandstone color	Monarch	Macleod-Brochet	High River	Sandstone	Calgary	Glenbow-Cochrane	Red Deer	Entwistle
Very yellow								X
Yellow					X			
Buff	X							
Gray-yellow			X	X		X	X	
Gray		X						
Blue	X			X				X

Table 5. General physical characteristics of the Paskapoo sandstones (Allan, 1920)

	I.	II.	III.	IV.	V.	VI.	VII.
Specific gravity.	2.691	2.688	2.687	2.665	2.672	2.677	2.679
Weight per cubic foot, lbs.	138.64	140.02	131.48	134.19	136.24	144.66	137.54
Pore space per cent	17.47	16.56	21.72	19.34	18.26	12.83	17.66
Coefficient of saturation	.71	.79	.69	.68	.72	.76	.72
Dry crushing strength, lbs. per sq. in.	7,092	6,796	5,985	7,631	9,617	11,119	8,306
Wet crushing strength, lbs. per sq. in.	3,963	4,708	3,874	5,640	7,007	7,224	5,613
Frozen crushing strength, lbs. per sq. in.	2,976	3,679	2,782	3,896	4,212	6,524	4,065
Transverse strength, lbs. per sq. in. .	308	556	398	554	658	582	521
Shearing strength, lbs. per sq. in. . . .	459	512	431	497	642	586	531
Loss on corrosion, grams per sq. in.. .	.0223	.0255	.06746	.04301	.05031	.04194	.04558
Drilling factor, mm	21.4	.....	25.2	21.0	26.6	17.8	22.7
Chiselling factor, grams	27.40 II	8.55 II	9.44 II	6.87 II	14.66 II	4.72 II	11.16 II

I. The blue Monarch stone
II. The buff Monarch stone
III. The yellow Calgary stone (Oliver's quarry and Beddington)
IV. The gray-yellow Glenbow stone
V. The gray-yellow Cockrane stone (Shelley quarry)
VI. The gray Macleod-Brocket stone (Porcupine Hills and Crowsnest Stone quarry)
VII. The average of the previous 9 commercial stones

The Paskapoo sandstone industry was inactive in Alberta when Allan (1920) published his report and he cited several reasons for the low ebb in the industry, including the fact that this stone was not really a first class sandstone for building stone applications. Nonetheless, there is now a revival in the Paskapoo sandstone building stone industry because of the thrust, backed by legislation (Alberta, 1984) towards preservation and restoration of Alberta heritage structures. Most of the original sandstone quarries are now inaccessible and new sources must be found. Of equal significance is the fact that the skilled tradesmen have also disappeared. Both of these problems became significant in the process of restoring the McDougal School, Calgary. A search was undertaken to find stone at inactive quarry sites (Monarch was ultimately used) and the rough blocks were then shipped to Nova Scotia for dressing and carving.

Research Needs

1. The Alberta Government needs to have ready access to sources of Paskapoo sandstone blocks of the relevant colors for ongoing restoration projects. Part of this supply can undoubtedly come from the salvage of blocks from existing structures that are being or will be demolished. However, there is an additional need to undertake a search for alternative sources of rough blocks to satisfy the restoration needs of the future (next 10 years. Prospective sites should be proven and the Government should hold or place under disposition enough stone to guarantee its foreseeable needs.

2. A methodical survey of the dimension stone potential of Alberta is needed to properly assess this resource. Little has been done towards this end in the past 60 years. The lithologies listed in table 2 make a good start. Additional igneous rock prospects could include the Crowsnest Volcanics (Coleman) and the Purcell intrusions (Waterton).

TECHNOLOGY

Mining and processing

Stone extraction operations are in three categories: pit quarries, hillside quarries, and underground workings. A hillside quarry is the most common type and may turn into a pit quarry and eventually be continued underground. The objective in quarry extraction is the production of rectangular blocks with minimal destruction of pay material, taking advantage as much as possible of the natural preferred splitting directions in rock.

Working areas are usually cleaned of overburden and loose rock debris by hydraulicking; joints are better exposed, cut can be planned, and the jamming of wire saws is reduced.

A summary of quarry extraction methods and practices is tabulated below:

(a) by cutting action:	drilling-broaching (plug and feather) wire saw catenaries
(b) by mechanical devices (usually in combination):	jacking levelling hydraulic breaking water jet
(c) by heat action:	jet piercing plasma electrical rock fracture
(d) by explosives:	detonation cord block powder

Industrial processing of stone is carried out in a mill, processing plant, or masonry shop. Utilization of stone depends on the availability of skilled masons for "fixing" at the building site. Tool selection is important. Hammering with pneumatic hand-held tools is preferred to working with a hand hammer, which may bruise the rock surface.

Primary sawing, using frame-saws or gang-saws, is done in the "heavy" section of the mill. Cut-off or secondary sawing, polishing and finishing are done in other sections. Blocks are initially squared by either wire saw, band saw, or a single disc saw, and then the trimmed block can be fed into the gang-saw.

Practices in polishing vary according to locality and the variety of stone. The most commonly used polishing agent are: oxalic oxide, tin oxide and aluminum oxide.

The trend in stone processing is towards the application of mass production techniques, a dramatic departure from the days of the stone mason craftsman. The result has led to centralization of plant facilities, with large automated plants, fewer operators, and large production volumes in an effort to reduce unit costs.

ECONOMIC FACTORS

Prices and costs

Table 6 presents materials cost data for a variety of wall coverings which have been indexed for a Calgary, Alberta location. The unit cost of rock cladding materials is notably higher than for any other materials. However, when the life cycle costs are included in the total analysis, much of the materials cost disparity may well disappear.

Transportation

The transportation factor is of prime importance where dealing with a low value, high bulk commodity such as dimension stone.

Table 6. Comparative materials cost data per square meter, indexed for Calgary, Alberta (Murray, 1983)

Brickwork, 200mm wall	$130.00	
Stonework, 387mm wall, 100mm ashlar limestone, sawn face	250.00	
Steel, 0.711mm, baked enamel + 300mm concrete block backing	106.00	
Aluminum, 0.813mm, baked enamel + 300mm concrete block backing	115.00	
Cedar, 19x235mm bevelled siding + 250mm concrete block backing	75.00	
Asbestos, 6mm flatboard + 250mm concrete block backing	97.00	
Tile, terracotta, 1/2 inch thick, 150 x 150mm	57.00	
Marble, 3/4 inch thick travertine	250.00	
Rough stone, field stone, split, random	172.25	
limestone, split	91.50	
Limestone, sawn face	80.75	
Cut stone, granite gray 1 1/2 in. thick, flamed finish (4in.)	317.50	($430.50)
honed finish (4in.)	355.25	($484.50)
polished finish (4in.)	376.75	($516.75)
marble, white 3/4 in. thick, honed finish	336.50	
marble, white 1 1/2 in. thick, honed finish	441.25	
limestone, ashlar coursing 3 5/8 in. stone, sawn finish	223.50	
limestone, ashlar coursing 3 5/8 in. stone, rubbed finish	236.80	
sandstone, ashlar coursing, standard grade	148.00	
sandstone, ashlar coursing, selected grade	183.00	

At the national scale, it was the network of railways connecting east to west that provided the opportunity for the better stones to trade beyond their local boundaries and to emerge as a commodity of national importance (for example - Manitoba Tyndall Limestone). The influence of transportation was no less important at the provincial level. The growing network of provincial railways and roadways provided the means for distribution of the soft Paskapoo sandstone from more than 20 quarries between the Crowsnest Pass and Edmonton.

OPERATING FACTORS

Environmental issues

Environmental concerns typically focus on the visual scars of fresh quarry faces and the customarily adjacent stone waste pile. An active stone quarry might also be a source of smoke, dust (insignificant if there is not auxiliary crushing operation) and noise from diesel engines (compressors, cranes, trucks, front-end loaders, bulldozers). Surface water and groundwater contamination are not normally a concern. One of the more likely sources of concern would involve possible conflict of land use where the quarry is in proximity to either urban or rural residential development.

Former building stone quarries have been transformed into the magnificent parks - such as Queen Elizabeth Park in Vancouver, and Butchart Gardens near Victoria, B.C. In Edmonton, the much larger former gravel pit at Beverly next became a garbage dump and was then relandscaped to become Rundle Park.

STRATEGIC CONSIDERATIONS

Alberta does not have a distinctive native building stone of high quality which has been developed for production. All of our current stone requirements for quality prestigious structures must be imported. Our existing institutional buildings make no statement on Alberta heritage, except for those built from the inferior, and now troublesome, Paskapoo sandstone.

The physical resources for a high-quality granite dimension stone are available in Alberta, in the Precambrian Shield at Fort Chipewyan (Godfrey, 1979). The economic base of this community, in this remote region of northeastern Alberta, would be greatly strengthened if the Government of Alberta were to initiate a new granite building stone industry. At the same time, a world class quality, native Alberta building stone would become available for institutional and cultural construction uses.

Initiative in the above, together with the commitment to preserve and restore the historical Paskapoo sandstone structures, could form the basis of a development strategy for building stone in Alberta.

OUTLOOK

Supply and demand

Although undeveloped resources exist, the supply of building stones from Alberta is vitually non-existent. The demand is significant inasmuch as many new buildings are being clad with imported dimension stone in the urban centres of Alberta. The statistics on stones imported into Alberta are not presently identifiable.

New products

With the advent of plastic and other bonding agents, it has been possible to cement broken rock fragments together and generate artificial stone. This man-made product using cements or thermo-setting resins as a matrix and filler looks very much like natural stone. Varieties are known as: cultured marble, simulated marble, fortified marble, agglomerates, and reconstituted stone.

"Marbling" and other decorative effects are imparted by pigments or metallic flakes which are stirred into the mix. In the United States of America, sales of cultured marble have increased from $3 million in 1964 to $77 million in 1970 and were expected to exceed $500 million in 1975.

Recent information from stone suppliers indicate that there is presently no market for reconstituted stone in Alberta. However, research and development continues locally and may lead to an economical, acceptable product.

Research and development needs

1. In Alberta, there is an immediate need to develop sources of Paskapoo sandstone of various colors for the needs of restoration projects.

2. An exploration and general survey of potential building stone sources in Alberta could be timely and take advantage of the current increase in usage and interest in natural stone products for construction.

3. There is a corresponding need for skilled tradesmen and experienced masonry consultants to carry out the restoration programs. The stone industry of the west could be stimulated by establishment of a school for restoration. If items '1' and '2' are satisfactorily accomplished, then the potential for new construction becomes more attractive for architects.

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GYPSUM

by

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GYPSUM

INTRODUCTION

Background

Alberta has a well established, gypsum-based building products industry, but has no crude gypsum production of its own. Gypsum deposits known for many years to exist in Alberta (Allan, 1920, 1929), have remained undeveloped, while the industry relies on sources outside the province. This report examines the use of gypsum in Alberta, the resource potential of indigenous deposits, and the needs for information in aid of future development.

Definition of terms, properties, grades, specifications

Gypsum is a naturally occurring mineral of hydrous calcium sulphate ($CaSO_4.2H_2O$). It is associated geologically with anhydrite ($CaSO_4$), the mineral form of calcium sulfate without the combined water. When calcined at controlled temperatures (120 - 205^{o}C), gypsum will release three-quarters of its combined water and convert to a hemihydrate form — $CaSO_4.1/2\ H_2O$ — known as Plaster of Paris. In this form it has the ability when mixed with water to be molded or spread, followed by a return to its rigid state upon "setting". This property accounts for the primary use of gypsum in plasterboard or wallboard manufacture. A major secondary use is in the manufacture of portland cement, where the gypsum acts as a retarder to control set (Stonehouse, 1986).

Gypsum occurs in bedded deposits commonly with intermixed impurities. The minimum purity required for ore-grade material is 80 percent gypsum; however, commercial deposits generally have purities in the range of 85 to 95 percent. White colour is another preferred property, although off-white to grey colours are acceptable for most applications. Much more critical is the presence of soluble chloride salts, particularly sodium chloride, which cannot be tolerated in amounts greater than 0.05 weight percent (1 pound per ton) in gypsum wallboard manufacture.

INDUSTRY SETTING

Canadian production and consumption

Canada is the world's second largest producer of gypsum (behind the USA), with 8.4 million tonnes in 1985. The Canadian gypsum industry is developed in three main regions of the country (figure 1): the Maritimes, which is by far the major producing region (largely for export markets); Ontario, which leads in gypsum products manufacture because of the concentration of population in central Canada; and Western Canada, which embraces a very large region extending from Manitoba to British Columbia. The production of gypsum is compared for the three regions in table 1.

Because gypsum is a low-cost, high-bulk commodity, it is generally consumed within the region of its production. Deposits are developed as closely as possible to the markets for gypsum products. The Maritime deposits are an exception because of unusually high quality, cheap mineability, and availability of low cost shipping on tidewater for those deposits (Stonehouse, 1986). In Western Canada, practically all the production goes into manufacture of building products for the local construction industries.

Western Canada and Alberta

The industry in Western Canada includes 22 operations involving the mining and processing, or consumption of crude gypsum as outlined in table 2. Alberta has a pivotal position within the industry as the leading consumer of gypsum in the region, even though the province has no gypsum production of its own. Several deposits known to exist in Alberta are undeveloped owing to remote or restricted locations, or difficult accessibility (Hamilton, 1982). All the requirements currently are hauled in by truck or rail from British Columbia, from

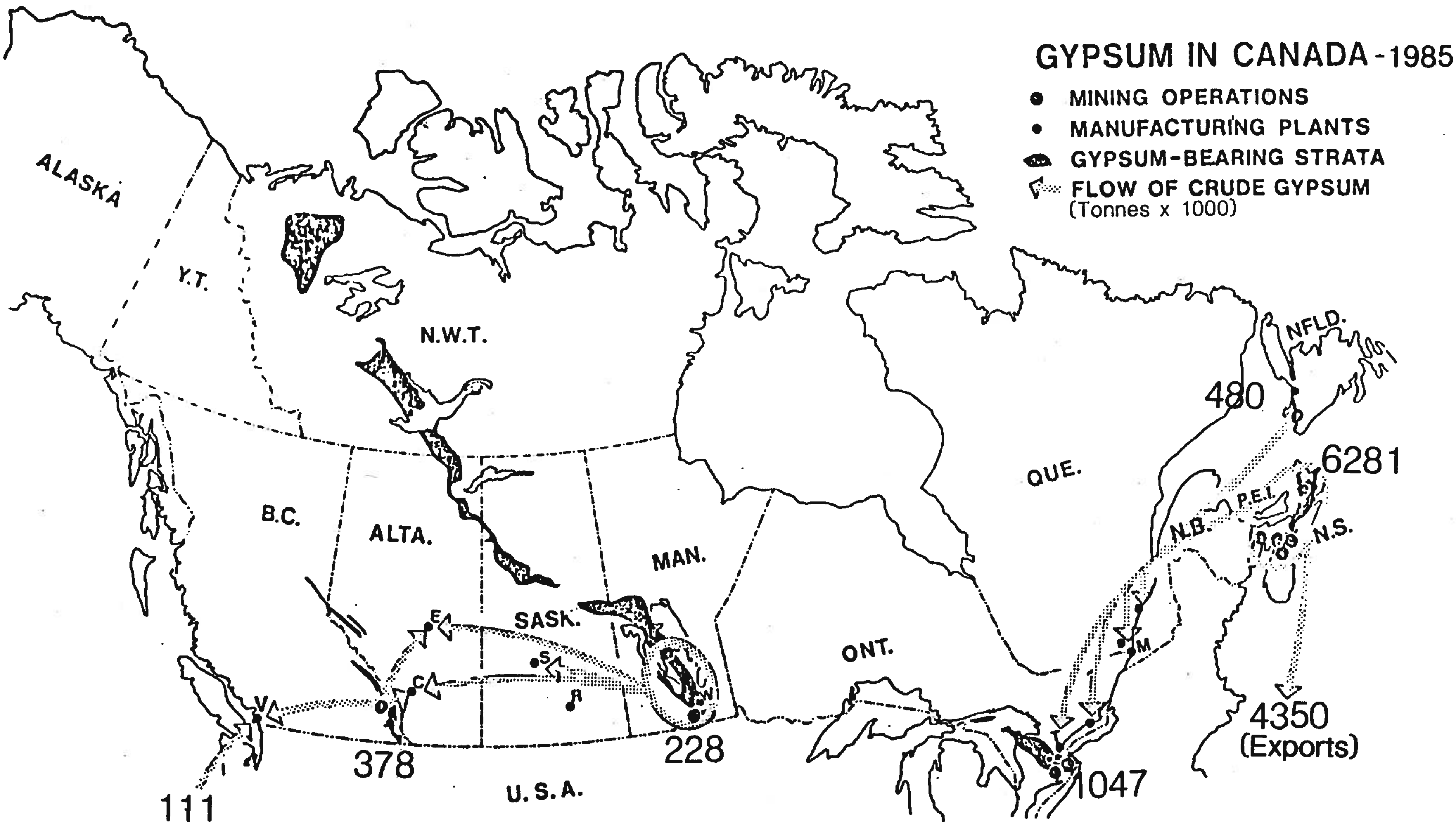

Figure 1 (modified from Godfrey, 1975)

TABLE 1. Gypsum Production in Canada by Regions

	1984			1985		
	tonnes	$000	(Ave.$/t)	tonnes	$000	(Ave.$/t)
British Columbia	411,824	4,076	(9.90)	377,772	4,340	(11.49)
Manitoba	172,656	1,848	(10.70)	227,718	2,605	(11.44)
Subtotal, Western Canada	584,485	5,924	(10.14)	605,490	6,945	(11.47)
Ontario	1,183,193	12,716	(10.75)	1,046,631	15,823	(15.12)
Nova Scotia	5,476,643	38,373	(7.01)	6,281,417	52,216	(8.31)
Newfoundland	530,761	4,549	(8.57)	450,000	5,337	(11.86)
Subtotal, Maritimes	6,007,404	42,922	(7.14)	6,731,417	57,553	(8.55)
Total, Canada	7,775,082	61,562	(7.92)	8,383,538	80,321	(9.58)

Source: EMR Canada, Statistics Canada

TABLE 2. Gypsum Mining, Processing, and Consuming Operations in Western Canada, 1986

COMPANY	LOCATION	OPERATION	Estimated 1985 PRODUCTION (tonnes)	Estimated 1985 CONSUMPTION (tonnes)	GYPSUM SOURCE
MANITOBA					
Domtar Inc.	Gypsumville[1]	Open-pit mining	140,000	-	*
	Winnipeg	Wallboard manufacture	-	58,000	1
Westroc Industries Ltd.	Amaranth[2]	Open-pit mining	88,000	-	*
	Winnipeg	Wallboard manufacture	-	74,000	2
Canada Cement Lafarge Ltd.	Fort Whyte	Cement manufacture	-	9,800	2
Genstar Cement Ltd.	Winnipeg	Cement manufacture	-	5,700	1
			228,000	147,500	
SASKATCHEWAN					
Domtar Inc.	Saskatoon	Wallboard manufacture	-	75,000	1
Genstar Cement Ltd.	Regina	Cement manufacture	-	4,000	2
				79,000	
ALBERTA					
Domtar Inc.	Calgary (to be closed Sept/86)	Wallboard and "Gypcrete" manufacture	-	57,000	3
Domtar Inc.	Edmonton	Wallboard manufacture	-	75,000	3,1
Westroc Industries Ltd.	Calgary	Wallboard manufacture	-	56,000	4
Canada Cement Lafarge Ltd.	Exshaw	Cement manufacture	-	23,000	4
	Edmonton	Grinding (cement clinker)	-	4,000	4
Genstar Cement Ltd.	Edmonton	Cement manufacture	-	24,000	3,4
			-	239,000	
BRITISH COLUMBIA					
Domtar Inc.	Canal Flats[3]	Open-pit mining	122,000	-	*
	Vancouver	Gypsum products mfg.	-	58,000	6
Westroc Industries Ltd.	Windermere[4]	Open-pit mining	250,000	-	*
	Vancouver	Gypsum products mfg.	-	83,000	4
Canada Cement Lafarge Ltd.	Falkland[5]	Open-pit mining	5,700	-	*
	Kamloops	Cement manufacture	-	5,700	5
	Richmond	Cement manufacture	-	16,800	6
Genstar Cement Ltd.	Tilbury Island	Cement manufacture	-	27,000	6
			378,000	190,500	
		TOTAL	606,000	656,000	

[6]Imported gypsum from Mexico and/or California

Sources: Statistics Canada
EMR Canada, Mineral Bulletin MR 204

quarries in the Windermere and Canal Flats areas. Lesser amounts have been brought in by rail from Manitoba at various times in the past. The gypsum is used for wallboard and cement manufacture in the six Alberta plants indicated in table 2.

Alberta's consumption of gypsum (and production of gypsum products) is tied directly to the level of activity in the construction industry, which has been declining since its peak year of 1982. Exact consumption figures are not available, but the approximate total for the province in 1985 was 239,000 tonnes (see table 2) valued at $6.4 million. The major portion of this value is transportation cost.

GEOLOGY AND RESOURCES

Geologic setting

Gypsum deposits are found in sedimentary rock successions of all ages. Gypsum and anhydrite are evaporites - calcium sulfate minerals deposited by precipitation from brines concentrated from sea water in enclosed basins or supratidal flats under arid conditions (Harben and Bates, 1984). Gypsum undergoes alteration to anhydrite with burial and compaction, but will reconvert to gypsum by subsequent uplift of the deposits and exposure to near-surface conditions. For this reason, gypsum rarely exists at depths below 200 m and most commercial deposits are less than 100 m deep.

Typically, a gypsum deposit occurs as beds or lenses of gypsum interlayered with minor amounts of other evaporites (mainly anhydrite), carbonates, and shales, in lenticular bodies several tens or even hundreds of metres thick. Commercial beds range up to 30 m thick, the most common being 2 to 6 m. Generally, the deposits are extensive and the purity is high, 85 to 95 percent. Because gypsum is weakly to moderately soluble, deposits will often have a karstic surface expression, which is a clue to their existence and extent in the shallow subsurface.

Distribution of Alberta deposits

Several deposits of gypsum are known in Alberta (figure 2), although none is developed. Evaporite sequences (the source rock units for gypsum) are widespread in the Alberta subsurface, but in most places the evaporites are too deep to allow the transformation of anhydrite into gypsum. Where they do approach the surface the evaporites give rise to gypsum deposits, but these are in remote or restricted locations, or have difficult accessibility.

The gypsum deposits occur in strata of Devonian and Triassic ages, as outcrops or near-surface projections of extensive evaporite-bearing formations which are indicated in table 3. Middle Devonian strata include the Kananaskis deposit in the Rocky Mountains of southwestern Alberta, and the Salt River, Fort McMurray (Athabasca and Clearwater), and Peace Point deposits in northeastern Alberta. The Head Creek deposit, in the southwestern Alberta Foothills, is Upper Devonian. The Fetherstonehaugh Creek and Mowitch Creek deposits, both in the west central Alberta mountains, are Triassic.

The characteristics of Alberta's gypsum deposits are summarized in table 4. The deposits have little development potential for the short-term future. For the longer term, potential exists for at least two - Peace Point and Fort McMurray. The other deposits, on the basis of location and grade, are given very low to zero potential ratings for the present, but these ratings could improve with better data. Further assessment work is in order for all the deposits.

Both the Peace Point and Fort McMurray deposits are remote, so any development may have to await the industrialization in northeastern Alberta expected with future oil sands development. A significant change in the economics of gypsum imports or in the use of gypsum in Alberta could influence earlier development. The Peace Point deposit is the best, with 1 billion tonnes of quarriable reserves grading 95 percent. Its National Park location does not rule out development entirely, for it lies on lands subject to pending Indian land claims

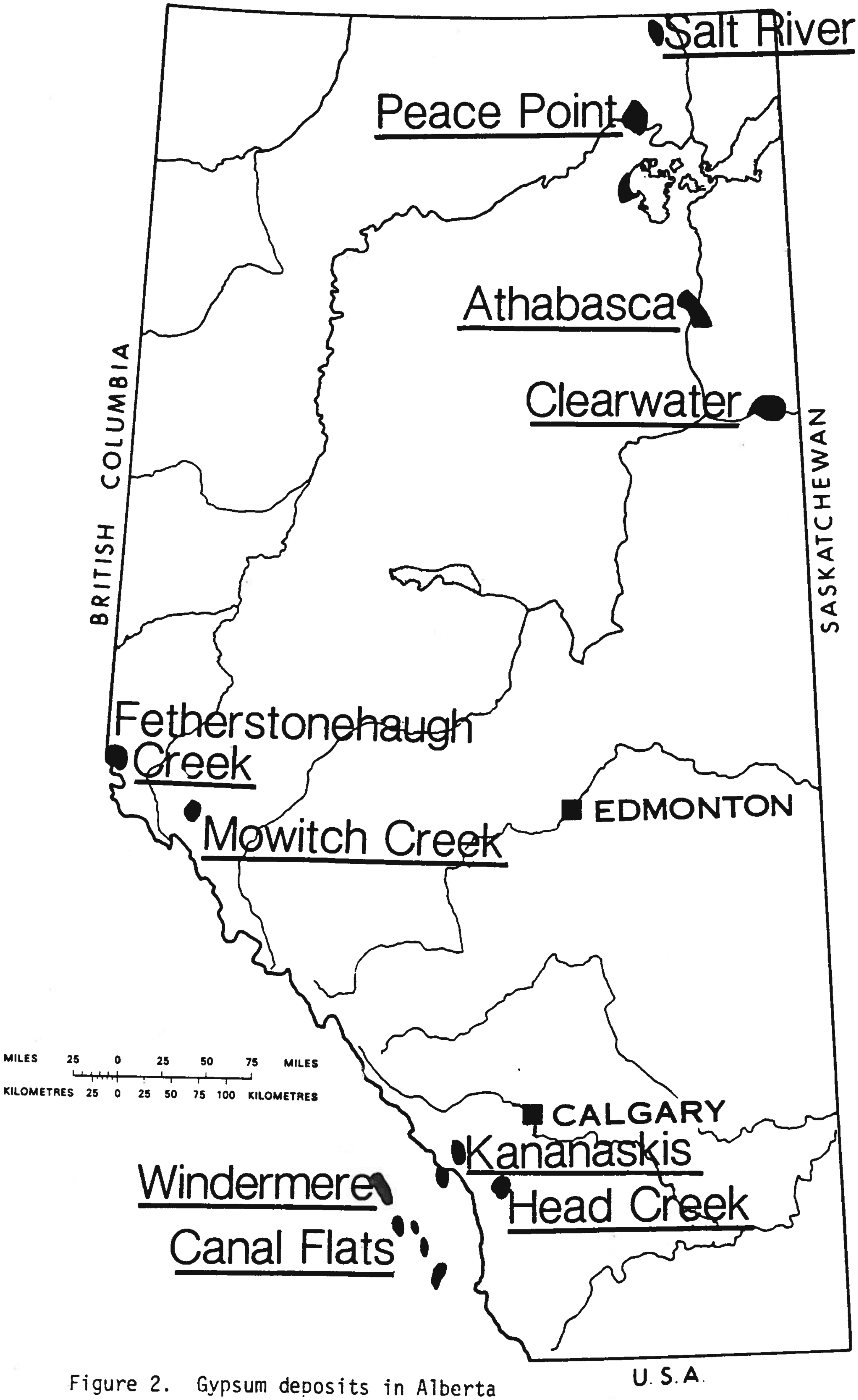

Figure 2. Gypsum deposits in Alberta

settlement. The Fort McMurray deposit on the Athabasca River is less remote and free of constraint, but is of lower grade and would require underground mining.

Exploration for new deposits

Prospects exist for undiscovered gypsum deposits in Alberta. These are mainly for buried deposits in the mountain region, where in certain structural situations, gypsiferous sections could be preserved at shallow depth (less than 100 m), although leached in outcrop (Hamilton, 1982). These deposits would only be evident at the surface as a leached zone of carbonate breccia. In most cases they will only be discovered by test drilling, involving shallow coring to provide a conclusive sampling of the near-surface material (0 to 150 m depth). Chance discovery of buried gypsum deposits through oil and gas drilling is unlikely, because the shallow "surface hole" section of these drill holes rarely gets logged.

Discovery of an economic gypsum deposit in the central Alberta mountains would have enormous impact for markets in Calgary and Edmonton, which must now import gypsum from distant sources in British Columbia or Manitoba.

Alternative sources

A factor which may affect future development of gypsum deposits in Alberta is the availability of phosphogypsum, a waste byproduct of the phosphate fertilizer industry. Four fertilizer plants in Alberta have a combined phosphogypsum production of 1.3 million tonnes annually (Hamilton, 1982). No use is made of the material at present, due to high processing costs and a potential radiation hazard carried over from the sedimentary phosphate rock (which can contain uranium and radium). However, technology is available from Japan and Europe, which in those countries allows for substitution of phosphogypsum in a full range of gypsum products.

Research needs

1. For known deposits that have development potential for the foreseeable future, studies are needed to better define the resource aspects. The Fort McMurray deposit, postulated only from regional well control, requires test drilling to confirm its existence, establish its grade and extent, and evaluate the rock characteristics for underground mining. The Fetherstonehaugh Creek and Head Creek deposits require further sampling to ascertain grades and reserves.

2. New exploration studies are needed to identify and evaluate prospects for shallow unexposed deposits in Alberta's mountain region. Upper Devonian, Mississippian, and Triassic evaporitic strata offer favourable prospecting targets. These studies require analysis of existing information to identify prospective sites and also the acquisition of new drilling data.

TECHNOLOGY

Mining and processing

Gypsum is mined by open-pit or underground mining methods, most commonly the former. Commercial deposits tend to be flat-lying beds at or near the surface and amenable to quarrying by conventional methods. Underground mining is confined to deposits where the higher costs are compensated by proximity to market, or by higher quality ore. Where practised, underground mining normally is by room-and-pillar, which under good mining conditions, allows 80 percent recovery of the gypsum (Appleyard, 1975).

The processing of crude gypsum depends on its end use. For the manufacture of wallboard, gypsum is crushed, pulverized and calcined to form "stucco", which is then mixed with water and various additives to form a slurry. The slurry is introduced between sheets of heavy absorbent paper, allowed to harden, and then cut to wallboard dimensions. A flow sheet for the processing of gypsum to finished products is shown in figure 3.

Crude gypsum used in portland cement needs only crushing, to 20 - 40 mm, before being added to the clinker in the grinding stage. For filler and agricultural uses, the gypsum is pulverized to 100 mesh or finer.

Phosphogypsum, a byproduct from phosphoric acid manufacture, is reclaimed in some countries for use in the manufacture of gypsum products. The material requires special treatment for removal of residual phosphates and other contaminants, including uranium and radium. None is utilized in Canada at present.

