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Hon. Alan W. Pope
Minister

W. T. Foster
Deputy Minister

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FOREWORD

The 27 papers included in the Proceedings of the 19th Forum on the Geology of Industrial Minerals were presented during the four days of meetings and field trips held in Toronto on May 24-27, 1983. The three theme sessions, which covered Ontario, Canada, and International sectors, gave the delegates an opportunity to listen to a wide range of informative subjects. The Ontario Geological Survey is pleased to have participated in the Forum and to make the papers available in this volume, not only to delegates, but also to the larger audience of people everywhere whose work involves industrial minerals.

It is through meetings such as the Forum on Industrial Minerals that the importance of all minerals receives wider recognition by the public at large, as well as by specialists. Through that recognition, mineral resources can be protected and developed in ways appropriate to the needs of present and future generations.

E.G. Pye
Director
Ontario Geological Survey

PREFACE

The Ontario Ministry of Natural Resources was pleased to be the host for the 19th Forum on the Geology of Industrial Minerals which was held in Toronto on May 24-27, 1983. In order to provide a wide latitude for papers and for the interests of all industrial minerals specialists, the Forum Planning Committee chose the theme: *Industrial Minerals in Ontario, Canada, and the World.*

An excellent selection of papers and field trips was presented that ranged across a wide spectrum of current knowledge on many topics. The delegates had the opportunity to hear about early Indian industrialists in Arkansas, the colourful 'granites' of Quebec, a host of industrial minerals that are being developed and mined in China, and the world-wide markets for industrial minerals, to name but a few of the subjects covered.

The Proceedings of the Forum are published by the Ontario Geological Survey as Miscellaneous Paper 114, and contain all the papers presented during the four days of meetings and field trips. While there has been some editing, the papers are printed essentially as received from the authors. A companion volume of the Proceedings is Ontario Geological Survey Miscellaneous Paper 111, titled "19th Forum on the Geology of Industrial Minerals, Guidebook for Field Trips", prepared for distribution to delegates participating in the field trips. It describes the glass container manufacturing plant and the industrial mineral deposits visited in southern Ontario as well as the road-side geology encountered along the way. These publications have been financed in part through a generous donation by the Society of Economic Geologists Foundation, Inc. whose continuing support of the Forum is gratefully acknowledged.

It goes without saying that the Forums depend for their success on the undiminished enthusiasm year after year by the delegates, for their special field of endeavour—industrial minerals. Some 180 persons gathered for the four days to exchange knowledge and information about the current state of activities throughout North America and around the world. As well as participating in the scheduled meetings and field trips, many delegates took the opportunity to visit other mineral deposits in the Province and to enjoy its hospitality.

The Forum Planning Committee extends its thanks and appreciation to the authors of the papers in the Proceedings, and to the many other individuals associated with government and companies whose contributions of time and funds helped to make the 19th Forum an informative and memorable meeting.

S.E. Yundt
Chairman
19th Forum on the Geology of Industrial Minerals

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ANNUAL MEETINGS OF THE FORUM ON THE GEOLOGY OF INDUSTRIAL MINERALS

1st	1965	Columbus, Ohio
2nd	1966	Bloomington, Indiana
3rd	1967	Lawrence, Kansas
4th	1968	Austin, Texas
5th	1969	Harrisburg, Pennsylvania
6th	1970	Ann Arbor, Michigan
7th	1971	Tampa, Florida
8th	1972	Iowa City, Iowa
9th	1973	Paducah, Kentucky
10th	1974	Columbus, Ohio
11th	1975	Kalispell, Montana
12th	1976	Atlanta, Georgia
13th	1977	Norman, Oklahoma
14th	1978	Albany, New York
15th	1979	Golden, Colorado
16th	1980	St. Louis, Missouri
17th	1981	Albuquerque, New Mexico
18th	1982	Bloomington, Indiana
19th	**1983**	**Toronto, Ontario**
20th	1984	Baitimore, Maryland
21st	1985	Arizona
22nd	1986	Arkansas
23rd	1987	Illinois

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FORUMS ON THE GEOLOGY OF INDUSTRIAL MINERALS

Year, Place, Theme	**Sponsor**	**Source of Proceedings**
First, 1965, Columbus, Ohio "Industrial Limestone and Dolomite"	Ohio State University Dept. of Geology	Ohio Academy of Science 445 King Avenue Columbus, OH 43201 (Ohio Journal of Science, vol. 66, no. 2, p.97-191)
Second, 1966, Bloomington, Indiana, "Cement Raw Materials"	Indiana Geological Survey and Indiana University	Indiana Geological Survey, Dept. of Natural Resources, Indiana University 611 North Walnut Grove Bloomington, IN 47401 (A Symposium on Geology of Cement Raw Materials) (out of print)
Third, 1967, Lawrence, Kansas, "Industrial Mineral Exploration and Development"	State Geological Survey of Kansas and University of Kansas	State Geological Survey of Kansas University of Kansas Lawrence, KS 66044 (Spec. Distribution Pub.34, 174 p.)
Fourth, 1968, Austin, Texas "Geology of Chemical Raw Materials" and "Depositional Models in Economic Stratigraphy"	Texas Bureau of Economic Geology and University of Texas at Austin	Texas Bureau of Economic Geology Box X, University Station Austin, TX 78712 (Proceedings of the Fourth Forum on Geology of Industrial Minerals, 174 p.)
Fifth, 1969, Harrisburg, Pennsylvania, "Geology of Sand and Gravel Deposits" and "Can Industrial Mineral Production Survive Urbanization and Conservation?"	Pennsylvania Bureau of Topographic and Geologic Survey	Pennsylvania Bureau of Topographic and Geologic Survey Bureau of Publications 10th and Market Streets, Harrisburg, PA 17125 (Mineral Resources Report M 64, 278 p.)
Sixth, 1970, Ann Arbor, Michigan, "Chemical and Industrial Rocks and Minerals" and "Building and Construction Stones and Minerals"	Michigan Geological Survey, University of Michigan, and University of Toledo	Information Services Center Michigan Dept. of Natural Resources Box 30028 Lansing, MI 48909 (Michigan Geol. Survey Miscellany 1, 155 p.)
Seventh, 1971, Tampa, Florida, "Geology of Phosphate, Dolomite, Limestone, and Clay Deposits"	Florida Bureau of Geology	Florida Bureau of Geology P.O. Box 631 Tallahassee, FL 32302 (Spec. Pub.17, 228 p.)
Eighth, 1972, Iowa City, Iowa, "Limestone, Gypsum, and Shale"	Iowa Geological Survey, University of Iowa, Iowa State University, and University of Northern Iowa	Iowa Geological Survey 16 West Jefferson St. Iowa City, IA 52240 (Public Inf. Circ. 5, 194 p.)
Ninth, 1973, Paducah, Kentucky, "Geology of Fluorspar"	Kentucky Geological Survey and Illinois State Geological Survey	Kentucky Geological Survey 307 Mineral Resources Building Lexington, KY 40506 (Series X, Spec. Pub.22, 107 p.)

Tenth, 1974, Columbus, Ohio, "Reclamation of Pits and Quarries" and "Carbonate Rocks in Environmental Control"	Ohio State University Dept. of Geology and Ohio Geological Survey	Ohio Geological Survey Dept. of Natural Resources Fountain Square Columbus, OH 43224 (Misc. Rept.1, 100 p.)
Eleventh, 1975, Kalispell, Montana, "Industrial Minerals of Montana and Contiguous States and Provinces"	Montana Bureau of Mines and Geology and Flathead Valley Community College	Montana Bureau of Mines and Geology Room 203-B, Main Hall Montana College of Mineral Science and Technology, Butte, MT 59701 (Spec. Pub.74, 186 p.)
Twelfth, 1976, Atlanta, Georgia, "Industrial Minerals of Georgia and the Southeastern States"	Georgia Geological Survey and Georgia State University	Georgia Geological Survey Department of Natural Resources 19 Hunter Street, SW Atlanta, GA 30334 (Inf. Circ.49, 78 p.)
Thirteenth, 1977, Norman, Oklahoma, "Gypsum, Silica-Rich Sediments, Natural Brines, and Energy in the Industrial-Minerals Industry"	Oklahoma Geological Survey and University of Oklahoma	Oklahoma Geological Survey 830 Van Vleet Oval, Rm.163 Norman, OK 73069 (Circular 79, 107 p.)
Fourteenth, 1978, Albany, New York, "Geology of Industrial Minerals in the 1970's"	New York State Geological Survey, Empire State Concrete & Aggregate Producers Assoc., State Univ. of New York at Albany, New York Dept. of Transportation, New York Dept. of Environmental Conservation, Renssalaer Polytechnic Inst., and Dunn Geoscience Corp.	New York State Geological Survey State Education Building Albany, NY 12234
Fifteenth, 1979, Golden, Colorado, "Industrial Minerals in Colorado and the Rocky Mountain Region"	Colorado Geological Survey, Colorado School of Mines Research Inst., and Colorado Sand & Gravel Producers Assoc.	Colorado Geological Survey 1313 Sherman St., Rm. 715 Denver, CO 80203 (Resource Series 8)
Sixteenth, 1980, St. Louis, Missouri, "Geology of Barite, Fireclay, and Stone Deposits, and Planning for Industrial Mineral Development"	Missouri Geological Survey, Department of Natural Resources and University of Missouri (Rolla)	Missouri Geological Survey Department of Natural Resources Division of Geology and Land Survey, P.O. Box 25, Rolla, MO 65401 (Information Circular 28)
Seventeenth, 1981, Albuquerque, New Mexico, "Industrial Rocks and Minerals of the Southwest"	New Mexico Bureau of Mines and Mineral Resources	New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801 (Circular 182)
Eighteenth, 1982, Bloomington, Indiana, "Construction Materials"	Indiana Geological Survey and Department of Geology Indiana University	Indiana Geological Survey Department of Natural Resources, 611 North Walnut Grove Avenue Bloomington, IN 47405 (Geological Survey Occasional Paper 37)

19th Forum on the Geology of Industrial Minerals

Proceedings

Geology of Ontario*

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Toronto, Ontario

ABSTRACT

The Province of Ontario is underlain by rocks of Precambrian, Paleozoic, Mesozoic, and Quaternary age. The Precambrian rocks underlie more than 60% of the Province and the Paleozoic rocks occur in both the north and the south of the Province. Rocks of Mesozoic age occur in a small area in northern Ontario. Deposits of the Quaternary Period are present throughout the entire Province.

