DIMENSION STONE
GYPSUM
PHOSPHATE
SILICA

ALBERTA MINERAL COMMODITY PROFILES
(Reprint Volume)

Prepared for
Canada-Alberta MDA Project M92-04-015

Alberta Geological Survey
Alberta Research Council
Box 8330, Station 'F'
Edmonton, Alberta T6H 5X2

Alberta Geological Survey
Alberta Research Council
Open File Report 1993-05
May, 1993

FOREWORD

Alberta Mineral Commodity Profiles is a series of resource analysis synopses on non-hydrocarbon mineral commodities found in Alberta. Each profile presents a review and evaluation of an individual mineral, in a standardized capsulate format, addressing the essential elements of a comprehensive resource analysis. It serves as a technical sourcebook for the mineral, and as a guide in the formulation of research and exploration programs.

Profiles in this series are formatted to address the broad headings of *Industry Setting, Geology and Resources, Mining/Mineral Technology, Economic Factors, Industry Operating Factors, Strategic Considerations and Outlook.* It should be noted that the amount and quality of information available for any given section of the format may vary markedly with different commodities.

This first report in the series is a reprint volume that covers four commodities; **dimension stone, gypsum, phosphate,** and **silica**. These are commodities that were profiled in 1986 under a previous program sponsored by the Alberta Department of Energy and Natural Resources (now Alberta Energy). Initially conceived for department use primarily as a resource management tool, the profiles were found to have direct benefit to the mineral industry. However, distribution was limited. With the resurrection of the program under the Canada-Alberta Partnership Agreement on Mineral Development (1992-1995), it was decided to re-issue these four commodity profiles in a single reprint volume, as the first in the new series of Alberta Mineral Commodity Profiles. Although some of the information presented for 1986 may be outdated in certain topic areas, such as *Industry Setting,* the resource status of the four commodities is essentially unchanged.

W.N. Hamilton
Project Leader
Minerals and Coal Geoscience Section
Alberta Geological Survey

ACKNOWLEDGEMENTS

Funding for the production of this reprint volume was provided by the Canada-Alberta Partnership Agreement on Mineral Development (1992-1995) and by the Alberta Research Council. The original funding for preparation of the commodity profiles in 1986 was provided by the Alberta Department of Energy and Natural Resources (now Alberta Energy). The profiles were prepared by staff of the Alberta Geological Survey or by independent mineral consultants on contract to the Alberta Geological Survey. Individual authors are cited with their contribution. W.A.D. Edwards and W.N. Hamilton of the Alberta Geological Survey reviewed and edited the manuscripts.

CONTENTS

	Pages
Foreword	i
Acknowledgments	ii
Dimension stone, by J.D. Godfrey	**I** - 1 to 21
Gypsum, by W.N. Hamilton	**II** - 1 to 18
Phosphate, by D.E. Macdonald	**III** -1 to 21
Silica, by W.N. Hamilton	**IV** -1 to 31

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

DIMENSION STONE

by

John D. Godfrey[1]

[1]J. D. Sons & Associates Management Ltd.
(formerly of the Alberta Research Council)

Mineral Resources Group
Alberta Geological Survey
Alberta Research Council
July, 1986

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).

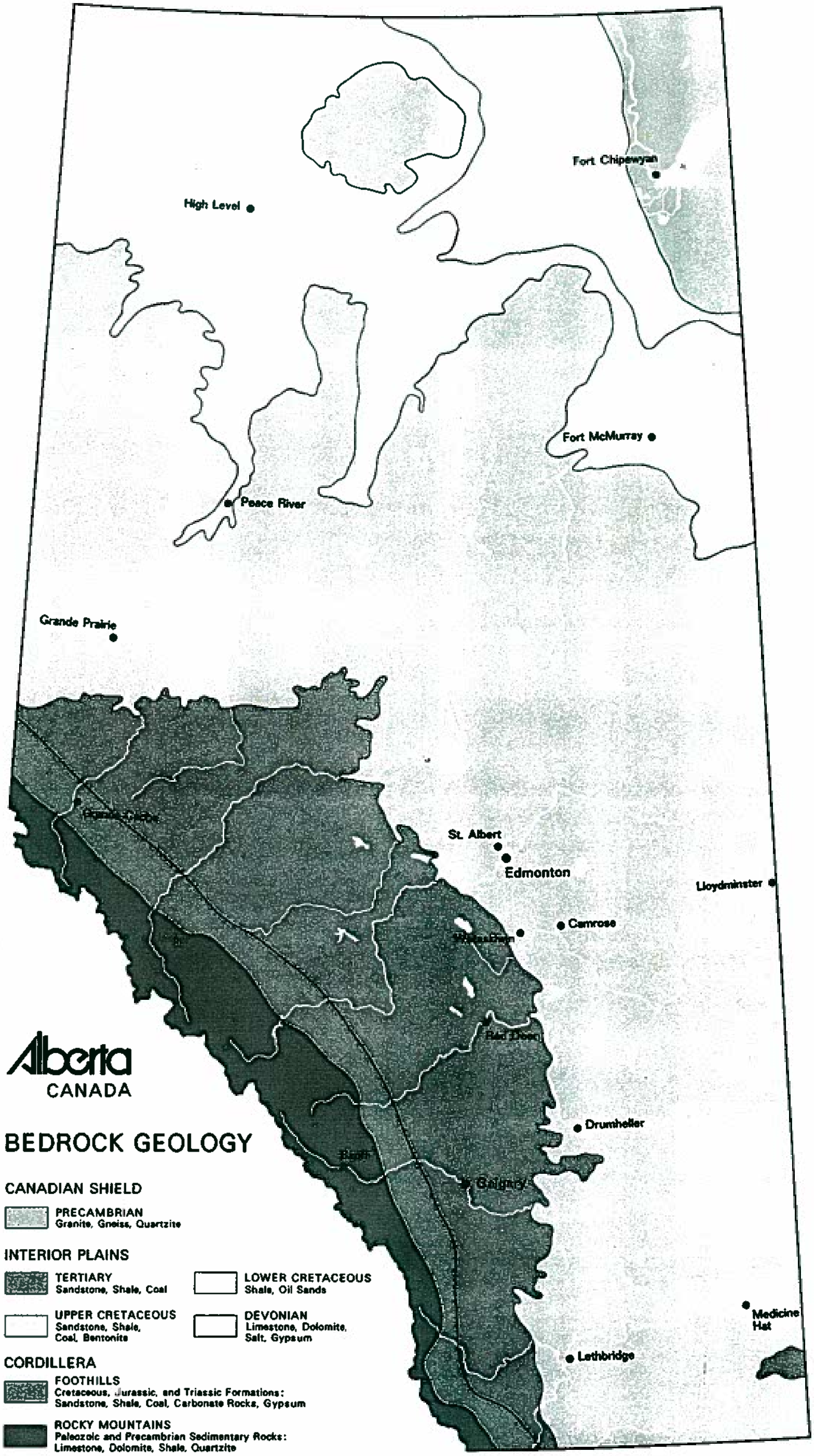
Exploration, development and distribution of deposits

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



Produced by the Alberta Bureau of Surveying and Mapping © 1983

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).

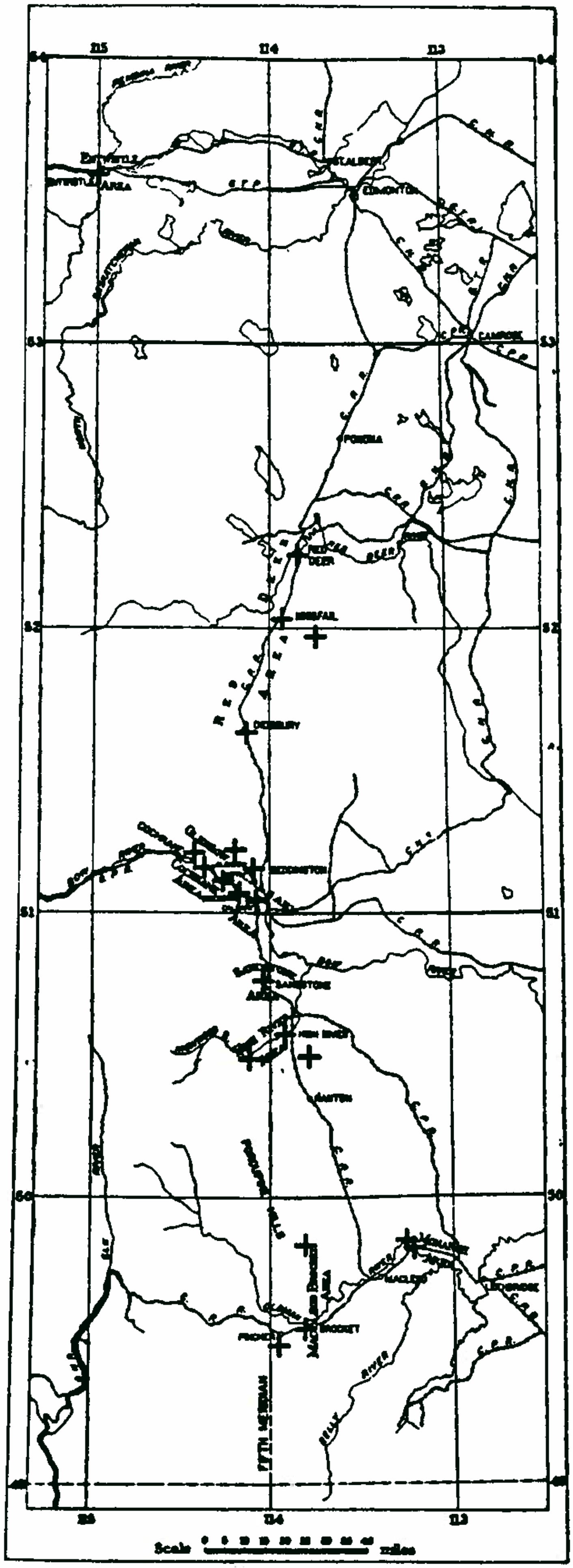


Table 4. Distribution of Paskapoo sandstone by color from former quarry regions (based on Allan, 1920).