Research needs

Research progress on the use of phosphogypsum for gypsum products manufacture needs to be closely monitored, and supplemented where appropriate by studies on Alberta material. The focus for Alberta should be on the potential use of this waste material in specialized industrial applications, i.e., other than conventional gypsum products.

One possible use that merits particular attention is as paper filler. Recent experiments in France have produced paper with a 20 percent phosphogypsum content as filler (Stonehouse, 1986). This research should be intensively reviewed for its potential application to Alberta's needs (re the proposed establishment of a paper industry), followed by specific laboratory investigations and tests with locally produced material.

ECONOMIC FACTORS

Prices and costs

Canadian gypsum production of 8.4 million tonnes in 1985 was valued at $80.3 million, for an average value of $9.58 per tonne (table 1). This figure refers to the value of gypsum at the mine or quarry site, i.e. excluding shipping costs.

In Western Canada, the average value of mined gypsum is $11.43 - $11.48 per tonne, almost $2 per tonne higher. The difference is mainly in higher production costs as compared with the high-volume, low-cost production from the Maritimes region. Part of the difference, however, lies in the fact that the Maritime production is largely captive, and receives an "assigned value" which reflects production costs only (Stonehouse, 1976). Western Canada gypsum, on the other hand, is valued mainly according to competitive market pricing. When crude gypsum is supplied to unrelated consumers, a contract price is negotiated which is influenced by the price of the next available source. There are no market quotations for crude gypsum.

Transportation

A major factor in the economics of the gypsum industry is transportation. The nearest developed source of gypsum for the Calgary area (Windermere) involves a rail haul of 400 km. For the Edmonton area, the rail haul is 700 km. These translate into freight costs currently of $11-12 per tonne to Calgary, and $19-20 per tonne to Edmonton. The total cost of gypsum delivered to Edmonton accordingly is $30-32 per tonne. The problem, however, is that the freight costs have been rising steadily in recent years and continue to escalate, in the face of declining markets for gypsum products. The effect is a growing economic burden for Alberta gypsum plants. If a closer source of gypsum within Alberta were to be developed, the economics of the gypsum industry could be very positively affected, especially for the Edmonton market.

Transportation costs for finished gypsum products are significantly higher than those for crude gypsum. Therefore, processing plants are located close to the market and not at the mine site (Stonehouse, 1976).

OUTLOOK

Supply and demand

Resources of gypsum in British Columbia are substantial and more than adequate to meet Alberta's future needs. Rising freight costs are a major problem and an increasing burden for the Alberta gypsum industry. These freight costs will likely keep Manitoba gypsum out of the Alberta market (or with a very small share only) as long as supplies from southeastern British Columbia remain adequate. The remoteness of known deposits in Alberta remain a deterrent to their development as an alternative local source.

The demand for gypsum is closely tied to the construction industry, particularly housing construction. Demand in Alberta fell off abruptly from the peak years of 1980-81, and has been fairly flat and stable since. No major change in demand is likely for the near future.

A factor that could alter Alberta's supply-demand situation would be the development of byproduct gypsum sources, principally phosphogypsum. Industrial use of phosphogypsum is technically feasible even now, and the economics will improve with the rising freight costs for distant, conventional gypsum sources. As phosphogypsum waste piles continue to accumulate in Alberta, disposal costs will further encourage its use. A potential radiation hazard exists with the material, but this apparently has been overcome in Japan and Europe. It seems very probable that phosphogypsum will be reclaimed for use in some parts of Alberta in the future. Its possible use as paper filler could be the catalyst to bring about development. The Alberta Government has a strong interest in establishment of a fine paper mill in the province, and is currently attempting to locate sources of white mineral filler as one of the essential raw materials.

New uses

The use of gypsum as a filler has not had application in Alberta, although it could have if local sources were developed. In other regions, gypsum has limited use as a mineral filler, for paper, paints and pesticide manufacture (Severinghaus, 1975). As white paper filler, it is cheap, attractive, has excellent colour and brightness, imparts a distinctive feel to the paper, and improves sizing. However, the poor refractive index and the mineral's natural solubility have led to a decline in its use in the paper industry (Harben, 1984). This may indicate only that more information is needed on the limitations posed by these deficiences and how they might be overcome. The suitability of gypsum for use as paper filler, at least as partial replacement for more expensive fillers, seems well established. The recent experiments in France with using phosphogypsum as paper filler (Stonehouse, 1986) indicate a potential for broader development of this use.

Another use of gypsum not previously applied in Alberta is in agriculture, where as a soil conditioner it neutralizes alkaline and saline soils, provides sulphur, and promotes nitrogen fixation for maximum fertilizer utilization (Pressler, 1980).

Gypsum is a potential source of sulphur. However, existing chemical processes for converting gypsum to sulphuric acid are uneconomic because of large alternative sources (Appleyard, 1975). If better methods are discovered, or if sulphur prices increase considerably, then a new market for gypsum would be opened.

Summary of research needs

Research on gypsum in Alberta is needed in the areas of geology and processing technology. Geological research is essential for a thorough understanding of the resource potential, for possible discovery of new deposits, and perhaps ultimately to prevent the loss of an industry. Gypsum plants in Alberta face a growing economic imbalance because of rising freight costs of crude gypsum from sources outside the province. A new source located within the province would have enormous positive impact for the industry.

Apart from the direct economic implications, there is a need to know the full extent of gypsum resource potential for purposes of land-use planning. A case history is cited of the Kananaskis gypsum deposit, which had positive resource aspects for the Alberta gypsum industry, but which is lost to future development by its incorporation within a provincial park. The point is not whether the deposit should be open to development, but rather that all essential information be available for such decision-making.

Need for processing technology research relates to new product uses such as paper filler. The current interest in locating a source of white mineral paper filler in the province maybe a key to realization of Alberta's gypsum resource potential.

Specific research studies identified in this report are summarized below.

1. Further geological investigation is needed of known gypsum deposits in Alberta that have development potential, to better define their resource aspects and to evaluate economic factors against those of established sources. These investigations should be in consideration also of potential new uses for gypsum in Alberta (e.g. paper filler).

2. A framework for exploration of new deposits should be established, by mapping prospective areas for the occurrence of shallow gypsum in the disturbed belt.

3. Research on the utilization of phosphogypsum should be reviewed (in particular its use as paper filler) and research needs identified in respect of Alberta sources, followed by laboratory tests as required.

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The Metallic and Industrial Minerals of Alberta
Mineral Commodity Profile
Open File Report No. EO 1986 - 13(c)

PHOSPHATE

by

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Mineral Resources Group
Alberta Geological Survey
Alberta Research Council
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PHOSPHATE

INTRODUCTION

Background

Phosphate rock is used extensively in Alberta, primarily in producing agricultural fertilizers. However, no phosphate rock is mined in Alberta or in Canada. Knowledge of its resource potential in Alberta and Western Canada is of vital importance to the long term stability of the agricultural industry. This profile outlines the resource potential of sedimentary phosphate rock in Alberta, primarily as an industrial mineral commodity and secondarily as a possible source of by-product uranium and vanadium.

Definition of terms, grades, specifications

There are many conflicting and confusing usages of terms in describing phosphatic rocks and phosphate products. Within this report the following terms and corresponding definitions have been adopted:

Phosphate Rock - Commercial term used to denote a rock type that can be economically mined and used for its phosphorous content in the production of phosphate fertilizers or elemental phosphorous. Canadian fertilizer plants are designed to accept raw phosphate rock in the 31.1 to 33.0 percent P_2O_5 range.

P_2O_5 - Standard means of expressing phosphorous content of phosphate rocks or fertilizers as phosphorous pentoxide. Other forms used to express phosphorous content, and their conversion, include: BPL (Bone Phosphate of Lime) = 2.1852 x P_2O_5, P (Elemental Phosphorous) = 0.4364x P_2O_5.

Phosphate - Chemically precipitated minerals of the apatite family, usually carbonate fluorapatite.

Phosphorite - A rock type composed predominantly of carbonate-flourapatite minerals - a lithologic term.

Phosphatic - An adjective for a rock type containing an anomalously high amount of phosphate (when compared to the crustal average, about 0.27 percent p_2O_5).

INDUSTRY SETTING

Status of industry in Alberta

There has never been any mining of phosphate rock in Alberta. Exploration was carried out up until the mid 1960's, however no recent exploration permits have been granted. Nearly all of the phosphate in Alberta is found within presently restricted land use areas in the province.

Historical development

Phosphate, as apatite veins and pockets within igneous intrusive rocks, was mined in Quebec and Ontario during the period from 1829 to 1919 (Spence, 1920). The discovery in the early 1890's of the vast, easily exploitable sedimentary phosphate deposits in Florida undercut the Canadian industry and it slowly collapsed. Interest in phosphate shifted to sedimentary phosphate deposits in Western Canada with the discovery by Adams and Dick (1915) of phosphate near Banff in Banff National Park. Leo Telfer in 1925 conducted an extensive phosphate exploration program in the Rocky Mountains in Alberta for Consolidated Mining and Smelting Company (later Cominco) (Telfer, 1933). During the period 1925 to 1975 Cominco held several phosphate leases in southeastern British Columia and in the Crowsnest Pass area of Alberta.

In the 1960's renewed interest in phosphates saw a surge of exploration in Alberta and British Columbia, and again in the period 1972-74 when the world price of phosphate nearly tripled. The most recent activity was centered in the southeastern Fernie Basin and northeastern areas of British Columbia. In the 1980's the Alberta Research Council undertook a phosphate evaluation study (Macdonald 1984, 1985) as did the Geological Survey of Canada (Christie, 1979, 1980, 1981). Detailed stratigraphic and chemical analyses of several hundred stratigraphic sections examined for phosphate are given in Macdonald (1984).

Uses and markets

Four main products are produced from phosphate rock: elemental phosphorous, phosphoric acid, phosphatic fertilizers and phosphate chemicals. In Western Canada, phosphoric acid is produced at six plants (table 1), most of the product being used in the manufacture of fertilizers, with a minor amount used to produce calcium phosphate. There are three main producers in Alberta, Esso Chemicals, Western Co-operative Fertilizers and Sherrit Gordon. Phosphate fertilizers produced are mainly of the ammonium phosphate variety.

Most of the phosphate fertilizer manufactured in Alberta and Western Canada finds markets within the western provinces. A small export market to the U.S.A. exists; however, Canada as a whole is a net importer of phosphate fertilizers.

Production and source of supply

Total Western Canadian production of these fertilizers amounts to 788,000 tonnes P_2O_5 per year (table 1), while the Alberta based production accounted for 625,000 tonnes P_2O_5 of this total. Canadian production of phosphate related fertilizer products totaled approximately 1.4 million tonnes in 1985, with 1.1 million tonnes sold domestically and the remainder

Table 1. Western Canada, Phosphate Fertilizer Plants, 1981 (From EMR, 1985).

COMPANY	Plant Location	Annual Capacity (Tonnes P_2O_5	Basis For Source Of Phosphate Rock	H_2SO_4 Supply For Fertilizer Plants
Cominco Ltd.	Kimberley, B.C.	86,000	Montana and Utah	SO_2 pyrite roast
	Trail, B.C.	77,300	Utah	SO_2 smelter gas
Esso Chemical Canada	Redwater,	370,000	Florida	Sulphur
Sherritt Gordon Mines Limited	Fort Saskatchewan, Alberta	50,000	Florida	Sulphur
Western Co-operative Fertilizers Limited	Calgary, Alberta	140,000	Idaho	Sulphur
	Medicine Hat, Alberta	65,000	Idaho	
Total, phosphate fertilizer		788,300		

sold on the export market. Figure 1 shows the total sales volumes of the phosphate based fertilizers, in comparison to the other two main types, i.e., nitrogen and potash.

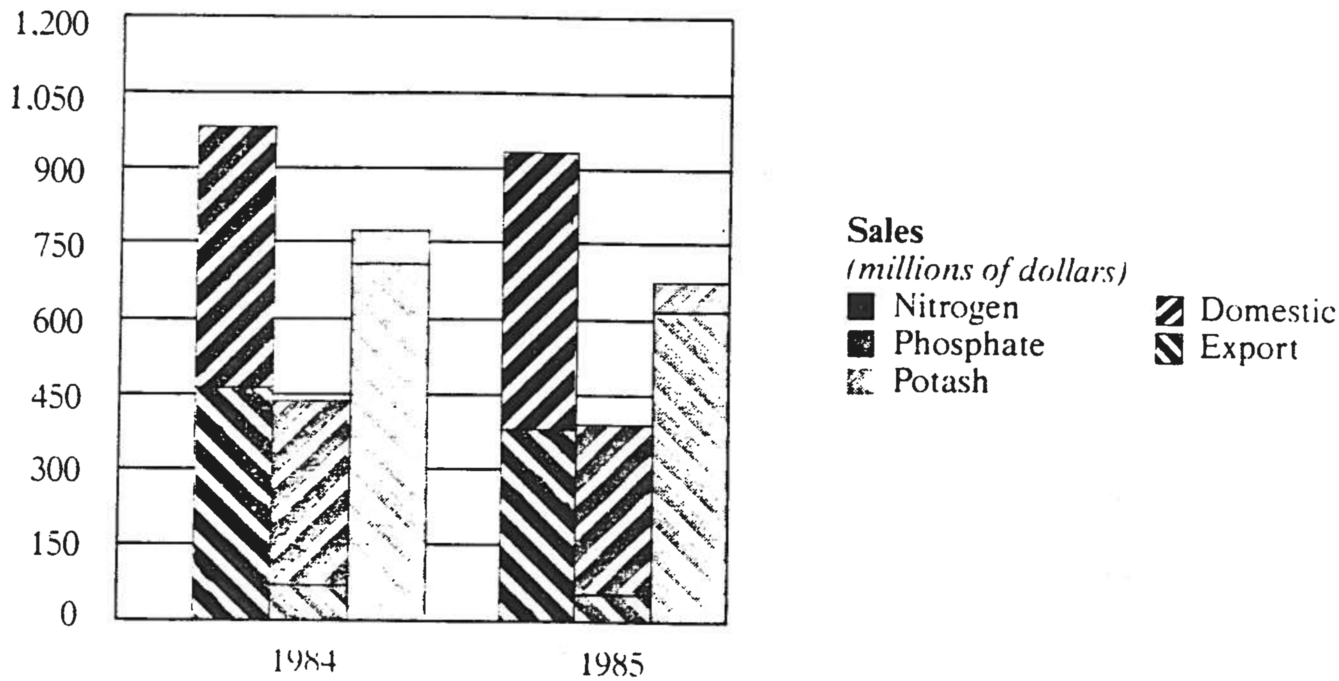

Figure 1. Domestic and export sales of fertilizers in Canada 1934-85 (from Canadian Fertilizer Institute, 1985)

Figure 1

All of the phosphate rock used in Western Canada fertilizer plants is imported from the U.S.A. (table 2). Cominco, Simplot and Western Co-operative Fertilizers all own and operate their own phosphate mines in Utah, Idaho and Montana. The other producers obtain phosphate from Florida via shipping up the west coast to Vancouver and then rail transport to Alberta.

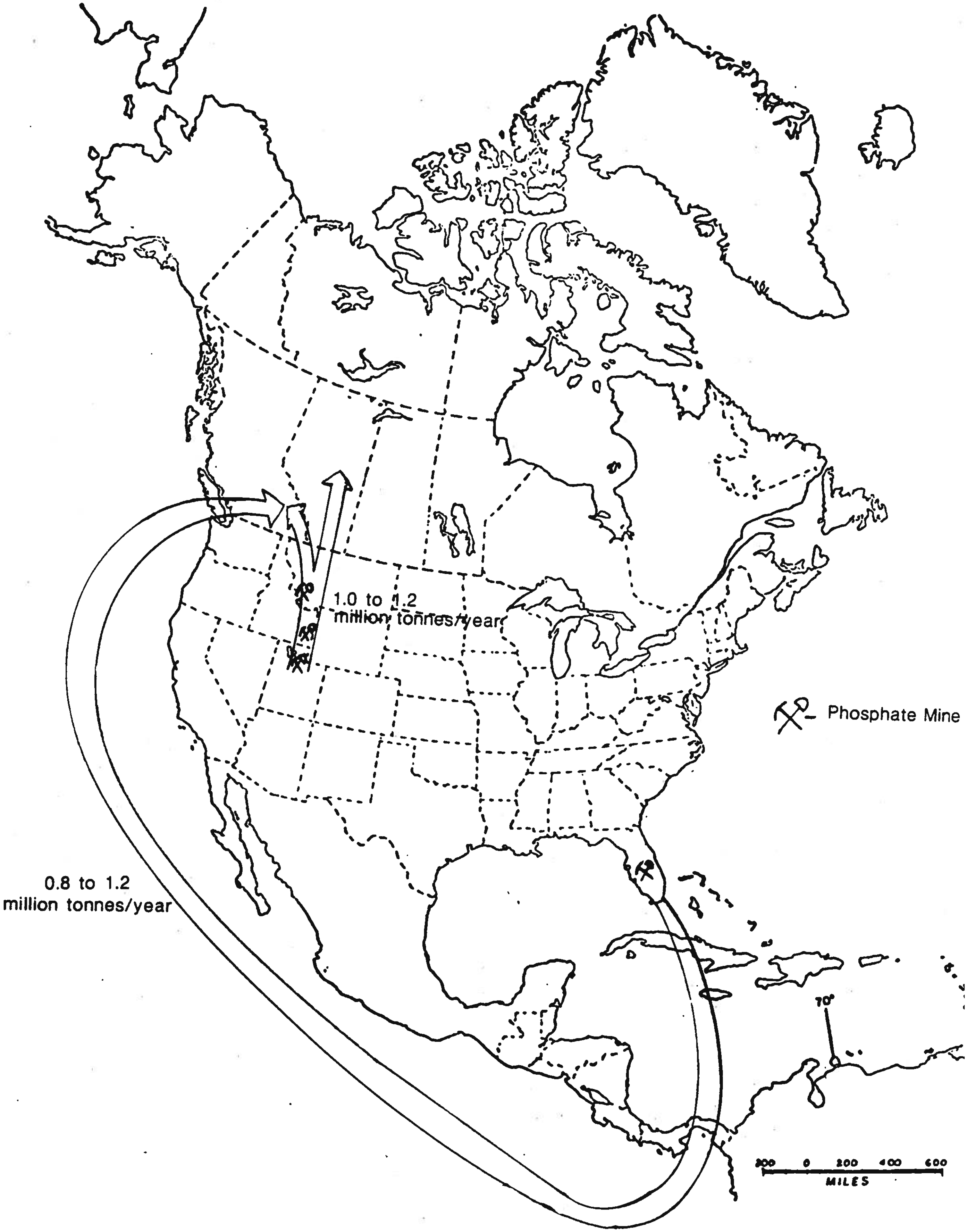

Figure 2. Sources of imported phosphate rock to Western Canada (modified from EMR, 1982)

The fertilizer industry is mature and well established throughout Western Canada. Combined dollar sales of all fertilizer products in Canada was $2.0 billion in 1985 (figure 1). The industry was slightly depressed in 1984 and 1985, but has shown a stronger overall growth since 1965 than, for example, the mining or pulp and paper industries. The Canadian phosphate fertilizer industry imported a total of 2.66 million tonnes of phosphate rock in 1983 (Energy, Mines and Resources, Canada, 1985) at an estimated cost approaching U.S. $239 million.

GEOLOGY AND RESOURCES

Sedimentary phosphate deposits are believed to have formed in oceanic environments and are dependent upon seven basic parameters (Sheldon, 1981).

- A supply of phosphorous.
- Storage and accumulation of oceanic phosphorous.
- Upwelling of stored phosphorous to shallower levels.
- Concentration of phosphorous at the ocean floor from organic material, derived from biota that flourished in upwelling zones.
- Correct chemical conditions to induce apatite precipitation.
- Apatite precipitation by biogenic, diagenetic and/or primary sea floor precipitation.
- Concentration of phosphate deposits to economical deposits.

Whenever these conditions have come together in the geologic past, phosphate deposits have formed.

Geologic setting

Phosphate is found in ten geological formations which crop out in the Cordilleran region of Alberta and southeastern British Columbia (figure 3).

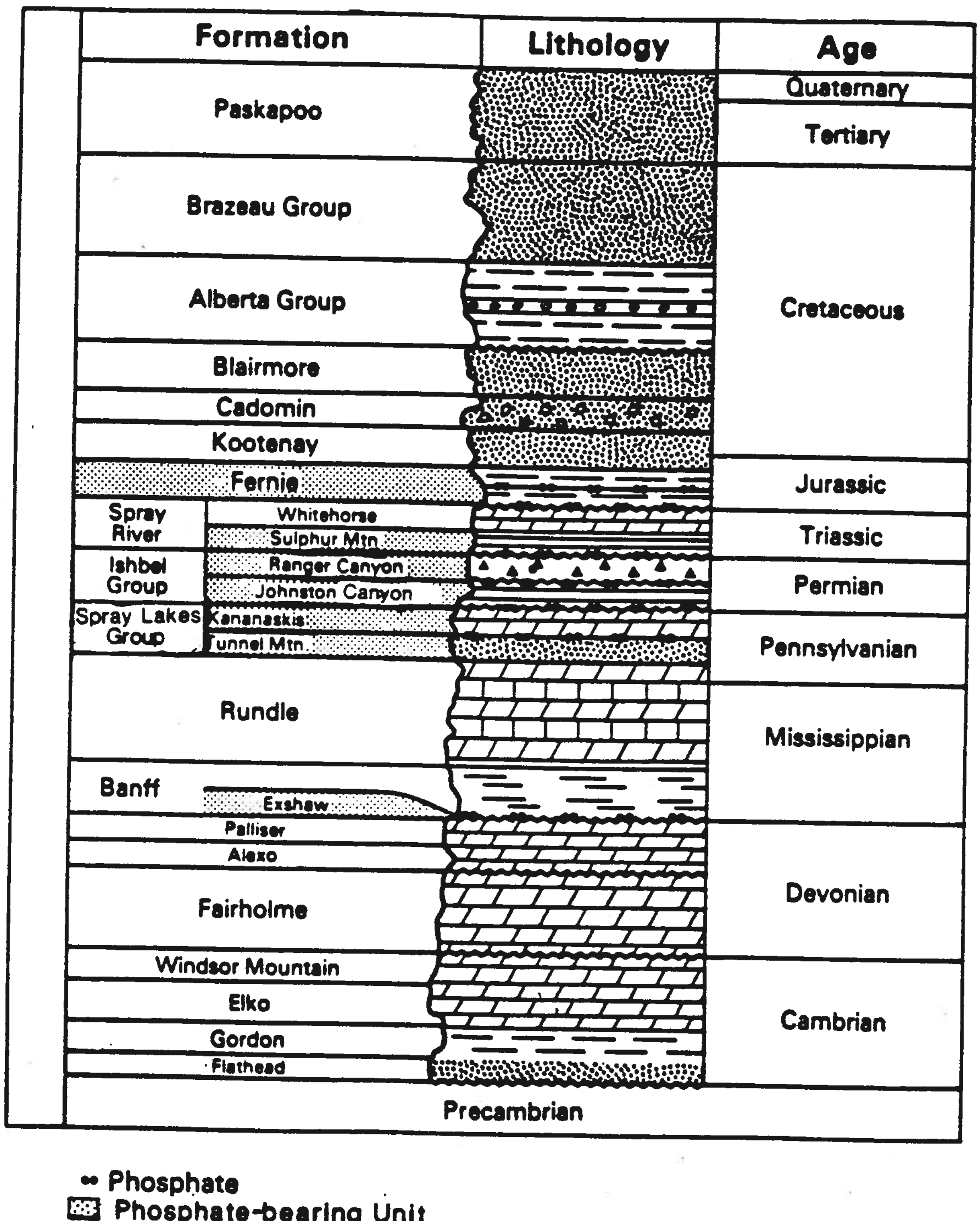

Figure 3. Generalized stratigraphic section — Cordilleran region and major phosphate bearing units (modified from Jackson, 1975).

Phosphate was deposited in the Late Devonian-Mississippian Exshaw Formation, the Pennsylvanian Spray Lakes Group, the Permian Ishbel Group, the Triassic Spray River Group, and the Jurassic Fernie Group. The Exshaw, Ishbel and Fernie phosphates are the most widespread and are the ones of main economic interest. Figure 4 shows the typical structural/-stratigraphic setting of the main phosphate-bearing formations. The Exshaw Formation typically is exposed along the eastern flanks of the mountain ranges at high elevations, and is overlain by a considerable thickness of younger strata. The Spray Lakes, Ishbel and Spray River Groups tend to occupy the western "backside" of the ranges, often forming an exposed dipslope. The Fernie Group tends to occupy the valley regions between major thrust sheets.

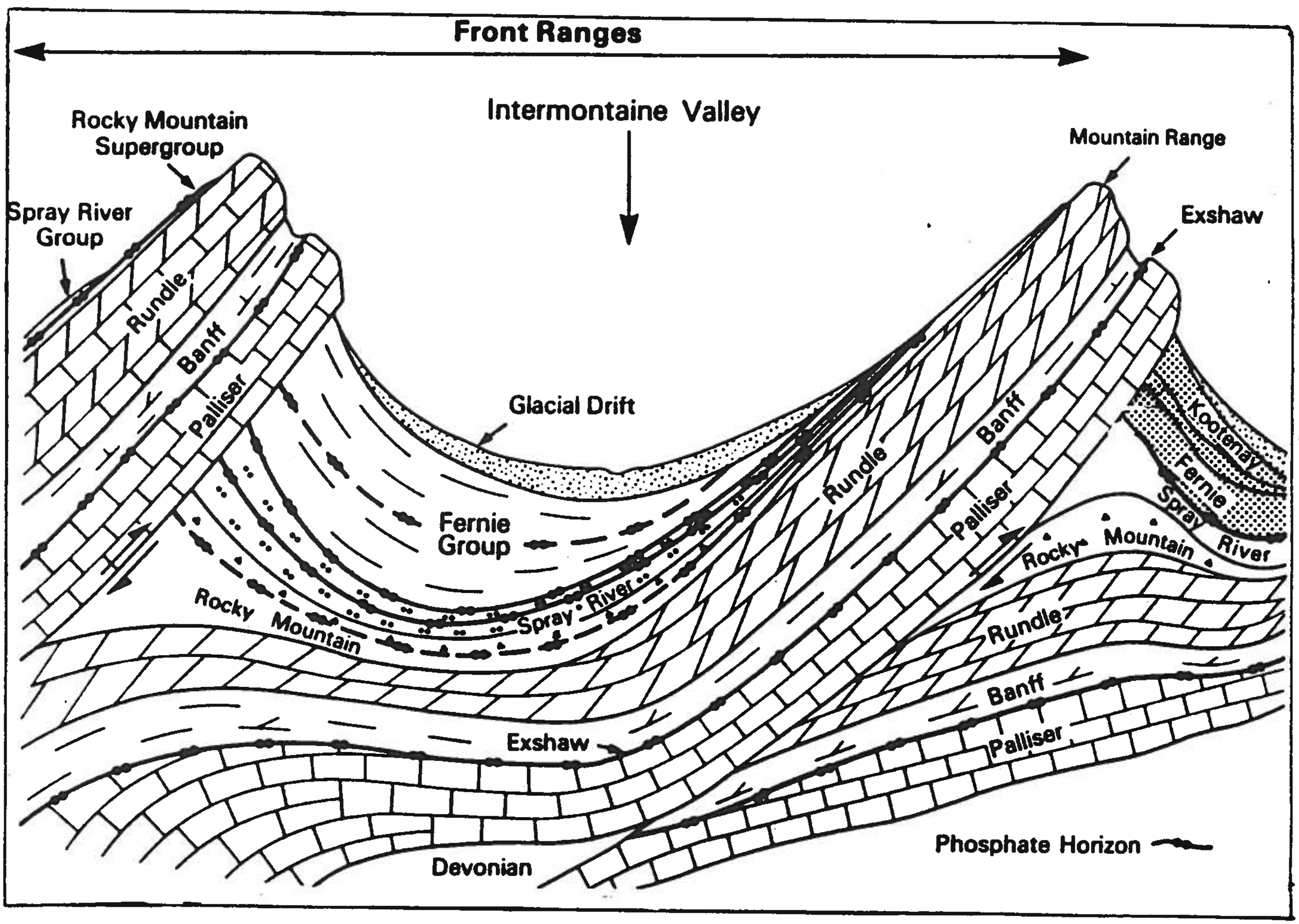

Figure 4. Idealized sketch of the Canadian front ranges and the typical structural/ stratigraphic setting of the main phosphate bearing units

Distribution of deposits

The ten main phosphate-bearing formations (figure 3) are exposed only within the Front Ranges and Foothills of the Cordilleran region. Outcrop configurations are typically narrow and lenticular, broken up and contorted along strike by folding and faulting. The distribution pattern is the result of the Laramide orogenic event that produced a series of low angle, imbricate, southwest to westward-dipping thrust faults - thereby breaking up geological formation outcrop patterns (figure 4).

Potential resources

Exshaw Formation. Phosphate deposits in the Exshaw Formation are found at the base, within, and at the top of the formation. The most important ones are found within the formation in the Crowsnest Pass region of Alberta. In this region phosphate grades are in the 6-10 percent P_2O_5 range for a minimum 1 m thickness. Grades tend to drop off to the north and south of Crowsnest Pass, with P_2O_5 values being in the 1-3 percent range for a 1 m thickness.

The structural/stratigraphic configuation of the Exshaw Formation, in the Crowsnest Pass is not a favorable one with respect to mining potential. Generally, the formation dips into the High Rock Range and has several hundred metres of Banff/Rundle Formation overlying (figure 4); open pit mining is therefore not feasable. Strip or slot-trench type mining may be possible in the main passes where the Exshaw subcrops at low elevations.

Permo-Pennsylvanian. Phosphate is present in all of the formations of the Permian-Pennslvanian Spray Lakes and Ishbel Groups (figure 3). The most important phosphates are within the Johnston Canyon Formation and at the base of the Ranger Formation, both of Permian age.

Phosphate within the Johnston Canyon Formation, in Alberta, has a limited lateral distribution, being confined to the area south of the town of Banff and entirely within Banff National Park. Phosphate grades are commonly greater than 13 percent P_2O_5 for a minimum 1 m thickness in this region. Low grade phosphatic rocks (1-6 percent P_2O_5) exist in the Kananaskis area. The best grades of phosphate within this formation in British Columbia.

One of the most widespread phosphate-bearing stratigraphic zones in Alberta is at the base of the Ranger Canyon Formation. This zone extends from Willmore Wilderness Park south to the Fernie Basin are in British Columbia. Figure 5 shows a map of best phosphate potential. In terms of potential, three localities in Alberta are worthy of mention.