The Precambrian rocks in Ontario are divided into three geological provinces as follows:
i) the Superior Province, which includes a wide range of Archean (Early Precambrian) intrusive rocks, and metamorphosed sedimentary and volcanic rocks;
ii) the Southern Province, which includes a range of relatively unmetamorphosed Proterozoic sedimentary and volcanic rocks which occur in the vicinity of Lakes Huron and Superior; and
iii) the Grenville Province which forms the southernmost portion of the Shield in Ontario and consists generally of highly metamorphosed rock. Included here are the older supracrustal rocks intruded by igneous rocks. To the south, the supracrustal rocks are unconformably overlain by a sequence of volcanic rocks, associated limestone, dolostone and clastic sedimentary rocks, which also host a variety of intrusive rocks and have been generally intensely metamorphosed and deformed, except in isolated localities (e.g. in the vicinity of Madoc).

The Precambrian rocks provide not only all of Ontario's metallic mineral wealth but also a wide range of nonmetallic industrial minerals which include materials such as nepheline syenite, quartz, talc and barite.

Paleozoic limestones, dolostones, shales and associated salt and gypsum underlie most of the more densely populated areas of southern Ontario as well as the sparsely populated area around Hudson Bay and James Bay. Except for a complexly faulted area in eastern Ontario, the Paleozoic rocks are generally tectonically undisturbed and almost flat-lying. In the south they provide the great bulk of the industrial mineral wealth of the Province and in the north have considerable resource potential. Mesozoic sands and clays, restricted to a relatively small area of the Moose River Basin in northern Ontario, contain appreciable potential resources of kaolin, silica, and lignite.

The Quaternary deposits which cover the entire Province were essentially deposited directly by the ice or the meltwaters derived therefrom. The deposits include a variety of coarse- to fine-grained tills, sands and gravels deposited as moraines and outwash bodies and silts and clays deposited in glacial lakes. These deposits provide 70% of the total mineral aggregate production of the Province and useful quantities of clay for the manufacture of field drain tile. Vast areas underlain by peat deposits in northern Ontario have the potential to supply the raw materials for energy production and horticultural and chemical products in the future.

INTRODUCTION

The land mass of Ontario can be geologically described as a core of Precambrian rock overlapped on both the north and the south by thick deposits of Paleozoic sedimentary rocks (Figure 1). Over a small area in the north, Mesozoic deposits cover the Paleozoic rocks. All these older rocks are, in turn, mantled by a variable thickness of Quaternary glacial and postglacial sediments.

The Precambrian rocks, which underlie 60% of the land surface of the Province, are the host rocks for the considerable metallic mineral wealth of Ontario whereas the Paleozoic rocks are the source of much of the industrial minerals. The Quaternary deposits provide the largest portion of the structural industrial minerals such as sand and gravel as well as some clay.

PRECAMBRIAN

The Precambrian terrane is readily divided into three areas or geological provinces based on the age of the rocks, the degree of metamorphism and the structural style.

The Superior Province, which constitutes most of the Precambrian terrane in Ontario, extends from within Manitoba on the west, through Ontario, and into Quebec and Labrador on the east. The Superior Province rocks are mostly of Archean age, i.e. older than approximately 2500 Ma (million years).

The Southern Province includes rocks of Proterozoic age, that is from 600 to 2500 Ma before the present. In Ontario, such rocks are found at the western end of Lake

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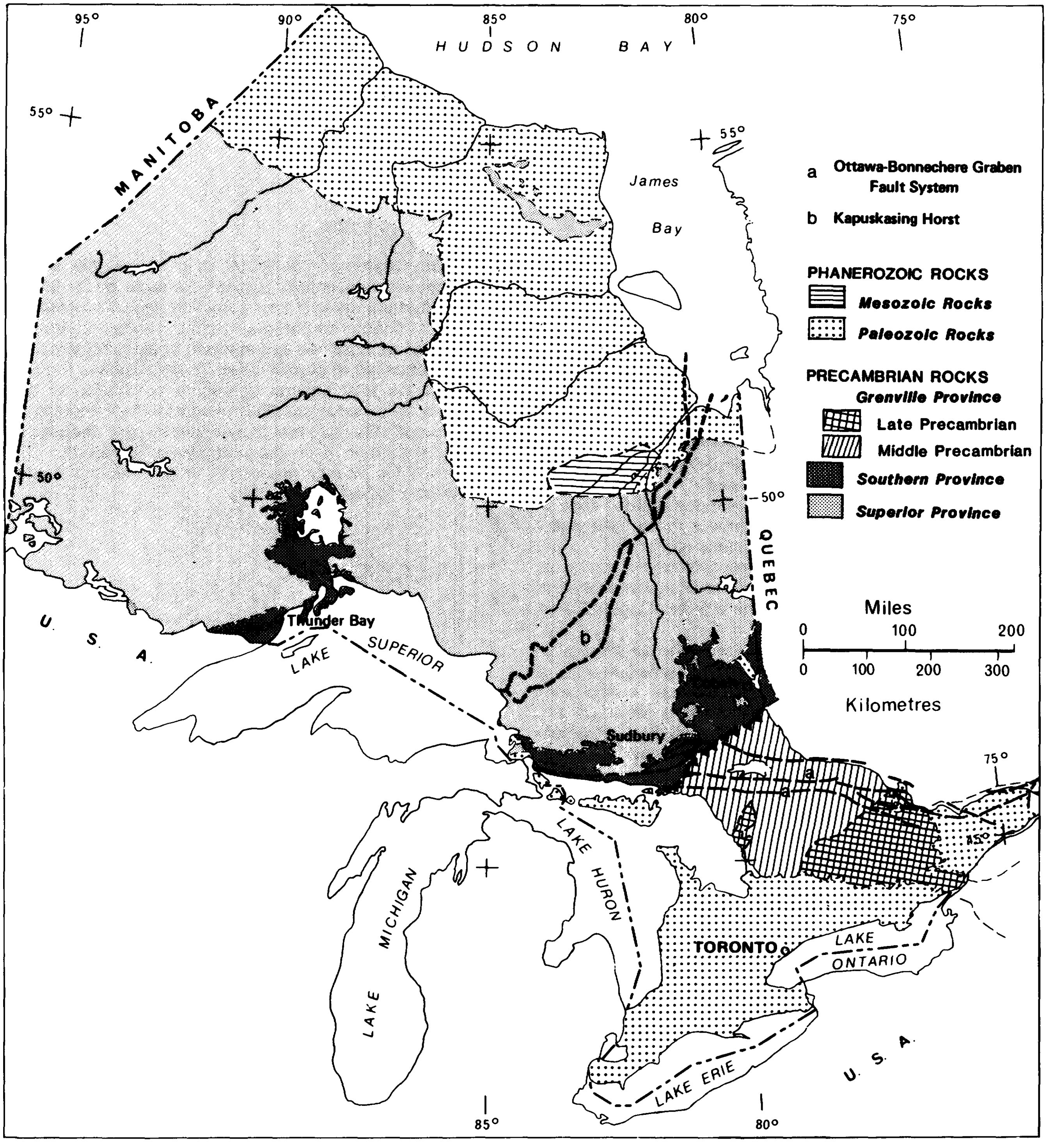

Figure 1. Generalized bedrock geology of Ontario.

Superior, around Lake Nipigon, and from Sault Ste. Marie along the north shore of Lake Huron through Sudbury to just east of the Quebec border. Although mountain building periods did occur during the Archean and the Proterozoic, many Precambrian rocks are today relatively undeformed. Of the three Precambrian provinces in Ontario, the Southern Province rocks generally have been the least disturbed.

The rocks of the Grenville Province occur in southern Ontario, extend east into Quebec and Labrador and probably extend as a basement complex to underlie southwestern Ontario and the north central USA. These rocks range in age from Archean to Proterozoic and include the youngest Precambrian rocks which represent the last period of Precambrian metamorphism and deformation in Ontario. Of all the Precambrian rocks in Ontario, those of the Grenville Province exhibit the greatest degree of structural complexity.

Superior Province

The surface expression of the Superior Province is essentially that of a plain with little expression of relief except for the occasional low fault scarp and the numerous lakes, many of which occupy fault-controlled valleys and basins. Almost all surface features are related to the underlying geology enhanced by bedrock erosion related to Pleistocene glaciation or to surface deposits remaining after the disappearance of the Wisconsinan glaciers.

Geochronology has shown that the oldest rocks in the Superior Province are in the northwestern part of the province, the youngest in the southeast. The ages range from in excess of 3000 Ma to about 2600 Ma. The fundamental subdivisions of the Superior Province separate areas underlain by (1) volcanic and sedimentary rocks intruded by batholithic granitic rocks and (2) gneissic, mostly sedimentary rocks, also intruded by batholithic granitic rocks. The volcanic-sedimentary assemblages ('greenstones') show evidence of multiple cycles of volcanism, sedimentation and granitic intrusion. Gneissic rocks in some of the sedimentary-batholithic areas may represent early sialic crust. The volcanic-sedimentary assemblages are generally of low metamorphic grade, the sedimentary-granitic areas are generally of high metamorphic grade. A period of deformation, late in the Archean, called the Kenoran Orogeny involved folding and development of large scale fault structures.

These Archean formations provide the host rocks for many of Ontario's major metallic producers. The major producing gold camps at Red Lake, Timmins and Kirkland Lake are all located in these rocks as are the two newly discovered gold deposits now under development at Detour Lake and Hemlo. Likewise, the major massive sulphide deposits at Kidd Creek, and the sideritic iron deposit at Wawa are also in Archean metavolcanic-metasedimentary belts. Two major stone producers operate granite quarries profitably at Vermilion Bay, in northwestern Ontario.