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.
pecific gravity	2.691	2.688	2.687	2.665	2.672	2.677	2.679
eight per cubic foot, lbs.	138.64	140.02	131.48	134.19	136.24	144.66	137.54
ore space per cent	17.47	16.56	21.72	19.34	18.26	12.83	17.66
oefficient of saturation	.71	.79	.69	.68	.72	.76	.72
ry crushing strength, lbs. per sq. in.	7,092	6,796	5,985	7,631	9,617	11,119	8,306
et crushing strength, lbs. per sq. in.	3,963	4,708	3,874	5,640	7,007	7,224	5,613
rozen crushing strength, lbs. per sq. in.	2,976	3,679	2,782	3,896	4,212	6,524	4,065
ransverse strength, lbs. per sq. in.	308	556	398	554	658	582	521
hearing strength, lbs. per sq. in.	459	512	431	497	642	586	531
oss on corrosion, grams per sq. in.	.0223	.0255	.06746	.04301	.05031	.04194	.04558
illing factor, mm	21.4	.....	25.2	21.0	26.6	17.8	22.7
hiselling 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.

REFERENCES

Alberta, (1984): Historical Resources Act, revised statutes of Alberta, 1980, chapter H-8 with amendments in force as of June 6, 1983; 28 pages.

Alberta Culture (1985): Designated historical resources in Alberta; Archeological Survey of Alberta, 75 pages.

Allan, J.A. (1920): First Annual Report on the Mineral Resources of Alberta; pp. 13-27.

Campbell, R. (1986): Architecture's new look; the 1986 World Year Book, the Annual Supplement to the World Book Encyclopedia, pp. 126-143.

Canada, Department of Regional Industrial Expansion (1985): Granite, shaped or dressed; Market Information and Analysis Division, Market Development Branch; Publication No. 34-85, 9 pages.

______ (1986): Marble, shaped or dressed; Market Information and Analysis Division, Market Development Branch; Publication No. 43-86, 10 pages.

Davey, N. (1976): Building stones of England and Wales; Standing Conference for Local History by the Bedford Square Press, 47 pages.

Goddard, E.N., chairman (1963): Rock-color chart; The Rock-Color Chart Committee; distributed by the Geological Society of America.

Godfrey, J.D. (1979): Chipewyan Granite - a building stone prospect in Alberta; Bull. Can. Inst. Min. Met., vol. 72, no. 805, pp. 105-109.

Goudge, M.F. (1933): Canadian limestones for building purposes; Canada Department of Mines, Mines Branch; No. 733, 196 pages.

Mattar, S., H. Morstead and C. Campbell (1985): Stone in new buildings: lessons from ancient problems; Canadian Society for Civil Engineering Annual Conference, Saskatoon, Sask., pp. 293-313.

Murray, J.A. (editor)(1983): 1983 yearsticks for costing; cost data for the Canadian Construction Industry; Construction Data Systems Ltd. and Southam Business Publications, 168 pages.

Parks, W.A. (1916): Report on the building and ornamental stones of Canada, Vol IV, Provinces of Manitoba, Saskatchewan and Alberta, No. 388, 333 pages.

United Nations (1976): The development potential of dimension stone; Department of Economic and Social Affairs, United Nations, New York; ST/ESA/34, 95 pages.

Wilson, J.A. (1985): Geology of the Athabasca Group in Alberta; Alberta Research Council, Bulletin No. 49, 78 pages.

Reprinted from:

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

II

GYPSUM

by

W. N. Hamilton

Mineral Resources Group
Alberta Geological Survey
Alberta Research Council
July, 1986

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

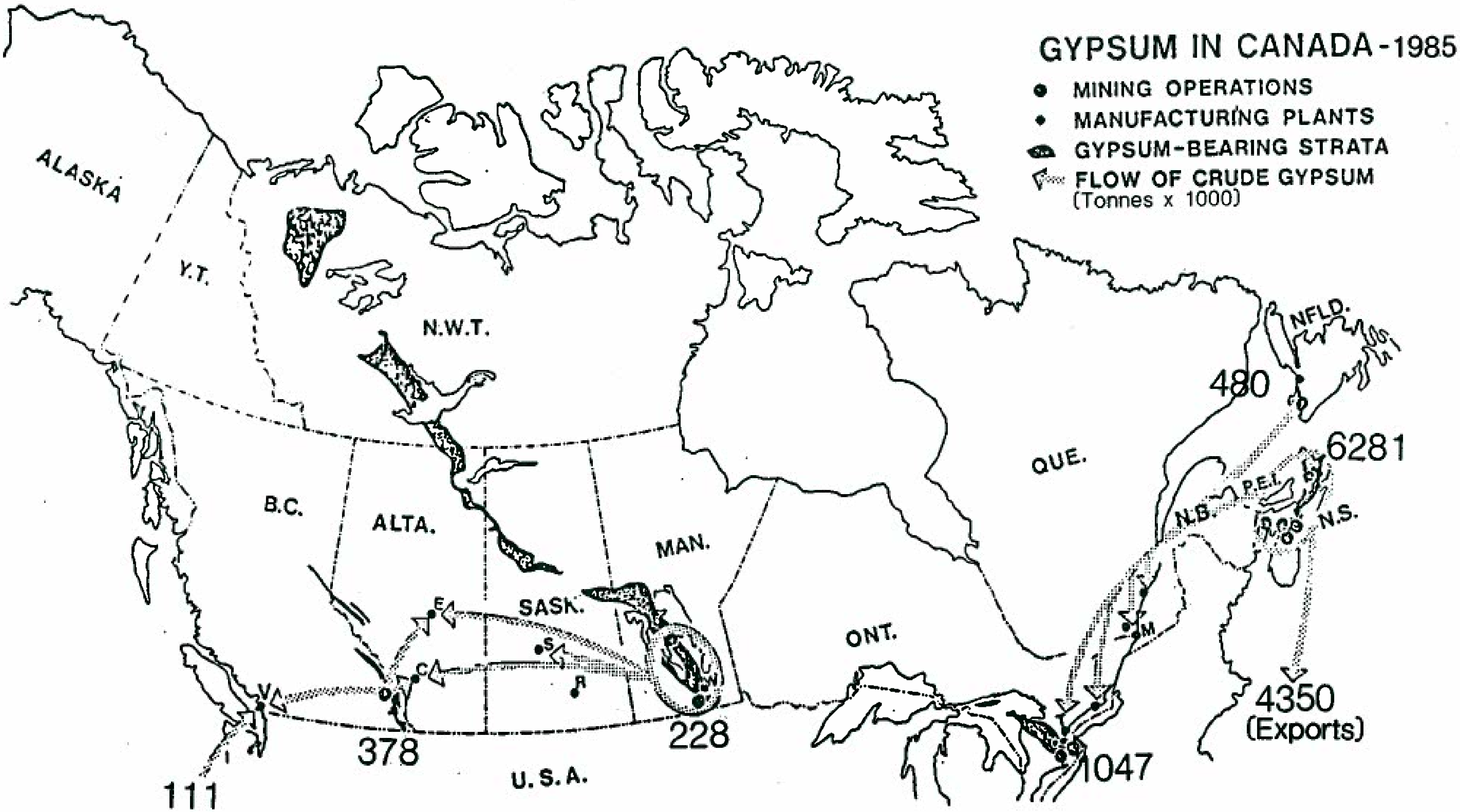


Figure 1 (modified from Godfrey, 1975)