North Saskatchewan River - Two areas, one centered on and one north of the North Saskatchewan River have grades in the 6-12 percent P_2O_5/1 metre range.

Kananaskis Park - Phosphate grades in this area are in the 6-12 percent P_2O_5/1 metre range.

Crowsnest Pass Area - a single deposit in this area showed phosphate grades of 12-18 percent P_2O_5 over a 2 m thickness.

Estimates of the phosphate resources potentially available in Alberta from the Johnston Canyon and Ranger Canyon Formations (that contain at least 6 percent P_2O_5/1 metre) were found by Macdonald, 1985 to be a maximum of 241 million tonnes. Ninety percent of this resource lies within currently restricted land use areas.

Fernie Group. Phosphate is found at the base of the Fernie Group, directly above an uncomformable contact with the underlying strata. The best phosphate potential for this horizon exists in the Fernie basin area of British Columbia, the Cascade River Valley (Banff Park), and the North Saskatchewan River region (figure 5).

Grade/thickness combinations are highest in the Fernie basin area of British Columbia (24 percent P_2O_5 for a minimum 2 m thickness) and decrease

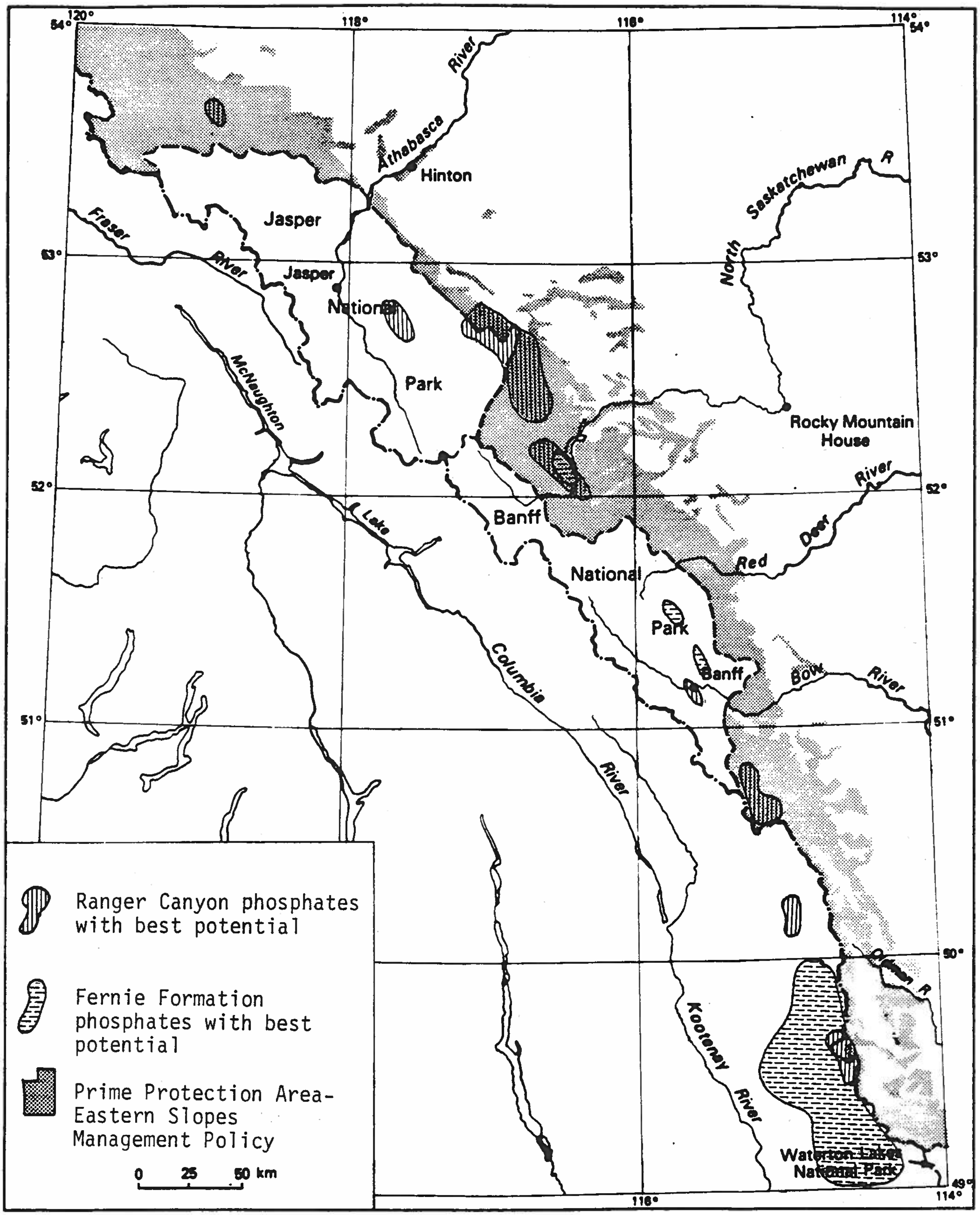

Figure 5. Phosphate potential in Alberta and southeastern British Columbia

northward into Alberta (6-12 percent P_2O_5 for a minimum 1 m thickness in the North Saskatchewan River region). The North Saskatchewan River region (excluding portions in Banff Park), have the best potential of this zone for Alberta. In the Cascade River Valley in Banff Park, phosphate rock reaches a maximum grade/thickness combination of 12-18 percent P_2O_5/1 metre. The best phosphate potential within the Fernie Group, and the overall best potential within Western Canada, lies within the Fernie basin region of southeastern British Columbia (figure 5).

The Fernie Group occupies a structural/stratigraphic/topographic position that is favorable to either open pit or underground mining (figure 4). The Group generally subcrops in intermontaine valley areas, at relatively low elevations, with dips somewhat flatter than those found in the mountain ranges, and the basal phosphate zone is overlain by soft shales. On the other hand, due to the incompetent nature of the Fernie, local structural folding, faulting, and near-surface creep can complicate mining conditions. Structural thickening of the phosphate zone by faulting is known to exist in the vicinity north of Crowsnest Pass.

The phosphate zone at the base of the Fernie Group is the only zone in Western Canada with economic potential for the foreseeable future. The amount of surface-mineable phosphate rock present in the zone is estimated to be 650 million tonnes within Alberta and British Columbia (Macdonald, 1985). About 60 percent of this resource lies within British Columbia as do the best grades of rock. In Alberta 59 percent of the available resource lies within the two national parks and only 3 percent lies in what is currently a potentially exploitable area in the Crowsnest Pass.

Research needs

Potential for phosphate rock is believed to exist in the subsurface of the plains region of Alberta. A geological evaluation needs to be undertaken to ascertain this resource potential.

TECHNOLOGY

Mining and processing

Phosphate rock in the western states (Idaho, Utah, and Montana) is found in highly deformed regions of the Rocky Mountain region, similar to the setting of Alberta phosphates. The mining method most commonly practised is open-pit. In the Florida region the phosphate deposits are flat lying and are found within very soft Tertiary-age sediments. Here the method most commonly practised is strip mining.

The first step in the processing of phosphate rock into the production of fertilizers is producing phosphoric acid. This is done by either the "dry" or "wet" process. In the dry process, phosphate rock is thermally reduced to elemental phosphorous in a furnace. The P is then oxidized to form P_2O_5 and finally absorbed in water to yield H_3PO_4. This process produces a very high quality acid, however the high cost involved usually precludes it as the most favorable method in making fertilizers.

The wet process involves acidulating raw phosphate rock (finely ground to 200 mesh sieve size) with a strong acid such as sulfuric, nitric, phosphoric or hydrochloric. Sulfuric acid is the one favored in Western Canada because of its low cost, high availability and lower corrosiveness. The resulting crystallized gypsum is removed and the "Filter Acid" (26 to 30 percent P_2O_5) is evaporated under vacuum to produce concentrated "plant phosphoric acid" (40 to 44 percent P_2O_5) or higher grade "commercial" or "merchant" grade acid (45 to 54 percent P_2O_5). "Superphosphoric" acid, though not widely produced in Canada, is formed by further concentration to the 69 to 72 percent P_2O_5 range. Plant phosphoric acid is then transferred to the fertilizer production units where varying amounts of ammonia are added. The final step is the formation of uniform size granules, and the drying of the granules. The overall production of ammonium phosphate fertilizers by the wet process is about 88 to 92 percent efficient in recovering the available P_2O_5 in the raw phosphate rock.

Research needs

The most important future research need in Alberta with respect to phosphate rock is in beneficiating low grade ores. Alberta fertilizer plants are set up to accept a fairly narrow range of high grade raw ore. This presents little problem at the present time, as this high grade of ore can probably be supplied at least until the turn of the century. If, however, imported rock becomes less certain, the Alberta and British Columbia sedimentary phosphate deposits may be considered for exploitation.

Another research need is in the area of in situ solution mining of phosphate rock. Several phosphate-bearing geologic units that crop out in the foothills/mountains region are also present at depth beneath the plains region of Alberta. Their potential for phosphate is undetermined, but at least one company in the province has looked into this subsurface potential and methods of in situ extraction.

ECONOMIC FACTORS

Prices and costs

Phosphate is a commodity of world trade and is priced on the International market. The price of phosphate rock showed a general overall increase up until 1975 (about U.S. $65.00/tonne for Morroccan 74 percent BPL), then dropped to around U.S. $48.50 during 1976 and has stayed at about this price to the present (June, 1986). Florida phosphate rock has shown a little more varibility since 1973, reaching a low of U.S. $36.26, to the present 1986 price of U.S. $50.20 (both for 74 percent BPL grade rock). Alberta fertilizer companies pay in the range Cdn. $70-85/metric tonne for phosphate rock delivered to the plant.

Transportation

Phosphate rock from Florida is transported to Alberta via cargo ships through the Panama Canal, up the west coast to Vancouver, and then by rail across the mountains. Sea going cargo vessel freight rates for phosphate rock vary between $U.S. 10-20/ton at the present time (June, 1986). Western U.S. phosphate rock is shipped to Canada via rail (figure 2).

OPERATING FACTORS

Environmental issues

Environmental issues relating to the mining and upgrading of the phosphate rock are mainly a concern for producers, in this case, the American producing companies. The main problem is in the beneficiating processes which produce large quantities of "slimes" that prove difficult to settle out of suspension ponds. Raw phosphate rock is rarely brought into Alberta, with most consumers purchasing an upgraded beneficiated product.

The main environmental concern for Alberta is a result of the processing of the beneficiated rock into phosphoric acid. Gypsum is produced in large quantities as a waste byproduct of phosphoric acid production and is disposed of in tailings piles at the present time. Attempts to find profitable markets for this material have been unsuccessful. The other area of concern from this processing area is the presence of low amounts of radioactive minerals commonly associated with phosphate rock. Uranium and other radioactive elements can become concentrated within the processing plant if proper monitoring is not adhered to.

A potential strategic consideration for Canada and Alberta with respect to phosphate rock is in the area of national self-sufficiency. All phosphate rock at the present time is imported from the U.S.A. End users in Alberta do not perceive this as a problem, as suppliers from the U.S. are considered to be reliable for the foreseeable future. Phosphate can also be purchased on the international market very easily. This consideration seems to be more of a concern for government than industry.

OUTLOOK

Supply and demand

Canada has been dependent on U.S. exports of phosphate rock since about 1912. No disruption of this supply is anticipated through the 1980's. By the year 1991, however, reserves of the better Florida rock will be exhausted, and leaner grade ores will be mined, so that exports will be a more upgraded and expensive product (Weaver and Thomas, 1978). By the next century it is anticipated that U.S. domestic demands will equal production capacity and available rock for exports will gradually drop off (U.S. Bureau of Mines, 1981).

At that time (2000 A.D.) Canadian consumers may have to look for alternate supplies of phosphate rock. The alternatives are several and include Mexico (which at the present time is trying to establish a phosphate mining industry based on the Baja California deposits), Morocco, and Africa in general (estimated to hold 68% of the world reserves of phosphate). Another alternative would be an examination of Canadian phosphate deposits, including the carbonatite-hosted apatite deposits of eastern Canada (e.g. Cargill or Nemegos deposits in Ontario), and the sedimentary phosphorites of Alberta and British Columbia.

The demand for phosphate rock is not expected to increase significantly in the foreseeable future. A steady demand, with growth rates of 3.5 to 4.5% annually after 1986 is predicted (Barry, 1986).

Potential new markets

Phosphates contain significant amounts of a number of potentially exploitable elements, which could be extracted as byproducts. Uranium, vanadium, fluorine and a number of rare earth elements are most commonly reported. Uranium has probably the best potential for receovery as a byproduct in a phosphate processing plant. Uranium is easily extractable in phosphate rock acidizing procedures (DeVoto and Stevens, 1980) and one fertilizer plant in southern Alberta is doing this, from imported phosphate rock (Energy, Mines and Resources, 1982). Phosphate rock from Alberta was found to have a mean uranium value of 34 ppm (Macdonald, 1985).

Vanadium is currently produced as a byproduct in one phosphate mine in Idaho (Kuck, 1983). Alberta phosphates were found to have vanadium values in the 46 to 255 ppm range (Macdonald, 1985). However, the vanadium market is somewhat slumped as world production exceeds demand.

Fluorine is recovered as flurosilic acid from two phosphate rock processing plants in Canada (Erco Industries, Ontario; Cominco Ltd., British Columbia-Boyd, 1980) and eleven plants in the U.S.A. However, most fluorine available from phosphate processing plants is not recovered and is usually dumped in settling ponds.

A number of rare earth elements (REE) are found in phosphates in anomalously high quantities. Two of the main problems seen by producers in recovering any of these potential byproducts is the cost, and whether the removal of any of these elements will upset the end products (i.e. the fertilizer) effectiveness.

Summary of research needs

The development of a local, low cost source of phosphate rock is one of the phosphate fertilizer industries' major concerns. Transportation costs involved in moving phosphate rock from U.S. or other international markets are substantial, even when there is an overabundance of phosphate rock worldwide. There is a need to examine the surface and subsurface phosphate deposits in southeastern British Columbia, and to a lesser extent, the subsurface deposits of the plains region of Alberta.

The development of new, cost efficient mining methods may be another area of future research. This may lead to new methods such as the previously mentioned in situ leaching technique that has been proposed by at least one company.

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The Metallic and Industrial Minerals of Alberta
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SILICA

by

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SILICA

INTRODUCTION

Background

Alberta has significant production of industrial sand which is marketed as "silica sand", but which is a comparatively low grade material serving a variety of specialized industrial applications. Requirements for high-grade silica (primarily for use by the provinces's glass industry) are met by imports, although local undeveloped sources exist. This report examines possibilities for development of high-grade silica sources in Alberta, and for expansion in the production of lower grade silica sand for the various industrial markets it serves.

Definition of terms

The term "silica" refers to the compound silicon dioxide (SiO_2), which occurs naturally in several distinct mineral forms. Quartz is by far the most common form and essentially the source of all industrial silica. It is exploited from three principal rock types; sandstone, quartzite, and vein or pegmatitic quartz.

Sandstone and quartzite are the rock types most widely exploited. The term "sandstone" refers to a sedimentary rock comprised essentially of sand-sized grains of quartz and other minerals, cemented by silica, calcite, clay or various other cementing agents. Much commercial high-silica sandstone is only weakly cemented and is easily disaggregated into "sand", one of the chief commodity forms of silica.

In addition to quartz, mineral particles may consist of feldspar, mica, iron oxides, heavy minerals, chert and rock fragments. Qualifier terms silica sand, quartz sand, and industrial sand denote sands with an uncommonly high quartz content and few impurities; these terms are interchangeable to some extent, although silica sand has a higher purity connotation, implying greater than 95 percent SiO_2 (McLaws, 1980). They all refer to sands with special chemical and/or physical attributes for industrial applications, as opposed to sands used for aggregate and general construction purposes.

A sandstone subjected to metamorphism may be transformed into a "quartzite". In this rock type, individual quartz grains have been compressed and welded together into a crystalline mass, which must then be crushed for its various uses as industrial silica. Quartzites, like sandstones, can be very pure or can include various mineral grain and cementitious impurities.

Specifications

Specifications for industrial silica vary with the many end uses. The major uses and important specifications are summarized below (Anon., 1976) and in table 1. Most of these have some present application in Alberta.

Table 1. Main uses and general specifications for silica (from Coope and Harben. 1977

End use	min SiO_2	max Al_2O_3	max Fe_2O_3	max CaO/MgO	Grain size	Remarks
Glass sand						
Optical	99.5	variable	0.008		0.1–0.5mm.	Must be less than 6 ppm chromium and 2 ppm cobalt. 0.01–0.05% TiO_2. Grain size and purity constant.
Colourless domestic	99.5	variable	0.013		0.1–0.5mm.	
Container/flat	98.5	0.1–0.5	0.030		0.1–0.5mm.	
Foundry sand	88–99	Extremely variable			20–200 mesh	Chemical composition variable; 98–99% SiO_2 now preferred. Sub-angular to rounded grains.
Silica flour	97–98	0.5	0.2		micron sizing	
Silicon carbide	99.5	0.06–0.25	0.1	absent	+100 mesh	No phosphorus allowed. 0.25% Al_2O_3 sand for black SiC, 0.1% for green SiC.
Silicon	98.0	0.4	0.2	0.2 each	>1 inch diameter	No phosphorus or arsenic allowed.
Ferrosilicon	96	0.4	0.2		>1 inch diameter	0.1% phosphorus maximum.
Silica brick (refractory)	96–98	0.1		low	–8 mesh	
Sodium silicate	99	0.25	0.03	0.05	20–100 mesh	Broadly the same specifications as glass-grade sand.
Silica flux	90	1.5	1.5	0.2	<5%—? inch	

The above figures are general indications only

The principal uses for industrial (silica) sand are as glass sand, foundry and metallurgical sand, as abrasives, fillers, filtration sand,

and hydraulic fracturing (proppant) sand. In all cases, the sands fulfil their requirements on the basis of their quartz composition. In some, the sands enter into a chemical reaction and are valued for their chemical (SiO_2) purity; in others, they are valued for their physical properties (hardness, grain strength, refractoriness, etc.) which also relate to quartz (silica) purity.

Glass sand must meet rigid specifications with respect to SiO_2 content. Freedom from iron oxides and chromium compounds (or other impurities that act as strong colorants) is critical. Grain size is also closely specified.

Foundry sands must offer resistance to high temperatures, and their particle size and grading are important. For abrasive uses (sandblasting, stone sawing, etc.), purity specifications vary with the type of abrasive action but generally call for high silica content, with sound and closely sized sand grains.

Silica sand used for filler applications must be very pure and have a high degree of brightness and reflectivity when finely ground. Uses and specifications for silica in fillers are given in table 2; non-filler applications for ground silica are given with specifications in table 3.

In hydraulic fracturing sand, the principal requirements are for grain size and shape, and compressive strength. A high degree of grain roundness is of critical importance.

A major use of quartzite as industrial silica is in the production of ferrosilicon and silicon metal. Here, silica is required in a form called "lump silica", obtained by crushing quartzite, well indurated sandstone or vein quartz into lumps 20 mm to 150 mm in diameter. Requirements are for high-silica purity (98 percent SiO_2 or better), no phosphorous, arsenic or sulphur, less than 0.2 percent each of lime and magnesia, and a very low alumina content (Harben and Bates, 1984). The use of lumps reduces the surface area of the quartz, where much of the

Table 2. Major filler uses and specifications for silica (from Guillet and Kriens, 1984).

Applications	Function	General Specifications
Paint	Silica is used in paints to provide good scrubbability and film toughness. In exterior paints, it provides good weathering. Used in block fillers, porch and floor enamels and traffic paints.	Grades ranging from 325 mesh to 10 microns are used. Some cryptocrystalline grades of silica have very fine sizes with low average particle size. Silica ground from crystalline silica usually has a higher average particle size. High brightness and low oil absorption is essential.
Plastics	Silica is used in different polymer systems. Silica provides excellent dielectric properties, compression and flexural strength. It is used in potting compounds made from epoxy or polyester resins.	Natural or cryptocrystalline grades of silica are used in plastics. Some grades are surface coated or treated with coupling agents to aid dispersion and better bonding with the polymer. High brightness grades of 325 mesh to 5 microns are used.
Putty, Caulks, Sealants	Finely ground silica is used in epoxy based sealants and silicone caulking compounds. Used in electrical applications, silica provides good dielectric properties and has low binder demand allowing high loading levels.	Fine grades of 10 to 30 microns particle size are used in this application. High brightness is required.
Rubber	Finely ground silica is used in silicone rubbers as an extender pigment.	Fine, 30 to 10 micron products are used. High brightness is important.
Adhesives	Finely ground silica is used in the compounding of vinyl adhesives.	Fine ground 40 to 10 micron grades.
Wood fillers	Finely ground silicas are used in paste wood fillers.	Grades from 30 to 5 microns.

Table 3. Major non filler uses and specifications for ground silica (from Guillet and Kriens, 1984).

Applications	Function	General Specifications
Ceramics	Finely ground silica is a major ingredient in many ceramic products such as sanitary ware, dinnerware and electrical porcelain.	Grades from 200 to 400 mesh. High purity, low iron, white firing.
Glass	Fine silica is used in the manufacture of reinforcing and textile fiberglass in which it is a major constituent of the glass batch.	325 mesh grade. Low in iron and alkalies.
Bricks	Finely ground silica is used in the manufacture of silica-lime brick.	200 mesh silica. Low purity is adequate.
Concrete block	Fine silica is used in the manufacturing of autoclaved concrete block.	100 to 200 mesh silica of low purity.
White cement	Fine silica is used in the manufacture of white cement.	200 mesh product. Medium purity.

contamination comes from. Physically, the silica needs to be tough material that will not crumble in the furnace, and must contain no fines.

Quartzite is used also as a source of glass sand and other silica sand applications in which exceptionally high silica purity is required. The quartzite must be crushed and sized to the specified particle sizes, but for many sand uses the sharp angular nature of the particles thus produced is not suitable.

INDUSTRY SETTING

Canadian production and consumption

Canada's silica industry is dominated by Ontario and Quebec, which had a combined production of 1.7 million tonnes out of a total for the country of 2.5 million tonnes in 1985. Breakdown of Canadian production by regions is shown in table 4. Most of the silica is consumed within the region of its production. Consumption for the country as a whole exceeds production, so about 1 million tonnes are imported annually (mostly from the USA). Canadian consumption of silica by use is shown in table 5.

Table 4. Silica Production in Canada by Regions

	1982		1984		1985	
	tonnes	$000 (Ave.$/t)	tonnes	$000 (Ave.$/t)	tonnes	$000 (Ave.$/t)
Western Canada	353,153	5,965 (16.89)	521,000	9,589 (18.40)	546,000	11,377 (20.84)
Ontario	438,394	8,227 (18.77)	1,147,602	12,125 (10.57)	1,013,460	11,929 (11.77)
Quebec	661,000	x	763,515	14,703 (19.26)	738,000	15,428 (20.98)
Atlantic Provinces	250,415	x	227,000	4,428 (19.51)	240,000	5,322 (22.18)
Total	1,702,962	31,864 (18.71)	2,658,932	40,845 (15.36)	2,537,884	44,110 (17.38)

Source: EMR Canada, Statistics Canada

x Not published

TABLE 5. Canadian Silica Production and Consumption by Use 1982[1]

	tonnes	$000	(Ave. $/t)
PRODUCTION			
Glass and fiberglass	430,000	11,906	(27.69)
Flux	391,000	2,114	(5.41)
Ferrosilicon	155,000	925	(5.97)
Other[2]	727,000	16,919	(23.27)
Total	1,703,000	31,864	(18.71)
CONSUMPTION			
Glass and fiberglass	1,120,565		
Flux	387,482		
Foundry sand	336,119		
Refractory brick mixes, cements	262,541		
Matallurgical	164,987		
Concrete products	149,539		
Artificial abrasives	112,785		
Chemicals	36,877		
Fertilizer, stock poultry feed	3,398		
Gypsum products	2,878		
Other[3]	46,092		
Total	2,623,263		

Source: EMR Canada, Statistics Canada

1 Latest year of available figures for breakdown by use.

2 Includes foundry, sandblasting, silica brick, concrete products, cement manufacture, building products and silicon carbide.

3 Includes asbestos products, ceramic products, frits and enamels, paper and paper products, roofing and other minor uses.

Western Canada

In Western Canada, silica production occurs in all four provinces. All the production is consumed within the region, the largest market being the glass industry. Current major producers and consumers in Western Canada are summarized in table 6. The regional setting with respect to markets and sources is shown in figure 1.

The best known and most exploited silica source in Western Canada is the Black Island silica sand deposit in Manitoba. This has been the major source of high-grade silica for the region since the mid 1960s. Prior to that, the requirements were met by imported sand, mostly from Illinois (McLaws, 1980). In the last decade, new sources have been developed in British Columbia and Alberta to serve specific local markets. Recently (June, 1986), an announcement was made of a new deposit of silica sand in Saskatchewan (the "Red Deer River" deposit) to be brought on production, mainly for the foundry and sandblasting sand market (P. Guliov, personal communication).

Alberta production, uses and markets

In Alberta, the main silica-consuming industries are the container glass and fiberglass industries (table 6). Other principal uses are in oilwell hydraulic fracturing, in foundries, and for sandblasting. Except for hydraulic fracturing, all of the requirements are now met by silica sand produced in Western Canada, although only about two-thirds is produced within the province. The rest is mostly from Selkirk, Manitoba (the Black Island deposit). Alberta has no current consumption (nor production) of lump silica.

Figures on consumption of silica sand by Alberta's glass industries are not published, but are estimated to be about 120,000 tpa. About 40,000 tonnes comes from Manitoba, supplying the Domglas plant at Redcliff and other smaller markets. The Manville Canada Inc. plant at

Table 6. Silica Mining, Processing and Consuming Operations in Western Canada 1986

COMPANY	LOCATION	OPERATION	PROCESS	PRODUCTS	CAPACITY	SI SO
MANITOBA						
Inco Ltd.	Manasan[1]	Open-pit mining	Crushing, sizing	Flux sand		
Steele Bros. Canada Ltd.	Black Island,[2] Lake Winnipeg	Open-pit excavation	Washing, attrition	Silica sand	1500 tpd	
	Selkirk	Sand processing plant	Drying, screening and blending	Silica sand	450 tpd	
SASKATCHEWAN						
Hudson's Bay Mining & Smelting	Flin Flon[3]	Surface excavation	-	Flux sand	125,000 tpa	
Red Deer Silica Inc.	Armit[4]	Surface excavation & processing	Drying, screening and bagging	Silica sand	3.3 million tpa (proposed)	
ALBERTA						
SIL Silica Ltd.	Bruderheim[5]	Surface excavating & processing	Washing, drying, screening, magnetic separation	Silica sand	400 tpd	
Altaglass	Medicine Hat	Glass manufacture	Hand-made, blown glassware	Artistic glass products		
Domglas Ltd.	Redcliff	Glass manufacture	Gas and electric regenerative furnaces	Glass containers	146 million pieces/year	2,
Fiberglas Canada Ltd.	Edmonton	Fiberglass manufacture	Gas furnace	Glass fibre insulation	24,000 tpa	
Mannville Canada Inc.	Innisfail	Fiberglass manufacture	Electric furnace	Glass fibre insulation		
BRITISH COLUMBIA						
Bert Miller Contracting	Nicholson[6]	Open-pit mining & processing	Crushing, sizing, washing	Lump silica (quartzite)	40,000 tpa	
Mountain Minerals Ltd.	Golden[7]	Open-pit mining & processing	Crushing, screening, washing	Silica sand	50,000 tpa	
Pacific Silica Products Ltd.	Oliver	Open-pit mining & processing	Crushing, sizing, washing	Roofing & stucco chips, filter sand, decorative and blasting sand	90 tpa	
Consumers Glass Ltd.	Vernon	Glass manufacture	Gas regenerative furnaces	Glass containers	95,000 tpa	
Domglas Ltd.	Burnaby[8]	Glass manufacture	Gas & electric regenerative furnaces	Glass containers		
Fiberglas Canada Ltd.	Mission	Fiberglass manufacture		Glass fibre insulation		

[1]Used as flux in Thompson smelter
[3]Used as flux in Flin Flon smelter
[4]New development 1986

[6]Exported to Washington state for ferrosilicon manufacture
[8]Plant closed in 1985
[9]Imported silica sand from USA

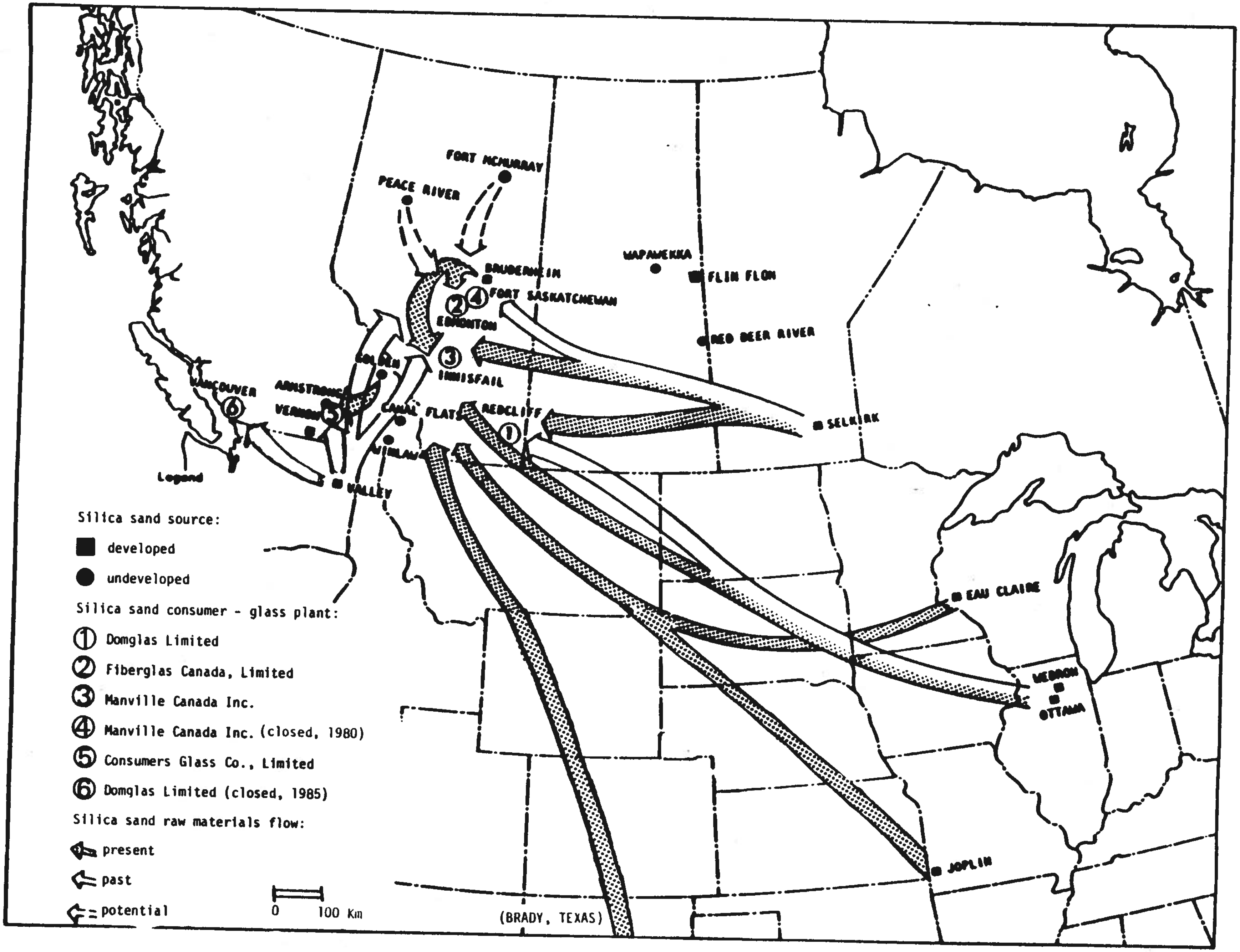

Figure 1. Markets and sources for silica sand - Alberta and Western Canada

Innisfail and the Fiberglas Canada plant at Edmonton use silica sand supplied by SIL Silica Ltd. from local sources.