Southern Province

The rocks of the Southern Province provide some of the more spectacular scenery of the Ontario Precambrian terrane such as Mount McKay and other diabase-capped hills in the Thunder Bay area. Other features such as the Ouimet Canyon owe their form to gently dipping strata eroded by post-glacial meltwaters gouging out zones of weakness in the bedrock. Otherwise the undulating to rough terrane provides a setting for numerous lake basins throughout the Southern Province.

In the Lake Superior area, rock types range from the conglomerate, sandstone and shale of the Sibley Group to the volcanic rocks of the Osler Group and the prominent dikes and sills of intrusive Keweenawan diabase. In the Lake Huron region the characteristic rocks are the medium- to coarse-grained sedimentary rocks of the thick Huronian Supergroup and the intrusive Nipissing Diabase sills. To the east in the Sudbury area, the important metal-bearing mafic intrusive rocks of the Sudbury Igneous Complex are overlain by a sequence of younger sedimentary and volcanic rocks.

In the Lake Superior area, the rocks of the Southern Province are generally flat lying to gently dipping. The volcanic and sedimentary rocks around the basin of Lake Superior generally dip south or southeast toward the basin. The diabase intrusions form prominent mesas and ridges. Where valleys have been cut through sills, steep walled canyons have been produced. Generally though these Proterozoic rocks have been little affected by tectonic disturbance.

In the Lake Huron area, deposition of the thick sequence of sediments occurred between about 2500 and about 2150 Ma ago when the Nipissing Diabase was intruded. During and after their deposition these rocks were subjected to periods of deformation resulting in a number of east-trending folds and faults. The intensity of folding and faulting and of metamorphism varies from relatively simple deformation and slight alteration in the Elliot Lake area to complex deformation and medium grade metamorphism in the Sudbury area.

The Sudbury Igneous Complex (and associated metallic mineral deposits) is located at the contact between the rocks of the Superior Province to the north and those of the Southern Province to the south. Its origin is the subject of much debate, being physically part of a structure that has been attributed either to explosive volcanic processes or meteorite impact.

The economic mineral deposits found in the rocks of the Southern Province range from the rich copper deposits such as were mined at Bruce Mines in 1846 and bonanza silver deposits on Silver Islet in Lake Superior in 1868 to the very significant uranium deposits of Elliot Lake and the copper-nickel-platinum deposits of the Sudbury area, first discovered 100 years ago this year. Other important mineral deposits of the Southern Province include the cobalt and silver deposits at Cobalt. Major industrial mineral deposits of the Southern Province include the silica of the La Cloche Mountains. Amethyst – the officially designated mineral emblem of Ontario – is mined at Thunder Bay.

Grenville Province

The contact between the rocks of the Southern Province and those of the Grenville Province trends northeast just to the south of Sudbury. Known as the Grenville Front, the contact marks a major change between the extensively deformed and highly metamorphosed rocks to the south and the less deformed and metamorphosed rocks to the north.

Tectonic and metamorphic activity continued in the Grenville Province for several hundreds of million years (i.e. from about 1400 to 900 Ma ago) after such activities had ceased in the Southern Province. The Grenville rocks extend several hundreds of miles eastward from Georgian Bay to Labrador and the Atlantic Ocean, southward to Lake Ontario and across into New York State, and to the southwest they dip below a thick cover of younger Paleozoic sedimentary rocks.

There is a great variety of rocks in the Grenville Province but the abundance of marble especially in the south sets the Grenville apart from the Southern and Superior Provinces. In the north, the Grenville rocks are mostly clastic metasediments which have been intruded by granite and syenite. To the south there is a northeast-trending zone of nepheline and alkalic syenites. South of this zone of alkalic complexes, the geology becomes much more complex and a wide variety of clastic and carbonate metasediments, metavolcanics, and felsic, mafic and ultramafic intrusive rocks are present.

In general, the rocks of the Grenville Province are the most highly deformed and metamorphosed Precambrian rocks in Ontario, but not consistently so over the whole area. In much of the area the rocks exposed at the surface represent the deep seated roots of a former mountain range. Further south, in the Madoc area, the exposed rocks have not been subjected to such intense deformation.

Bancroft has been the site of uranium mining operations and although uranium mining has now ceased, Bancroft remains a very popular locality for rockhounds because of the great variety of minerals to be found in the general area. At Madoc, iron mining and smelting was initiated in 1837 and operated for seven years and intermittently up to 1872. Fluorspar, pyrite, lead and marble have all been produced in the area and in 1866 the first gold discovered in Ontario was found a few miles north of Madoc at Eldorado.

Talc has been continuously produced in the Madoc area since 1896. At Nephton and Blue Mountain nepheline syenite is presently being mined and produced by two companies.

PALEOZOIC

Rocks of Paleozoic age occur in both northern and southern Ontario. In both areas the range of lithologies is similar. However our knowledge of the rocks in the north is miniscule compared with our knowledge of the rocks in the south.

The Paleozoic rocks of southern Ontario supply 30% of the total provincial production of mineral aggregates as well as the whole of the provincial production of gypsum and salt. In contrast, industrial mineral production from the northern Ontario Paleozoic rocks is as minute as is our knowledge thereof. But the little we do know of the rocks in the north suggests that considerable potential lies ahead for economic development.

Southern Ontario

Paleozoic rocks in southern Ontario extend from Windsor some 800 km east to Quebec, with an interruption in continuity where the Precambrian rocks of the Grenville Province come to the surface along the Frontenac Arch. The Paleozoic rocks extend northward from the shores of Lakes Erie and Ontario to where they overlap onto the Canadian Shield and, in the case of Manitoulin Island, 450 km from Lake Erie (Figure 2).

The rocks range in age from the sandstones of Cambrian age to the shales and sandstones of Upper Devonian age and embrace a range of lithologies which includes limestone and dolostone as well as the complete range of clastic sedimentary rocks from claystone through siltstone to sandstone. Associated with these sedimentary rocks are extensive beds of salt and gypsum both of which make significant contributions to the industrial mineral production in Ontario. The dolostone and limestone are the source rocks for the large production of mineral aggregate (crushed stone) and cement, with high purity limestone and dolostone being used for the production of lime and metallurgical stone and other chemical industry products. It is in these rocks that Ontario's first mining operation was established in 1649 when a limestone quarry was opened for the extraction of building stone and the manufacture of lime for the construction of Sainte-Marie among the Hurons, near Midland.

The Paleozoic strata also provide the host rocks for Ontario's oil and natural gas production which has been continuous since oil was first commercially produced on the North American continent in 1858 near the villages of Oil Springs and Petrolia (near Sarnia). At the present time, four black shale units in the Ordovician and the Devonian are being investigated by the Ontario Geological Survey for their potential for shale oil production. Shale oil was first produced in Ontario in 1859 but production was halted a few years later after the successful development of the oil fields in the Oil Springs area.

In southwestern Ontario, deposition of the Paleozoic sediments in the Michigan Basin and the Allegheny Trough of the Appalachian Basin was virtually continuous from the Cambrian through to the Upper Devonian except for a period during the Lower Ordovician. The maximum thickness of Paleozoic sedimentary rocks in Ontario has been

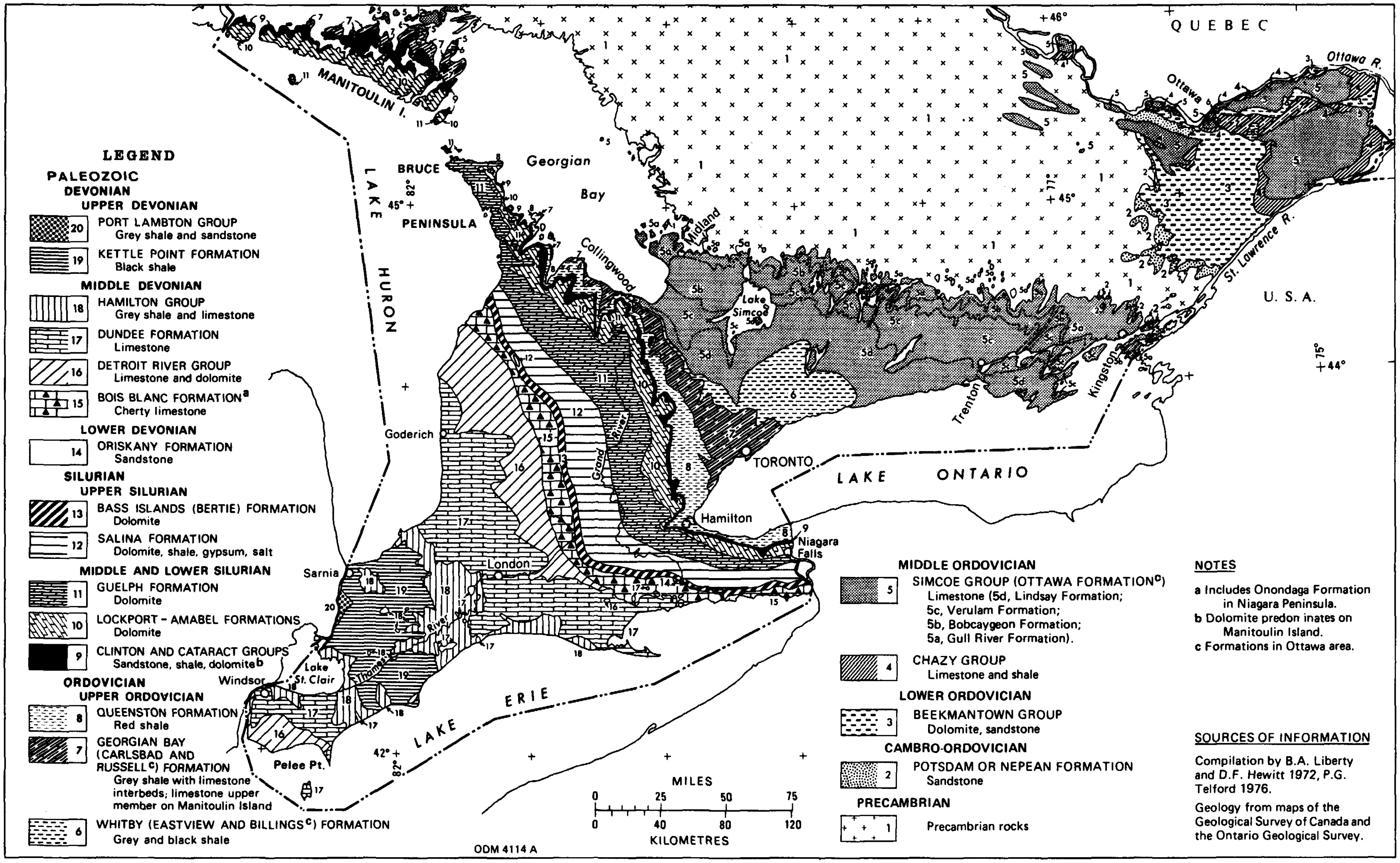

 Figure 2. *Paleozoic geology of southern Ontario*

reported as 1480 m but deposition thins appreciably over the northeast-trending Precambrian basement feature known as the Algonquin Arch. In general, the Paleozoic rocks appear to be flat lying although regional dips are fairly constant at 5.5 to 8.5 m/km west into the Michigan Basin or south into the Allegheny Trough. In general, the rocks in southwestern Ontario are tectonically undisturbed and although seismic events have been reported, the rocks appear to have remained unaffected since their formation.