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

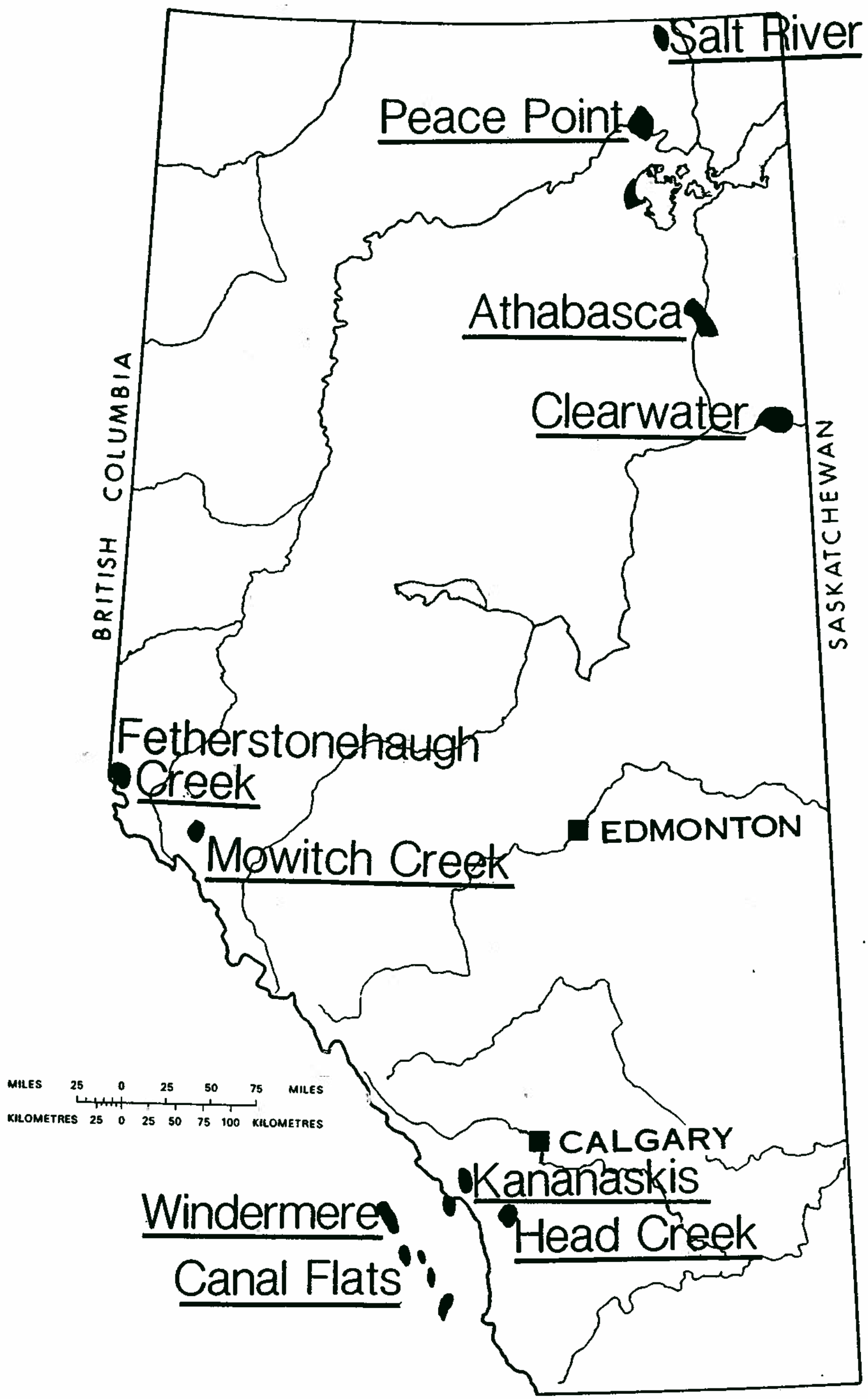


Figure 2. Gypsum deposits in Alberta

TABLE 3. Age and relationship of gypsum deposits in Alberta (Hamilton, 1982)

Age	Group or Formation		Gypsum Deposits
Triassic	Whitehorse Fm.		Mowitch Creek Fetherstonehaugh Ck.
Late Devonian	Palliser Fm. Wabamun Grp.		Head Creek —
Middle Devonian	Fort Vermilion Fm.		Peace Point
	Elk Point Group	Upper	Fort McMurray
		Lower	Salt River — —
	Bumais Fm.		Kananaskis

TABLE 4. Summary of mineral potential factors for gypsum deposits in Alberta (Hamilton, 1982)

Deposit	Grade[1] (%)	Thickness[2] (m)	Extent (km)	Reserves (tonnes)	Recoverability	Accessibility	Development Potential[3]
GYPSUM DEPOSITS							
Mowitch Creek	<80	43	4.8 x 1	Undetermined	Poor: ridge-top exposure, beds dip 35-78°; gypsum beds thin and lensing, much interbedded non-gypsum strata	Poor: remote location, rugged mountain terrain; no road access	None: in Jasper National Park
Fetherstonehaugh Creek	80-95	15-40	1.8 x 1.6	25,000,000?	Poor to Fair: surface deposit, <1 m overburden; contorted bedding, structural setting and bedding succession uncertain	Poor: remote location on Alta.-B.C. border, rugged mountain terrain; no road access, 65-80 km from rail	Poor to Fair: in prime protection zone (Willmore Wilderness), but just on edge; unencumbered in B.C.
Head Creek	65-70	5	300 m x 150 m	Undetermined	Fair: dip-slope quarrying situation, light overburden, beds dip 35°; ridge top exposure	Poor to Fair: close to Calgary (100 km), but existing road and trail access difficult, rugged terrain, 40 km from rail	Poor: in prime protection zone; subeconomic grade and reserves
Peace Point	95	12-15	22 x 3	1,000,000,000	Good: beds flat lying to undulatory, light overburden (<6 m)	Poor to Fair: remote location, but on navigable waterway 500 km by barge from rail (Fort McMurray)	None if retained in Wood Buffalo National Park; Fair to good if passed to Indian control
Fort McMurray – Athabasca	90+[4]	9-15	50 x 7	2,000,000,000	Not quarriable. Subsurface deposit to 90 m depth, requires underground mining; beds nearly flat lying	Poor to Fair: remote location, but on navigable waterway, 100 km from rail (Fort McMurray), road access to within 50 km	Fair: no land use zoning constraints; mining feasibility uncertain
Fort McMurray – Clearwater	84	9-15	29 x 5	1,000,000,000	Not quarriable. Subsurface deposit to 90m depth, requires underground mining; beds nearly flat lying	Poor: remote location, no road access, 50 km from rail (Fort McMurray)	Poor: subeconomic grade for underground mining, mining feasibility uncertain
Salt River		15	60 x 20	Undetermined	Fair to Good: Beds flat lying, very widespread; heavy overburden where gypsum thickest	Poor: remote location; indirect road access from Fitzgerald (50-80 km); at Fitzgerald 550 km by barge from rail	None: largely in Wood Buffalo National Park, extremely remote
Kananaskis	84-88	30	400 m x 200 m	Undetermined	Not quarriable. Underground mining required; beds dip 50°	Fair to Good: close to Calgary (100 km); in rugged mountain terrain, but road access to within 1 km, 40 km from rail	Poor: in prime protection zone (Kananaskis Provincial Park)

1 Grade is % NaCl for salt deposits, % $CaSO_4 \cdot 2H_2O$ for gypsum deposits; given as average for deposit, or range where average grade is undetermined.
2 Thickness is the maximum or the observed range of thickness of the deposit.
3 Development potential rating is based on all factors of grade, thickness, etc., and also on local site conditions (land use zoning, etc.).
4 Estimated from wildcat well core data (no direct test drill sampling of deposit).

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.

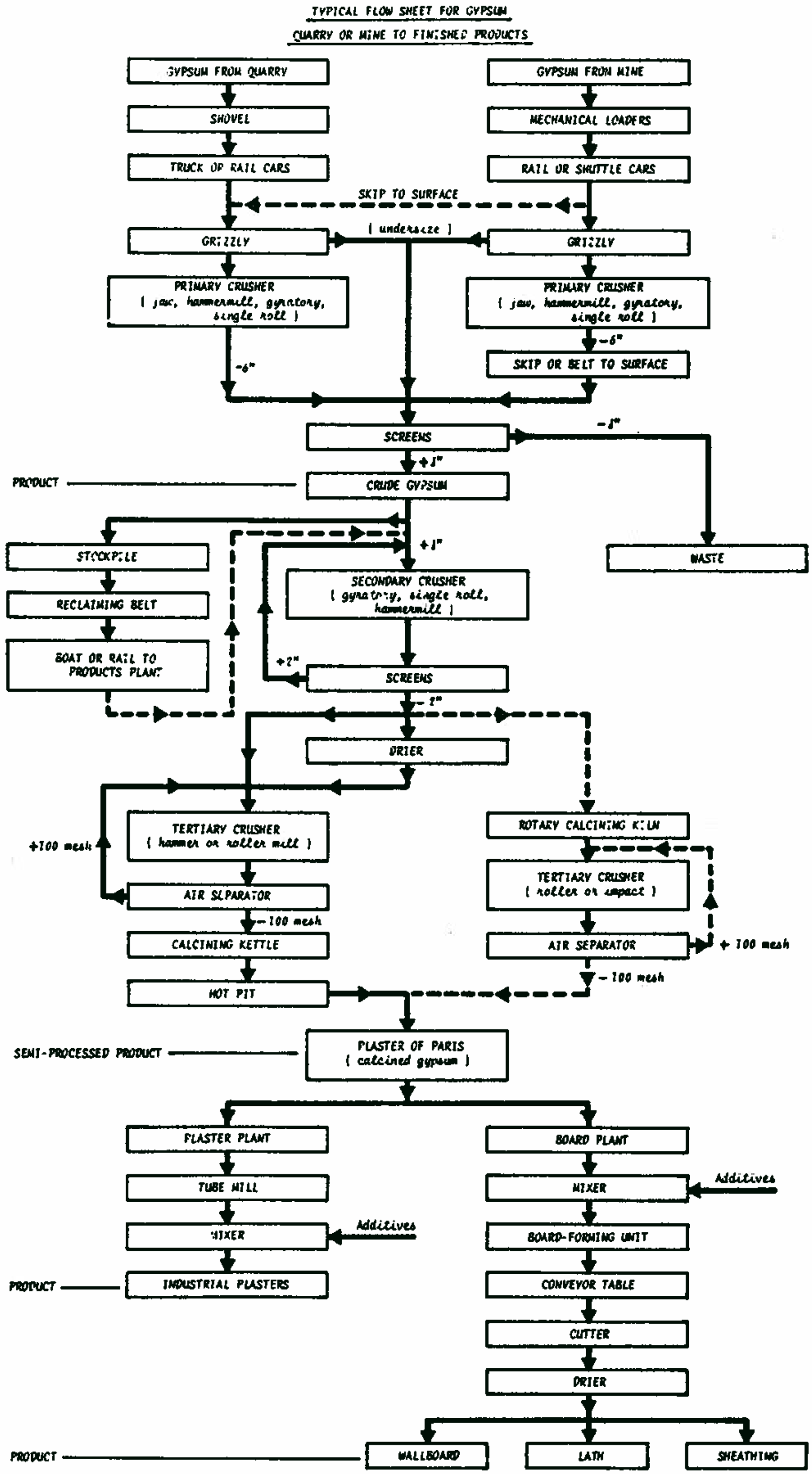


Figure 3 (from Stonehouse, 1976)

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.