Consumption of silica for other uses is highly variable. In hydraulic fracturing it has ranged as high as 45,000 tons in 1977 (McLaws, 1980), but has declined since 1983 to where it is currently negligible. Frac sand is a premium quality product and most of it has been imported from Texas. Foundry sand is consumed in Alberta foundries at a rate of about 5,000 tpa, most of it from Manitoba. Sandblasting uses approximately 30,000 tpa, supplied largely from local sources.

GEOLOGY AND RESOURCES

Silica occurs in at least seven distinct mineralogical forms (Murphy, 1975), but by far the most common of these is quartz. Most quartz originated in igneous rocks as a late crystallized phase from a silicate melt. Some originated as hydrothermal deposits in veins and fissures. However, the quartz of commerce is largely sedimentary quartz, derived from older sources by erosion, redeposition and compaction. Because quartz is one of the hardest, most abrasive and chemically stable of minerals, it resists chemical and mechanical breakdown and will survive repeated geologic cycles of reworking.

Geologic setting

Sedimentary quartz is the main type of silica occurrence in Alberta. The province lies largely in a sedimentary geological regime (the Western Canada sedimentary basin) where vein or pegmatitic quartz is not found, but sandstones and quartzites are common. The sandstones are mainly in Mesozoic strata and the quartzites in lower Paleozoic and Precambrian strata.

Sandstones in Alberta typically contain an abundance of detrital impurities - mostly clays, feldspars, iron oxide minerals, rock fragments, and chert. Although chert is a form of silica, it is considered an impurity because of undesirable properties related to its cryptocrystalline texture (dark colour, brittleness, etc.).

Unconsolidated surficial sand deposits of Pleistocene age are widespread in Alberta. These sands originate mostly as stream deposits of glacial meltwater and have a high content of impurities - mainly granitic disintegration products. Reworked beach and dune sand deposits derived from glacial sands are naturally sorted, resulting in some enrichment in quartz content. Some of these deposits qualify as industrial sands for low-grade silica markets.

Potential resources

Table 7 outlines the potential sources of industrial silica in Alberta. These are divided into two groups - bedrock and surficial - and classified according to their depositional origin (McLaws, 1971). Locations of known deposits (developed or undeveloped) and areas of potential are plotted in figure 2.

Table 7. Potential sources of industrial silica in Alberta (from McLaws, 1971)

Type of Material	Stratigraphic Position		Origin		
			Fluvial	Shoreline	Aeolian
Surficial (sands and gravels)	Recent	Postglacial	alluvial	lacustine	dunes
	Pleistocene	Glacial	outwash	lacustrine	
		Preglacial	Saskatchewan Sands and Gravels		
Bedrock (sandstone and conglomerate)	Tertiary		Cypress Hills conglomerate		
	Mesozoic		McMurray Formation	marine sandstones	
	Paleozoic and Late Precambrian			quartzites	

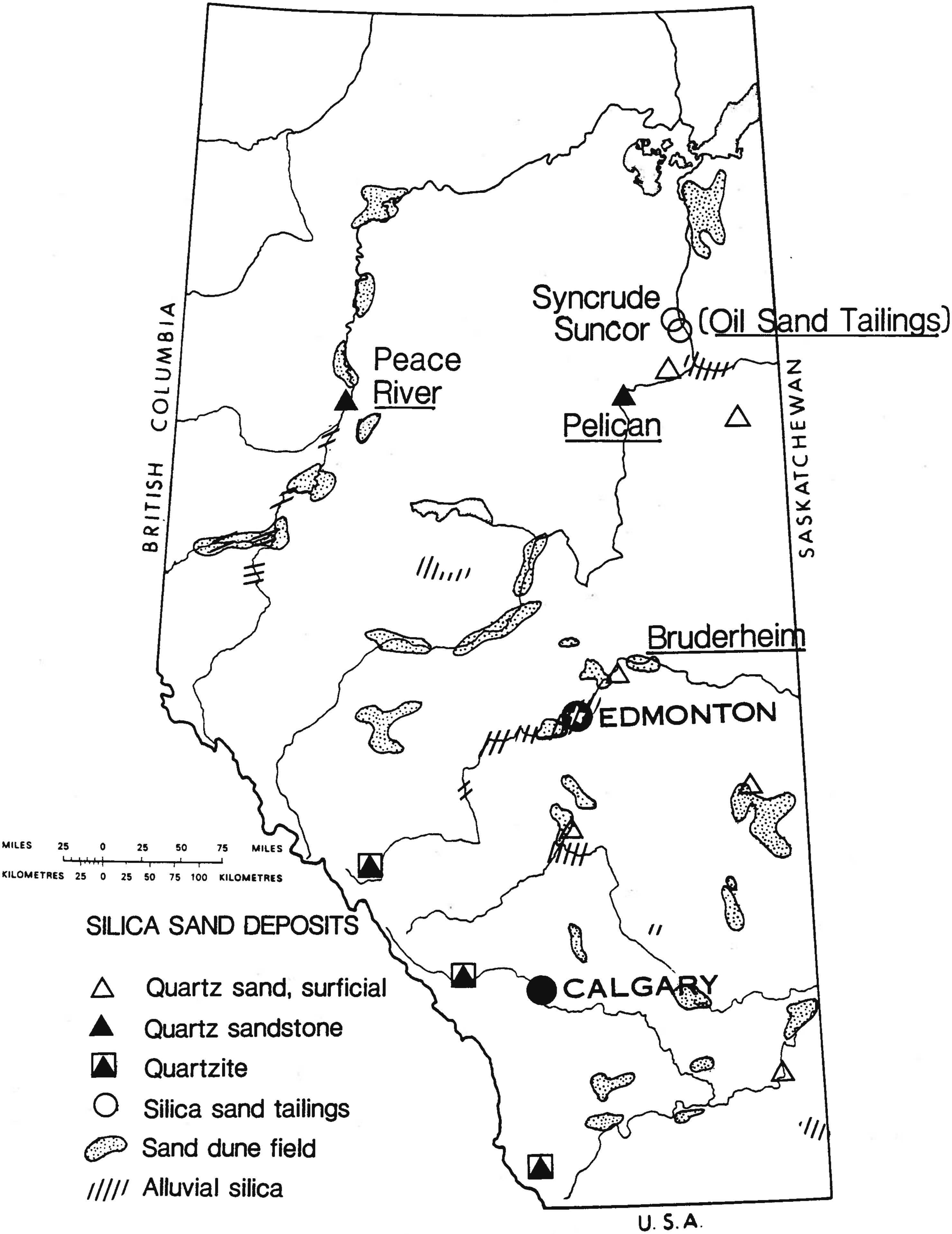

Figure 2. Silica sand deposits in Alberta

1. Bedrock sources

Quartzites occur in several formations of Paleozoic and Precambrian ages in Alberta, mostly in the Rocky Mountains. The quartzites that have potential include the Precambrian Appekunny and Grinnell and the Cambrian Flathead Formations - all in the Clarke Range area south of Crowsnest Pass, the Cambrian Gog Group in the David Thompson Corridor region, and the Pennsylvanian Spray Lakes Group ("Rocky Mountain Quartzite") in the Canmore Corridor region. None of these units has been evaluated.

The Ordovician Mount Wilson Formation is an excellent quartzite unit and a proven silica source in southeastern British Columbia. However, known exposures in Alberta are confined to the National Parks.

Marine sandstones with exceptional quartz purity are present at several localities in northern Alberta. Of Cretaceous age, these sandstones are poorly cemented and friable, composed of well sorted, subrounded quartz grains deposited probably as beach sands along the margins of Cretaceous seas. The best known deposit is in the Peace River Formation, and is described further below. Similar sandstones outcropping on the lower Athabasca River southwest of Fort McMurray (Pelican Formation) have not been tested for silica sand potential.

The McMurray Formation, host rock of the Athabasca oil sands, is exposed along the Athabasca River near Fort McMurray. Sandstones of this unit are dominantly of continental origin, deposited as channel sediments in a major Cretaceous northwestward-flowing fluvial system (Flach and Mossop, 1985). The sandstones are highly quartzose, with minor feldspar and mica impurities (Carrigy, 1966).

Interest in the McMurray Formation is not so much for the sandstones directly as for the tailings they give rise to when processed for bitumen extraction. Oil sand tailings are discussed further below.

Other Cretaceous non-marine sandstones of fluvial and fluvial-deltaic origin may have silica potential, but are untested. Of particular interest would be any sandstone units having a strong marine influence (e.g., basal Horseshoe Canyon Formation sandstone).

Cypress Hills Conglomerate forms a Tertiary bedrock cap on the upper slopes of the Cypress Hills in southeastern Alberta. It is composed mainly of quartzite pebbles and boulders cemented by calcareous sandy material (Vonhof, 1965). The pebbles, derived from erosion and redeposition of older quartzite formations, are the potential source of silica. The deposit has been evaluated for its silica potential in Saskatchewan (Guliov, 1975) where the main body of conglomerates lies, but has not been tested in Alberta. Similar Tertiary deposits cap the Hand Hills northeast of Drumheller, and the Swan Hills south of Lesser Slave Lake.

2. Surficial sources

Surficial sands and gravels overly bedrock or other unconsolidated deposits of Pleistocene and Recent ages in many areas of Alberta. Most are of glacial origin or derived from glacial deposits and vary widely in composition. Few are sufficiently high in quartz to be a source of silica sand, but some - with beneficiation - have found acceptance for lower grade silica sand applications.

"Saskatchewan Sands and Gravels" are preglacial deposits lying between bedrock and glacial deposits in various parts of central and southern Alberta. Of fluvial origin, they consist dominantly of quartzite particles but also have a high proportion of sedimentary rock fragments (Stalker, 1963). Their value is solely as construction aggregates.

Outwash sands and gravels are glaciofluvial sediments deposited marginal to a melting ice sheet. Widely distributed in Alberta, these deposits are generally poorly sorted with a high proportion of feldspar and rock fragments, and have little potential as a source of silica.

Some have found limited use as abrasives, mainly for sandblasting.

Lacustrine sands deposited along the shorelines of preglacial lakes are common in certain areas of Alberta, derived mostly by reworking of glacial outwash deposits. They are generally better sorted and cleaner than the parent materials and, consequently, could be a potential source of silica sand where they form extensive deposits.

Dune sands are common in many parts of Alberta. Of wind-blown origin, the sands generally are well sorted, fine grained, and more siliceous than their parent glacial deposits. The accessibility, texture, and relative purity of these sands make them acceptable for a variety of industrial sand uses in Alberta (Carrigy, 1970). Sands of this type used for fiberglass manufacture are discussed further below.

Alluvial sands and gravels are found along most of Alberta's river valleys, in the river bed and as older terrace deposits above the present river levels. Investigation of the coarser (pebble) fractions of these deposits indicate that the more quartzose gravels may have some potential as a source of industrial silica (Halferdahl, 1969)

Known deposits

Quartzose deposits in Alberta that show the best industrial silica potential of those that have been evaluated include the Peace River "glass sand" deposit, the oil sand tailings (McMurray Formation) sand, and some of the widespread dune sands. The silica composition and properties of these deposits are summarized in table 8. Only the dune sands have had any development to date.

The Peace River deposit occurs as a friable zone 12 to 18 m thick at the top of a marine sandstone unit in the Cretaceous Peace River Formation (Crockford, 1949). The sandstone unit is exposed as

Table 8. Summary of Properties of Alberta Silica Deposits*

DEPOSIT/LOCATION	Chemical Analysis (%) SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Sieve Analysis (% retained) 20	40	50	70	100	140	200	Pan
Peace River Formation sandstone[1]	98.44	.18	.73	.04	Tr	8.8	17.9	34.1	19.4	12.9	5.9	.6	.4
Oil sand tailings (1)[2]	97.60	.18	1.07	.05	.02	1.7	2.1	5.1	15.2	41.5	21.3	8.5	4.6
(2)	98.36	.05	.89	.01	.01								
McMurray Formation sandstone[3]	96.72	.23	1.07	.11	.09	1.5	2.1	5.7	38.7	36.4	9.3	2.1	4.2
Clearwater dune sand[4]	97.66	.13	.91	.11	.06	.1	3.3	26.2	50.6	16.4	2.6	.4	.4
McMurray dune sand[5]	93.32	.73	3.02	.44	.19	.1	.4	3.2	25.2	42.7	17.5	4.1	6.8
Bruderheim dune sand[6]	92.06	1.11	3.76	.49	.30	-	.4	11.1	55.5	21.8	6.7	2.1	2.4
Red Deer dune sand[7]	87.15	1.53	5.74	.66	.40	.7	5.2	22.4	39.3	16.6	7.0	2.3	6.5
Medicine Hat dune sand[8]	86.55	1.27	5.24	1.39	.30	1.3	17.6	28.1	24.3	17.4	5.8	1.4	4.1

DEPOSIT/LOCATION	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	(% retained - mm) 128	64	32	16	8	4	Percent Gravel[11]	Percent Quartzite[12]
Athabasca River alluvial quartzite (3)[9]	96.85	.35	.05	.13	.23	-	20.9	23.1	25.8	6.7	2.2	76.5	96.6
(4)	97.73	.23	.00	.18	.23	-	20.5	23.0	24.8	5.6	-		
North Saskatchewan River alluvial quartzite (3)[10]	90.66	.68	.95	2.86	.72	2.4	16.9	24.8	20.2	13.6	4.8	77.9	82.4
(4)	94.95	.55	.10	1.46	.50	2.4	14.7	22.3	15.4	9.4	2.4		

* Analyses are for raw bulk samples except where otherwise indicated.

1 Weighted average for 3 sample sites in deposit 7 - 12 m thick (Crockford, 1949).
2 GCOS (Suncor) plant tailings (McLaws, 1980).
(1) untreated except for removal of oil residue
(2) washed modal fraction
3 Weighted average for 19-m section, High Hill River (McLaws, 1980).
4 Samples 17 and 18 (McLaws, 1980).
5 Sample 26 (McLaws, 1980).
6 Sample 4 (Carrigy, 1970).
7 Sample 9 (Holter, 1972).
8 Sample 4 (Holter, 1971).
9 Sample 576 (Halferdahl, 1969).
(3) includes all lithologies in gravel.
(4) quartzites only.
10 Sample 253A (Halferdahl, 1969).
11 Weight percent of sample in size fraction > 8 mm.
12 Weight percent of quartzite in +8 mm fraction.

flat-lying, cliff forming beds along the Peace River valley, 11 km north of the town of Peace River. The deposit, a localized beach facies of the main sandstone unit, consists of a relatively pure quartz sand of variable texture, easily upgraded to glass sand quality.

Interest in this deposit dates back to the 1940's and efforts to develop it as a glass sand source have been made from time to time. Its relatively remote location has prevented development to date. Rights to the deposit are currently held by Peace River Industrial Resources Limited, which has carried out considerable private evaluation of the deposit, including test drilling. Reserves are claimed to be in excess of 1 million tonnes.

Oil sand tailings, the tailings sand from the oil extraction process, grades 98 percent silica without any treatment and is probably the best potential source of high grade silica in Alberta (Hamilton, 1976). The sand is derived from the Cretaceous McMurray Formation, a potential silica source in its own right. However, the tailings sand is a more favourable source because of its availability (i.e., already "mined") and because it has had some beneficiation in the processing, through incidental removal of mica and heavy minerals. Even so, further beneficiation is required to eliminate "fines" and residual oil film (McLaws, 1980).

"Reserves" of oil sands tailings are enormous. A single day's production from one plant could yield 150,000 tonnes of tailings, which exceeds Alberta's total annual silica sand market.

No development of this source has occurred, mainly because of its remoteness from existing markets - particularly glass making. From a quality standpoint, it compares favourably with established commercial sources (table 9).

Table 9. Comparison of beneficiated oil sand tailings with imported glass sands used in Alberta (from McLaws, 1980)

Source	Constituent (Wt. %)			
	SiO_2	Fe_2O_3	Al_2O_3	TiO_2
Fort McMurray, GCOS	99.10	0.07	0.66	0.06
Acid treated	-	0.02	-	0.04
Selkirk, Manitoba	99.19	0.01	0.00	0.08
Valley, Washington	99.43	0.03	0.011	0.05

Dune sands are widely distributed in Alberta. The deposits are mostly of Recent age, derived from adjacent glacial sands laid down during late Pleistocene time. After the ice receded, but before a cover of vegetation was established, much of this sand was reworked locally by wind, forming extensive sand dune fields in which individual dunes range from 3 to 15 m in height (Carrigy, 1970). Because of their wind-blown origin, the dune sands normally are cleaner, more quartzose, and better sorted than their parent materials.

Alberta's dune sands have been tested in several localities and consist of well sorted, fine grained sand. Mineral composition and texture are variable, however, depending on the nature of the parent material. Quartz contents range mostly from 85 to 95 percent, with impurities comprising feldspar, chert, mica and dark minerals. In a very general way, the dune sands show improvement in silica quality from south to north (table 8). Dune sands in the Fort McMurray area (McLaws, 1980) are of higher quality than those in the Edmonton area (Carrigy, 1970), which in turn, are better than the dune sands in the Red Deer and Medicine Hat areas (Holter, 1972, 1971).

The only development of dune sands is in the Edmonton area. SIL Silica Ltd. produces a silica sand product primarily for fiberglass from sand dunes near Bruderheim, 35 km northeast of Edmonton. The sand is washed, screened and dried but otherwise unbeneficiated (Guillet and Kriens, 1984).

Exploration

Many of the potential sources discussed above are geologically mapped, but are untested. Exploration for a commercial silica source would involve specific geological studies of the potential sources, to identify quarriable sites favourably located with respect to transportation and markets. The next step is field sampling by appropriate methods depending on the nature of the quartzose material, followed by laboratory analysis. Analyses routinely performed include chemical, mechanical, and petrographic (mineralogical and textural). Local geological site conditions are also appraised.

The best exploration prospects for high-grade silica in Alberta are the Cambrian quartzites in the David Thompson Corridor, and the Cretaceous marine sandstones of the Pelican Formation outcropping in the Athabasca River valley southwest of Fort McMurray. The latter, although not easily accessible at present, is closer to potential Edmonton markets than most other sources. Another worthy prospect, because of its good location and access, is the Pennsylvanian quartzite outcropping in the Canmore Corridor.

The ideal exploration target for silica is a marine transgressive sandstone unit, where the objective would be to locate a beach facies of the unit. Alberta has few (if any) prospects specifically of this kind (other than the Peace River deposit), but the Pelican Formation comes close. Similar environments may exist in the basal sandstones of some of the Cretaceous non-marine units (e.g., Horseshoe Canyon Formation).

Research Needs

1. Resource studies are needed to evaluate a number of potential industrial silica sources in Alberta that are untested. These should include geological investigation and identification of favourable sites for development, followed by field studies and thorough sampling and analyses, with assessments of beneficiation needs for each prospect. Initially, these studies should focus on sources identified as the best exploration targets:

   (a) Cambrian Gog Group quartzite sections in the David Thompson Corridor region,

   (b) Cretaceous Pelican Formations sandstones on Athabasca River southwest of Fort McMurray,

   (c) Pennsylvanian "Rocky Mountain Quartzite" sections in the Canmore Corridor region.

2. A compendium study is needed to collate and synthesize all published and unpublished information existing on numerous scattered silica occurrences in Alberta. The study would have the objective of establishing regional geological trends and models for siliceous units in the province. These models, refined with data from new studies as completed, would provide a predictive capability for silica resource potential in untested areas.

TECHNOLOGY

Mining

Methods of mining of silica materials vary widely, depending on the nature and location of the deposit. Open-pit excavation of friable sandstones or unconsolidated sands, and conventional quarrying of harder sandstones and quartzites, are the usual practices for silica operations in Canada (Guillet and Kriens, 1984). At the SIL Silica Ltd. operation northeast of Edmonton, excavation of the dune sands is accomplished by dredging with a backhoe, most of the deposit being below water table.

Hydraulic mining is used effectively with some poorly consolidated sandstones in the USA. The sandstone face is excavated by water jets and the sand slurry removed to the plant by pipeline. Hydraulic mining or dredging have the advantage of obtaining the material in a fluidized state, thus allowing its removal by pumps. This is both economic and provides a measure of attrition scrubbing as an aid to beneficiation (Shufflebarger Jr., 1977).

Most silica mining operations are at the surface. Underground mining has been used rarely, in the USA, where overburden thickness is excessive.

Processing

Conventional practice in silica processing (Murphy, 1975) embraces coarse and fine crushing, generally followed by tertiary grinding. The next stage is washing, which may be followed by high-density attrition scrubbing to remove surficial impurities of clay or iron. If necessary, remaining impurities consisting of detrital minerals can be reduced through the use of froth flotation, magnetic separation, or high tension electrostatic separation. These beneficiation steps are then followed by drying, in steam-static, rotary kiln, or fluid-bed types of equipment. The dried, cleaned sand is then screened into the commercial sizes required. Some of the dried sand may be directed to pebble mills where it is pulverized into various grades of silica flour for filler uses.

Some natural sands can be upgraded to acceptable quality by simply washing, desliming, screening and drying. The presence of iron-bearing minerals is usually the cause for more elaborate treatment.

A generalized flow chart for silica processing and treatment is given in figure 3. Figure 4 is a flow chart for a suggested treatment method for producing glass sand-grade silica from Alberta oil sand tailings.

Research Needs

Silica sand beneficiation is a fairly advanced technology, and the application of this technology should be an integral part of future silica studies in Alberta.

A specific area of needed research is in developing a method of separating grain shapes, in order to upgrade the roundness factor of silica sands. A method involving spiral cone concentrators appears to hold promise (E.F. Bertram, pers. comm.). Methods for artificial rounding should also be investigated.

ECONOMIC FACTORS

Prices and Costs

The production of silica in Canada in 1985 was 2,500,000 tonnes valued at $44.1 million, for an average value of $17.38 per tonne (table 4). A breakdown of Canadian production by use is not available for 1985, but is given for 1982 in table 5, which shows average values for different silica products in that year. Production tonnage figures are not published separately for Alberta, although the value of 1985 production is given as $4.7 million.

The average price of different silica products in the USA is given in table 10. It is difficult to get an accurate price for silica that is valid throughout North America. Prices vary depending on the local market, the grade of the sand, the degree of processing required and several other factors (Dickson, 1984).

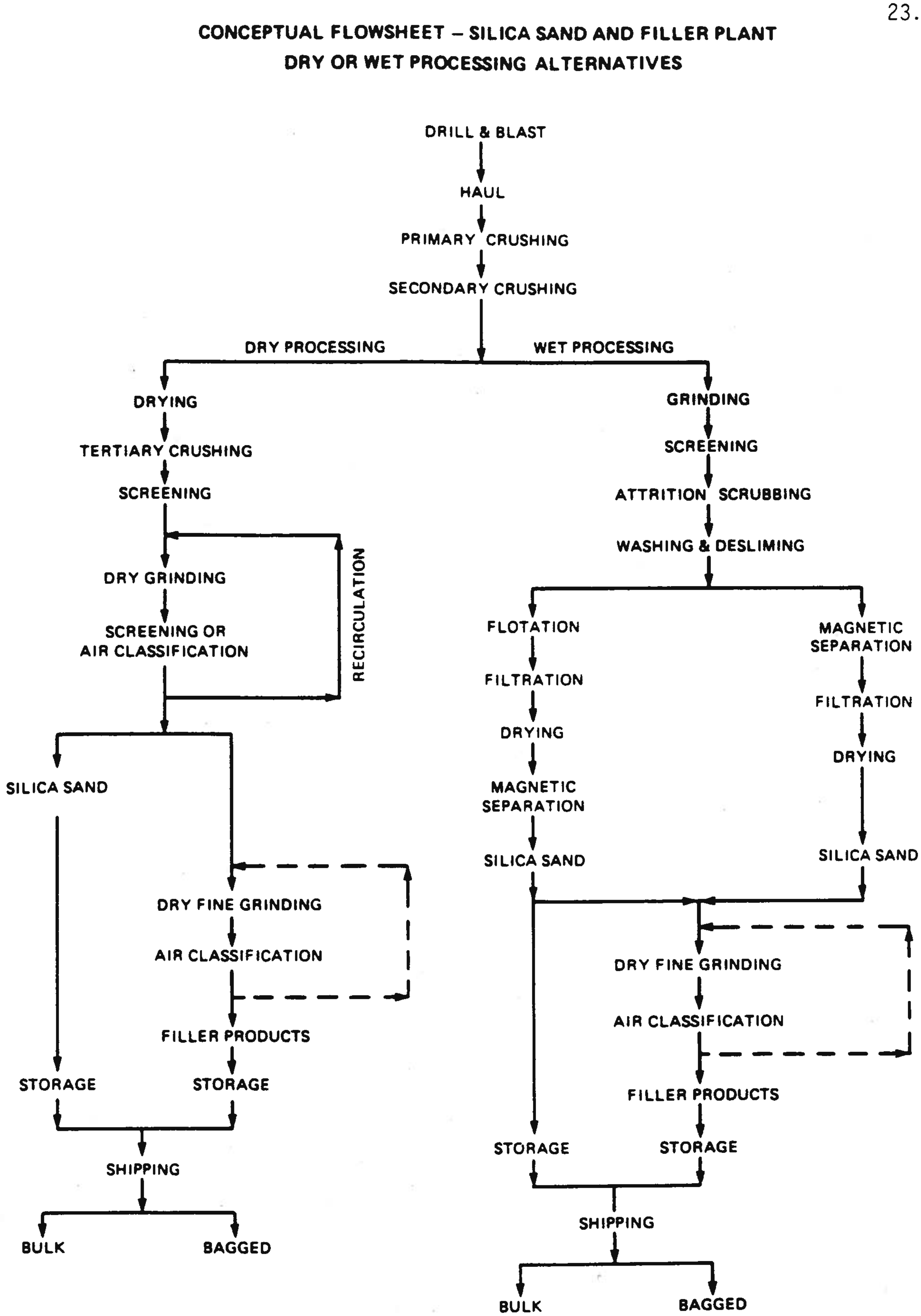

Figure 3. Generalized flowchart for processing of silica sand (from Guillet and Kriens, 1984)

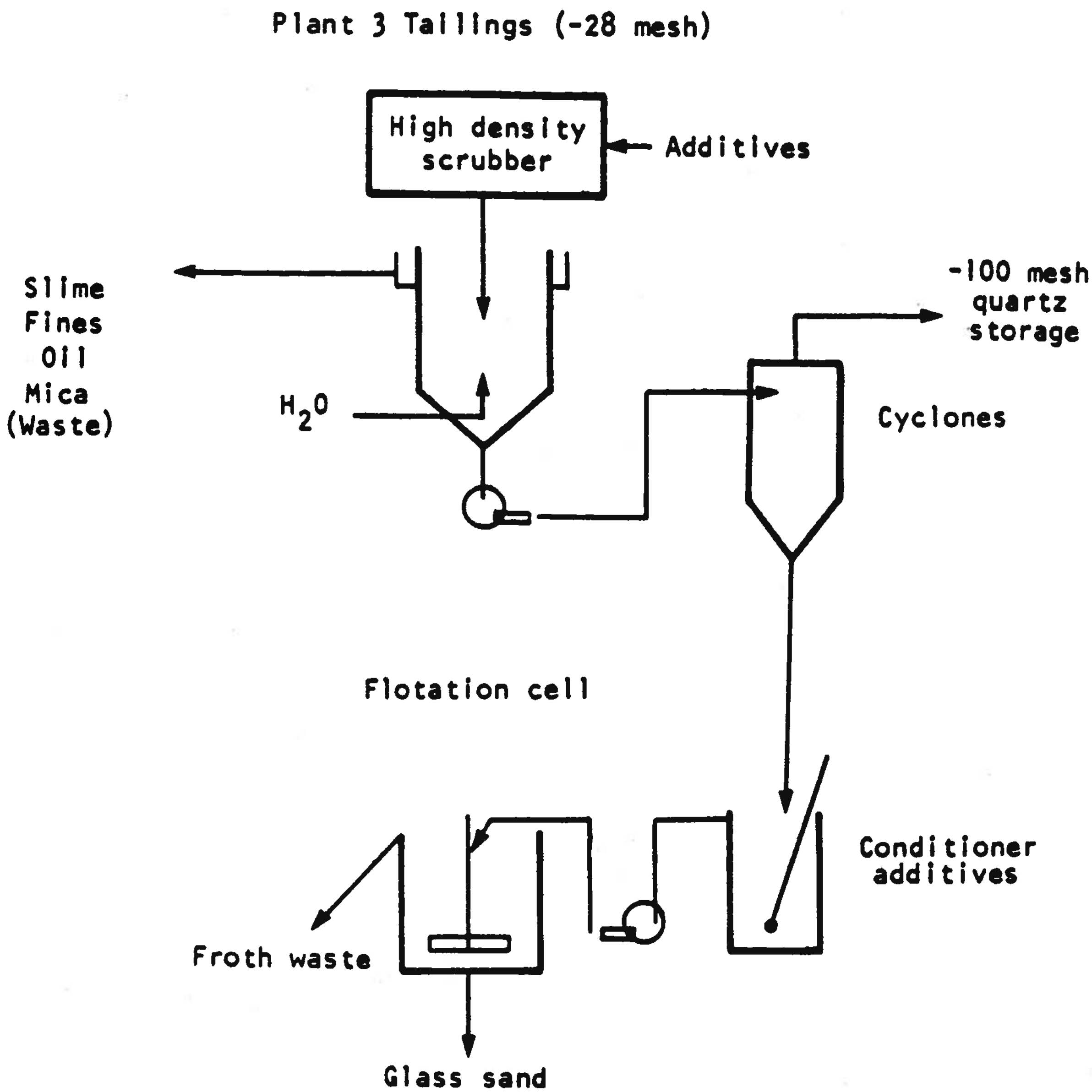

Figure 4. Flowchart of suggested treatment method for upgrading Alberta oil sand tailings to glass sand (from McLaws, 1930)

Table 10. Average prices of different silica products in the United States in 1985 (from Boucher, 1986)

Silica	$US/t fob mill or manufacturing plant
Metallurgical	7
Glass & Fiberglass (insulation)	7-16
Foundry	12-16
Frac sand	24
Filler	33
*Amorphous silica	
coarse (+93%-200 mesh)	35-70
very fine (99%-8 microns)	100-200
Pyrogenic (fumed) silica[1]	5,000-9,000
*Quartz rock crystals	
for fusing	500-2,700
for piezo-electrical and optical use	5,500-13,000
Cultured quartz[1] (as ground bars)	55,000-90,000

Source: Personal communications with industry and *Published prices by Engineering & Mining Journal, October 1985 and Chemical Reporter.