In eastern Ontario, the stratigraphic sequence and the tectonic history differ from those in southwestern Ontario. Deposition of the Paleozoic rocks in eastern Ontario appears to have been continuous from the Cambrian to the Upper Ordovician when deposition ceased after the formation of the red shales of the Queenston Formation. As in the southwest, the rocks are gently inclined (especially to the south in the vicinity of the St. Lawrence River), but, in the north along the Ottawa River, the rocks have been heavily faulted and in places are tilted, especially within fault blocks. Folding is not evident but faulting occurred probably over several extended periods of time. The maximum thickness of the Paleozoic sedimentary rocks in eastern Ontario is reported as about 800 m.

In many areas of southern Ontario the upper surface of the Paleozoic rocks is fairly flat to undulating. In eastern Ontario, an irregular Precambrian surface does impart some irregularity to the Paleozoic surface. However in the southwest, the Paleozoic rocks form the major physiographic feature in the Province, the Niagara Escarpment. Extending from New York State westward then northward across Ontario to the Bruce Peninsula and Manitoulin Island, the scarp is formed by the resistant Lockport-Amabel dolostone cap-rock. The lower portions of the Escarpment are formed from a variety of rock types of Silurian age. To the west of the Escarpment, the bedrock surface is formed of Silurian and Devonian rocks whereas to the east the plain is underlain by rocks of Cambrian and Ordovician age to a thickness up to 600 m. Other features of the Paleozoic sedimentary rocks include the steep sided valleys eroded by the Pleistocene ice sheets and the even deeper valleys which predate the Pleistocene having formed, probably, during the long period of erosion from the end of the Devonian to the onset of the Pleistocene.

Northern Ontario

Despite the wide occurrence of the Paleozoic rocks in northern Ontario, very little is known about them except where they have been studied in the natural exposures along the river valleys. Fully detailed drill cores are certainly few in number in this area. In recent years however, subsurface investigations, especially in the Moose River Basin have penetrated into the Paleozoic formations, adding substantially to our knowledge of this remote part of the Province.

The Paleozoic rocks in this area are flat lying to gently dipping rocks which were deposited in two sedimentary basins. The Hudson Basin extends to the north so that the deposits in Ontario represent only the southern fringe of the basin deposition. The Hudson Basin is separated from the smaller Moose River Basin to the south by the Precambrian basement high in the northeast-trending Cape Henrietta Maria Arch which comes right to the surface in the Sutton Lake area. Rocks in both the Hudson Basin and the Moose River Basin range in age from Ordovician to Devonian and include the usual range of clastic sedimentary rocks from shale to sandstone as well as limestones and dolostones. High-calcium limestone, dolostone and high purity gypsum deposits have all been identified in the area.

MESOZOIC

The only known Mesozoic deposits in Ontario occur in the Moose River Basin although Cretaceous sands are suspected in several localities in northern Ontario below a cover of Pleistocene sediments.

The Moose River Basin occupies an area of about 100,000 km^2 and lies just north of the north-facing Precambrian scarp located about 70 km north of Kapuskasing. The Mesozoic deposits are present in the southeastern part of the Basin and the deposits identified there include unconsolidated and varicoloured, calcareous clays and calcareous quartz sands and kaolinitic clays with lignite. The lignite deposits in the Onakawana area have been extensively studied over the years with the expectation that they could be developed. Palynological studies suggest that the age of these deposits ranges from Middle Jurassic to early Cretaceous. Maximum thickness is believed to be about 140 m decreasing towards the northern edge of the deposits.

QUATERNARY

The whole Province was completely covered by ice sheets on several occasions during the Quaternary Period but of all the materials deposited as a result of glaciation, the majority, by far, of existing deposits are attributed to the youngest or Wisconsinan glaciation. Very few deposits have been found in Ontario that can be attributed to older glaciations or to inter-glacial stages.

The mantle of glacial drift is extensive though not everywhere continuous. Thick drift covers the Paleozoic formations both in southern Ontario (up to 300 m) and in northern Ontario (up to 175 m in the Moose River Basin). In contrast, bare Precambrian bedrock is exposed over much of the Canadian Shield. Even in southern Ontario, drift can be thin to nonexistent in some places such as in the limestone plains of eastern Ontario. More commonly, drift averages approximately 15 m thick over much of southern Ontario where the Paleozoic rocks form the underlying bedrock and approximately 2 m thick over much of northern Ontario where the Precambrian rocks form the bedrock.

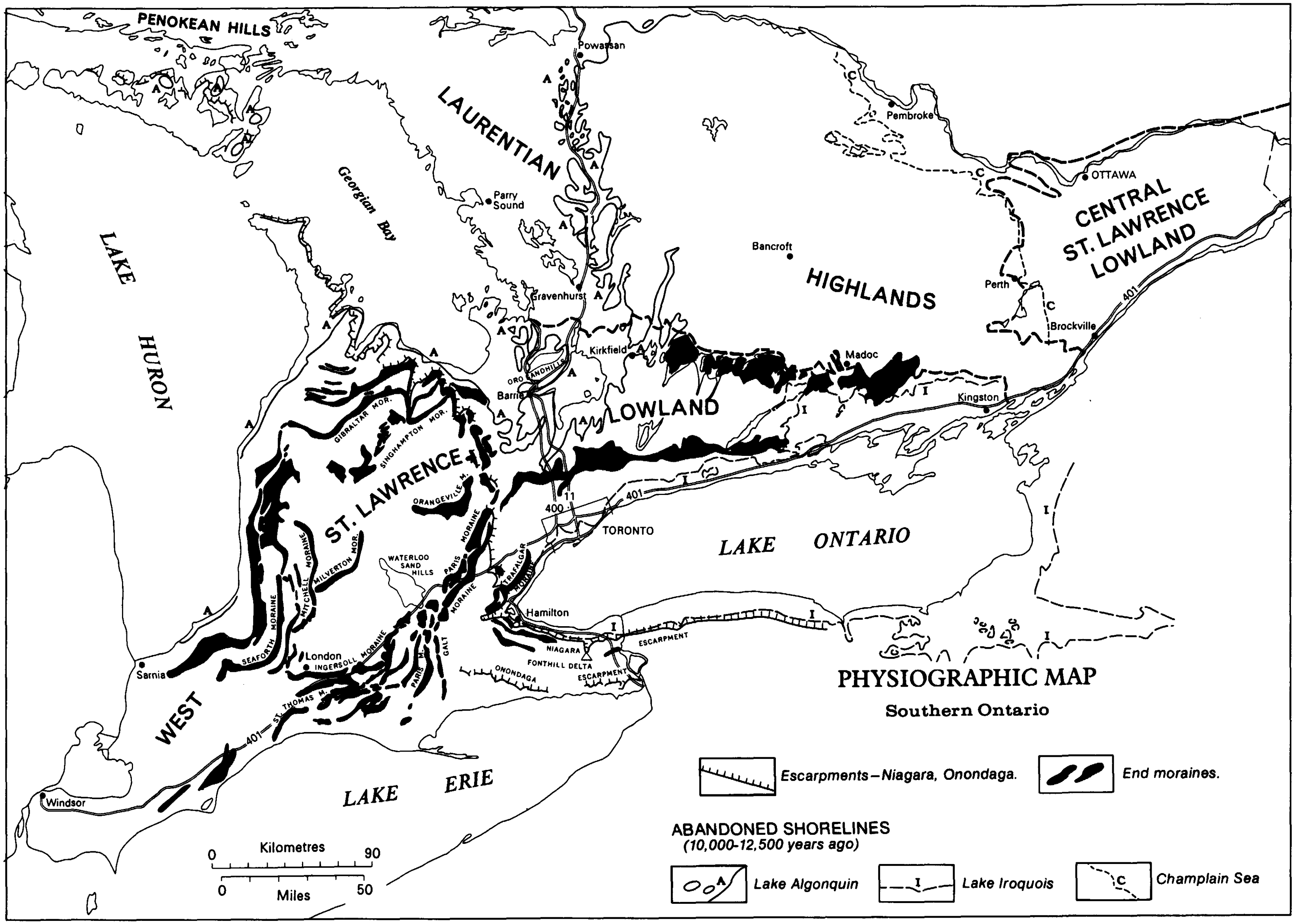

Figure 3. *Physiography of southern Ontario*

The distribution and character of the glacial drift has a profound effect upon the activities of the citizens of Ontario. Not only does the drift control the design and layout of the infrastructure of the community but it also supplies 70% of the 105 million tonnes of mineral aggregate consumed in Ontario each year.