REFERENCES

Allen, J.A. (1920): The mineral resources of Alberta; Alberta Research Council Report No. 1, p. 87-102.

Allen, J.A. (1929): Salt and gypsum in Alberta; Canadian Institute of Mining and Metallurgy Transactions, V. 32, p. 232-254.

Appleyard, F.C. (1975): Gypsum and anhydrite, in Industrial Minerals and Rocks, 4th edition; American Institute of Mining, Metallurgical and Petroleum Engineers Inc., New York, p. 707-723.

Energy, mines and resources, Canada (1985): Mining and Mineral Processing Operations in Canada in 1984; Mineral Bulletin MR 204, 68 pages.

Godfrey, J.D. (1975): Gypsum and granite in Alberta; Alberta Research Council Contribution Series 750, 31 pages.

Hamilton, W.N. (1982): Salt and gypsum in Alberta; Canadian Institute of Mining and Metallurgy Bulletin, V. 75, No. 846, p. 73-89.

Harben, P.W. (1984): Introduction to paper, in Raw Materials for the Pulp and Paper Industry; Metal Bulletin Inc., New York, p. 4-13.

Harben, P.W. and R.L. Bates (1984): Geology of the nonmetallics; Metal Bulletin Inc., New York, 392 pages.

Pressler, J.W. (1980): Gypsum, in Mineral Facts and Problems; U.S. Bureau of Mines, Bulletin 671, p. 395-404.

Severinghaus, Jr., N. (1975): Fillers, filters, and absorbents, in Industrial Minerals and Rocks, 4th edition; American Institute of Mining, Metallurgical and Petroleum Engineers Inc., New York, p. 235-249.

Stonehouse, D.H. (1976): Gypsum; Mineral Bulletin MR 151, Mineral Policy Series; Energy, Mines and Resources, Canada, 19 pages.

Stonehouse, D.H. (1986): Gypsum and anhydrite; Preprint chapter in Canadian Minerals Yearbook 1985; Mineral Policy Sector, Energy, Mines and Resources, Canada, p. 30.1-8.

Reprinted from:

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

III

PHOSPHATE

by

D. E. Macdonald

Mineral Resources Group
Alberta Geological Survey
Alberta Research Council
July, 1986

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.

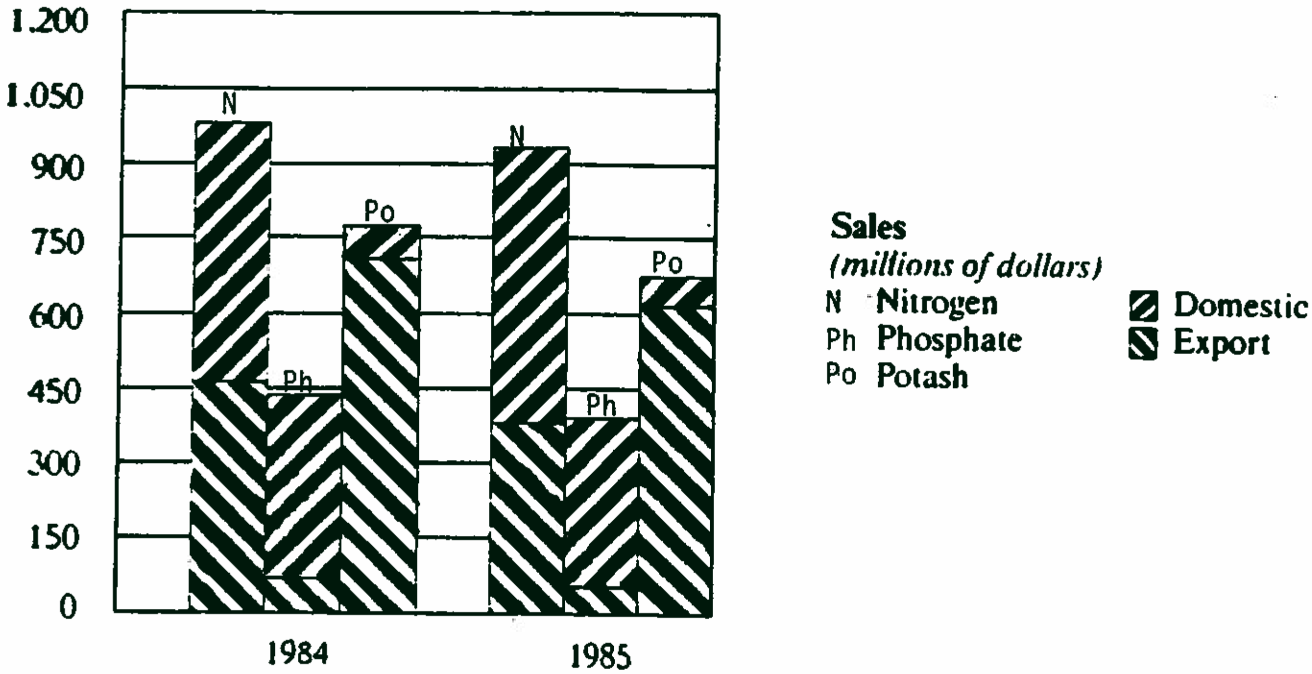


Figure 1. Domestic and export sales of fertilizers in Canada 1984-85 (from Canadian Fertilizer Institute, 1985)

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.

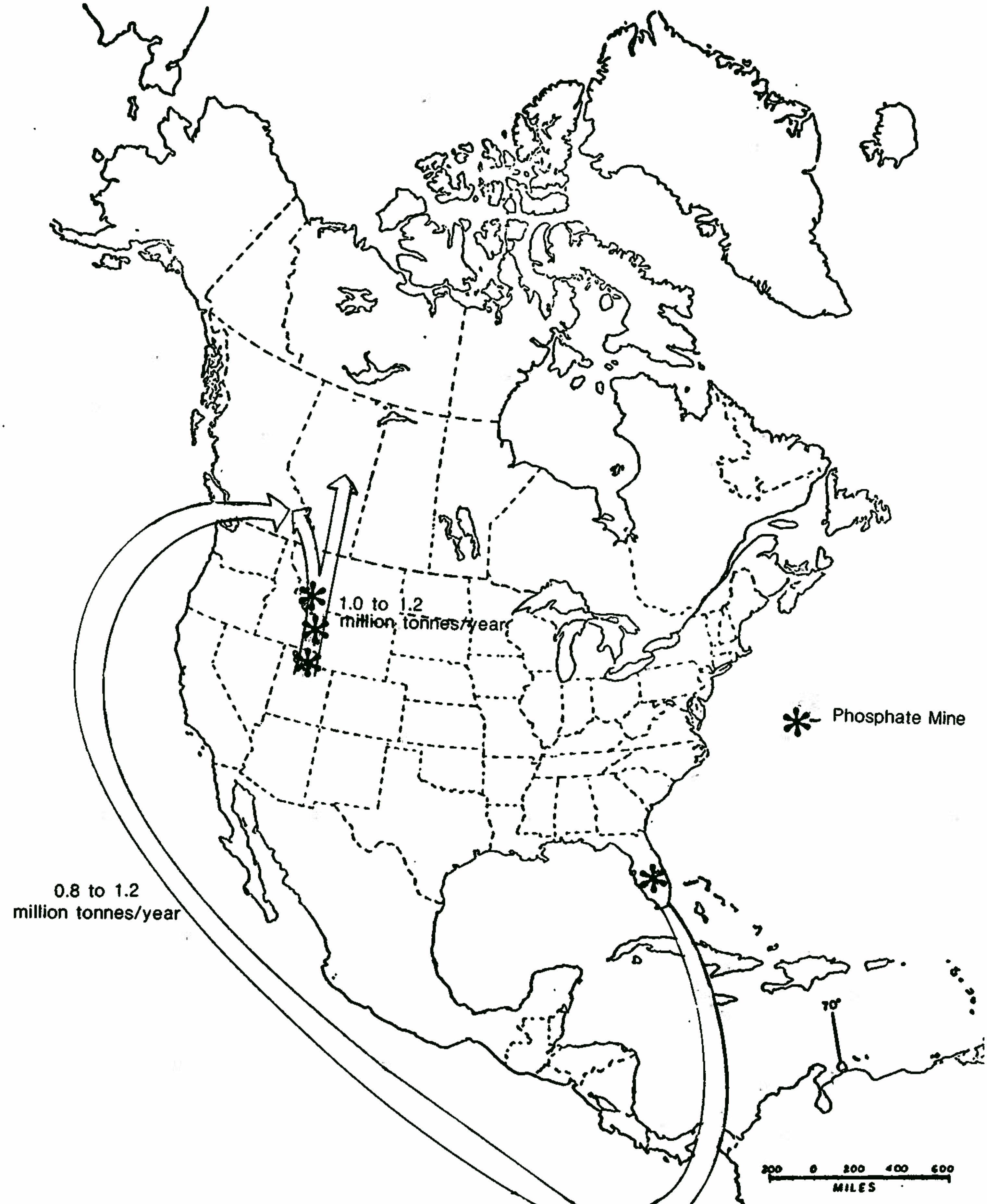


Figure 2. Sources of imported phosphate rock to Western Canada (modified from EMR, 1982)

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).