[1] Manufacturing plant.

Transportation

As with most high bulk, low unit-value commodities, transporation cost is a major factor in the economics of silica. Transportation costs commonly are as much as, and in some cases more than double the mine value of silica. Even so, long distance haulage of silica occurs in many regions, generally because the cost of transporting a high purity material is less than the cost of processing a local impure one (Anon., 1976). This may change, however, as escalating rail freight rates are outpacing the beneficiation costs associated with utilization of local deposits (Guillet and Kriens, 1984).

Much of the silica sand consumed in Alberta is hauled from Manitoba, a distance of more than 1,000 km. Transport by bulk rail shipment currently is at a cost of $29 per tonne, about 1 1/2 times the F.O.B. plant value. Silica sand coming from Wisconsin, Illinois, and Missouri (Fig.3) has higher freight costs proportionate to the greater distances. Frac sand from Brady, Texas has more than double the freight cost of Manitoba sand. These costs are a heavy burden for Alberta's silica consuming industries, and as rail freight rates continue to escalate, provide strong encouragement for reappraising the potential sources within the province.

Transport of silica over distances greater than 250 km is almost entirely entirely by rail (Shufflebarger, Jr., 1977). Truck transportion becomes competitive for distances less than 250 km, with the advantage of schedule and route flexibility.

Research Needs

An economic study is needed to evaluate various cost factors associated with the importation of silica sand to Alberta versus the development of local sources. The objective would be to determine the margin of cost savings in transportation against beneficiation costs for local materials.

OUTLOOK

Supply and Demand

Resources of low-grade silica deposits are fairly widely distributed in Alberta and are adequate for foreseeable needs in most areas. Reserves of high-grade deposits in Manitoba probably also are adequate for Alberta's future requirements from that source. Rising freight costs eventually may lead to beneficiation and use of lower grade sources within the province, the resources of which are substantial.

Other specialty sands (frac sand, foundry sand, etc.) imported from the USA have broadly based supply sources. Future supplies will be limited only by transportation costs. The Brady, Texas frac sand deposit - standard reference material for the industry and historically the source for Alberta - is dwindling in reserves, but is being increasingly substituted with closer materials. Current interest in the Peace River silica sand deposit is particularily for the frac sand market; the sand has good distribution of grain sizes and fair (though substandard) roundness.

Demand in existing markets is not expected to rise dramatically in the near future, although Alberta's silica-consuming industries have performed generally better than the rest of the economy. In the container glass industry, re-design of beer bottles (following the introduction of new beers on the market) has been a strong positive factor (Dickson, 1984). Production at the Redcliff plant is up also because of closure of the Burnaby, B.C. plant in 1985. Fiberglass insulation, although tied to the construction industry, has held up better through the retro-fit market in existing buildings. The frac sand market is currently depressed, but the long-term outlook is promising.

New Uses and markets

Potential exists for the establishment of a flat glass producing facility in Western Canada, where no such plants exist (Boucher, 1986). Alberta would be a strong contender for such a plant, with potential high-grade silica sources and comparatively inexpensive natural gas or electricity.

Higher quality and higher value silica products could eventually be manufactured in Alberta. Such products could include optical quartz, solar-grade silica, fused quartz and fused silica products, based on inexpensive electricity (Boucher, 1986).

Summary of research needs

Need for research on silica in Alberta is identified in three areas; geology, processing technology, and resource economics. This research is essential for realization of the potential of Alberta's silica resources, which currently have only minor development. All of the province's high-grade silica requirements are supplied from outside its borders, and the rising freight costs on these supplies are an increasing burden for Alberta's industry. The commodity is essential to many aspects of secondary industry, and future growth in this sector may well hinge on the availability of raw material sources within the province.

Specific research studies identified in this report are summarized below. These studies would provide the information needed to encourage and promote development of in-province silica sources to replace costly imported materials, and to establish a solid indigenous resource base for secondary industry development.

1. Geological resource studies are needed on several potential silica units in Alberta that are untested. These should focus initially on the most favorable prospects - (Cambrian Gog Group, Cretaceous Pelican Formation, Pennsylvanian Spray Lakes Group) - and should

include field studies with thorough sampling and analyses.

2. A geological compendium study is needed to collate and synthesize all existing information on scattered silica occurrences in Alberta. The study objective would be to establish regional geological trends and models for siliceous units in Alberta.

3. Silica sand beneficiation technology should be applied integrally with geological resource studies. In addition, specific processing technology research is needed on enhancement of grain roundness in silica sands.

4. An economic study is needed to evaluate cost factors associated with the importation of silica sand to Alberta versus the development of local sources.

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LEAD AND ZINC

by

John D. Godfrey

Alberta Geological Survey
Alberta Research Council
March 29, 1985

ACKNOWLEDGEMENTS

This report forms part of a series of commodity studies for the Resource Evaluation and Planning Division, Alberta Energy and Natural Resources. This particular study resulted from the combined efforts of a team which incldued: Philip Chung, William Buchan, Dixon Edwards and Wylie Hamilton.

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LEAD AND ZINC

INTRODUCTION

The series of reports attempts to review the status of geology-related studies (published and unpublished) which reflect on the evaluation of a specific resource or commodity.

Literature references are incorporated and classified according to the level and type of field exploration detail supplied.

These reports should provide the background and basis from which:

1. an assessment can be made of the level of exploration information currently available;
2. the most relevant literature can be selected through a system of classified references; and,
3. an economic feasibility for locating and/or developing a primary resource or commodity can be assessed from the geological characteristics and conditions as presently understood in Alberta.

The close geological and spatial relationships between these two metals (commonly found as co-existing galena and sphalerite) means that they can be conveniently described together in this documentation. The great lead-zinc deposits of the world are found in stratiform or stratabound configurations, and are most commonly hosted by carbonates. An important factor in the economic evaluation of many lead-zinc deposits is the grade of silver that accompanies the base metals. Other potential economic by-products to be noted include bismuth and cadmium.

Alberta has abundant and widespread carbonate sequences but there has been very little indication of a major lead-zinc deposit within Alberta.

Carbonate lithologies crop out in two major regions of Alberta:

1. Interior Plains of northeastern Alberta; and
2. Rocky Mountains.

In northeastern Alberta, Devonian carbonates onlap the Precambrian Shield crystalline basement and the Athabasca Group. The extent of the carbonate outcrop and subcrop is shown on figure 4. The carbonate bedrock in this region has been extensively eroded and now occupies low ground. Hence much of the potential outcrop area is hidden by wetlands and glacial cover.

Inliers of these Devonian carbonates are found to the south in the Athabasca and Clearwater River valleys (near Fort McMurray) and in the floor of the oil sands open pit excavations.

In the Rocky Mountains, the main ranges consist largely of carbonate lithologies. Outcrop is extensive and typically continuous, and despite the prohibition of any mineral exploration and development within the national parks, there is a good chance that any obvious metallic mineralization would have been noted by the countless hikers. Nothing significant has been thus far reported, formally or informally.

The closest major lead-zinc mining district is that of Pine Point, N.W.T., some 100 km north of the Alberta boundary. Here, a group of several major deposits are essentially strung along the ENE striking McDonald Fault at the south shore of Great Slave Lake. These deposits are hosted by a typically reefal facies of the Devonian Presqu'il Formation. The principal geological elements in the localization of these deposits hinges on the interplay of 1) the porous reefal carbonate host, and 2) the regionally important fault that not only seats in the underlying Precambrian basement but was also responsible for a significant vertical step in basement topography, thereby creating a warm, shallow-water environment on the south side, favourable for coral reef development.

The principal lead-zinc potential is in carbonate rocks, but there is some potential in other lithologies. For example, 1) the galena

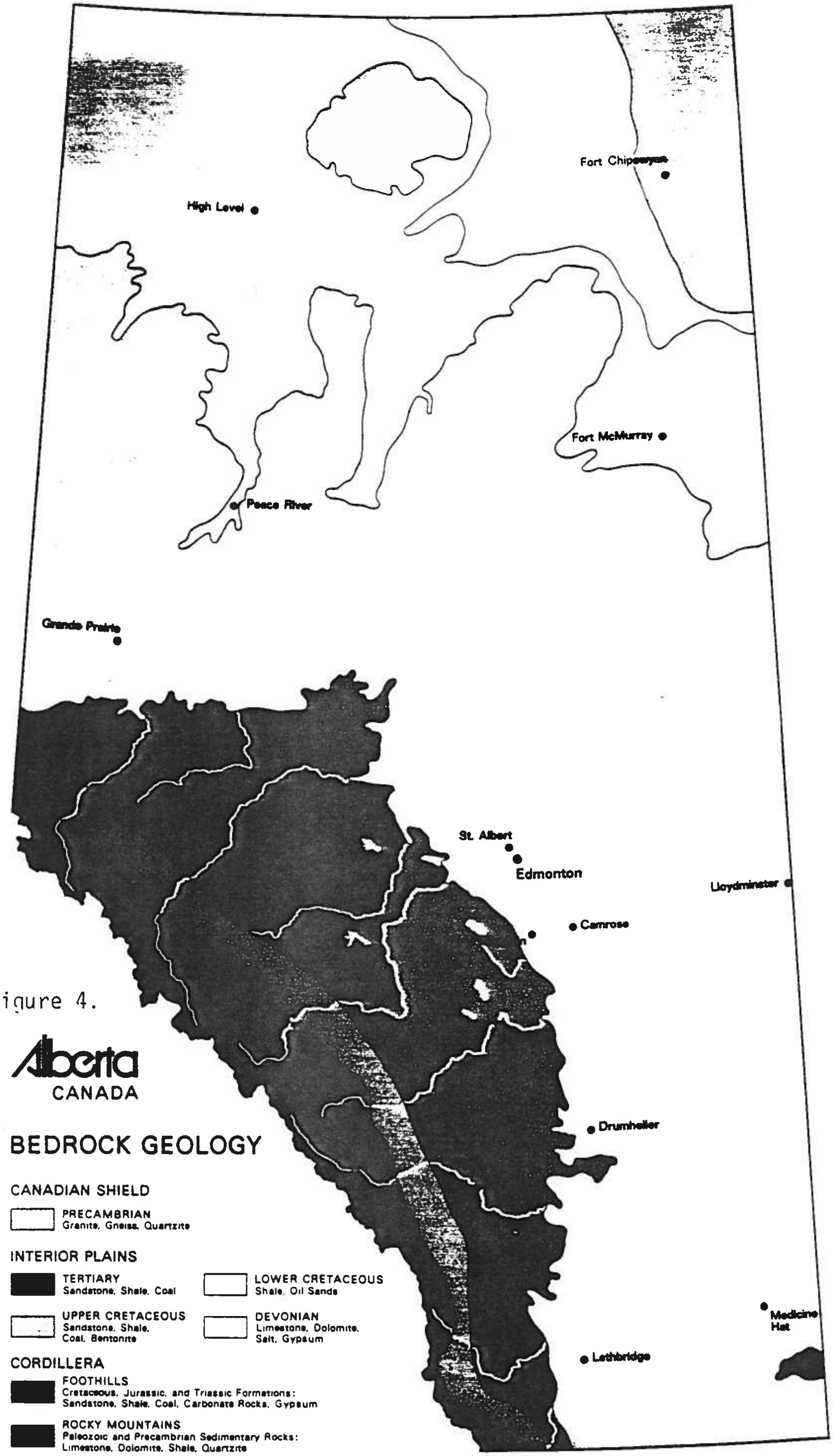

Figure 4.

Produced by the Alberta Bureau of Surveying and Mapping © 1983 mineralization intersected during the uranium exploration program of Golden Eagle in the Athabasca Sandstone, south of Lake Athabasca; and, 2) geochemical zinc anomalies in the late Proterozoic formations of the Clark Range in southwestern Alberta.

The Lead-Zinc Potential and Exploration Status For The Interior Plains Region

Much of this carbonate region is inaccessible and a combination of wetlands and glacial cover renders surface exploration a difficult, expensive and perhaps largely unsatisfactory exercise in exploration evaluation. An ideal exploration target would be the duplication of those geological controls associated with the Pine Point deposits.

Geological mapping on the Shield of northeastern Alberta reveals several regional faults in the crystalline basement that trend and extend westerly beneath the Devonian carbonate cover. Also, the southwesterly structural trend of Lake Athabasca (projecting along the northern flank of the Birch Mountains) qualifies as a speculative regional exploration target. The extensive Peace-Athabasca delta deposits obscure the bedrock in this region. The interpretation of aeromagnetic surveys and subsurface exploration data from the petroleum industry could be useful in the identification and position of possible subsurface fault structures.

Wood Buffalo National Park policy eliminates much of the prospective ground from exploration west of the Slave River. Stories of hand specimens with lead-zinc mineralization, reportedly from the park, were in circulation some 25 years ago. In the late 1950s or so, the Alberta Research Council conducted a survey in the park (Govett?) and geochemical samples were probably subjected to trace element analysis. This unpublished study should be examined and evaluated.

The Alberta Research Council (Green, 1971) undertook a reconnaissance scale geochemical exploration survey over a substantial area of northeastern Alberta where Paleozoic carbonates are in outcrop or subcrop. The survey area included all of Wood Buffalo National Park in Alberta, north of the Peace River. Till and stream sediment samples were collected and analysed for copper and zinc. Results in terms of possible lead-zinc occurrences were not encouraging. Low-level zinc anomalies are related to Cretaceous shale outcrops, and a copper anomaly is related to a known secondary copper occurrence in the regolith between basement rocks and the Paleozoic cover at Stony Islands (Godfrey, 1973).

Diamond drilling on the western edge of the Athabasca Basin in Alberta by the Saskatchewan Mining Development Corporation Ltd. (SMDC) intersected the thin erosional edge of Devonian carbonates which onlap the Athabasca Sandstone (Walker, 1981). It was suggested that the reefal facies and conditions generally were similar to those at Pine Point, and therefore favourable for lead-zinc occurrences.

The Lead-Zinc Potential and Exploration Status For The Rocky Mountains Region

For the size of the belt and the extent of outcrop, there has been very little indication of lead-zinc showings in the Rocky Mountains Region of Alberta.

A number of lead-zinc deposits and occurrences are listed below relative to the Central Rocky Mountain Belt of Alberta and adjoining British Columbia (figures 5 and 6):

1. Kicking Horse Mine (B.C.)
2. Monarch Mine (B.C.)
3. Baker Creek (Alta.)
4. Eldon (Alta.)
5. Hawk Creek (B.C.)
6. Spray Lake (Alta.)
7. Oldman River (Alta.)

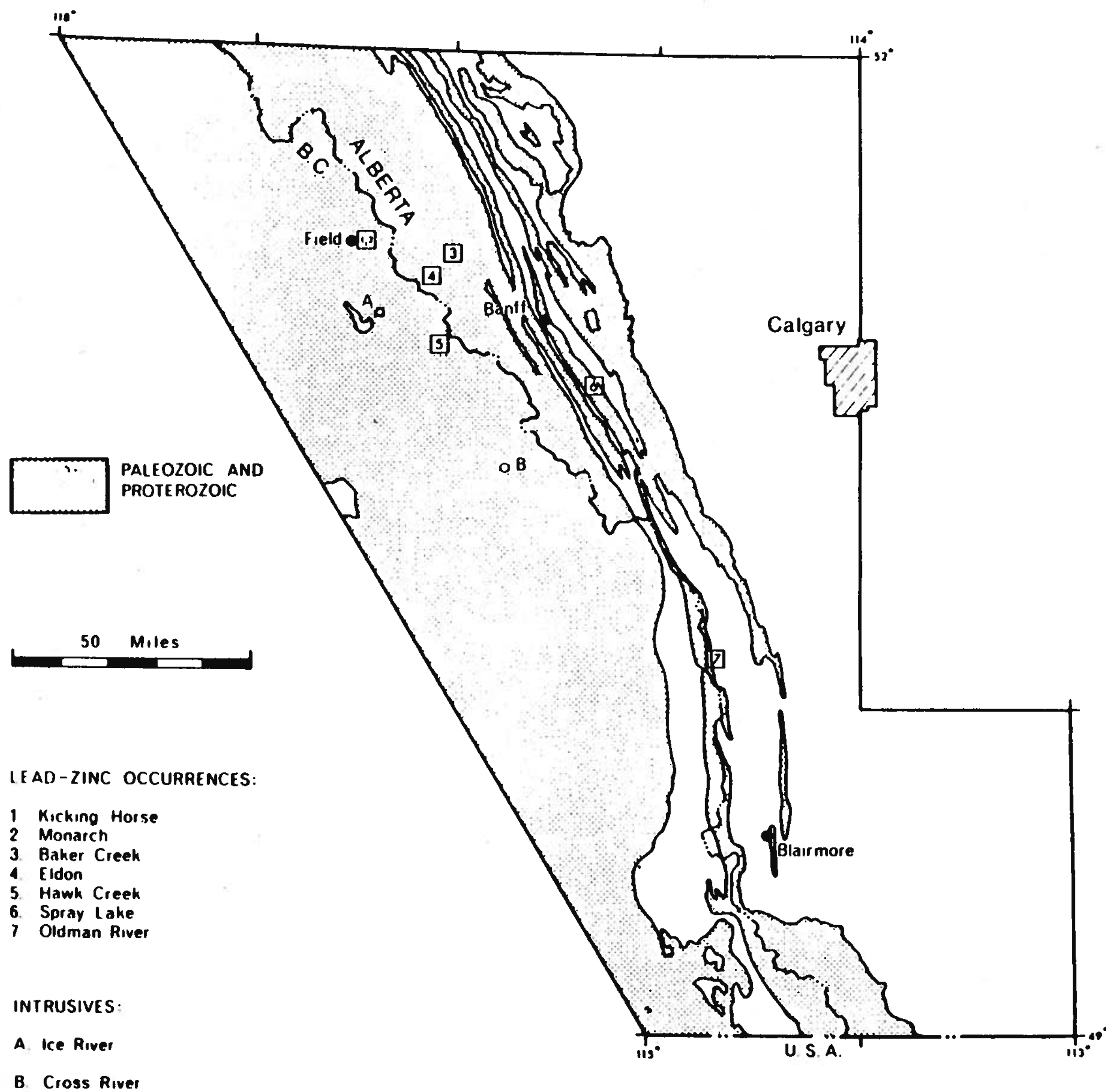

Figure 5. Sulfide occurrences of the east-central Cordillera (Holter, 1973)

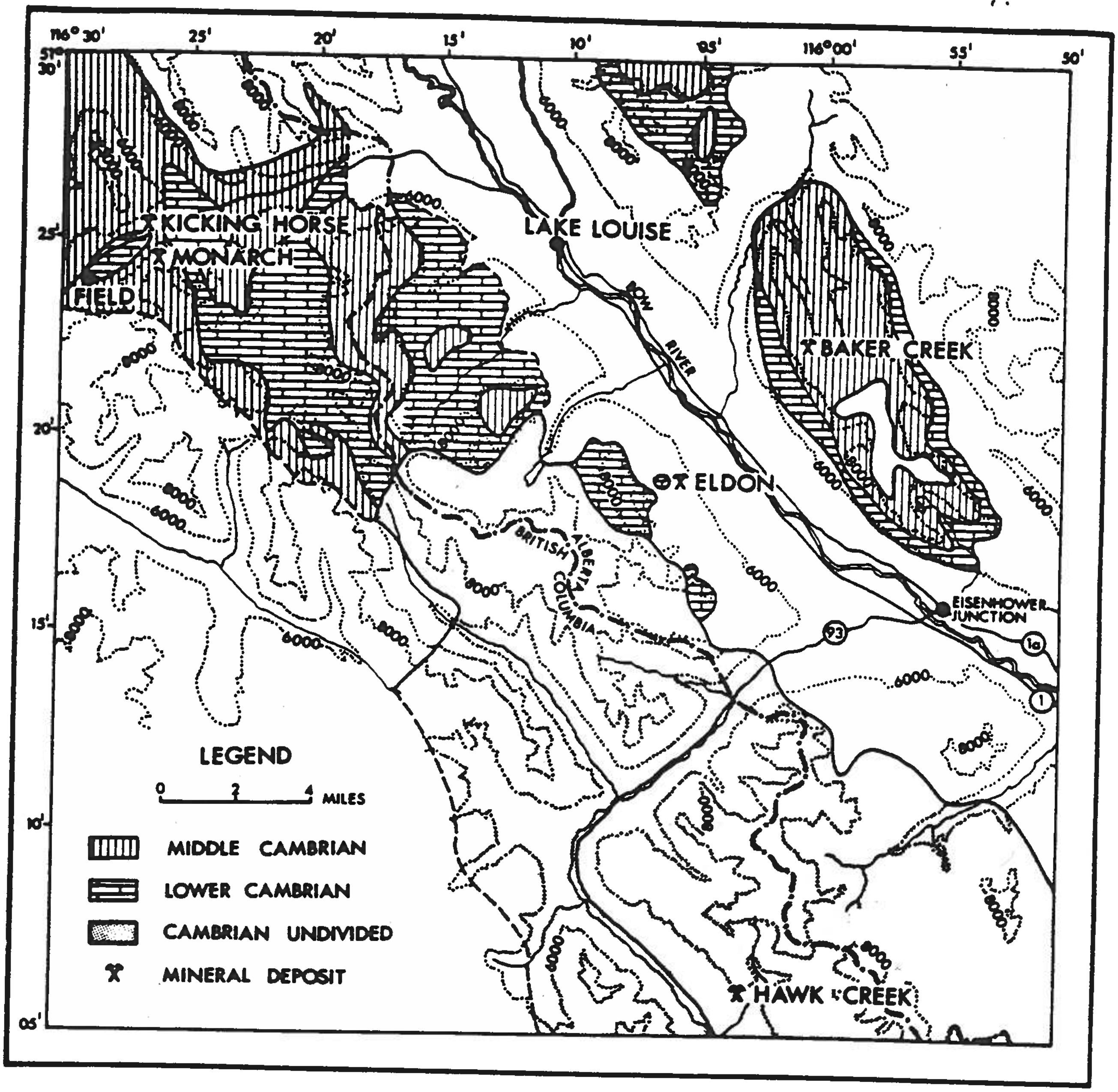

Figure 6. Detailed location of the deposits in the Banff-Field area (Evans, 1968)

Kicking Horse and Monarch Mines (B.C.) (1 and 2)

These lead-zinc deposits are treated together inasmuch as they exhibit very similar geologic characteristics and controls and are situated across from each other on either side of the Kicking Horse Pass. The Kicking Horse Mine on Mt. Field is located on the north side of the pass and the Monarch Mine is opposite on Mt. Stephen.

The ore bodies are hosted by dolomitic limestone beds in the Cathedral Formation of Middle Cambrian age. Mineralization consists of galena-sphalerite-pyrite within a brecciated dolostone. The sulfides replace the breccia, sharing some preference for the matrix, but locally the clasts are also replaced. Bands of massive ore in the order of one foot thick occur sporadically. The ore bodies have a flat, oval pad or cigar shape, about 2400 feet long. The ore controls are both structural and lithological. The orebodies are located at the intersection of northwest striking, steeply dipping faults with the contact of brecciated dolostone overlying thin bedded, black dolomitic limestone. The ore replaces brecciated dolostone accompanied by dolomite, and a little quartz and barite.

Baker Creek (Castle Mountain, Silver City) (3)

Very little technical information is available on this operation. It is little publicized, probably in keeping with the interests of the National Parks system. During the First World War there was some small production from galena-sphalerite mineralization on the flank of Castle Mountain, near Banff. A small community called Silver City was established to support this mining operation.

The mineral showings on the northwest flank of Castle Mountain occur in black dolomite veined by coarse-grained, white dolomite, of probable Middle Cambrian age. These rocks belong to the Cathedral Formation and resemble the host lithologies at the Kicking Horse-Monarch Mines. Galena, in small amounts, was the only sulfide mineral found at the entrance to an exploration adit.

Eldon Showing (4)

There is very little technical information on this copper-lead-zinc occurrence. However, the Alberta Research Council (Green, 1957) made a cursory examination of the site on Protection Mountain, Banff National Park, and Evans (1965) referred to this site in a survey of lead-zinc 'deposits' in western Canada. Green (1957) mentions three adits and reference is made to quartz veins with very minor copper mineralization and pockets of galena, all within a dolomite host. Evans (1965) states that the host calcareous and argillaceous rocks of probable Lower or Middle Cambrian age are cut by an east-striking shear zone dipping at 40° north. Mineralization in the adit dump includes: sphalerite, chalcopyrite, galena and minor pyrite along with a gangue of quartz and siderite. The presence of quartz, siderite and chalcopyrite makes this mineral occurrence unique with respect to most other showings in the Rocky Mountains.

Hawk Creek (5)

Henderson (1953) provides the best technical information on this base metal showing. The lithologies underlying the region are interbedded limestones and argillites of Upper Cambrian or Ordovician age. A northwesterly striking, steeply dipping shear zone is associated with the mineralization. Massive sphalerite replaces limestone at the intersection of the shear zone and a particular limestone bed, that is, there are both structural and lithologic controls. Small amounts of galena and pyrite accompany the sphalerite. With the aid of diamond drilling, Henderson estimates a cigar-shaped pod 250 feet long to contain 29 500 tons of ore grading 12.5 percent zinc.

Spray Lake (6)

At this point no literature can be referenced other than a location in Holter (figure 5, 1973).

Oldman River Lead-Zinc Occurrence (7)

The best summary of this mineralization is presented by Holter (1973) who examined the deposit along with W.N. Hamilton in 1970, on behalf of the Alberta Research Council. This report is essentially a summary of earlier work, no new information was presented.

Controls for the mineralization are related to the intersection of faults within a Devonian carbonate sequence. This mineralization has been explored underground by means of two adits and two short drill holes from which results were generally disappointing. Forty-six assays are reported, but a general lack of detail on the sampling procedures more or less reduces the value of the assay results to little more than grab samples.

The most meaningful assays are from a bulk sample (probably hand-cobbed) of unstated size, that gave 31.5 percent lead; 7.3 zinc; trace gold; and 2.2 oz/s.t. silver. The critical aspect of <u>type of sample</u> (for example, channel, chip, representative, grab) is not addressed for another 45 assays. Therefore it is not possible to assign any particular significance or weight to the assays and develop an average value or a value of relevance to a projected mining operation. The silver ratio is low.

In summary, the exploration to date is of a preliminary nature. No indication of base metal grade or tonnage can be given for this occurrence. Based on existing data, the outlook should be cautious, although there appears to be scope for further study. Reconnaissance exploration in the form of outcrop prospecting and geochemical exploration could be conducted.

<u>Other Lead-Zinc Prospective Regions</u>

(a) Clark Range, southwestern Alberta: Widespread exploration activity for stratabound copper mineralization in the late Proterozoic Grinnell and associated Formations also encountered geochemical lead-zinc anomalies (Halferdahl, 1971). Different segments of the exploration region (adjoining and north of Waterton Lakes National Park) were subject to exploration by various companies according to option agreements. The anomalous lead-zinc region appears to be associated with the Sheppard Formation in the following areas: north of Whistler Mountain, near Table Mountain, and south of North Kootenay Pass. Reports on this exploration work, carried out by Cominco, are not presently at hand for a more critical appraisal.

(b) Athabasca Basin: This basin constitutes a highly prospective uranium exploration target in northern Saskatchewan where it forms one of the world's leading uranium-producing districts. Ten percent of this sandstone-filled basin extends into Alberta. Diamond drilling to test deep uranium targets in Alberta intersected disseminated galena-sphalerite in one drill hole. The disseminated galena-sphalerite is associated with a 100 m thick fracture zone in sandstone at a depth of about 500 m (Nelson, 1978).

OUTLOOK

1. The geological environments represented by the carbonate rocks of the Rocky Mountains and the plains of Alberta are considered to be clearly favourable for the development of Mississippi Valley-Type lead-zinc deposits. These deposits are characterizied by (Evans et al, 1968):

    1. Absence of an obvious igneous-related source of ore solutions,
    2. Simple mineralogy - that is, galena and sphalerite,
    3. Low precious metal content,
    4. Limestone or dolomite host,
    5. Replacement and vein mineralization, breccia zones,
    6. Tectonically undeformed regions,
    7. Low temperature of formation, that is, shallow depth, and,
    8. Structurally positive regions and solution features.

The abundant hydrogen sulphide gas phase commonly associated with petroleum in western Canada is a particularly attractive feature in terms of providing a source of sulphur for base-metal deposits. (The similarity in sulphur isotopic composition between the petroleum and lead-zinc occurrences of Alberta is considered to be highly significant in the genesis of these base metals. Similarly, this has proven to be the case for the Pine Point deposits).

The occurrence of highly porous reefs in the subsurface of Alberta is an additional distinctly favourable geologic feature for the development of base-metal deposits.

A small amount of shallow subsurface drill-testing for base metals (lead-zinc-copper) in Devonian carbonates has been done by Gulf Minerals Canada Limited (Germundson and Fischer, 1978). This 5-hole test in the Steen River area did not yield any significant geochemical anomalies and the exploration was terminated.

In view of the stratigraphic relationships of the Kicking Horse and Monarch Mines near Field, B.C., and several minor lead-zinc occurrences in the Rocky Mountains of Alberta, the Middle Cambrian formations appear to be particularly prospective in the mountain belt.

By contrast, in the plains region the Pine Point Mine deposits, and zinc occurrences in the plains subsurface (Haites, 1960), focus attention on reefal facies of the late Devonian.