All the usual materials and landforms associated with a glaciated terrane are to be found in Ontario. Extensive till plains, with tills that range from a high clay content to those with a high sand and boulder content, are found in both northern and southern Ontario. In southern Ontario, the several major systems of moraines, deposited 14,000-10,000 years ago as the position of the ice front retreated to the north, provide some of the more prominent physiographic features in the area (Figure 3). Frequently found associated with these moraines are the extensive meltwater deposits which are the source of much of the sand and gravel produced in the Province. These moraines and the associated meltwater deposits are extensive in central and southwestern Ontario but not so prominent in eastern Ontario. Over the Canadian Shield, massive moraine systems extend for considerable distances. These deposits provide a source of pit run gravel for fill (and sometimes for road bases) and often become the setting of major transportation routes across the sparsely populated north. Kames and eskers also are major sources of mineral aggregate supplies, both in the north and the south.

With the melting of the ice sheets, vast quantities of meltwater were impounded in extensive glacial lakes. Many of these lakes were long lived and sediments deposited therein are not only areally extensive but of considerable thickness. Glacial lake deposits in other areas are quite thin and merely provide a thin clay veneer over a pre-existing, gently undulating till plain or bedrock surface. These glaciolacustrine clays provided the raw material for the clay tile and brick industry of the Province and, although at present most clay bricks are produced from bedrock shale deposits, the clay tile industry still uses some lacustrine clay (and sometimes clay tills) as its raw material.

Following disappearance of the ice (12,000-10,000 years ago in southern Ontario and about 8000 years ago in northern Ontario), the sea encroached upon what is now the present land surface and extensive glacio-marine deposits were formed. In eastern Ontario and especially along the Ottawa River Valley, the clays of the Champlain Sea (also called Leda clays) were deposited. These clays, somewhat sensitive to disturbance, are the materials involved in many unstable slopes found along the various river valleys in eastern Ontario.

Glacio-marine clays also cover extensive areas in northern Ontario, especially in the Hudson Bay Lowlands. As the land surface rose due to isostatic adjustment, the seas withdrew to the north, leaving an extensive plain, floored by relatively thin deposits of the marine clays, and interrupted by low, sandy ridges which mark the temporary positions of the shoreline.

Subsequent to the disappearance of the ice sheets, and largely because of deranged and/or immature drainage systems and the cold climate, extensive deposits of peat have formed throughout Ontario and especially so in the north. Ontario has over 260,000 km^2 of peatland but only in recent years has an inventory of this natural resource been attempted. Peat has been mined, processed and marketed for years as a horticultural material but the motivation for the current inventory comes largely from the potential of peat as a fuel source and chemical feed stock.

CONCLUSION

Ontario exhibits a wide variety of geologic terranes which endows the Province not only with a vast storehouse of mineral wealth but with a range of conditions and environments that enhance the living and recreational opportunities for its citizens and visitors.

The Precambrian Canadian Shield in Ontario has made Ontario the world's largest producer of nickel and nepheline syenite and Canada's largest producer of gold, platinum, silver, uranium and copper. The Province is also the largest Canadian producer of salt and, as befits the Canadian province with the largest population and manufacturing sector, also of structural materials. We also produce large quantities of iron, zinc, asbestos etc., but we don't have everything – despite the obvious advantages of having a dynamic geologic laboratory at hand, we are not disturbed with our lack of "facilities" providing competition for Mt. St. Helens or the San Andreas Fault.

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Industrial Minerals of Northern Ontario*

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ABSTRACT

Most of Ontario lies north of a line from Parry Sound on Georgian Bay to Mattawa on the Ottawa River. This area is referred to as northern Ontario. Development in northern Ontario is characterized by low population density (total about 890,000) and limited industrial diversification. Pulp and paper, mining, agriculture, and tourism are the major industries. Highway, airport, and building construction are subordinate to these endeavours.

Northern Ontario is underlain by Early Precambrian rocks in general, by Middle to Late Precambrian rocks in and adjacent to Lake Superior, Lake Nipigon, the north shore of Lake Huron and the area from Sudbury to Cobalt, and by Phanerozoic formations in the James Bay Lowland and the Timiskaming Valley. In many areas, the bedrock is covered by glacial formations, marine clay, and/or Recent river and bog deposits.

Active industrial mineral development in the area includes production of silica, barite, talc, building stone, peat, amethyst and construction aggregates, as well as production of sulphur and arsenic as by-products of metal mining.

There is geologic potential for development of deposits of magnesite, asbestos, chromite, magnetite, nepheline syenite, mica, feldspar, spodumene, kyanite, garnet, graphite, calcium carbonate, wollastonite, phosphate, niobium-tantalum, rare earths, fireclay and kaolinite. Asbestos was mined previously and a clay products industry operated until recently. Some commodities, e.g. phosphate, have been newly developed to the point of production while others will depend for their development on growth of local markets and diversification of consuming industries capable of taking advantage of the available resources.

Discussed are the geology and exploration history of some industrial minerals in production or best suited for immediate development. The latter are asbestos, calcium carbonate, chromite, magnesite, nepheline syenite, feldspar, kyanite, phosphate, fireclay and kaolinite. Niobium-tantalum and rare earths may form important by-products of phosphate mining if separation can be achieved. Kaolinite is of potential benefit to the local paper manufacturing industry provided that efficient production can be obtained, possibly by adapting bore hole mining techniques. Programs in place to stimulate development of the mineral industry are the Ontario Mineral Exploration Program (OMEP), the Small Rural Mineral Development Program funded by the Ontario Board of Industrial Leadership and Development (BILD), and the Northern and Eastern Ontario Subsidiary Agreements of a Provincial-Federal Development Agreement.

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INTRODUCTION

Ontario has traditionally maintained a significant production of a wide range of industrial minerals. This production, which had a value of $774 million in 1981 (Minnes 1982), is centred in southern Ontario, and serves largely to satisfy long-established markets and uses for the commodities produced. Recent technological advances in such diverse industries as iron and steel, plastics, electrical, cosmetics, construction and agriculture have indicated new uses for some of these commodities, as well as potential markets for as yet undeveloped commodities. Looking to future demands, exciting prospects are seen for the development in Ontario of integrated high technology industries based on industrial minerals which may be locally abundant. In order to take advantage of these opportunities, new geological studies to document the sources of these commodities will be necessary, in tandem with imaginative industrial leadership.

Approximately 90 percent of Ontario's vast land mass, more than 800,000 km^2, is considered "northern". This enormous area is inhabited by 10 percent of the Province's population; the inhabitants are employed principally in the mining, forestry and tourism industries, with only a minor involvement in agriculture. The northern Ontario mining industry, with an estimated annual production value of $3.8 billion, far exceeds the other industries in its contribution to the Province's economy. Approximately 10 percent of this contribution is from industrial minerals.

Given the vast land mass of northern Ontario, its geological diversity, and new market developments, the potential exists for substantially increased production from the industrial minerals sector.

HISTORICAL PERSPECTIVE OF INDUSTRIAL MINERAL DEVELOPMENT IN ONTARIO

Much of the industrial minerals industry in Ontario continues to be based upon high volume-low value commodities, primarily for construction purposes, that must be located close to their market to be viable. Largely for this reason, industrial mineral development in northern Ontario has lagged behind that of southern Ontario, with its concentrations of people and industry. Nevertheless, industrial mineral resources have been identified and, in some cases at least, developed in northern Ontario to fill traditional markets. These developments provide a background against which possible future developments, based upon new markets, can be contrasted.

Asbestos

The largest industrial mineral development to date in northern Ontario has been the mining of asbestos from altered Archean ultramafic rocks in the Abitibi greenstone belt. Canadian Johns-Manville Company Limited, the major producer, marketed some 380,000 tons of fibre to 1965 (Vos 1971; Kretschmar and Kretschmar 1982), largely from the Munro Mine east of Matheson. Similar undeveloped deposits are known to occur elsewhere in the belt of ultramafic rocks that extends from southwest of Timmins to the Quebec border. However, health and environmental concerns about asbestos make further production from these deposits uncertain.

Talc

Significantly, the same belt of ultramafic rocks which hosts asbestos deposits also hosts talc-magnesite deposits. The talc in these deposits is platey, free of fibrous contaminants, and is characterized by low calcium, high iron and high nickel contents (Kretschmar and Kretschmar 1982). Ontario's talc, presently produced by Canada Talc Industries Limited at Madoc in southern Ontario and by Steetley Talc Industries Limited at Penhorwood Township southwest of Timmins, is used for pitch control in the manufacture of paper, as fillers and extenders in paints and plastics, and, to a lesser extent, in the pharmaceutical and cosmetics industries. Steetley Talc has, since initiating production in 1978, successfully marketed its product to the paper industry in Ontario, displacing talc imported from the USA, and is currently expanding production to 37,000 tons per year from 25,000 tons per year. The company is actively pursuing the high-value cosmetics and pharmaceutical markets, which require an extremely high quality product.

Nepheline Syenite

Nepheline syenite is mined at Blue Mountain near Peterborough in the Grenville Province in southern Ontario to provide materials to the glass and ceramics industries; proven reserves at this deposit are sufficient to last 40 years at current rates of production. The nepheline syenite produced at Blue Mountain is valued in international markets for its consistent composition, notably a relatively constant Na_2O/K_2O ratio, and a low iron content. A similar nepheline syenite in Bigwood Township, 55 km south of Sudbury, is being investigated by Steep Rock Iron Mines Limited (Vos 1980; 1982a).

Syenite and nepheline syenite also occur in carbonatite complexes in the Superior Province in northern Ontario. Some nepheline syenites in the Port Coldwell Complex, near Marathon on Lake Superior, have been tested for use in the ceramics industry; the results of these tests indicate an unacceptably high iron content (Puskas 1967).

Silica

Orthoquartzite is quarried by Indusmin Limited from the Huronian Bar River Formation on Badgeley Island, 75 km southwest of Sudbury on Lake Huron. The quartzites are a source of silica for ferrosilicon production and the glass and ceramics industries.

Barite

Barite is mined by Extender Minerals of Canada Limited from veins in Yarrow Township, 12 km southwest of Matachewan, for use as a filler and extender in paints and plastics.

Building and Facing Stone

Numerous quarries have operated intermittently throughout Ontario to provide stone to local housing and construction industries. Currently, dimension stone is quarried in granites near Vermilion Bay, 70 km east of Kenora, and in anorthosite in Dana Township, 60 km northeast of Sudbury. The raw blocks from these operations are shipped to finishing plants in eastern Canada and Vermont, for use primarily as monument stone.