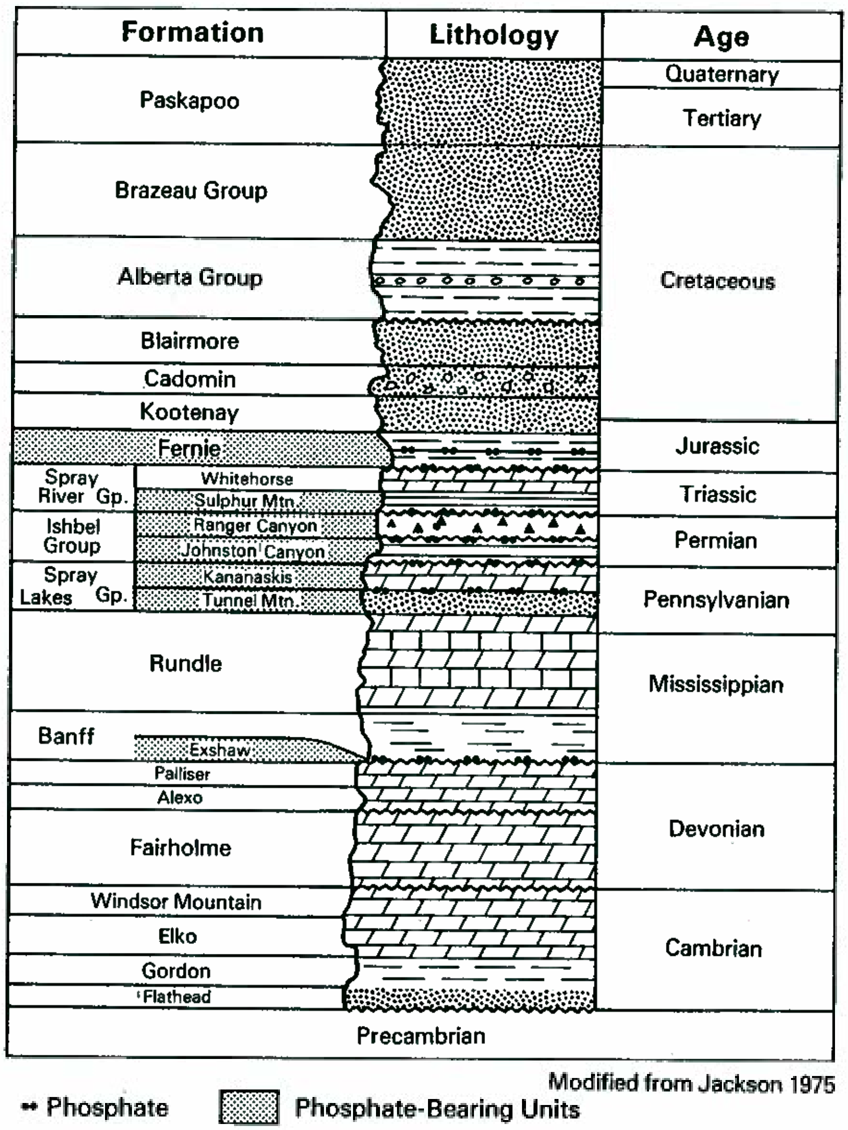


Figure 3. Generalized stratigraphic section — Cordilleran region and major phosphate bearing units

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.

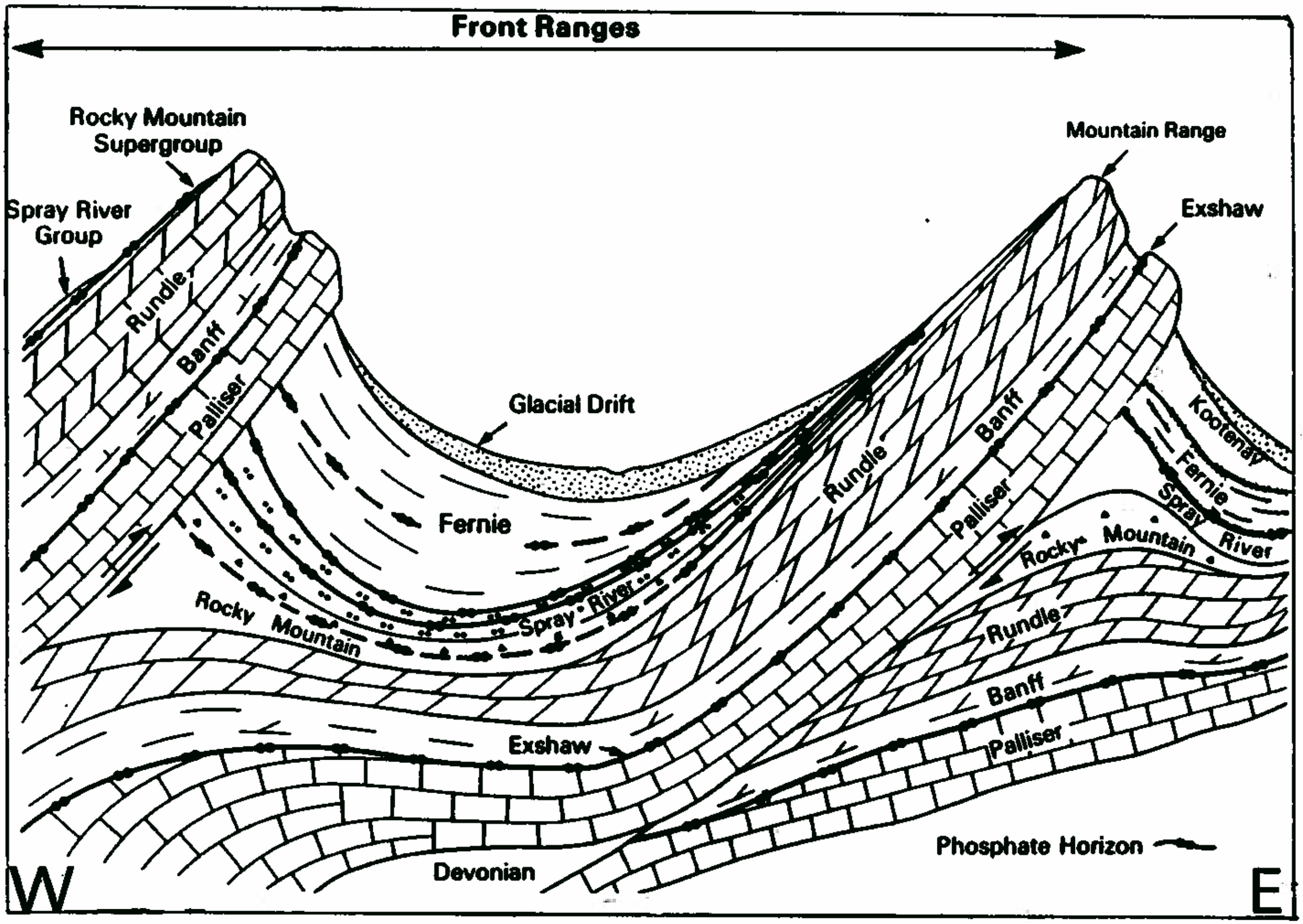


Figure 4. Idealized sketch of the Canadian front ranges and the typical structural/ stratigraphic setting of the main phosphate bearing units

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

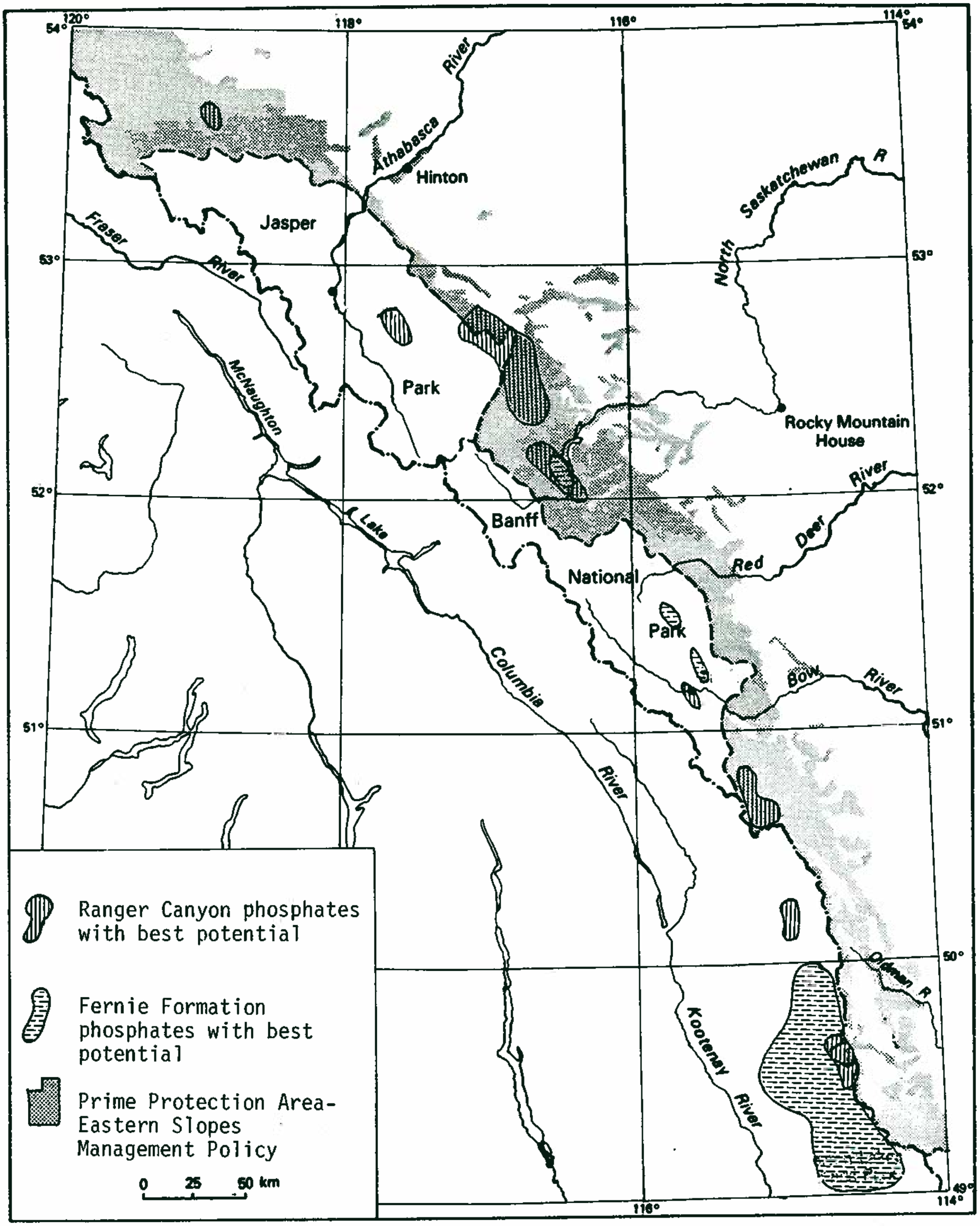


Figure 5. Phosphate potential in Alberta and southeastern British Columbia

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.