2. The intensely explored subsurface of the Western Canada Sedimentary Basin offers an unparalleled opportunity to initiate a broad-based subsurface data search for base-metal deposits in Alberta. The situation is particularly attractive in view of the methodical filing of subsurface data and core under the jurisdiction of the ERCB authority.

3. In the Rocky Mountain carbonate belt, despite the extensive blocks held under the national parks system, there remains considerable opportunity for reconnaissance exploration in outcrop.

RESEARCH PROJECTS

1. Although much of the prospective outcrop/subcrop carbonate area of the Interior Plains lies within the Wood Buffalo National Park, other parts are available for surface exploration. Any program of geochemical-geophysical surface reconnaissance exploration would be based initially upon the interpretation and extrapolation of subsurface data collected in the course of petroleum exploration. Regional geophysical surveys and limited coverage by drill hole data would provide the basis for any lead-zinc exploration program in this region. The shallow-buried Devonian carbonates that fringe the Precambrian Shield would prove the most attractive because of the projected lower costs of mining.

   A great deal of potentially valuable data are available through the exploration efforts of the petroleum industry, particularly during the past 40 years or so. At surface, aeromagnetic, seismic and gravity survey data are available. In the subsurface downhole geophysical logs, lithologs, and core and cuttings samples are available. The amount of hard data could be awesome. Initially, an overview is desirable. This could be obtained through an interview or questionnaire process with selected exploration companies and personnel, seeking out those managers with long-term experience in Alberta. In this way some regions should be identified worthy of exploration targeting, for a further level of detail and refined evaluation.

   The next step would be to select one or two pilot test areas. Data should be assembled, compiled, and stored in a computer data bank for processing and readout in a suitable graphic and/or map form.

2. In the Interior Plains there is further scope for geochemical exploration additional to the broad reconnaissance reported by Green (1971) over part of this region.

3. In the Rocky Mountain belt there is considerable scope for surface exploration in the carbonates outside of the national parks. Geochemical surface sampling could be employed on a regional reconnaissance exploration survey. There are a few keys that could be used as guides. If a literature search proves unsatisfactory the Baker Creek (Silver City) lead-zinc occurrence might be studied in the field to ascertain the geological controls of the mineralization. Likewise, the past lead-zinc producers (Monarch and Kicking Horse Mines) in the Kicking Horse Pass near Field, B.C. (Ney, 1957) provide direction as to the favoured host stratigraphy and the structural control. The latter deposits are well documented and clearly the dolomitic phase of the Cathedral Formation is an exploration key.

   There is scope beyond the National Park boundaries to explore the favoured Cambrian and Devonian carbonates both in outcrop and by geochemical survey. A very good geological bedrock map base is already developed on which to base reconnaissance exploration.

   The present report on the lead/zinc resources of Alberta is based on an assessment using only selected and readily available references. A fuller, more accurate and meaningful study would result if time was available to assemble, catalogue, and evaluate information from a wider spectrum of literature and enquiries; that is, functioning more in a research mode. This current report is a step towards that direction, but I feel that it is somewhat superficial at the moment in view of the limited effort possible in the short time available. Provision for an in-depth, comprehensive study for this commodity is recommended.

SUMMARY OF DATA GAPS

1. In the Interior Plains, where so much of the Paleozoic carbonate fails to crop out in the potential area of exposure, regional interpretation of aeromagnetic surveys would serve to provide data on the broad structural framework. The regional interpretive aeromagnetic coverage could be usefully extended into areas of thin Cretaceous overburden. Following the widely accepted geological assumption that Mississippian Valley-Type lead-zinc deposits are favoured by large-scale faults and reef accumulations, the interpretive aeromagnetic survey approach to defining such features in the Paleozoic carbonates should be an important step towards the identification of exploration targets.

2. Also in the Interior Plains, there is an almost overwhelming volume of well log and seismic data available from many sources, but much of it is housed by E.R.C.B. It would seem prudent to harness this mass of data on a selected target area basis and not for the Western Canada Sedimentary Basin as a whole in Alberta. A regional summary of the tectonics of this basin [now being assembled on a collaborative basis under the direction of Dr. Donald Cook (G.S.C., Calgary)] could provide some useful input to an initial regonal structural analysis. Contact, discussion and enquiry with selected long-term management in the petroleum industry could introduce some useful bias and shortcuts in the selection of exploration areas for more detailed study.

OUTLINE FOR REFERENCE CLASSIFICATION: RESOURCE INVENTORY

A. Resource (Commodity) Evaluation References
   1. General Overview
   2. Specific Commodity Overview
   3. Exploration - Reconnaissance Scale
   4. Exploration - Site Specific Scale

B. Supporting References
   1. Concepts and Principles
   2. Indirect Exploration - Reconnaissance Scale
   3. Indirect Exploration - Site Specific Scale

C. Background and Miscellaneous

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B. SUPPORTING REFERENCES

1. Geological Concepts and Principles

2. Indirect Exploration - Reconnaissance Scale

3. Indirect Exploration - Site Specific Scale

C. BACKGROUND AND MISCELLANEOUS

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John D. Godfrey
March 31, 1985

Open File Report 1986-13 (f)

SODIUM SULFATE

by

John D. Godfrey

Alberta Geological Survey
Alberta Research Council
March 31, 1985

ACKNOWLEDGEMENTS

This report forms part of a series of commodity studies for the Resource Evaluation and Planning Division, Alberta Energy and Natural Resources. This particular study resulted from the combined efforts of a team which included: Philip Chung, William Buchan, Dixon Edwards and Wylie Hamilton.

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SODIUM SULFATE

INTRODUCTION

The series of reports attempts to review the status of geology-related studies (published and unpublished) which reflect on the evaluation of a specific resource or commodity.

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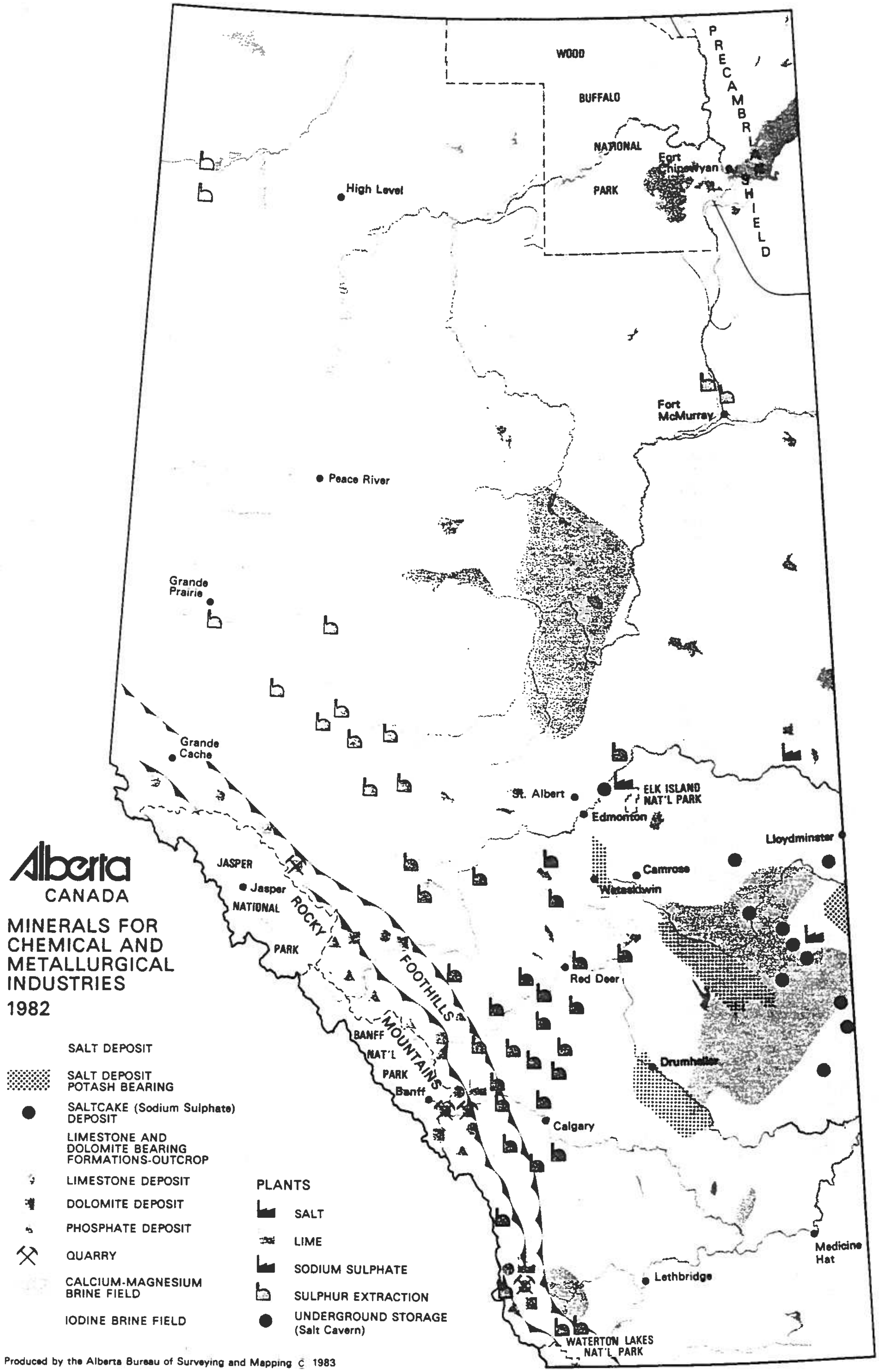
1. an assessment can be made of the level of exploration information currently available;
2. the most relevant literature can be selected through a system of classified references; and,
3. an economic feasibility for locating and/or developing a primary resource or commodity can be assessed from the geological characteristics and conditions as presently understood in Alberta.

Sodium sulfate deposits result from high evaporation rates of ponded or seepage waters that contain dissolved minerals, such as those lakes situated in east-central Alberta (figure 9). Lakes which exhibit a high dissolved salt content are referred to as saline or alkaline lakes. This region of high evaporation is continuous eastward into the central plains of Saskatchewan.

Sodium sulfate crystals are deposited on the margins and bottoms of alkaline lakes that shrink during the high evaporation rates of the summer.

The last significant published summary of sodium sulfate deposits in Alberta was based on a survey by Govett (1958) of the Alberta Research Council. This summary is now almost 30 years old, and unlike


Alberta
CANADA
MINERALS FOR CHEMICAL AND METALLURGICAL INDUSTRIES
1982
SALT DEPOSIT
SALT DEPOSIT POTASH BEARING
SALTCAKE (Sodium Sulphate) DEPOSIT
LIMESTONE AND DOLOMITE BEARING FORMATIONS-OUTCROP
LIMESTONE DEPOSIT
DOLOMITE DEPOSIT
PHOSPHATE DEPOSIT
QUARRY
CALCIUM-MAGNESIUM BRINE FIELD
IODINE BRINE FIELD
PLANTS
SALT
LIME
SODIUM SULPHATE
SULPHUR EXTRACTION
UNDERGROUND STORAGE (Salt Cavern)
WOOD BUFFALO NATIONAL PARK
PRECAMBRIAN SHIELD
Fort Chipewyan
High Level
Fort McMurray
Peace River
Grande Prairie
Grande Cache
St. Albert
ELK ISLAND NAT'L PARK
Edmonton
Lloydminster
Camrose
Wetaskiwin
JASPER NATIONAL PARK
Jasper
ROCKY MOUNTAINS
FOOTHILLS
Red Deer
BANFF NAT'L PARK
Banff
Drumheller
Calgary
Medicine Hat
Lethbridge
WATERTON LAKES NAT'L PARK
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most other commodities under review, because of its mode of formation, the nature of these deposits may be significantly different in this relatively brief period of time.

The limited amount of exploration and related literature on sodium sulfate occurrences in Alberta, probably reflects several factors:

- the specialized industrial applications;
- limited local uses; and,
- excess production capacity from an established industry in nearby Saskatchewan.

Govett (1958) showed from his survey in southern Alberta that only one deposit in over 250 lakes visited met the requirements for economic development.

OUTLOOK

1. From the purely geological standpoint, Govett's study (1958) indicated that there is at least one sodium sulfate deposit in Alberta that is capable of supporting a commercial operation. There may be others, depending upon the results of more detailed exploration.

2. There is a well established natural sodium sulfate producing industry in Saskatchewan that appears to have excess capacity. Such circumstances may thwart attempts to initiate production in Alberta, assuming that increased consumption in the Alberta marketplace needs to be satisfied.

3. The trend in manufactured sodium sulfate production (i.e. sodium sulfate produced as a byproduct of the industrial chemical industry) should be assessed. Although in 1953, byproduct sodium sulfate accounted for only 0.2 per cent of the total Canadian production of sodium sulfate.

4. The principal industrial use for sodium sulfate is in the manufacture of kraft paper pulp, the source of brown wrapping paper. Other uses are in the manufacture of: plate and sheet glass; chemicals such as sodium carbonate, sodium aluminum sulfate, sodium silicate and sodium sulfide; rayon, wool, and other textile fibres; detergents and pharmaceuticals. The market for sodium sulfate in Alberta appears to be largely geared to the pulp and paper industry, which is not experiencing a particularly strong growth at present.

5. Unless there is a strong economic resurgence in the pulp and paper industry of Alberta, or an entirely new industrial application introduced, the traditional pattern of need and supply appears to be stable and adequate.

RESEARCH PROJECTS

1. In view of the mode of formation of natural sodium sulfate and the 30 year gap since the last geological survey was conducted, it would be appropriate to reassess the current situation. A reconnaissance areal photographic interpretive survey should be undertaken to outline the prospective region. Followup on-the-ground investigations of the more promising sites could be undertaken according to the findings of the areal photographic study in conjunction with Govett's (1958) earlier assessments.

2. Exploration of the extent, grade and tonnage of a deposit cannot be established without subsurface data. These data can best be obtained through use of a drill and sample-collecting program.

3. In the economic interests and potential value of any site-specific detailed exploration, it would be apropro to initially examine the status of the sodium sulfate industry in Saskatchewan and the current and projected trade patterns.

The outlook for this commodity in Saskatchewan could have a profound influence on any development and production plans for Alberta.

4. Despite the small amount of technical literature on sodium sulfate occurrences in Alberta, a more significant summary could be generated beyond the limitations encompassed within the present study. The constraints placed on this 'overview-type brief' by the minimal effort allowed by the existing contract do not necessarily permit extraction, compilation and sythesis of the pertinent information.

SUMMARY OF DATA GAPS

1. An up-to-date geological survey outlining the potential region of sodium sulfate occurrences, with an on-site detailed examination of the more promising occurrences, is needed to establish the production potential of this commodity for Alberta.

2. Consideration should be given to assessing the economic outlook for sodium sulfate (market potential and production capacity/utilization in Saskatchewan) before proceeding with any extensive exploration for this commodity in Alberta.

PROPOSED OUTLINE FOR REFERENCE CLASSIFICATION: RESOURCE INVENTORY

A. Resource (Commodity) Evaluation References
   1. General Overview
   2. Specific Commodity Overview
   3. Exploration - Reconnaissance Scale
   4. Exploration - Site Specific Scale

B. Supporting References
   1. Concepts and Principles
   2. Indirect Exploration - Reconnaissance Scale
   3. Indirect Exploration - Site Specific Scale

C. Background and Miscellaneous References

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A. RESOURCE (COMMODITY) EVALUATION REFERENCES

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2. Specific Commodity Overview

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B. SUPPORTING REFERENCES

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2. Indirect Exploration - Reconnaissance Scale

3. Indirect Exploration - Site Specific Scale

C. BACKGROUND AND MISCELLANEOUS

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GOLD

by

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Alberta Geological Survey
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Gold deposits are usually divided into two broad categories based on the grossly different mining and processing conditions normally required:

a) placer deposits;
b) lode deposits.

The geological history and makeup of Alberta readily defines areas which are prospective for each category of gold occurrence.

PLACER DEPOSITS

Placer deposits (that is, concentrations of heavy minerals) are formed under either river transported or shoreline conditions. These conditions can occur in sedimentary rocks of any geologic age.

Modern river systems flowing easterly and/or northerly across Alberta from the Rocky Mountains have suitable hydraulic conditions for the placer concentration of heavy minerals. All of these major rivers have been the subject of attention by early prospectors, particularly in the latter part of the 19th Century.

Prospecting activity in Alberta seems to have intensified at the time of the Klondike gold rush to the Dawson City area of the Yukon Territory (1896-99). Consequent upon that activity substantial dredging took place along the North Saskatchewan River in the vicinity of Edmonton.

Map (figure 1) (Government of Alberta, 1952) summarizes the extent of placer gold occurrences and activity in Alberta for the first part of the 20th Century. This figure is probably based on mineral (placer) permit applications, newspaper articles, production reports, and discussions between government and prospectors, rather than upon data gathered through a research-type methodology.

The production of placer gold in Alberta, as reported to the Provincial Government, is presented in table 1 and figure 2. The increase in activity and production reported from the 1970s and onward is primarily due to recoveries achieved from gravel washing plants that process preglacial (late Tertiary) gravels, particularly those in the Edmonton area.

In the last few years there has been renewed interest in attempting to recover the fine placer gold (flour gold) typically found in Alberta rivers such as the North Saskatchewan River. This interest was spurred by the surge in the price of gold in the 1970s.

Placer Gold Studies in Alberta

Very little technically reliable data are available on the placer gold occurrences of Alberta. Halferdahl (1965) conducted a survey of

Figure 1. Placer mining areas of Alberta (Department of Mines and Mineral Resources, 1952)

Table 1. Gold Production in Alberta (MacGillivray et al, 1984)

Year	Kg	Year	Kg	Year	Kg	Year	Kg	Kg[1]
1887	3.2	1911	0.3	1935	4.7	1959	10.5	
1888	1.8	1912	2.3	1936	3.4	1960	5.9	
1889	30.0	1913	-	1937	1.4	1961	5.3	
1890	6.0	1914	1.5	1938	9.5	1962	5.8	4.1
1891	8.3	1915	6.1	1939	11.2	1963	4.1	1.3
1892	15.8	1916	2.6	1940	6.7	1964	1.8	6.3
1893	14.5	1917	-	1941	6.7	1965	6.2	4.7
1894	22.6	1918	0.8	1942	1.1	1966	5.7	5.2
1895	75.2	1919	0.7	1943	0.7	1967	4.5	-
1896	82.8	1920	-	1944	1.6	1968	4.5	3.1
1897	75.2	1921	1.5	1945	0.2	1969	4.1	5.0
1898	37.6	1922	-	1946	3.4	1970	4.7	2.6
1899	22.6	1923	-	1947	2.4	1971	2.5	2.1
1900	7.5	1924	-	1948	2.4	1972	0.1	-
1901	22.6	1925	-	1949	3.6	1973	5.4	4.1
1902	15.1	1926	-	1950	4.8	1974	3.0	6.0
1903	1.5	1927	1.3	1951	3.0	1975	7.7	8.5
1904	0.7	1928	2.1	1952	3.5	1976	5.6	19.2
1905	3.8	1929	0.2	1953	2.0	1977	2.1	10.6
1906	1.2	1930	-	1954	6.2	1978	34.7	26.6
1907	1.0	1931	6.1	1955	6.7	1979	42.0	19.5
1908	1.6	1932	2.6	1956	3.7	1980	133.0	12.9
1909	0.8	1933	10.1	1957	1.3	1981	121.0	30.6
1910	2.8	1934	12.1	1958	9.6	1982	11.0	15.6
						1983	21.0	

1887-1934 from Robinson (1935)

1935-1948, 1953-1959 from Giusti (1983)

1949-1952, 1960-1983 from Statistics Canada Catalogue 26-201/Canadian Mineral Review

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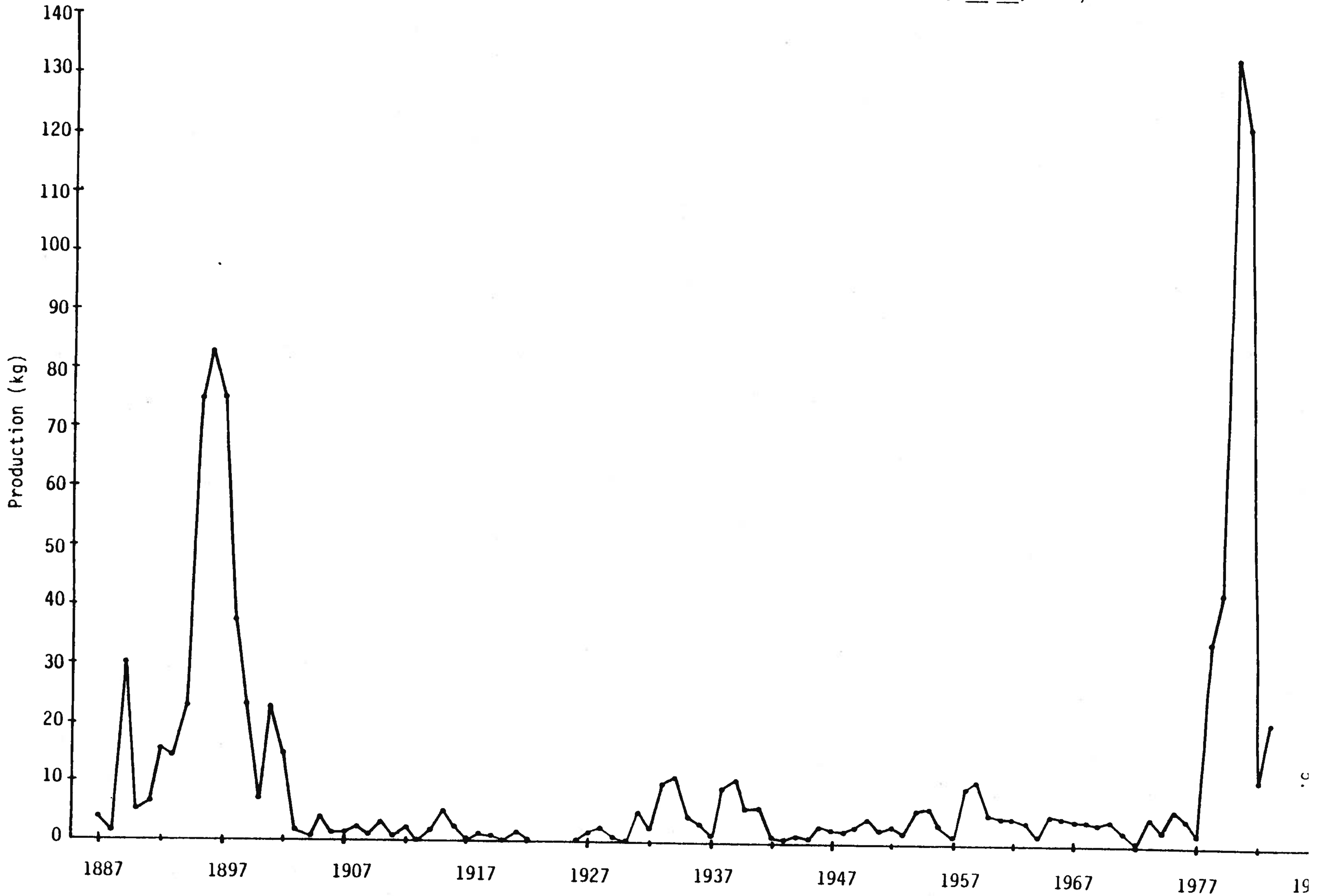
[1] 1962-1982 from Alberta Department of Energy and Natural Resources mineral royalities file.

Figure 2. Placer Fine Gold Production in Alberta (Based on MacGillivray _et al_, 1984)



the major drainage basins in Alberta. The study was regional in scope, therefore the conclusions are accordingly abbreviated and reconnaissance in nature.

Two studies have been undertaken as theses requirements at the University of Alberta. Giusti (1983), under the supervision of Professor R.D. Morton, made a survey of placer gold occurrences in Alberta and also examined the mineralogy of raw gold with the aid of a scanning electron microscope. The latter study was directed in part towards determining the source of the placer gold in the Alberta river deposits.

One site-specific study has been conducted by a student in the Department of Mineral Processing (Romaniuk, 1981) under the supervision of Professor Vern Pitt. The object of this study was an evaluation of the placer gold content of preglacial gravels in the pit of Consolidated Concrete Ltd., Villeneuve, Alberta.

The Alberta Research Council (MacGillivray et al., 1984) undertook a critical placer gold study of sediments along a 17 km section of the North Saskatchewan River. The objectives were twofold:

1. To develop a reliable method for the representative sampling and estimation of gold concentrations in placer gold-bearing sediments;

2. To check the relationship between the placer gold contents of a preglacial channel (exposed in the modern river banks) and the adjacent downstream sediments of the modern North Saskatchewan River.

Their conclusions are that a gravity sluice recovery technique yields qualitative results only and there is a correlation between the preglacial channel and anomalous placer gold in the adjacent modern river sediments.

Problems, Outlook

1. The source of the placer gold in the modern Alberta river sediments is a matter of considerable interest for those engaged in placer exploration. It is unlikely that there is a single, unique answer to this question in that the placer gold is probably derived from several sources. The possible contributing sources are:
   a. glacial deposits;
   b. preglacial river channel deposits (upland preglacial gravels and Saskatchewan Sands and Gravels);
   c. Tertiary bedrock;
   d. Cretaceous bedrock.

   Bayrock (1960) suggests that glacial deposits are not a major source of placer gold for the modern river sediments of Alberta, despite the claims of Allan (1920). Limited knowledge of the distribution and concentration of placer gold in the modern river sediments points to the preglacial river channel deposits as a major contributor.

   Yet, significant contributions may also be expected from other placer concentrations within the Tertiary and Cretaceous bedrock of Alberta. Like the preglacial, Saskatchewan Sand and Gravel channel deposits, other contributions can be expected to be of a local, though significant nature. A definitive study is needed to isolate contributions from each of these possible sources.

2. The fine particle size of the placer gold in the modern river sediments of Alberta, and particularly those of the North Saskatchewan River (probably the best studied and documented drainage basin in Alberta) makes recovery extremely difficult. Recoveries of this far-travelled, fine-sized gold, by traditional sluice box methods, are thought to be inefficient; that is, it is difficult to estimate the losses, and hence to establish the efficiency of a system.

The limitations of gravity recovery systems on gold particlesless than 100 mesh in size are well documented (figure 3; Wang, 1979). An evaluation is needed of the gravity and alternate devices used in the recovery of gold from these types of modern fluvial sediments.

3. There are dozens, even hundreds, of at least intermittently active gravel-washing operations in Alberta each summer. In each case, at least in theory, there is an opportunity to recover the placer gold (or rather a heavy mineral concentrate containing placer gold). Not all gravels being prepared by washing, etc. for industrial use contain significant concentrations of gold; however, considerably more than the two or three in the west Edmonton region (where gold is now being recovered) would qualify as being in the range of economic interest and feasibility. This placer gold is now being lost.

4. The occurrence of precious metals other than gold are well known in the North Saskatchewan River sediments (Allan, 1920), however, precise knowledge is far more scanty than is the case for placer gold. Platinum is more difficult to detect or recover, and the cost of assays on a routine basis is generally forbidding for the individual prospector. There is also a further lack of knowledge amongst prospectors regarding the possibilities for the presence of platinum in Alberta river sediments.

   The distribution pattern of placer platinum is very unclear, but it would be surprising if it matched that of placer gold. Consequently, the same geological exercise needs to be followed as that used in the exploration and evaluation of the occurrence of placer gold, namely:

   a) Systematic sampling and assaying to determine the distribution pattern and concentrations for the modern

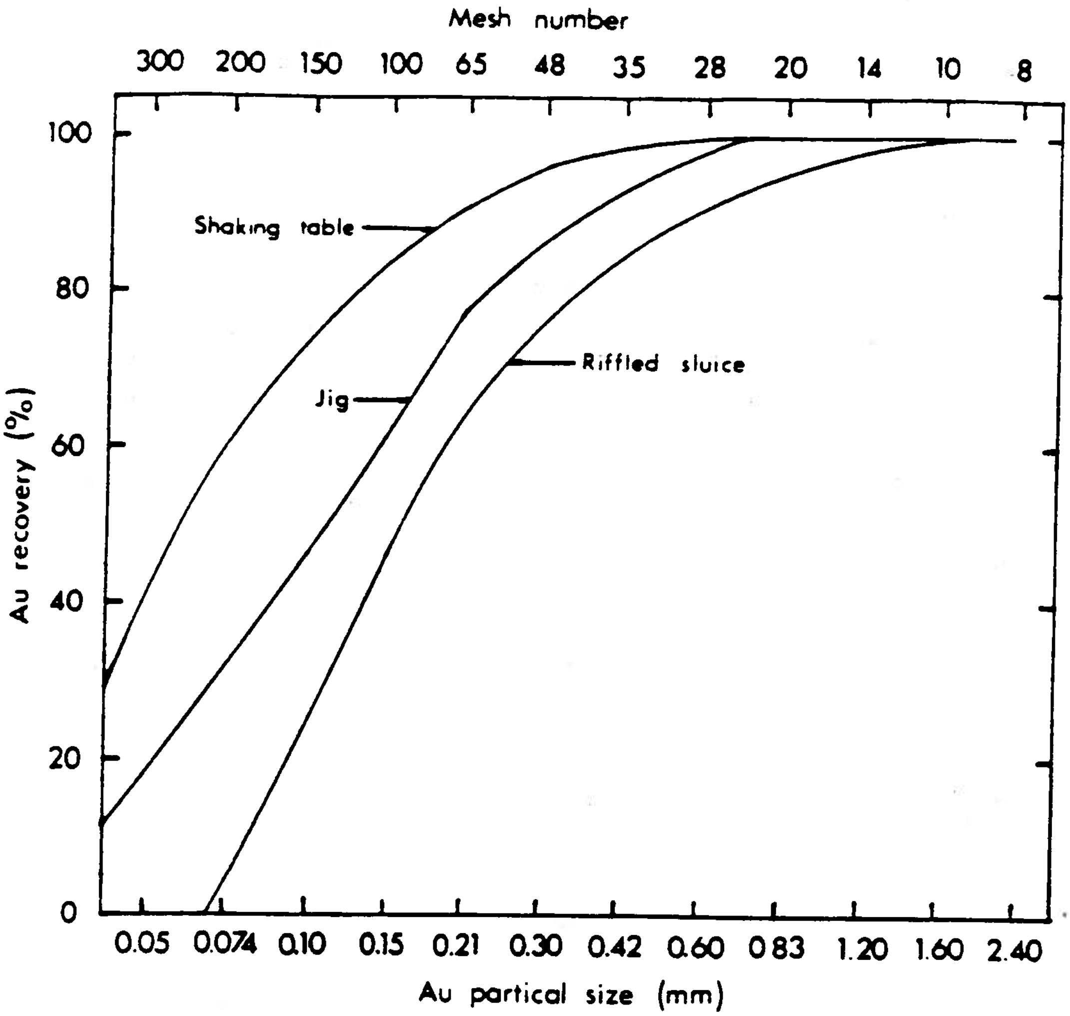


FIGURE 3 : Recovery of different size gold particles by gravity devices (from Wang, 1979).

river sediments;

b) Systematic sampling and assaying to determine the source rock(s) for the platinum.