Micaceous metasediments and colourful quartzites are quarried in McAuslan Township, 45 km north of North Bay, near Echo Lake, 30 km northeast of Sault Ste. Marie, and in Forgie Township, 30 km west of Kenora, to provide chips and facing stone for sidewalks and patios.

Pegmatites

Zoned granitic pegmatites near Sudbury and Mattawa in the Grenville Province in Ontario have been mined for feldspar, quartz and mica (Hewitt 1967), used in the past in ceramics and glass (quartz, feldspar) and electrical (mica, quartz) industries. These markets have, in large part, been lost to artificial and other natural commodities.

More complex granitic pegmatites in the Superior Province in northern Ontario have been explored, to date unsuccessfully, for production of lithium, beryllium, tantalum and rare earth elements. Such pegmatites are similar to the Tanco pegmatite deposit at Bernic Lake in Manitoba.

Amethyst

Amethyst from the north shore of Lake Superior has been known since 1846 and has been marketed as gemstone since 1887 (Vos 1976). The amethyst occurs in calcite-barite or breccia veins, primarily at the contact of the Keweenawan (Late Precambrian) Sibley sedimentary rocks and an underlying quartz monzonite body.

Unconsolidated Materials

Local deposits of sand and gravel are used throughout northern Ontario as aggregate in road and building construction. Clays have been used for brick production in the Thunder Bay area. Horticultural moss is produced from peat in the Rainy River District and marl is used in the conditioning of potting soil near Dryden. Larger marl deposits near Thunder Bay are potential sources of agricultural lime for local markets.

All of these developments are small scale and mainly serve to satisfy local demands. There is little probability of expansion, because the deposits are small, and transportation costs to larger, more distant markets are prohibitive.

THE FUTURE OF INDUSTRIAL MINERALS IN NORTHERN ONTARIO

The preceding discussion of industrial minerals production in northern Ontario points out a history of resource development for single commodities and/or markets. In most cases, raw materials are shipped after only minor processing, which typically includes little more than cleaning, sizing, and packaging. Such development is probably the only method of producing such commodities as nepheline syenite and silica, which have limited and well-defined applications. However, recent technological advances in the use of many industrial mineral commodities suggest alternative development of integrated industrial complexes incorporating a number of commodities that may be locally available from different sources, or the utilization of several commodities from a single source. Establishment of such industries in northern Ontario, to produce and market low volume-high value finished products, would be a marked departure from past utilization of industrial minerals resources. The volume and value of the products of such development, taken together, may be sufficient to overcome the transportation costs inherent to development in northern Ontario. In addition, these high technology industries employ a highly skilled, and highly paid labour force and are characterized by small, clean plants; both factors enhance their incorporation and acceptance into populated areas.

Linked Commodities

Some resources may be successfully developed by combining commodities to manufacture finished products. Such development will require generation of markets for new products and the capture of existing markets by displacing traditional products and suppliers. Some examples of possible linked commodities are listed below.

1. *Sulphur concrete.* Sulphur, which is available in northern Ontario as a by-product of metal refining, can be used with lime and aggregate to manufacture a hot thermoplastic concrete. This concrete has comparable strength to conventional concrete, sets and cures rapidly (an advantage in cold climates), and can be easily resurfaced (and recycled) by heating.

2. *Fertilizers and animal feedstocks.* Sulphuric acid and apatite are the raw materials for a range of fertilizers. Sulphuric acid is available from metal refining and the Cargill and Martison carbonatites are known sources of apatite.

A surprising amount of animal feed is manufactured to ensure nutritional requirements. Magnesite is an essential ingredient of feed for dairy cattle. Calcium is used in poultry feed and to a lesser extent in cattle feed. Trace elements are also added to such foodstuffs. Magnesite could be obtained from the talc-magnesite deposits of the Timmins area; calcium, as calcite, is available in limestones, marbles and carbonatite complexes in northern Ontario.

3. *Ceramics.* Modern ceramics developed for the automotive industry, steel-making, and for abrasives, are manufactured from raw materials that include dolomite, magnesia, carbon and oxides of alumina, boron, selenium, phosphorus, arsenic, zirconium, titanium, chrome and nickel. These are available in northern Ontario from kyanite, andalusite and sillimanite in high grade metamorphic rocks, from concentrations of rare elements in carbonatite complexes and from wastes from metal and precious metal processing. Silica for this ceramics industry is available from the sands of the James Bay Lowlands.

Other sources of raw materials for a ceramics industry in northern Ontario include beryl, flake graphite, barite and thorianite.

Multiple Utilization of Resources

A second alternative is the development of individual deposits or resource areas for a number of commodities. Several resources are known in northern Ontario that might benefit from this approach.

1. James Bay Lowlands. The Moose River Basin of the James Bay Lowlands contains known resources of high-calcium limestone, gypsum, silica sand, kaolin and fire clay (Vos 1982b). High calcium limestone has a range of applications in sealants, fertilizers and animal feeds, concrete, steel, ceramics and glassware, paints and plastics. Gypsum is used in adhesives and for wallboard and plaster. Silica sand is a raw material for ceramics and glass. Kaolin is used extensively in the paper industry and as filler in paints and plastics, and fire clay is used in the manufacture of refractory bricks and tiles and other heavy clayware. Individually, these commodities probably could not be developed, given the location so distant from markets. However, their combined value makes each more attractive to development.

2. Carbonatite complexes. The Cargill and Martison carbonatites are sources of apatite, vermiculite and rare earth elements. Apatite is a source of phosphorus for fertilizers. Vermiculite has been used in insulation applications (vermiculite board can be manufactured in plants modified from the manufacture of woodchip board), light weight concrete, in animal feedstuffs and in horticulture. The rare earth elements have applications in computer technology, in textiles, and have many applications in electronics. Many of these markets are expanding. Although major deposits of rare earth elements are currently mined elsewhere, the wide range of applications may make industrial development for specific finished products possible in northern Ontario. Again, complete utilization of resources such as occur in the Cargill and Martison complexes may be the best way in which they can be developed.

CONCLUSIONS

Industrial mineral resources have traditionally been developed for the production of large volumes of commodities of low value. Select commodities are shipped at great economic disadvantage from source to a separate industrial centre for incorporation into finished products. This development strategy means that many resources in northern Ontario cannot be developed because of transportation costs. Exciting new applications of many industrial minerals in the manufacture of high value products in high technology industry means that a new philosophy is necessary for the development of industrial mineral resources. This approach is one of utilization of all commodities contained within a single resource and the establishment of small, high technology manufacturing plants that are close to their commodity sources. A potential for significant industrial minerals development in northern Ontario exists if imaginative and aggressive industrial leadership pursues these opportunities.

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Ontario Industrial Minerals for Ontario in the 1980s

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ABSTRACT

With more than 34% of the nation's estimated $347 billion Gross National Product generated in the province where 8.6 million people live, Ontario requires large amounts of structural materials and non-metallic minerals. Industrial minerals production in 1982 was an estimated 103 million tonnes valued at $765 million. To continue to meet the Province's needs competitively and to take advantage of export opportunities, imaginative management will be required by Ontario's industrial minerals producers. The challenge to government will be to provide the background in resource identification and the social and commercial environment in which mineral producers can prosper. A healthy minerals industry is important to the economic well-being of the Province. This paper suggests ways in which Ontario's industrial minerals can help the nation in the 1980s.

INTRODUCTION

Some time ago, I thought that this paper would be describing the stable base of mineral production capacity that has been built in Ontario over the years. Indeed, a stable base has been built, and until last year the Province's industrial mineral producers seemed not to have been affected by the changing world-wide markets for those minerals or by the reduction in consumption that concern producers of metals. However, it is now clear that the general reduction in economic activity did hit Ontario industry in 1982 with the resulting lower demand for certain industrial minerals and drastic cost cutting measures in certain areas.

In this paper, I wish to describe briefly the major, non-metallic industrial mineral producers of Ontario, to mention some of the deposits that are worthy of investigation and to comment on the competitive environment in which our producing and consuming industries find themselves.

INDUSTRIAL MINERALS PRODUCTION

Non-metallic mineral production represents only 19% of the estimated $766 million value of industrial mineral production in the Province in 1982 (see Table 2). The structural industrial minerals of Ontario are the subject of another paper presented at this forum (see Scott, this volume).

Salt has led non-metallic industrial mineral production for many years, benefiting from the fortuitous location of high grade rock salt deposits of the Michigan Basin, adjacent to excellent deep-water shipping facilities at Goderich and Windsor. Brine wells at Sarnia and Amherstburg supply salt to Ontario and Michigan chemicals producers.

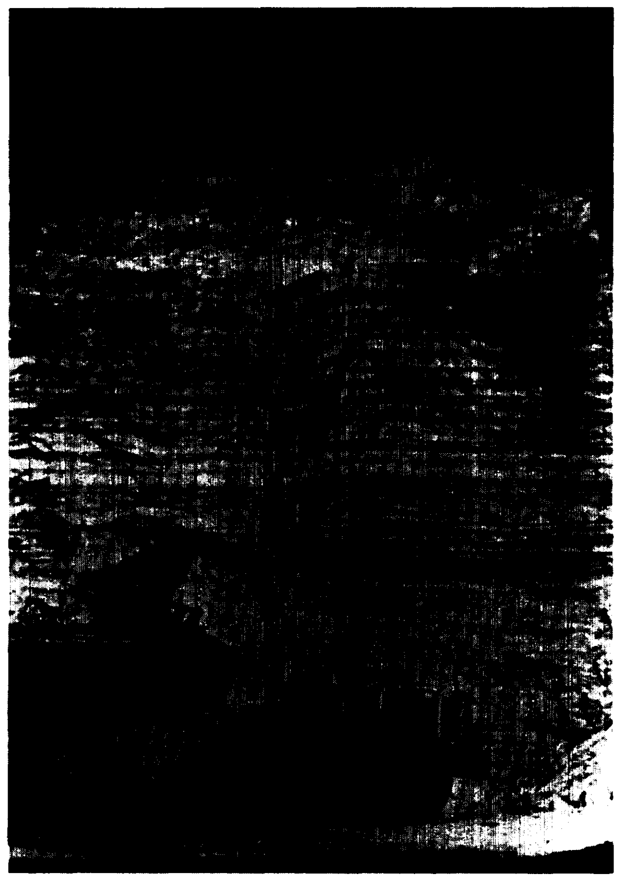

Figure 1. Rock salt mine at Goderich, Ontario, operated by Sifto Salt Division of Domtar Incorporated. Photo courtesy Domtar Incorporated.