REFERENCES AND SELECTED BIBLIOGRAPHY

Adams, F.D. and Dick, W.J. (1915): Discovery of Phosphate of Lime in the Rocky Mountains, Commission of Conservation Canada, p. 36.

Alberta Energy and Natural Resources (1977): A Policy for Resource Management of the Eastern Slopes, Alberta Energy and Natural Resources, 19 pp.

Barry, G.S. (1986): Phosphate; Canadian Mining Journal, February 1986, p. 77.

Boyd, B.W. (1980): Fluorspar; Energy, Mines and Resources Canada, 6pp.

Burnett, W.C. and Sheldon, R.P. (1979): Report on the Marine Phosphatic Sediments Workshop, Resource Systems Institute, East West Center, Hawaii, U.S.A., 65 pp.

Bushinsky, G.I. (1935): Structure and Origin of the Phosphorites of the U.S.S.R.; Journal of Sedimentary Petrology, Vol. 5, p. 81-92.

Canadian Fertilizer Institute (1985): A Profile of the Canadian Fertilizer Industry, Canadian Fertilizer Institute, 9 p.

Cathcart, J.B. (1978): Uranium in Phosphate Rock; U.S. Geological Survey, Prof. Paper 988-A, 6 pp.

Christie, R.L. (1978): Sedmentary Phosphate Deposits - An Interim Review; Geological Survey of Canada, Paper 78-20, 9 pp.

Christie, R.L. (1979): Phosphorite in Sedimentary Basins of Western Canada; Geological Survey of Canada Paper 79-1B, p. 253-258.

Christie, R.L. (1980): Paleolalitudes and Potential for Phosphorite for Phosphorite Deposition in Canada; Current Research, Part B, Geological Survey of Canada paper 80-1B, p. 241-249.

Christie, R.L. (1981): Phosphorites in Western Canada; CIM 3rd Annual General Meeting Preprint No. 55, 12 pp.

Cook, P.J. (1976): Sedimentary phosphate deposits; in K.H. Wolf (ed.) Handbook of Stratabound and Stratiform Ore Deposits: Amsterdam, Elsevier Publishing Company, Vol. 7. p. 505-535.

Cressman, E.R. and Swanson, R.W. (1964): Stratigraphy and Petrology of the Permian Rocks of Southwestern Montana; U.S. Geological Survey, Prof. Paper 313-C, p. 370-371.

DeVoto, R.H. and Stevens, D.N. (1980): Technology and Economics of Uranium Recovery from Phosphate Resources; in R.H. DeVoto and D.N. Stevens (eds), Usraniferous Phosphate Resources and Technology and Economics of Uranium Recovery, Vol. 2, p. 109-138.

de Schmid, Hugh, S. (1916): Investigation of a Reported Discovery of Phosphate in Alberta; Canada Department of Mines; Bulletin No. 12, p. 38.

Energy, Mines and Resources (1976): Phosphate; Energy, Mines and Resources Canada, Mineral Policy Series, Bulletin MR 160.

Energy, Mines and Resources Canada (1982): Phosphate Rock - An Imported Mineral Commodity; Energy, Mines and Resources Canada, Mineral Bulletin 193, 61 p.

Energy, Mines and Resources Canada (1985): Canadian Minerals Yearbook 1983-84, Energy, Mines and Resources Canada, Mineral Report 33, p. 45.1-45.17.

Howard, P.F. (1972): Exploration for Phosphorite in Australia - A Case History; Economic Geology, Vol. 67, p. 1180-1192.

Howard, P.F. (1979): Phosphate; Economic Geology, Vol. 74, No. 2, p. 192-194.

Jackson, P.C. (1975): Geological Highway Map of Alberta; Canadian Society of Petroleum Geologists.

Kenny, R.L. (1977): Phosphate Exploration in Southeastern British Columbia by Cominco Ltd.; talk presented at C.I.M. meeting, Ottawa.

Kuck, P.H. (1983): Vanadium; Mineral Commodity Profile, U.S. Bureau of Mines, 18 p.

Lowell, W.R. (1952): Phosphatic Rocks of the Deer Creek - Wells Canyon Area, Idaho; U.S. Geological Survey Bulletin 982-A, p. 38-39.

McDivitt, J.F. (1956): Economic Evaluation of Phosphate and Other Minerals in Southern Idaho, Idaho Bureau of Mines, Pamphlet No. 11, 48 pp.

McKelvey, V.E. (1959): The Phosphoria, Park City and Shedhorn Formations in the Western Phosphate Field; U.S. Geological Survey Paper 313-A, p. 1-47.

McKelvey, V.E. (1967): Phosphate Deposits; U.S. Geological Survey, Bulletin 1252-D, 21 pp.

Macdonald, D.E. (1984): Stratigraphic Sections Examined for Phosphate in Alberta, Alberta Research Council, Openfile 1984-24, 445 p.

Macdonald, D.E. (1985): Geology and Resource Potential of Phosphates in Alberta and Portions of Southeastern British Columbia., University of Alberta, unpublished M.Sc. thesis. 238 p.

Nielson, K.F. and Janke, W.E. (1980): World Resources of Phosphate and the Manufacture of Phosphate Fertilizers; Western Canada Phosphate

Symposium - Alberta Soil Science Workshop Proceedings, p. 149-158.

Powell, J.D. (1974): Evaluation of Phosphate Resources in Southeastern Idaho, Idaho Bureau of Mines, Information Circular No. 25, 33 pp.

Rhodes, J.A. (1976): Review of the Western Phosphate Field in The Eleventh Industrial Minerals Forum, Montana Bureau of Mines, Special Publication No. 74, p. 61-67.

Riggs, S.R. (1979): Phosphorite Sedimentation in Floride - A Model Phosphogenic System; Economic Geology, Vol. 79, No. 2, p. 285-314.

Roberts, A.E. (1978): California Phosphorite; U.S. Geological Survey Prof. Paper, Iss 1100:43.

Rule, A.R., Kirby, D.E. and Dahlin, D.C. (1978): Recent Advances in Benefication of Western Phosphates; Mining Engineering, Vol. 30, No. 2.

Sheldon, R.P. (1964): Exploration for Phosphorite in Turkey - a Case History; Economic Geology, Vol. 59, p. 1159-1175.

Sheldon, R.P., Maughan, E.K. and Cressman, E.R. (1967): Sedimentation of Rocks of Leonard (Permian) Age in Wyoming and Adjacent States; L.A. Hale (ed.) Anatomy of the Western Phosphate Field; Intermountain Association of Geologists Fifteenth Annual Field Conference, p. 1-13.

Sheldon, R.P. (1981): Ancient Marine Phosphorites; American Rev. Earth Planet Sciences, Vol. 9, p. 251-284.

Spence, H.S. (1920): Phosphates in Canada; Government of Canada, Mines Branch, p. 156.

Stowasser, W.F. (1977): Phosphate - 1977, U.S. Department of the Interior, Bureau of Mines, 18 pp.

Swanson, R.W. (1970): Mineral Resources in Permian Rocks of Southwest Montana; U.S. Geological Survey, Prof. Paper 313-E, p. 661-777.

Swanson, R.W. (1973): Geology and Phosphate Deposits of the Permian Rocks in Central Western Montana; U.S. Geological Survey, Paper 313-F, p. 717-833.

Telfer, L. (1933): Phosphate in the Canadian Rockies, C.I.M.M. Bulletin No. 260, p. 566-605.

U.S. Bureau of Mines (1981): A Supply Demand Analysis of the U.S. Phosphate Industry, Mineral Industry Surveys; U.S. Bureau of Mines.

Weaver, J.L. and Thomas, M. (1978): The Future of the Phosphate Industry in the South Eastern U.S.A.; Industrial Minerals, No. 133, p. 46-51.