Assay that identify the different platinoid metals would be of further interest.

5. Insofar as heavy mineral concentrates are the primary raw materials directly recovered by the traditional gravity placer systems (yielding in the order of about one to two pounds per cubic yard of feed gravels, thereby representing a concentration ratio of about 2000:1) it would seem appropriate to closely examine such concentrates. Heavy mineral concentrates from major drainage basins can potentially contain a variety of economically interesting (industrial) minerals (for example, magnetite, ilmenite, garnet, monazite, platinum). Focus on placer gold values alone may lead to overlooking a combination of smaller economic benefits which together could contribute significantly to the economic feasibility of a mining operation.

Research Projects

1. Systematic analysis of potential sources of placer gold within each major drainage basin, giving particular attention to: preglacial river channels, exposed Tertiary and Cretaceous lithologies.

   a). A great deal is known about preglacial bedrock river channels, because of their significance as subsurface aquifers, beginning with the studies of Farvolden (1963). However, a great deal more regional synthesis has taken place since that time and a careful province-wide synthesis, with heavy minerals in mind, would be appropriate at this time.

b) Investigation of bedrock units should be undertaken using appropriate sampling and study methods.

2. Close and continuing attention should be paid to research efforts (for example, Wang, Wenquian and Poling, 1983) directed towards the recovery of placer gold at the finer particle-size end of the spectrum.

3. Gravel-washing operations should be monitored and possibly classified according to their capability of producing black sand-heavy mineral concentrates. Assistance should be given to gravel companies and producers in the form of expertise in evaluating their deposits for gold content. Does this potentially represent a wasted resource in Alberta?

4. The occurrence of placer platinum is probably far more widespread in Alberta than is presently realized. Efforts should be directed towards an evaluation of the distribution, concentrations and primary sources of placer platinum in the modern major river sediments of Alberta.

5. Heavy mineral concentrates (commonly black sand) are the primary products of the traditional gravity placer recovery systems. A quantitative appraisal of potentially interesting industrial minerals should be made of Alberta river sediments.

6. This report cannot be considered to be an exhaustive study of all the relevant literature and ideas on the gold resources of Alberta. The input has been far too limited to arrive at an in-depth study. The report incorporates information and ideas largely based on personal knowledge. A broader base of information is available: in the literature, in the offices of the practising professional geologist and engineer, and in the gold pan, sluice box and 'black box' of the explorationist-prospector. The provision for an in-depth study

is recommended for this commodity in the near future. There is considerable scope for assistance and development of this neglected industry in Alberta.

LODE DEPOSITS

Lode gold deposits are commonly associated with: 1) igneous-metamorphic (Shield) terrains; 2) strata-bound conditions as in sedimentary sequences; or 3) volcanic piles characteristic of ocean floor spreading centers. In Alberta, these associations can be used to develop an exploration guide within the appropriate geological environments which identify the following exploration regions.

Igneous-Metamorphic Terrain

The Canadian Precambrian Shield of northeastern Alberta and the minor plutonic occurrences in extreme southwestern Alberta, for example, the Clark Range.

Strata-Bound (Sedimentary) Terrain

Cretaceous and/or Tertiary strata could be most prospective, especially those of fluvial origin (that is, potential paleo-placer deposits).

Thick Volcanic Piles

Thick volcanic piles, which have accumulated on the ocean floor associated with spreading centers have not been identified anywhere in the geology of Alberta, either at surface or in the subsurface.

Outlook

1. a) Studies in Igneous-Metamorphic (Shield) Terrain
   - i) The Precambrian Shield of northeastern Alberta, exposed for about 11 000 km^2 north of Lake Athabasca and

400 km^2 south of the Lake, has been extensively mapped by the Alberta Research Council. Good prospecting maps are available on a scale of two inches to one mile.

The best prospects for gold are at Waugh Lake, associated with a series of low-grade (greenschist facies) volcanogenic-clastic metasediments in which arsenopyrite is disseminated and tourmaline-quartz veins are locally concentrated. Both arsenopyrite and tourmaline are good indicator minerals for gold mineralization at the exploration stage.

Other metalliferous showings, some with arsenopyrite, are typically found in association with gossans within high-grade metasediments (granulite facies). Minor showings have been found also in the closely associated Archean granite gneisses.

Limited assays show low values of nickel and silver (pyrrhotite, arsenopyrite, pyrite) at Lindgren Lake; there are no gold assays. Hudson's Bay Oil and Gas Co. Ltd. (Burgan, 1971) prospected the Waugh Lake low-grade, metasedimentary-volcanic band and found sub-economic values in uranium and minor amounts of copper, nickel, silver and gold. There is scope for much more conventional surface prospecting in the Shield of Alberta, knowing that the metasediments, underlying about 10 percent of the outcrop area, are the primary prospecting target.

ii) Fort McMurray Drill Hole; it is understood that in 1911, when Sidney Ells drilled for the oil pool that was the supposed source of the oil found in the overlying oil sands, he cut gold-bearing "Laurentian granite" in the basement at a depth from 1105 to 1130 feet. An unconfirmed assay (possibly estimated by panning of crushed rock chips) suggests a gold value of about two-thirds of an ounce per ton. A value of $13.00 per ton is reported (Allan, 1920) (gold was $20.67/oz at that time). A mineral claim is now held over the drill hole site by Milton McDougall, and surrounding permits are held by Duncan Campbell, both of Edmonton.

b) Plutons of Southwest Alberta (Clark Range): Bosses of granitoid plutons are known in Alberta close to the interprovincial boundary with British Columbia just north of Waterton National Park. Late Proterozoic strata are cut by plutons and by basic sills and dykes, possibly of the Purcell Series.

Strata-bound copper mineralization has been found in the Grinnell and adjacent formations (Goble, 1970; Halferdahl, 1971). These showings have been prospected and the literature (mineral exploration reports) needs to be searched and checked for possible gold assays.

The unroofing and appearance of shallow-buried granitoid plutons should provide metalliferous prospecting opportunities. The potential area for the legendary "Lost Lemon Mine" should be viewed from this geological perspective.

2. Strata-Bound (Sedimentary) Exploration Potential

Cretaceous and Tertiary Bedrock: These sequences contain thick sections of clastic sediments, many of them deposited in continental or coastal environments. Therefore, in concept there should have been considerable opportunity for the development of drainage systems in which placer deposits could have formed.

The Lower Cretaceous of Alberta is well known for its fluvially transported, clean quartz sands (Peace River, Fort McMurray), which are indications of mature sediments, formed under rigorous climatic conditions. If geochemical conditions have remained favourable, the relatively stable mineral gold, and other heavy minerals, could have formed placer concentrations.

The Tertiary sediments of Alberta are essentially of continental origin and therefore should have been favourable for the accumulation of placers in fluvial channel deposits. The source(s) of these clastic sediments constitutes crucial data for the evaluation of this concept. It is possible that the transportation path of eroded lode and ancient placer gold deposits from interior B.C. (for example, Barkerville) can be traced (or even speculated upon) from interior B.C. to the Cretaceous strata of western Alberta, then reworked in part as source material for the Tertiary sediments. In turn, these Tertiary strata were a contributing source of sediment for the later alluvial deposits, including those of the modern river systems. Thus, in the course of reworking, the primary gold sources of interior B.C. could be responsible for the progressive and stepwise concentration of placer gold in successive clastic sediments of several geologic ages.

Research Projects

1. Shield terrains. A literature search should be undertaken of exploration reports, in particular with respect to gold assays, host lithologies, and indicator minerals and including the Fort McMurray drill hole to basement.

2. Granitoid plutons in the Clark Range of southwestern Alberta. A literature survey is needed to outline prospective areas, compile gold assays, and host lithologies, using government and mineral exploration reports, university theses, etc.

3. Paleo-placers, require extensive literature research, possibly supported by fieldwork, once segments of fluvial channel systems can be identified. Literature research is required into the compilation of gold assays in obvious fluvial channel-fill sediments. Failing the availability of suitable, decisive data, fieldwork (sampling) should be conducted at accessible, appropriate outcrops.

SUMMARY OF DATA GAPS

1. A reliable and methodically developed set of data are needed to evaluate placer gold concentrations in those segments of major modern river sediments known to contain anomalously high gold values.

2. A methodically developed and reliable data set are needed to quantitatively examine relationships between placer gold in the network of preglacial river channel deposits and placer gold in major modern alluvial deposits. Although all preglacial channels are theoretically prospective, some of these drainage systems, channels, and even segments of channels, will be more significant than others.

3. A methodically developed and reliable quantitative data set are needed to evaluate possible placer gold occurrences in the exposed Tertiary and Cretaceous bedrock of Alberta. The identification of paleo-fluvial systems and deposits is needed. This phase of research will require fieldwork to supplement data from existing literature.

4. Reliable quantitative and methodically developed data are needed on the mineralogy of heavy mineral concentrates (with special reference to platinum) from the major modern alluvial deposits.

5. Qualitative and quantitative data are needed on heavy minerals, placer gold and platinum values not being recovered from existing gravel-washing operations.

6. Synthesis and analysis of numerous exploration permit reports is needed to assess the potential of igneous-metamorphic related gold occurrences. Field work may be needed to supplement the findings of these reports in order to better establish the prospective mineral potential, especially for the little known granitoid-associated area of southwest Alberta.

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2. Specific Commodity Overview

3. Exploration - Reconnaissance Scale

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John D. Godfrey
March 26, 1985

Open File Report 1986-13 (g)

LIMESTONE/DOLOSTONE

by

John D. Godfrey

Alberta Geological Survey
Alberta Research Council
March 31, 1985

ACKNOWLEDGEMENTS

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LIMESTONE/DOLOSTONE

INTRODUCTION

The series of reports attempts to review the status of geology-related studies (published and unpublished) which reflect on the evaluation of a specific resource or commodity.

Literature references are incorporated and classified according to the level and type of field exploration detail supplied.

These reports should provide the background and basis from which:

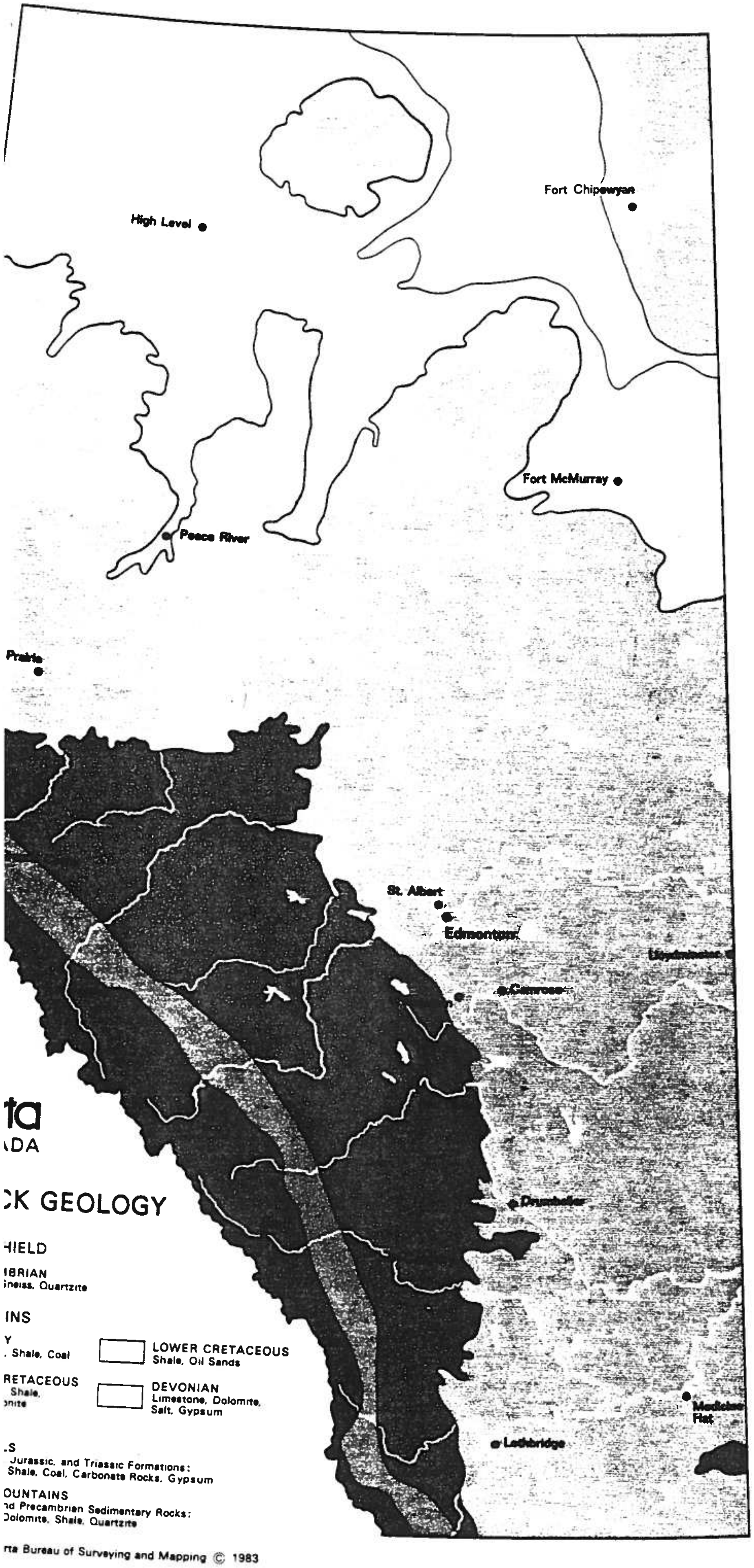
1. an assessment can be made of the level of exploration information currently available;
2. the most relevant literature can be selected through a system of classified references; and,
3. an economic feasibility for locating and/or developing a primary resource or commodity can be assessed from the geological characteristics and conditions as presently understood in Alberta.

Alberta has abundant sources of Paleozoic limestone/dolostone, they underlie the Sedimentary Basin of Western Canada. The outcrops and subcrops of these carbonates are found in two regions (figure 7):

1) the Interior Plains of the northeast where the Phanerozoic onlaps and surrounds the Canadian Shield of northeastern Alberta; and,
2) the Rocky Mountains Belt of the southwest.

Proximity to the network of principal urban centres and access to the east-west transportation corridors has favoured development of the better exposed carbonates in the mountains, especially in the southern portion of the belt.

1. The Interior Plains of northeastern Alberta: The relatively very low population density of remote northeastern Alberta suggests the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High Level
Fort McMurray
Peace River
Prairie
St. Albert
Edmonton
Camrose
Drumheller
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LOWER CRETACEOUS
Shale, Oil Sands
DEVONIAN
Limestone, Dolomite,
Salt, Gypsum
S
Jurassic, and Triassic Formations:
Shale, Coal, Carbonate Rocks, Gypsum
OUNTAINS
nd Precambrian Sedimentary Rocks:
Dolomite, Shale, Quartzite
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unlikelihood of extensive industrial development of carbonate rocks in this region. The expansion of open-pit operations in the Athabasca Oil Sands deposit may provide sufficient incentive for a limited industrial limestone development in the Fort McMurray area. Devonian limestone/dolostone floors the open pits and crops out for tens of kilometers along the Athabasca River and its major tributary streams.

2. The Rocky Mountains: Based on past and present production three industrially important carbonate formations are evident in the Rocky Mountains:

- the Lower Cambrian Eldon Formation
- the Upper Devonian Palliser Formation
- the Mississippian Livingstone Formation

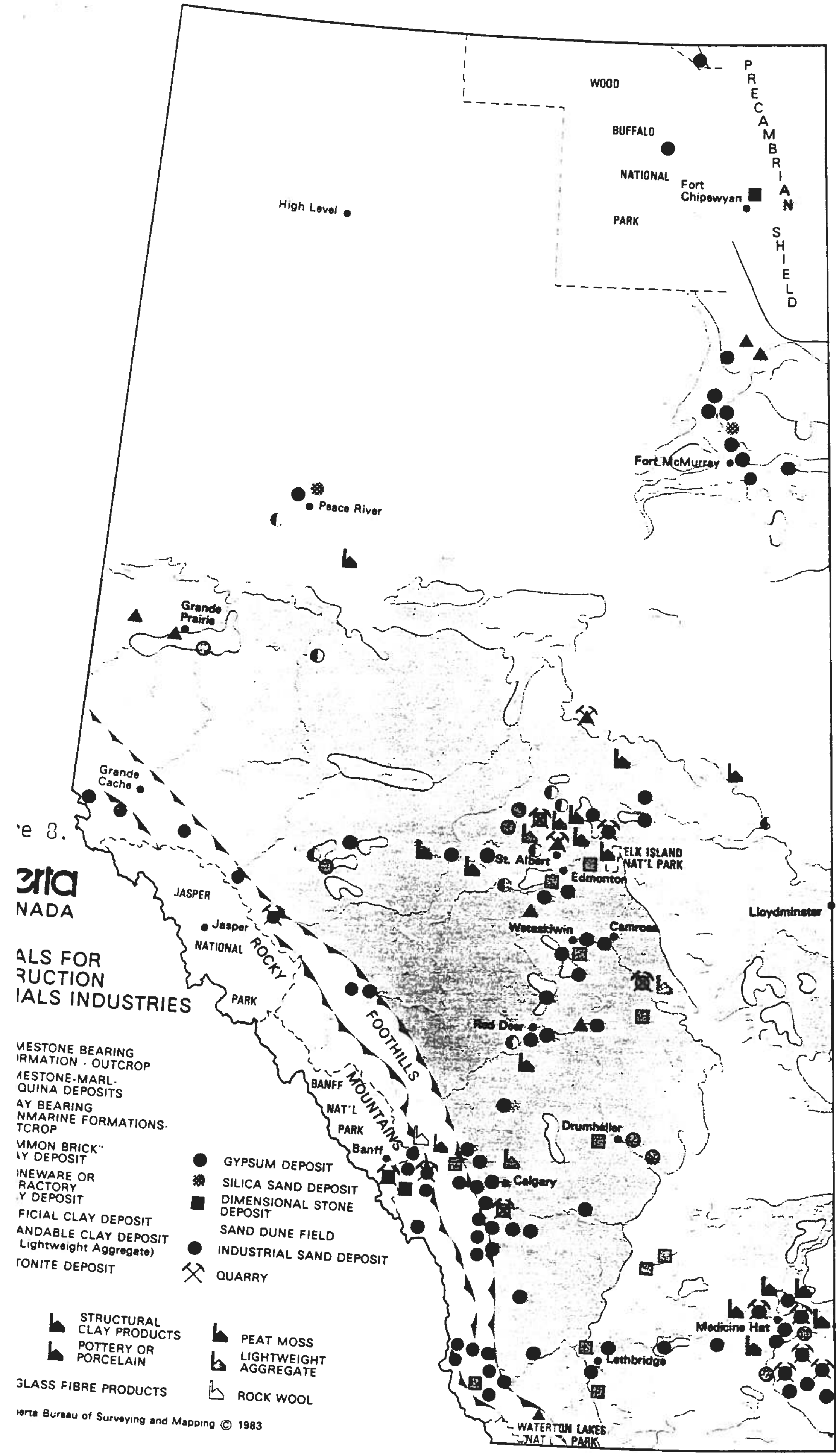
The emphasis in geological studies and evaluations to date has been largely related to the four main east-west transportation corridors (figure 8):

- the Crowsnest Pass
- the Kicking Horse Pass
- the David Thompson Highway (Howse Pass)
- the Yellowhead Pass

Some gaps are apparent in the information matrix summary presented in table 2. In terms of production volumes, the major quarries are situated in the Exshaw and Cadomin areas, serving the two major urban centres of Calgary and Edmonton.

OUTLOOK

1. Aglime (the practice of spreading either crushed carbonate rock or solutions to neutralize acidic soils thereby increasing fertility and productivity) is a fledgling industry in Alberta. However, it could become a major consumer of low-grade carbonate (waste) rock products in the future when the industry is better established and



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NADA
ALS FOR
RUCTION
IALS INDUSTRIES
WOOD
BUFFALO
NATIONAL
PARK
Fort Chipewyan
PRECAMBRIAN SHIELD
High Level
Fort McMurray
Peace River
Grande Prairie
Grande Cache
JASPER
Jasper
NATIONAL
PARK
ROCKY
FOOTHILLS
MOUNTAINS
BANFF
NAT'L
PARK
Banff
St. Albert
Edmonton
ELK ISLAND NAT'L PARK
Lloydminster
Wetaskiwin
Camrose
Red Deer
Drumheller
Calgary
Medicine Hat
Lethbridge
WATERTON LAKES NAT'L PARK
MESTONE BEARING
RMATION - OUTCROP
MESTONE-MARL-
QUINA DEPOSITS
AY BEARING
NMARINE FORMATIONS-
TCROP
MMON BRICK"
AY DEPOSIT
NEWARE OR
RACTORY
Y DEPOSIT
FICIAL CLAY DEPOSIT
ANDABLE CLAY DEPOSIT
Lightweight Aggregate)
TONITE DEPOSIT
GYPSUM DEPOSIT
SILICA SAND DEPOSIT
DIMENSIONAL STONE DEPOSIT
SAND DUNE FIELD
INDUSTRIAL SAND DEPOSIT
QUARRY
STRUCTURAL CLAY PRODUCTS
POTTERY OR PORCELAIN
GLASS FIBRE PRODUCTS
PEAT MOSS
LIGHTWEIGHT AGGREGATE
ROCK WOOL
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Table 2. Limestone/dolostone resources of Alberta; producers: present - ✓; past - (✓); potential - X

	(Miss[1]) *Livingstone Formation	(U. Dev.[1]) **Waterways Formation	(U. Dev.[1]) Palliser Formation	(L. Camb.[1]) Eldon Formation
Fort McMurray	-	X	-	-
Grande Cache	(X)	-	X	
Brule	?	-	X	
Cadomin	?	-	✓	
Nordegg	✓	-	?	
Exshaw	✓	-	✓	(✓)
Blairmore	(✓)	-	?	
Crowsnest	✓	-	✓	

- Not applicable
* Livingstone Formation - compositional problems with dolostone and siliceous impurities
(X) Limited potential
** Moderate quality, alumina and siliceous impurities
? No information, basic geologic data are needed

the cost/benefits better understood/accepted in the agricultural community.

2. Potential competitors for carbonate rock application in the aglime industry are marl and high-lime content sludges which are produced at hot- water plants for use in oil sands injection-recovery operations.

3. A major well-documented, reconnaissance-scale survey of marl deposits of Alberta (some deposits are discussed in more detail) has recently been completed by the Alberta Research Council (Macdonald, 1982). These deposits tend to be local and relatively small compared to carbonate rock exposures of the Rocky Mountains. Marl is principally seen to be of local and possibly short-term importance as a supply of aglime material. Post-glacial marl deposits are found at surface in the plains region (figure 8). Therefore, it has a possible advantage of being developed much closer to areas of acidic soil than the two prime belts of carbonate rock outcrop (southwest and northeast Alberta).

4. The production of high-lime sludges as a waste product of hot-water generation for oil sands operations is a relatively new development. The high-lime sludges result from the lime/soda ash softening of the produced water. The status and likelihood of using such sludges in the long-term as a soil conditioner/neutralizer is currently undergoing laboratory investigation at the Alberta Research Council (Alberta Research Council, 1985). If the tests prove positive, and the volume of sludge production meets the needs of the agricultural industry, then a useful waste/byproduct disposal will be achieved.

5. As an industrial mineral product, the use of carbonate rock in the traditional lime-cement products area should experience steady growth with population increases. There is essentially an unlimited supply of limestone/dolostone for these uses within Alberta. The Alberta Research Council report by Holter (1976)

presents a useful reconnaissance overview, with some local detail at active or prospective sites. Filling in the data base for the limestone/dolostone resources (see Research Project No. 1) would logically lead to an update and release to the public of a revised version of Holter's overview.

6. Many years ago (mid-1960s) an unsuccessful attempt to utilize marl as a raw material feed for a cement plant was made by Imperial Cement near Clyde. Today, one cement plant (Houg Cement Ltd. at Halfway Lake) uses marl for cement production. However, the natural variability in composition of marl deposits presents a major difficulty in controlling a uniform feed composition to plants. The energy cost in drying moist marl is another key economic factor. Attempts to substitute marl for limestone on a large scale seem unlikely in the near future and the traditional utilization of limestone is expected to continue.

RESEARCH PROJECTS

1. Field investigations and evaluations are appropriate to fill information gaps and to better define the "limited potential" of some formations as displayed in the information matrix of table 2.

2. A more accurate, comprehensive and in-depth appraisal of limestone/dolostone resources could be achieved from a wider search and assessment of the existing relevant literature. The full benefit of the present summary study is unfortunately foreshortened by the limited scope of the current program. Consequently, the report is somewhat superficial in its approach and conclusions. It is recommended that provision be made to undertake an appropriate research-oriented, broad-ranging study of this important commodity. Of particular relevance would be direct contact with the industry to obtain an update on current trends in technology, product lines and specifications.

3. To maximize the benefits, consideration should be given to aligning

the objectives and results of field studies to the direct needs of a potential industrial user. Better definition of average grade, grade variation, and the pattern of their distribution within the carbonate strata are needed to enable an industrial evaluation of deposits and to quantitatively compare these data with technical specifications for potential industrial applications; for example,

riprap - has no chemical specifications, but boulders of a minimum size are usually specified.

aglime - specifications cover a wide range of chemical composition; a heterogeneous composition is usually not a problem; for example, shale impurities do not present a quality control problem.

quicklime and portland cement - a high-calcium limestone is needed; a uniform composition and quality is important, and acceptable limits on the range of chemical variations are applied.

4. If not already available in the industry, it would be appropriate to produce a handbook or manual that gathers together the technical specifications for the common industrial uses of limestone/dolostone: that is, a manual similar in content to the Alberta Research Council publication on sand; report #71-4 by McLaws, 1971.

5. In the search for building stone, riprap, similar construction/engineering materials, and even in mining (quarry) operations, a knowledge of jointing characteristics is required. Although this feature is of critical significance in these potential industrial uses, most geological/technical field reports largely overlook systematic rock fracture data. Future technical studies of limestone/dolostone resources should address this geological factor in a systematic manner.

6. It would be of help in the course of resource evaluations to be aware of the possible variations in lithology and chemical composition on the scale of a potential quarry site. Does

government monitor active limestone/dolostone quarries in terms of changing geological/mineralogical/chemical characteristics? Does government have access to records of this type that would be routinely compiled for quality control by industry? Otherwise some valuable data are being lost as the quarry face advances.

7. Crushed stone is produced at several industrial plants and operations. However, not all crushed stone has a direct industrial use, and some of it ends up in large waste piles; for example,
(a) sub-grade limestone presently stockpiled at the Inland Cement quarry at Cadomin may eventually find a use as aggregate if the economics ever prove favourable;
(b) blocks smaller than the specified riprap size produced for the Dickenson Dam (Red Deer River) have been stockpiled as waste about 65 km southwest of Rocky Mountain House. However, this stockpile may be eventually crushed further for use as aglime.

In general, the accumulation of industrial wastes should be monitored and potential industrial uses reviewed and explored on every possible occasion.

SUMMARY OF DATA GAPS

1. Basic, reconnaissance-level geologic field data are needed for several of the industrially important carbonate formations in the major transportation corridors of the Rocky Mountains.

2. Data are absent for the quarry-scale of investigation. Variations in lithology and composition at the quarry scale of evaluation are available at active quarries.

3. Geological field investigations commonly omit the study of jointing, a feature of importance in some industrial uses and in quarry design and planning.

4. Consolidation of technical specifications for the multiple

industrial uses of limestone/dolostone would facilitate dissemination and access of these key data.

5. The geologic and compositional nature, volumes and rates of accumulation of industrial wastes (especially quarry and industrial plants) should be documented and efforts made to utilize such products.

OUTLINE FOR REFERENCE CLASSIFICATION: RESOURCE INVENTORY

A. Resource (Commodity) Evaluation References
   1. General Overview
   2. Specific Commodity Overview
   3. Exploration - Reconnaissance Scale
   4. Exploration - Site Specific Scale

B. Supporting References
   1. Concepts and Principles
   2. Indirect Exploration - Reconnaissance Scale
   3. Indirect Exploration - Site Specific Scale

C. Background and Miscellaneous References

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John D. Godfrey

March 31, 1985

The Metallic and Industrial Minerals of Alberta
Mineral Commodity Profile
Open File Report No. EO 1986-13 (I)

PLATINUM GROUP ELEMENTS

by

J. A. Wilson

Mineral Resources Group
Alberta Geological Survey
Alberta Research Council
October, 1988

PLATINUM GROUP ELEMENTS

INTRODUCTION

Background

The occurrence of placer Platinum Group Elements (PGE) in Alberta has long been noted (Hoffman, 1891; Uglow, 1920; Mackenzie, 1919; Halferdahl, 1965; Giusti, 1983). However, Alberta has no present or past production of PGE, or any known economic deposit. The recent increase in the world price of PGE, and the discovery of PGE deposits in Saskatchewan in a setting which may be present in Alberta, suggests that there is a potential in Alberta which is worth investigating. This report summarizes current thinking as it relates to Alberta, assesses the known potential in Alberta, and examines the needs for further work to aid future development.

Definition of terms and properties

The PGE comprise six closely related metals: platinum (Pt), palladium (Pd), rhodium (Rh), iridium (Ir), ruthenium (Ru) and osmium (Os). With silver and gold they constitute the precious or noble metals. They commonly occur together in nature as native alloys or mineral compounds in placer deposits. Table 1 shows the more common Platinum Group Minerals (PGM).

Metallic platinum and palladium are traded in a variety of forms, including powder, crystals, plate, bars, foil, wire and sponge. Sponge is the imperfectly consolidated metal produced from chemical refining. Rhodium, iridium, ruthenium and osmium are traded as powders or compact metal forms. All of the group are available as salts.