Salt production in 1982 in Ontario amounted to an estimated 5.5 million tonnes valued at $97,701,000 (see Table 2). At Goderich, Domtar Incorporated operates a 2.25 million tonne capacity rock salt mine (Figure 1). An expansion project, designed to increase capacity by 55%, is expected to be completed in April, 1983. Domtar also operates brine wells for the production of special salt products. At Windsor, the Canadian Salt Company Limited produces rock salt from an underground mine and vacuum salt products from brine wells, as well as brine for export from facilities having a rated capacity of more than 2 million tonnes annually. Dow Chemical of Canada Limited utilizes brine from wells at Sarnia for the production of caustic soda and chlorine. At Amherstburg, Allied Chemical Canada Limited produces brine from wells to manufacture sodium carbonate in one of only two plants remaining in North America that use the Solvay process to manufacture this important chemical compound. A secondary product at the Allied plant is calcium chloride, used for preventing dust on unpaved roads, as a well drilling fluid, and for certain other industrial applications.

Immense deposits of salt underlie a large part of southwestern Ontario and southern Lake Huron in beds of the Salina Formation of Silurian age. Salt horizons have been found in the Michigan Basin as far east as a curving boundary connecting Kincardine on Lake Huron, London, and New Glasgow on Lake Erie. The combined thickness of the six Salina salt beds amounts to as much as 215 m. The Canadian Salt Company mine at Windsor recovers salt at a depth of 297 m from an 8.2 m thick bed, while at Goderich, Domtar mines salt from a 24.4 m thick bed at a depth of 536 m beneath Lake Huron.

Although salt was first discovered at Goderich and produced there in 1866, the major growth in salt production has resulted from the use of rock salt for ice and snow control since the 1950s.

Nepheline syenite ranked second in value of production of non-metallics in 1982 amounting to about $17 million for an estimated 518,000 tonnes (see Table 2). A total of 414,785 tonnes valued at $15.765 million was exported that same year (see Table 4) to 22 countries. Ontario is the largest supplier of nepheline syenite used to make glass, ceramics, paints and plastics. Since production began in 1936 nepheline syenite has successfully competed with other sources of alumina, soda, and potash that are required for many useful products.

Sulphur ranked third in value in non-metallic production although elemental sulphur minerals do not occur in Ontario. Estimated production in 1982 was 236,000 tonnes valued at $14.5 million (see Table 2), well below 1981 levels of production and value. Sulphur is recovered in elemental form during petroleum refining or as sulphuric acid during roasting of metallic sulphide ores. Sulphur production has risen in recent years as companies reduce sulphur emissions to the atmosphere.

Quartz ranked fourth among non-metallics, having a production value in 1981 of $9.8 million. About 600,000 tonnes of production was flux stone while the remaining 400,000 tonnes was for other high quality purposes such as glass, ceramics and ferroalloys. In 1982 the reported value of production was $7.8 million, although the production tonnages did not include flux stone. Indusmin Limited is the sole Ontario producer of silica (quartz) for the

Figure 2. *Calcium carbonate plant at Perth, Ontario, operated by Calcite Division of Steep Rock Resources Incorporated.*

non-flux products. The company operates a mine on Badgeley Island in Georgian Bay and a processing plant at Midland with a total annual capacity of about 500,000 tonnes.

Crude gypsum was fifth in value of production in 1982 amounting to an estimated 506,000 tonnes valued at $4,506,000 (see Table 2). Most production was utilized by manufacturers of gypsum wallboard while talc production from Ontario's two mines amounted to an estimated $3.4 million in 1982. Steetley Talc Limited, in operation since 1978, produces micronized platey talc at Timmins. It is used mainly by the paper industry for pitch control, but is finding increasing use in extender/filler applications. Canada Talc Industries Limited produces talc at Madoc that is used as an extender filler in many applications ranging from auto body filler to paints and plastics. Planned expansions by both companies should result in significant increases of products available for domestic consumption and for export.

The white crystalline marble deposits of Precambrian Grenville age of eastern Ontario have been well-known and utilized in a small way for centuries. The naming of the town of Marmora which was built on marble is an indication of the earnest optimism of Ontario's citizens of the early 1800s. We too are optimistic that the new calcium carbonate mine and plant near Perth in Lanark County (Figure 2) will take its place among the great producers of this important industrial mineral.

Ontario has a wide variety of beautiful building and ornamental stones that have been produced over the years to construct many of our finest public buildings and private residences. There is a strong renewed interest in natural building materials. Examples of current activity are the dolomite quarries of Adair Marble Quarries near Lion's Head on Bruce Peninsula, the Belmont granite quarry operated by Fairmont Granite Limited (Figure 3) in Peterborough County and the Vermilion Bay granite in northwestern Ontario. A large producer of natural and artificially coloured roofing granules from basalt is 3M Canada Incorporated at its operations near Havelock.

INDUSTRIAL MINERAL OPPORTUNITIES

The market for industrial minerals has great potential in Ontario, considering that its 8.6 million population generated close to 34% of the entire Canadian Gross National Product estimated in 1982 to be $347 billion. Within 160 km of Toronto lies about one-third of the nation's buying power.

Since 1950, production of structural materials has grown from a value of $50 million to an estimated value in 1982 of $619 million. Production of non-metallic rocks and minerals has grown from $10 million to an estimated $147 million; roughly a 15-fold increase overall in value and a three-fold increase in quantity. In the same period, total mineral production in Ontario has grown from $372 million to over $3.1 billion, down though from the $4.1 billion in 1981. Provincial mineral production in 1950, 1980, 1981 and estimates for 1982 are shown in Tables 1 and 2. Consequently, consideration of factors affecting the production and consumption of all industrial minerals should be examined in light of the concentration of population and economic activity in a relatively small part of Canada and the opportunities thereby created.

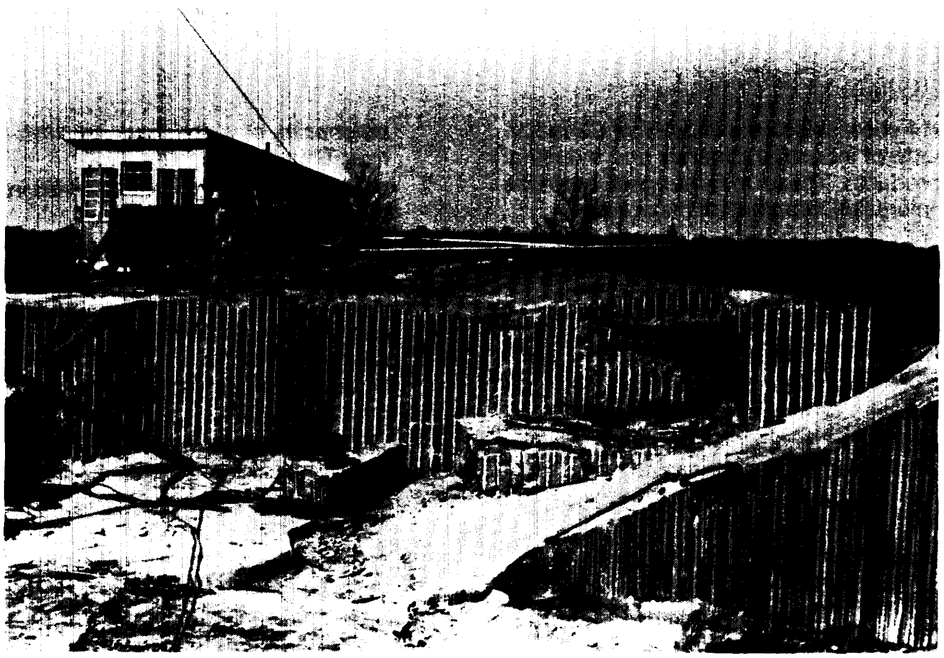

Figure 3. *New Pink Granite Quarry in Belmont Township, Ontario, operated by Fairmont Granite Limited.*

TABLE 1. ONTARIO MINERAL PRODUCTION, SELECTED YEARS, 1950 (ACTUAL), 1980 (ACTUAL) AND 1981 (ESTIMATED)

		1950(1)		1980(1)		1981(2)	
	UNIT	QUANTITY	VALUE $	QUANTITY	VALUE $	QUANTITY	VALUE $
Non-metals							
Arsenic	tonne	–	16,220	–	–	–	–
Asbestos	tonne	9,590	1,493,039	–	–	–	–
Barite	tonne	–	–	–	750,000	–	800,000
Feldspar	tonne	5,224	49,619	–	–	–	–
Fluorspar	tonne	7,816	262,643	–	–	–	–
Gemstones	kg	–	–	–	52,000	–	60,000
Graphite	tonne	–	390,815	–	–	–	–
Gypsum	tonne	180,778	875,217	740,000	5,729,000	688,000	5,353,000
Mica-amber	kg	441,336	28,299	–	–	–	–
-muscovite	kg	85,630	128,161	–	–	–	–
Nepheline syenite	tonne	–	842,886	600,000	15,936,000	606,000	17,834,000
Peat	tonne	5,091	206,625	8,000	795,000	8,000	787,000
Phosphate	tonne	–	712	–	–	–	–
Quartz	tonne	1,257,858	1,027,791	936,000	9,656,000	1,013,000	11,079,000
Salt	tonne	631,780	4,639,867	5,208,000	71,417,000	4,963,000	77,121,000
Soapstone, talc, pyrophyllite	tonne	13,844	182,048	–	1,437,000	–	2,684,000
Sulphur in smelter gas	tonne	–	131,540	521,000	12,539,000	505,000	12,155,000
Sulphur, elemental	tonne	–	–	21,000	906,000	22,000	1,200,000
Total, non-metals			10,275,482		119,126,000		129,073,000
Structural materials							
Clay products	tonne	–	9,323,263	–	58,000,000	–	69,366,000
Cement	tonne	843,389	10,953,896	3,397,000	163,056,000	3,620,000	200,115,000
Lime	tonne	518,341	6,030,228	1,759,000	87,950,000	1,711,000	103,500,000
Sand and gravel	tonne	27,462,358	15,553,186	76,621,000	132,894,000	75,000,000(3)	150,000,000
Stone	tonne	5,184,465	7,843,124	36,006,000	122,859,000	35,000,000(3)	122,000,000
Total, structural materials			49,703,697		564,759,000		644,981,000
Total, industrial minerals			59,979,179		683,885,000		774,054,000
Total, metals			302,540,548		3,862,253,000		3,454,323,000
Total, fuels			9,783,447		37,037,000		45,743,000
Grand total for Ontario			372,303,174		4,583,175,000		4,274,120,000

Source: (1) Mineral Statistics, Ministry of Natural Resources
(2) MNR/EMR – Estimate
(3) Projection Only: Not based on industry estimates. March 1982

Tables 3 and 4 show selected examples of Canadian imports and exports of industrial minerals and industrial mineral based products. These may suggest business opportunities to interested suppliers of minerals.