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

SILICA

by

W. N. Hamilton

Mineral Resources Group
Alberta Geological Survey
Alberta Research Council
July, 1986

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%—[illegible] 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	SILICA SOURCE
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	2
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		2
Domglas Ltd.	Redcliff	Glass manufacture	Gas and electric regenerative furnaces	Glass containers	146 million pieces/year	2,9
Fiberglas Canada Ltd.	Edmonton	Fiberglass manufacture	Gas furnace	Glass fibre insulation	24,000 tpa	5
Mannville Canada Inc.	Innisfail	Fiberglass manufacture	Electric furnace	Glass fibre insulation		5
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	7
Domglas Ltd.	Burnaby[8]	Glass manufacture	Gas & electric regenerative furnaces	Glass containers		9
Fiberglas Canada Ltd.	Mission	Fiberglass manufacture		Glass fibre insulation		5

[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

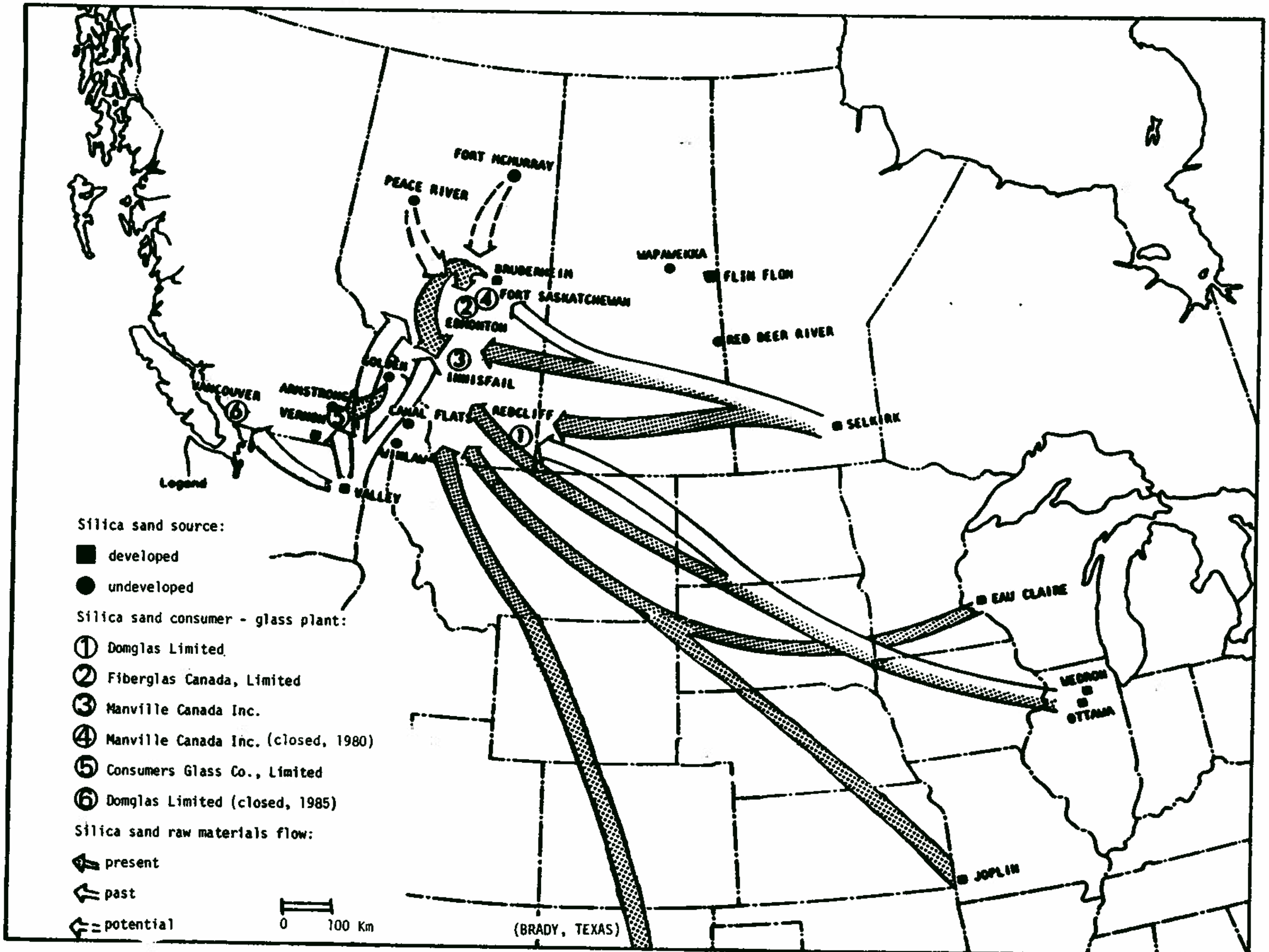


Figure 1. Markets and sources for silica sand - Alberta and Western Canada

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	

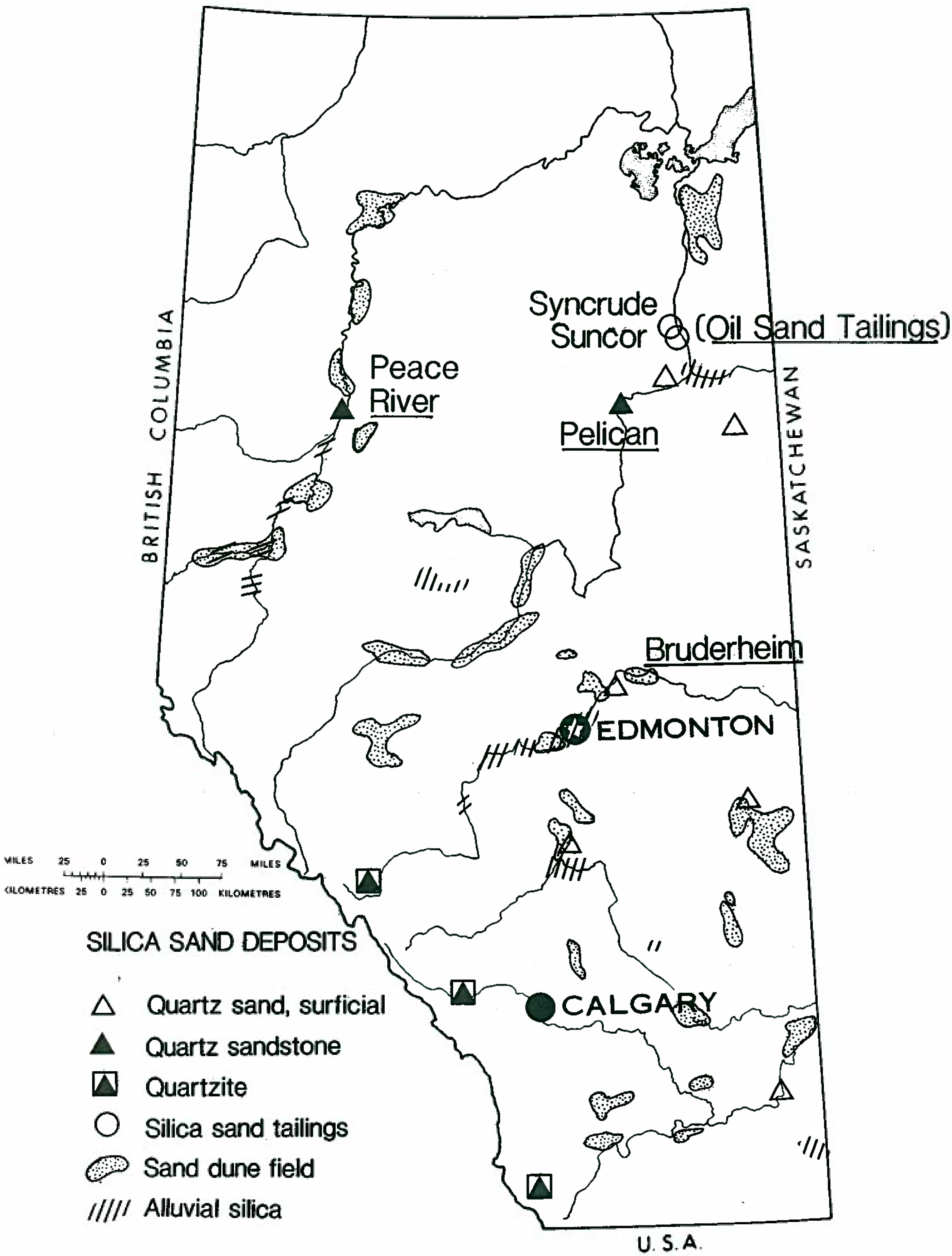


Figure 2. Silica sand deposits in Alberta

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).