In the last few years, research into the PGE has led to a dramatic increase in the number of known minerals. In 1965 only 23 PGM were known (Wright and Fleischer, 1965; *in* Hulbert et al., 1988, p. 5). By 1972 this figure had risen to 64 (Cabri, 1972;in Hulbert et al., 1988,

Table 1. The more common platinum group minerals, listed alphabetically (from Hulbert et al., 1988)

Mineral	Ideal formula
Braggite	(Pt,Pd)S
Cabriite	Pd_2SnCu
Cooperite	PtS
Erlichmanite	OsS_2
Isomertieite	$Pd_{11}As_2Sb_2$
Irarsite	IrAsS
Iridosmine	(Os,Ir)
Isoferroplatinum	Pt_3Fe
Kotulskite	PdTe
Laurite	RuS_2
Merenskyite	$PdTe_2$
Michenerite	PdBiTe
Moncheite	$PtTe_2$
Osmiridium	(Ir,Os)
Platarsite	PtAsS
Plumbopalladinite	Pd_3Pb_2
Polarite	Pd(Bi,Pb)
Rutheniridosmine	(Os,Ir,Ru)
Sperrylite	$PtAs_2$
Stannopalladinite	Pd_5Sn_2Cu
Sudburyite	PdSb
Taimyrite	$Pd_9Sn_4Cu_3$
Vysotskite	PdS

p. 5) and it currently stands at 84 (Hulbert et al., 1988). Platinum and palladium minerals dominate known PGM (table 1), reflecting their abundance relative to rhodium, ruthenium, iridium and osmium in nature. Sperrylite ($PtAs_2$) is the most common PGM, occurring in all deposit types.

INDUSTRY SETTING

World production

Over 90 percent of the world's production of PGE is from the Republic of South Africa and the Soviet Union. South Africa dominates platinum production while the Soviet Union dominates palladium (table 2). Canada was the world's major producer of PGE from 1934 to 1955, but now ranks third with about 5 percent. In 1987 production commenced from the Stillwater Complex in Montana, and it is anticipated that this will make the United States the fourth largest producer.

Canadian production

Canadian production of PGE is as a by-product of processing nickel-copper ore at Sudbury. Table 2 shows that Sudbury is low-grade compared to the other world-class deposits. Minor amounts of the PGE are also produced as a by-product of the Ni smelting at Thompson, Manitoba. The copper-nickel deposits at Lac des Illes and Marathon in northern Ontario both have PGE content and are in an advanced state of development. The by-product nature of Canadian PGE production means that the amounts produced from year to year do not vary with PGE price.

Canadian production in 1986 amounted to 8,793 kg. Reserves are estimated at about 280 million g (Bokovay, 1987), of which almost 90 percent is platinum and palladium in equal proportions. Production of PGE in Canada is far greater than consumption, so that Canada is a net exporter of PGE. Major importers are Japan, United States and Western Europe.

Table 2. Grades and Resources of Principal Magmatic PGE Deposits (after Hulbert et al., 1988)

	Price[1]	South Africa Merensky Reef	South Africa UG-2	South Africa Platreef	U.S.A J-M Reef (Stillwater)	Zimbabwe Great Dyke	U.S.S.R. Noril'sk Talnakh	Canada Sudbury
Ni	$1.76/lb	0.18%	0.09%	0.3%	0.24%	0.25%	2.4%	1.3%
Cu	$0.62/lb	0.11%	0.03%	0.2%	0.14%	0.25%	3.0%	1.1%
Pt	$ 462/oz	4.8 g/t	3.7 g/t	3.1 g/t	4.2 g/t	2.5 g/t	0.95g/t	0.34g/t
Pd	$ 116/oz	2.0 g/t	3.0 g/t	3.4 g/t	14.8 g/t	1.7 g/t	2.7 g/t	0.36g/t
Rh	$1157/oz	0.24g/t	0.70g/t	0.22g/t	1.7 g/t	0.22g/t	0.12g/t	0.03g/t
Ir	$ 414/oz	0.08g/t	0.20g/t	0.06g/t	0.53g/t	0.03g/t	?	0.01g/t
Ru	$ 73/oz	0.65g/t	1.0 g/t	0.29g/t	0.89g/t	0.22g/t	0.04g/t	0.03g/t
Os	$ 625/oz	0.06g/t	?	0.04g/t	?	0.03g/t	?	0.01g/t
Au	$ 368/oz	0.26g/t	0.06g/t	0.25g/t	0.12g/t	?	?	0.12g/t
Grade: PGE + Au		8.1 g/t	8.7 g/t	7.3 g/t	22.3g/t	4.7 g/t	3.8 g/t	0.9 g/t
Gross value[2]		$103/t	$102/t	$ 87/t	$203/t	$ 66/t	$163/t	$ 75/t
PGE + Au: % of Gross Value		92%	96%	83%	94%	80%	18%	12%
Resources[3] (tonnes contained PGE)		17,500	32,400	11,800	1,100	7,900	6,200	394

[1] Average 1986 price in U.S. dollars

[2] Gross value of contained metals per metric tonne of ore in the ground; no allowance is made for dilution, metallurgical recovery, etc.

[3] Generally equivalent to United Nations resource categories R1E and R2E: that is, reliable estimates of economically exploitable ore in known deposits and preliminary estimates of economically exploitable ore in extensions to known deposits and newly discovered deposits. Data from ISMI (International Strategic Minerals Inventory), except for Great Dyke which is from Naldrett et al., 1987.

Uses and Markets

The largest uses of the PGE are as catalytic convertors in the automotive industry and as electrical components. In addition they are used in the chemical and petroleum industries and in dentistry and jewelry. Current world consumption of the PGE amounts to about 235 tonnes annually, and it is anticipated that this demand will increase towards the end of the century. This increase will be due to the introduction of automobile emission standards in Europe, Australia and Korea with the consequent increase in the use of PGE as catalytic convertors. In the longer term, the increased use of fuel cells for electrical energy generation may also have a significant impact on demand for PGE.

GEOLOGY AND RESOURCES

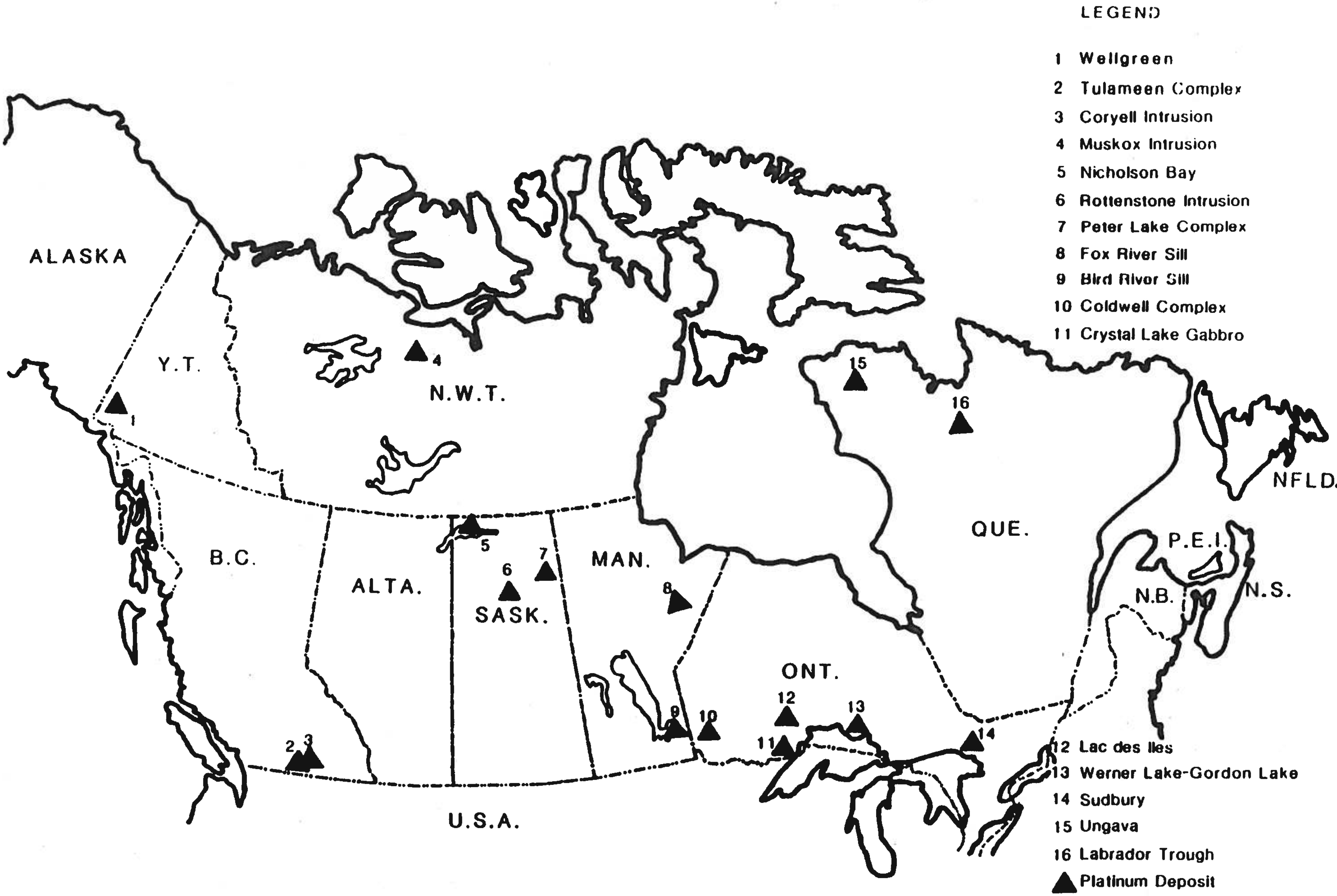
Geological setting

The PGE are commonly found in association with ultramafic to mafic rocks, particularly large-scale layered intrusions. The perception that this is the only place to find PGE deposits has been reinforced by the dominance of the Bushveld Igneous Complex in South Africa, the Noril'sk intrusives in the U.S.S.R. and the Stillwater Complex in the U.S.A. However, recent exploration has led to several potentially significant discoveries in other geological settings. Table 3 shows the most recent classification scheme for PGE deposits.

PGE deposits are divided into three main classes; magmatic, hydrothermal, and surficial (table 3). Economically the magmatic class is the most important. It is subdivided into three subclasses; stratabound, marginal, and discordant. The 'other' subclass contains deposits which are not well known and cannot be placed in a defined subclass. The stratabound subclass consists of deposits which are stratabound with respect to the igneous layering in an intrusion. The discordant subclass are deposits which are not stratabound with respect to the igneous layering. The marginal subclass consists of sulphide

Table 3. Classification of Platinum Group Element Deposits and Occurrences (from Hulbert et al., 1988)

Class	Subclass	Examples
MAGMATIC	Stratabound	Merensky Reef, Bushveld, southern Africa UG-2, Bushveld, southern Africa J-M Reef, Stillwater, Montana Picket Pin, Stillwater, Montana MSZ, Great Dyke, Zimbabwe *Cyclic units, Muskox Intrusion, N.W.T.* *ULCZ, Fox River, Manitoba* *Lower Chromitites, Bird River, Manitoba* *Cyclic Zone, Crystal Lake Gabbro, Ont.* *Delta North, Ungava, Quebec*
	Discordant	Dunite pipes, Bushveld, southern Africa
	Marginal	Platreef, Bushveld, southern Africa Noril'sk, U.S.S.R. *Coldwell Complex, Ontario* *Sudbury, Ontario* *Marginal sulphides, Muskox, N.W.T.* *Katiniq, Ungava, Quebec* *Donaldson West, Ungava, Quebec* *Bravo, Ungava, Quebec* *Rottenstone, Saskatchewan* *Coryell, British Columbia* *Wellgreen, Yukon*
	Other	*Roby Zone, Lac des Iles* *Werner Lake-Gordon Lake* *Tulameen, British Columbia* Zoned Complexes, U.S.S.R.
HYDROTHERMAL	Pt-Pd-Au-(Cu)	New Rambler, Wyoming Messina, southern Africa *Peter Lake, Saskatchewan* Unst, Shetland Islands, U.K.
	U-Au-Pt-Pd	*Nicholson Bay, Saskatchewan* Coronation Hill, N.T., Australia Shinkolobwe, Zaire
SURFICIAL	Alluvial	San Juan and Attrato Rivers, Choco District, Columbia Ural Mountains, U.S.S.R. *Tulameen, British Columbia* Goodnews Bay, Alaska
	Eluvial	Gilgarnia Rocks, Western Australia



PLATINUM DEPOSITS IN CANADA - 1988
Figure 1. (after Hulbert, et. al., 1988)

concentrations on the margins of intrusions. These marginal deposits probably owe much to contamination of the magma with country rock. The magmatic class accounts for 98 per cent of current measured reserves.

Hydrothermal deposits are not restricted by rock type. They are the result of PGE transport in, and deposition from, hot aqueous fluids. The deposits may be epigenetic (eg. vein-type) or concentrations in diagenetic and sedimentary exhalative environments. Although hydrothermal deposits are not significant producers on a worldwide scale, they are generally very high grade. Increased exploration is discovering them in more and more settings.

The most important subclass of the surficial deposits are found in the alluvial environment. This subclass includes the Tulameen River deposit in British Columbia and the Alberta occurrences. Eluvial deposits are not well known, although there is a suggestion of an association of PGE with laterite soils (Bowles, 1986).

Canadian deposits and potential

The major Canadian deposits are italicized in table 3. Figure 1 shows the location of these deposits. Although the bulk of current Canadian production is as a by-product of Ni-Cu, there are numerous other deposits of PGE in Canada which have significant proven or potential reserves. The data in this section are taken from Hulbert et al., 1988, unless otherwise referenced.

Recent annual production of platinum and palladium at Sudbury averages around 150,000 and 190,000 ounces respectively. Estimated reserves stand at 500 million tonnes averaging 1.3 percent Ni, 1.0 percent Cu and 1g/t total PGE.

The Lac des Iles Complex in Quebec is a late Archean mafic/ultramafic body with considerable potential for PGE production. The Roby deposit within the complex has reserves of 22.5 million tonnes grading 6.17g/t total PGE with a Pt:Pd ratio of 7:1.

Other intrusive bodies which have been worked in the past and have future potential are at Werner Lake-Gordon Lake and the Coldwell Complex in Ontario, Wellgreen in the Yukon, Coryell in British Columbia and Rottenstone in Saskatchewan. More speculative, are exploration plays currently being undertaken on the enormous Muskox layered intrusion in the Northwest Territories, the Fox River and Bird River sills in Manitoba, the Crystal Lake Gabbro in Ontario, the Labrador Trough and Ungava in Quebec and the Tulameen Complex in B.C. Anomalous hydrothermal PGE values are also being investigated in the Peter Lake Complex in Saskatchewan.

Recent exploration at Nicholson and Fishook Bays in Saskatchewan has outlined hydrothermal deposits of a U-Au-PGE association. Some of these deposits are spatially related to small mafic/ultramafic bodies; however, there is considerable doubt as to whether they are genetically related. Placer deposits of the PGE are known to be associated with the Tulameen Complex in B.C., and PGE are present in all major rivers in Alberta.

Alberta potential

Potential exists for at least two types of PGE deposits in Alberta. In addition to the known placer PGE, the setting in northeastern Alberta could be favorable for certain types of hydrothermal mineralisation.

Placer PGE have been recorded from the Peace River (Uglow, 1920) and the McLeod, Milk, North and South Saskatchewan and Red Deer Rivers (Halferdahl, 1965). No grades have been published and no systematic mineralogical studies done. What work that has been done suggests that the PGE in Alberta's rivers occur as small flakes between 0.25 and 0.5 mm across (Hoffman, 1891; Mackenzie, 1919) and are rarely magnetic. Analysis of a grain recovered from the North Saskatchewan River at Edmonton revealed a composition by weight of 93.15 percent Pt, 3.93 percent Fe and 3 percent "assumed" Rh (Miller, 1982: *in* Giusti, 1983 page 221). Another grain from a gravel pit at Villneuve was composed of 88 percent Pt, 8.69 percent Fe and 35 Rh. Table 4 shows the

Table 4. Composition (wt.%) of platinum grains from the North Saskatchewan River, Alberta (from Giusti, 1983)

Sample	Pt	Fe	Cu	Rh
P1	90.170	8.150	0.178	1.502
P2	88.254	5.988	1.705	4.053
P3	89.006	4.928	1.960	4.107
P4	90.182	8.239	0.192	1.387
P5	89.232	4.890	1.841	4.037
P6	90.116	8.045	0.319	1.519
P7	90.135	8.148	0.238	1.479
P8	88.583	5.547	1.789	4.081
P9	90.348	7.972	0.233	1.448
P10	88.824	5.429	1.751	3.997

analysis by Giusti (1983) of 10 grains from the North Saskatchewan River. Obviously much more work is required before anything certain can be said about the recoverable potential of the PGE from Alberta's rivers. However, the association of PGE with placer gold, magnetite and garnet makes them attractive commodities to search for.

The recent discoveries of PGE at Nicholson and Fishook Bays in Saskatchewan are only 60 km from the Alberta border. Their association with uranium, gold and shear zones, and their lack of association with well developed ultramafic intrusions, suggests a new type of deposit (Hulbert et al., 1988). Uranium showings are fairly common on the exposed shield of northeastern Alberta (Godfrey, 1986) and exploration is currently underway looking for unconformity-type deposits beneath the Athabasca Group. There are also a number of reported gold occurrences in the Shield rocks in the region. Small bodies of pyroxenite have been noted south of the Athabasca Group (Wilson, 1985, 1986) in an area where there is faulting and mylonite development. Thus all the conditions associated with PGE mineralization at Nicholson Bay are present in Alberta, suggesting potential for hydrothermal PGE deposits in Alberta.

Research needs

1. A study of the grade of the placer PGE deposits in Alberta's rivers is required to assess their potential. This could most conveniently be done in conjunction with a study of the placer gold. Analysis should be carried out for all the PGE if possible.

2. A study of the mineralogy of the PGE minerals in Alberta's placer deposits should be carried out as part of any grade study. The mineralogy will help to define the economic viability of any deposits and can also be used to determine a source for the PGE and possibly the placer gold as well.

3. Assessment of hydrothermal PGE potential requires a project to locate and map small ultramafic bodies in northeastern Alberta. This study would utilize aeromagnetic data, drill core data and

field examination to map these intrusions and to define any associated shear zones and uranium mineralization. The study would be followed up with geochemical analysis to define anomalous areas of PGE mineralization.

TECHNOLOGY

Mining and processing

The PGE are mined by underground or surficial methods, most commonly the former. The ore is crushed and milled then treated by flotation or gravity separation. Flotation concentrates are smelted and further separated before refining.

Conventional refining of the PGE involves dissolution in aqua regia to remove platinum, palladium and gold. The residue is then smelted with litharge, PbO, and the slag removed. The smelted lead is treated with nitric acid to remove lead and silver and the residue of rhodium, iridium, ruthenium and osmium undergoes numerous chemical processes to separate the metals (Loebenstein, 1985).

Recently a solvent extraction process has been developed which involves the leaching of the base metals and the dissolution of the PGE using chlorine and hydrochloric acid. PGE recovery is a continious process accomplished by the precipitation of insoluble salts or complexes.

ECONOMIC FACTORS

Prices and costs

The PGE are traded worldwide and are priced on the international market. The producer price is set by the major South African and Canadian producers and the dealer or spot price is set by U.S. precious metal dealers. Table 5 shows prices for the PGE for the years 1963 to 1983. Generally they show an increase, although ruthenium has decreased

Table 5. Time-price relationships for platinum-group metals (from Loebenstein, 1985)

	Average annual producer price, U.S. dollars per troy ounce.					
Year	Platinum	Palladium	Rhodium	Iridium	Ruthenium	Osmium
1963	82	25	139	73	57	65
1964	90	31	155	85	57	95
1965	100	33	183	100	57	236
1966	100	34	196	145	57	350
1967	111	38	225	188	58	400
1968	117	45	247	188	58	400
1969	124	42	240	185	56	335
1970	133	38	215	156	53	215
1971	121	37	200	152	52	210
1972	121	42	197	162	52	212
1973	150	78	222	223	59	200
1974	181	133	329	391	60	200
1975	164	93	338	477	60	200
1976	162	51	348	325	60	200
1977	163	60	441	258	60	175
1978	237	71	510	300	56	150
1979	352	113	733	257	45	150
1980	439	214	766	505	45	150
1981	475	130	641	600	45	150
1982	475	110	600	600	45	150
1983	475	130	600	600	45	110

and osmium reached a high in the late 1960's and has since declined. The average 1986 price for the PGE in US dollars is shown in table 2.

Transportation

The high cost of the PGE and the restricted sources of supply mean that transportation is not a major factor in their economics. However, sources within the North American continent would reduce transportation costs for north American users.

Strategic Considerations

Platinum and palladium are considered strategic minerals since, although there are large resources, their supply is controlled by two countries. South Africa is not considered to be politically stable and the USSR does not necessarily have the same interests as the major consumers. Canada is currently in the enviable position of having an adequate domestic supply.

The United States currently consumes about one third of the world mine production and imports almost all of it. Despite the potential of the Stillwater Complex, the USA will remain a major importer for the forseeable future. Significant new deposits in Canada would find a ready market close at hand.

OUTLOOK

Supply and demand

Increased primary production from the Stillwater Complex and greater secondary production from recycling used automotive catalytic convertors in the USA will be balanced by an increase in the use of PGE in the electrical industry. World-wide, an increase in the use of PGE for catalytic convertors and for refining unleaded gasoline will lead to an increased demand for the PGE through the 1980's and 1990's. Continued unrest and instability in South Africa can only lead to pressure to find secure PGE supplies elsewhere. Thus it seems likely that finding a market for any mineable resources of PGE in Alberta would not be a problem.

Summary of research needs

The world-wide nature of the PGE supply and markets make PGE an extremely attractive resource prospect for Alberta. Although no economic deposits are known, reported showings and the occurrence of favourable geological settings indicate that potential exists.

Basic geological mapping and analysis are required to assess Alberta's potential for both placer and hydrothermal deposits of PGE. If this phase of investigation proves encouraging it should be followed up with further work to define areas of interest to guide explorationists in their search.

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The Metallic and Industrial Minerals of Alberta
Mineral Commodity Profile
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ZIRCONIUM

by

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March, 1989

ZIRCONIUM

INTRODUCTION

Background

Canadian needs for zircon and zirconium products are met entirely by imports. Zirconium resources exist in Canada, notably in the Athabasca Oil Sands in Alberta and at Strange Lake on the Quebec/Newfoundland border. This report summarizes the current situation with regard to zirconium, assesses the potential in Alberta and its relationship to possible markets, and examines the need for future work. Data in this report, unless otherwise referenced are taken from the U.S. Bureau of Mines Minerals Yearbook 1986, the Canadian Minerals Yearbook 1987, and "Zirconium, an imported mineral commodity", published in 1983 by Energy, Mines and Resources Canada.

Definition of terms and properties

Zirconium and hafnium occur together in nature, principally in the minerals zircon ($[Zr,Hf]SiO_2$) and baddeleyite ($Zr,1tfO_2$). They are found commonly as placer minerals in beach deposits, associated with ilmenite, rutile and monazite.

In addition to zircon and baddeleyite, zirconium is traded in a number of forms - most notably, zirconium oxide and hydride powders, zirconium oxychloride crystals, zirconium acetate solution and zirconium powder, sponge or sheet.

INDUSTRY SETTING

World production

Zircon is produced from beach sand as a by-product of titanium mineral production. The increasing demand for titanium oxide in recent years has been matched by the increasing development of new uses for zirconium. Baddeleyite is produced as a by-product of copper production at Palabora in South Africa. Nowhere, are zirconium minerals mined as primary products.

Australia dominates the world supply of zircon concentrates (table 1, although her share of the world market has declined in recent years. The drop in Australian production in 1986 was related to zircon production's dependence on titanium minerals. In 1986 new deposits of mineral sands were mined which contain a lower concentration of zircon. Environmental concerns have led to the recent shift in the centre of mining activity from the east to the west coast. The Republic of South Africa is the second largest producer with a growing share of the world market. Both the Soviet Union and the United States have significant production, but do not release statistics.

Canadian production

Canada has no production of zircon. However, alumina-zirconia is produced from imported baddeleyite and then exported to the United States for use in abrasives. Various zirconium alloys for use in the aerospace industry and in nuclear power plants are produced in Canada from imported raw materials.

Uses and markets

Over 80% of zirconium mineral demand worldwide is for foundry sands, refractories and ceramics. Zircon is unreactive and has a high thermal conductivity, which makes it ideal for use as foundry sand. However, other materials replace it in this use when there is even a small increase in price. Japan pioneered the use of refractory zircon as the lining of steel ladles, crucibles and furnaces. This use is gaining at the expense of foundry sand uses. Zircon is also used as an opacifying agent in ceramic glazes and enamels.

Zirconium and zirconia are used in a number of electronic and industrial applications. These include oxygen sensors in exhaust systems and in piezoelectric materials. Because of their low neutron

	1983	1984	1985[p]	1986[e]
		(tonnes)		
Australia	382 310	454 540	440 000	401 890
Republic of South Africa	162 280	153 120	160 530	160 030
U.S.S.R.[e]	81 700	81 700	86 200	86 200
United States[e]	50 000	60 000	70 000	85 000
India	11 390	11 790	14 800	15 970
China[e]	14 970	14 970	14 970	14 970
Brazil	7 430	7 020	12 750	11 970
Sri Lanka	5 720	3 710	4 060	3 990
Malaysia	2 550	7 610	11 650	6 990
Thailand	200	290	880	880
Total	718 550	794 750	815 840	787 810

Sources: U.S. Bureau of Mines Minerals Yearbook Preprint, Zirconium and Hafnium, 1986; Mining Annual Review 1987 Nuclear Metals; Industrial Minerals.

p Preliminary; e Estimated (from Canadian Minerals Yearbook, 1987)

Table 1. World Production of Zircon concentrates, 1983-86

Price ($US)	
Zirconium ore, per short ton	
Australia (1987)	155
United States (1987)	165
Baddeleyite imported concentrate, per kg. (1986)	2.13
Zirconium oxide powder, per kg. (1986)	9.35
Zirconium hydride powder, per kg (1986)	69.85
Zirconium oxychloride crystals, per kg (1986)	2.00-2.29
Zirconium acetate solution, per kg (1986)	2.13
Zirconium	
Powder, per kg (1987)	132-330
Sponge, per kg (1987)	26.46-37.48
Sheet, strip on bar, per kg (1987)	35.27-99.2

Table 2. Recent zirconium material prices (Minerals Yearbook 1986 and Canadian Minerals Yearbook 1987)

absorption, zirconium alloys are used as tubing to hold CANDU reactor fuel rods.

Future uses currently under developement are in the field of advanced ceramic material for diesel and turbine engines. These materials are desirable because of their high resistance to extreme temperatures and thermal shock.

GEOLOGY AND RESOURCES

Geological setting

Zircon is found as an accessory mineral in a wide range of granitic rocks. However, its economic potential is limited to unlithified clastic deposits, where it occurs with ilmenite, rutile, monazite and leucoxene. These sands are generally, only found in sufficient quantities along coastlines, but the potential exists for their occurrence in other depositional settings.

Canadian deposits and potential

The Iron Ore Company of Canada has long had an interest in the Strange Lake zirconium-rare earth property on the Labrador/Quebec border. This deposit is located some 300 km northeast of Schefferville, Quebec. It occurs in a Precambrian granite complex and could be open-pit mined. In addition, to high-grade yttrium and zirconium values, the deposit also contains significant amounts of beryllium, niobium and other rare-earth elements.

The zirconium at Strange Lake is present as the minerals gittinsite, armstrongite and elpidite. These are all acid-soluble minerals which can yield zirconium through solvent extraction. The zirconia produced in this fashion can be used to produce high-technology zirconia. A recent assessment of the commodity market by the Iron Ore Company of Canada has led them to decide against developing this resource.

Zircon and titanium mineral-rich sands also occur along the north and east shores of Graham Island in the Queen Charlotte archipelago (Hamilton and Hora 1987). The extent and richness of these deposits is unknown.

Alberta potential

The potential for the production of zircon in Alberta is centred on the Athabasca Oil Sand deposits north of Fort McMurray. This potential has received some attention in the literature in recent years (Kramers and Brown 1976, Trevoy et al. 1978. Trevoy 1984).

The Syncrude mine, north of Fort McMurray, extracts 97 million tonnes of oil sands annually. The solids in the tailings stream from the bitumen extraction process contains 20 to 25 percent heavy minerals, of which 7 percent is titanium and 2 percent zirconium. Extraction of the heavy minerals from the tailings stream produced by the production of 135,000 barrels per day would yield 41,000 tonnes per year of zircon and 94,000 tonnes per year of titanium minerals. If this product were processed with the tailings from the nearby Suncor plant, then the total would approach the annual total production from Western Australia.

The technological problem with processing zircon from the Syncrude tailings involves the complete removal of all bitumen from the concentrate prior to separation of the zircon. If this problem is overcome, Alberta will have a viable source of zircon. The economics of this potential depend upon world demand and the prices of zircon and the titanium minerals.

Potential may also exist in Alberta for zircon to be produced from placer or gravel operations. The lack of a local market and the very large volume required to make a venture of this sort economically viable makes it unlikely that this potential will ever be realised. However, if zircon is commercially recovered from the oil sand tailings in the near future, then this may provide an incentive for other sources to be explored.

Research needs

Any production of zircon in Alberta will be of a by-product nature, probably in conjunction with the titanium minerals. Thus, any large-scale placer operations should look at levels of these minerals in their mine with a view to possible stockpiling until an economic quantity is reached. There is a need, therefore, for a province-wide survey of the zircon and titanium mineral content of all granular materials which occur in quantities that are amenable to large-scale operation.

TECHNOLOGY

Mining and processing

Mining of zircon is by open-cast mining of beach sands and other surficial deposits. The bulk of the uses of zircon require only crushing and concentrating of the ore. Processing of these concentrates is only required where zirconium metal or alloys are needed.

ECONOMIC FACTORS

Prices and costs

Zircon is traded worldwide and priced on the international market. Because of its by-product nature, the price is closely dependent on the worldwide demand for the titanium minerals. Some recent prices are shown in table 2.

Transportation

The worldwide nature of the zircon trade, and the restricted sources of supply, mean that transportation is not a major factor in its economics. However, sources within the North American continent would reduce transportation costs for Canadian users.

Strategic considerations

A small proportion of zircon consumption is in zirconium alloys, which are used as fuel cladding in nuclear reactors. This gives the mineral a strategic value. However, the amounts used, relative to the total market, is so small that filling the need from alternative sources would not be a problem.

OUTLOOK

Supply and demand

The economics of zircon will continue to be tied to that of the titanium minerals for the foreseeable future. This is because, despite the small number of countries currently supplying zircon, the world's resources are considerably in excess of foreseeable demand. The world production of zirconium sponge and zirconium alloys is also potentially in substantial excess of demand. Unless there is a considerable increase in the demand for zircon and zirconium compounds in the future, new deposits will be exploited only if they are of very large size and contain economic quantities of other commodities.

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