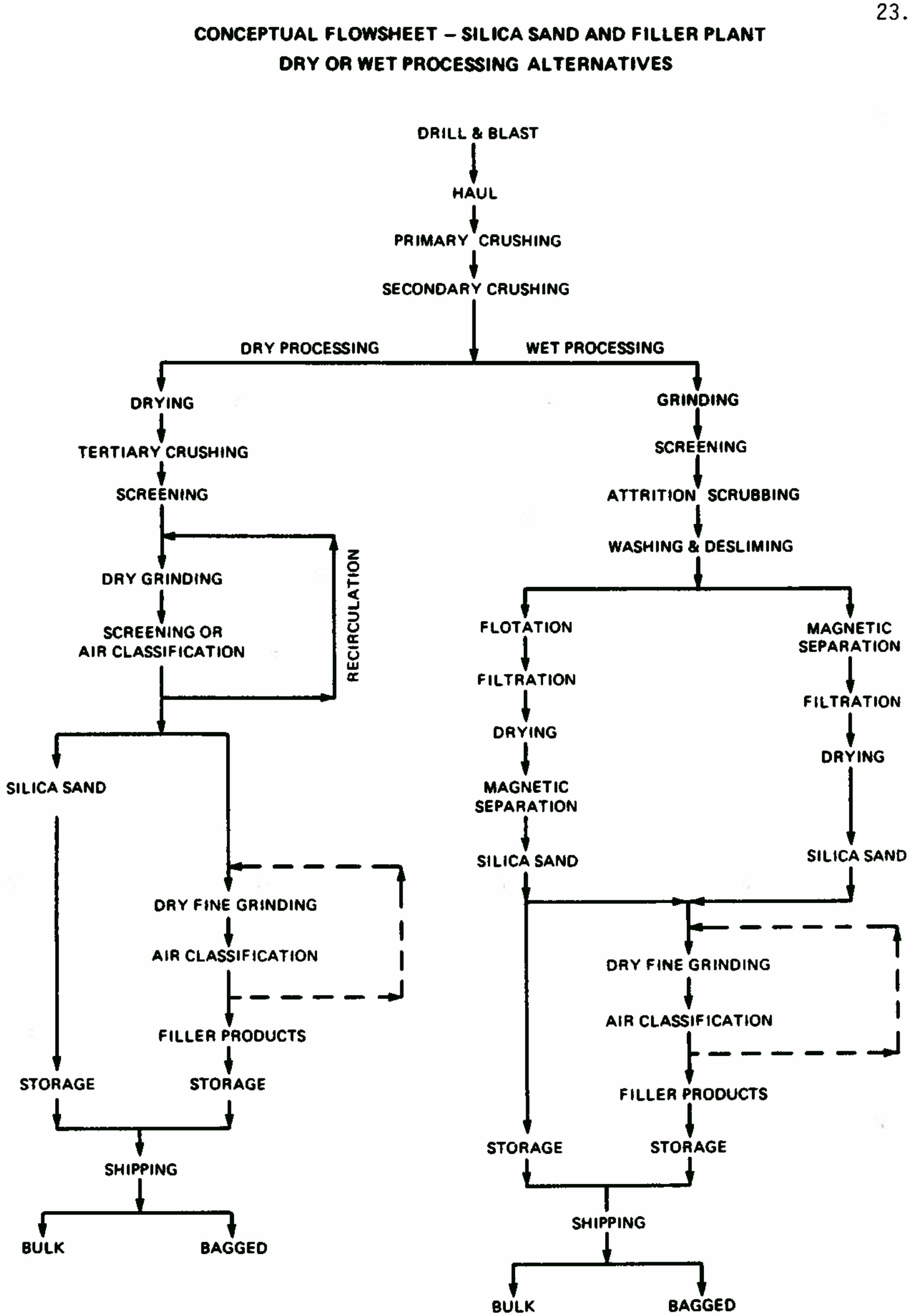


Figure 3. Generalized flowchart for processing of silica sand
(from Guillet and Kriens, 1984)

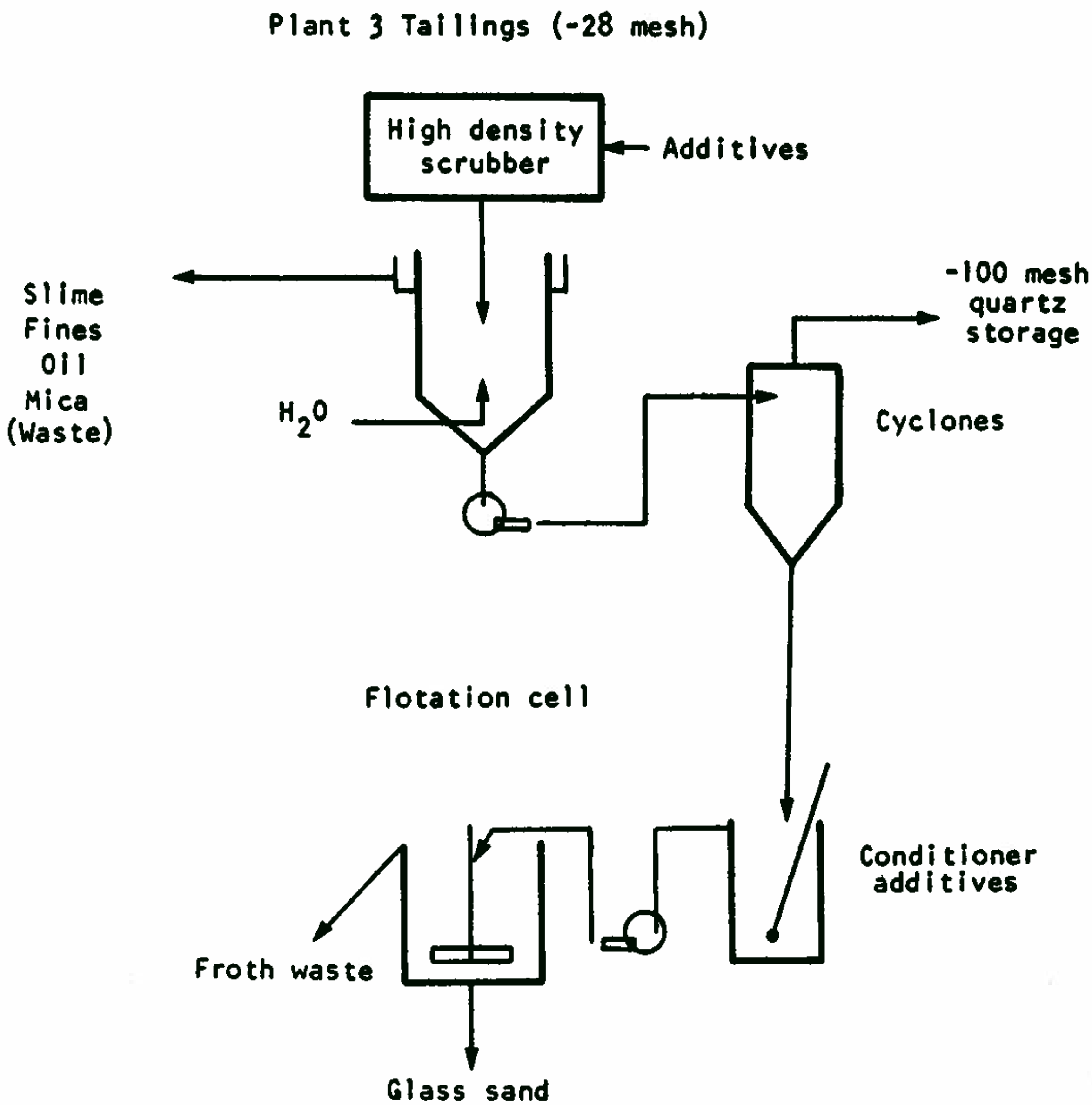


Figure 4. Flowchart of suggested treatment method for upgrading Alberta oil sand tailings to glass sand (from McLaws, 1980)

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.

REFERENCES

Anonymous (1976): Silica: world production, consumption and trade; "Industrial Minerals" May 1976 issue, p. 31-62.

Boucher, M.A. (1986): Silica; preprint chapters in Canadian Minerals Yearbook 1985; Mineral Policy Sector, Energy Mines and Resources Canada, p. 53.1-5.

Carrigy, M.A. (1966): Lithology of the Athabasca Oil Sands; Alberta Research Council Bulletin 18, 48 pages.

________ (1970): Silica sand in the vicinity of Edmonton, Alberta; Alberta Research Council Earth Sciences Report 70-1, 30 pages.

Coope, B.M. and P.W. Harben (1977): Silica sand; in Raw Materials for the Glass Industry; "Industrial Minerals" Glass Survey '77, p. 15-37.

Crockford, M.B.B. (1949): Geology of the Peace River glass sand deposit; Alberta Research Council Information series No. 7, 20 pages.

Dickson, T. (1984): North American silica sand; "Industrial Minerals" February 1984 issue, p. 39-45.

Flach, P.D. and G.D. Mossop (1985): Depositional environments of Lower Cretaceous McMurray Formation, Athabasca Oil Sands, Alberta; American Association of Petroleum Geologists Bulletin, V. 69, no. 8, P. 1195-1207.

Guillet, G.R. and J. Kriens (1984): Ontario and the mineral filler industry; Ontario Ministry of Natural Resources, Industrial Mineral Background Paper No. 5, 175 pages.

Guliov, P. (1975): High-silica gravel of the Cypress Hills Formation in southwest Saskatchewan; Saskatchewan Geological Survey report, 19 pages.

Halferdahl, L.B. (1969): Alluvial quartzite pebbles as a source of industrial silica; Alberta Research Council Earth Sciences Report 69-2, 22 pages.

Hamilton, W.N. (1976): Industrial minerals: Alberta's uncelebrated endowment; in Proceedings, 11th Forum on the Geology of Industrial Minerals; Montana Bureau of Mines and Geology Special Publication 74, p. 17-35.

Harben, P.W. and R.L. Bates (1984): Geology of the nonmetallics; Metal Bulletin Inc., New York, 392 pages.

Holter, M.E. (1971): Silica (dune) sand from the Medicine Hat area, Alberta; Alberta Research Council Earth Sciences Report 71-5, 19p.

Holter, M.E. (1972): Silica (dune) sand from the Red Deer area, Alberta; Alberta Research Council Earth Sciences Report 72-4, 19p.

McLaws, I.J. (1971): Uses and specifications of silica sand; Alberta Research Council Earth Sciences Report 71-4, 64 pages.

__________ (1980): Silica sands in the Fort McMurray area, Alberta; Alberta Research Council Economic Geology Report 6, 48 pages.

Murphy, T.D. (1975): Silica and silcon; in Industrial Minerals and Rocks, 4th edition; American Institute of Mining, Metallurgical and Petroleum Engineers Inc.; New York, p. 1043-1060.

Shufflebarger, Jr., T.E. (1977): Economics of glass sand prospects; "Industrial Minerals" September 1977 issue, p. 57-63.

Stalker, A. MacS. (1963): Quaternary Stratigraphy in southern Alberta; Geological Survey of Canada Paper 62-34, 52 pages.

Vonhof, J.A. (1965): The Cypress Hills Formation and its reworked deposits in southwestern Saskatchewan; in 15th Annual Field Conference Guidebook, Alberta Society of Petroleum Geologists, p. 142-161.