The number of industrial rocks and minerals found in Ontario is impressive. Many not now produced commercially have been produced in the past and may well be produced again as economic conditions permit. Some minerals that may represent an opportunity for future development are listed below.

refractory clays and ***kaolin*** in the Moose River Basin

potassic feldspar that occurs widely in pegmatites throughout the eastern and northeastern regions of Ontario

fluorspar

crystalline limestones of the Algonquin region

graphite

kyanite from the Sudbury and Mattawa areas

lithium pegmatites of the northern and northwestern regions

magnesite, of which there are several large deposits near Timmins.

a whole host of colourful ***marbles*** in the eastern and Algonquin regions

muscovite and ***phlogopite micas*** occurring in mica schists as well as in pegmatites in areas of Grenville age rocks

phosphates identified in carbonatite complexes of northern Ontario and in the Grenville crystalline limestones of eastern Ontario where they were formerly mined.

silica from sandstones of eastern Ontario, silica sands of north-central Ontario

tremolite and ***actinolite*** investigated as mineral fillers and extenders

vermiculite associated with ultrabasic rocks of the carbonatite complexes in north-central Ontario

attractive stones of sedimentary, igneous and metamorphic origin throughout the Province that are suitable for many building purposes

TABLE 2. ONTARIO MINERAL PRODUCTION, SELECTED YEARS, 1950 (ACTUAL), 1981 (ACTUAL) AND 1982 (ESTIMATED)

		1950(1)		1981(1)		1982(2)	
	UNIT	QUANTITY	VALUE $	QUANTITY	VALUE $	QUANTITY	VALUE $
Non-metals							
Arsenic	tonne	–	16,220	–	–	–	–
Asbestos	tonne	9,590	1,493,039	–	–	–	–
Barite	tonne	–	–	5,000	1,100,000	–	1,000,000
Feldspar	tonne	5,224	49,619	960	18,000	–	–
Fluorspar	tonne	7,816	262,643	–	–	–	–
Gemstones	kg	–	–	50,000	54,000	–	65,000
Graphite	tonne	–	390,815	–	–	–	–
Gypsum	tonne	180,778	875,217	649,546	5,477,033	506,000	4,506,000
Mica-amber	kg	441,336	28,299	–	–	–	–
-muscovite	kg	85,630	128,161	–	–	–	–
Nepheline syenite	tonne	–	842,886	587,565	17,531,692	518,000	17,338,000
Peat	tonne	5,091	206,625	9,205	1,201,993	4,000	525,000
Phosphate	tonne	–	712	–	–	–	–
Quartz	tonne	1,257,858	1,027,791	427,189	9,787,492	–	7,805,000
Salt	tonne	631,780	4,639,867	4,968,503	80,888,513	5,479,000	97,701,000
Soapstone, talc, pyrophyllite	tonne	13,844	182,048	21,901	3,079,471	–	3,429,000
Sulphur in smelter gas	tonne	–	131,540	417,772	16,735,943	214,000	12,673,000
Sulphur, elemental	tonne	–	–	29,065	1,842,410	22,000	1,870,000
Total, non-metals			10,275,482	7,116,756	137,716,547	6,743,000	146,912,000
Structural materials							
Clay products	tonne	–	9,323,263	–	66,660,263	–	50,946,000
Cement	tonne	843,389	10,953,896	3,787,237	205,062,550	2,800,000	215,208,000
Lime	tonne	518,341	6,030,228	1,836,168	94,699,716	1,463,000	99,484,000
Sand and gravel	tonne	27,462,358	15,553,186	70,191,371	134,335,610	60,000,000(3)	125,000,000(3)
Stone	tonne	5,184,465	7,843,124	37,573,175	126,796,566	32,000,000(3)	128,000,000(3)
Total, structural materials			49,703,697		627,554,705		618,638,000
Total, industrial minerals			**59,979,179**		**765,271,252**		**765,550,000**
Total, metals			302,540,548		3,319,635,000		2,307,710,000
Total, fuels			9,783,447		45,668,000		51,959,000
Total, other minerals			–		–		31,887,000
Grand total for Ontario			372,303,174		4,130,574,252		3,157,106,000

Source: (1) Mineral Statistics, Ministry of Natural Resources
(2) MNR/EMR – Estimate
(3) Projection Only: Not based on industry estimates. February 16, 1983

Those that appear to show near-term development potential are silica, calcium carbonate, potassic feldspar, muscovite mica, phosphate rock and certain building stones. Other minerals may well have possibilities; for instance, magnesite and vermiculite. In the past year, researchers at the University of Toronto, with the help of a grant from the Mineral Resources Group of the Ontario Ministry of Natural Resources, have developed promising methods of producing low-iron magnesia. Associated with the Cargill phosphate-carbonatite is a large band of vermiculite derived from adjacent pyroxenite. The measure of success achieved will depend on the perseverance of the developer, market conditions, and the return on investment.

GOVERNMENT PROGRAMS

Ontario has a number of complementary programs designed to assist investors in finding and developing industrial mineral deposits. First, there is the work of the Ontario Geological Survey, whose identification of mineral resources of all kinds has been so valuable. One really cannot name any current non-metallic industrial mineral production or resource target that was not found as a result of the work by either provincial or federal government geologists. In the past few years, reports dealing with industrial minerals of Algonquin region, Sudbury-North Bay, northwestern Ontario, marbles of eastern Ontario, feldspathic glacial sands near Timmins, and others, have been made available. Other reports dealing with graphite, talc and silica in eastern Ontario, have been prepared by regional staff geologists.

In the realm of exploration, there is the Ontario Mineral Exploration Program which will assist companies and individuals with up to 25% of approved mineral investigation costs. While this program has been utilized mostly by seekers of precious metals, a few companies have recognized its use to them for industrial mineral exploration.

In late 1981 the Ministry approved a $7.7 million Small Rural Mineral Development Program for industrial minerals.

TABLE 3. SELECTED MINERAL AND MINERAL PRODUCT IMPORTS TO CANADA, 1982

ITEM	TONNES	$000
Total Imports from all countries-		8,695,276
– Crude Materials, inedible		8,695,276
– Fabricated Materials, inedible		11,793,613
– End Products, inedible		41,186,974
– Total Imports		67,629,697
Oyster shells, crushed or ground	18,094	1,175
Bentonite	238,081	12,347
China Clay, ground or unground	205,955	22,254
Fireclay, ground or unground	33,575	2,782
Clays, ground or unground, N.E.S.	105,859	7,803
Diatomaceous Earth, crude or ground	23,130	5,074
Pumice and Lava, crude or ground	18,182	889
Abrasives, natural, N.E.S.	12,322	1,906
Silica Sand	788,764	15,595
Silica, including silicagel	8,644	13,253
Granite, rough	22,033	4,095
Granite, shaped or dressed	–	14,831
Marble, rough	7,058	3,282
Marble, shaped or dressed	–	1,709
Barytes, natural	23,456	2,153
Fluorspar	126,594	22,176
Gypsum	93,843	3,069
Phosphate Rock	2,511,708	103,207
Salt and Brine	1,526,852	21,887
Talc or Soapstone	34,521	5,616
Vermiculite, crude	24,077	3,413
Strontium, Barium, Magnesium oxides	19,099	6,060
Sodium Carbonate (incl. salt, soda)	121,958	14,960
Barium Carbonate	2,500	824
Whiting	12,033	3,235
Clays and Earths, activated	6,685	9,714
Roofing granules	57,024	2,817
Ceramic Tiles, floor and wall	–	43,709
Firebrick and similar	–	75,383
Sheet Glass	–	81,707
Fibrous glass, basic products	–	13,379
Artificial abrasives, crude grains N.E.S.	14,238	17,519
Plaster of Paris, wall plaster	18,925	3,724
Mica, block, sheets, ground	2,860	842
Mica, fabricated, N.E.S.	–	2,766
Drilling mud	11,413	3,331
Mineral Wool, except glass wool	4,717	7,251
Tableware, ceramic	–	92,679
Tumbler and Stemware, glass or crystal	–	22,479
Tableware, glass, N.E.S.	–	34,977
Cooking utensils, glass and Parts	–	10,456
Art and Decorative Ware, china	–	20,311
Art and Decorative Ware, glass	–	8,572
Bottles for alcoholic beverages, glass	–	14,169
Shipping Containers, glass, parts, N.E.S.	–	17,857

NES – Not Elsewhere Specified
Source: Statistics Canada, May 20, 1983

TABLE 4. CANADA, SELECTED MINERAL AND MINERAL PRODUCT EXPORTS, 1982

ITEM	TONNES	$000
Total Exports from all countries		
– Fabricated Materials, inedible		27,899,033
– End Products, inedible		28,552,693
– Crude Materials, inedible		14,775,724
– Total Exports (domestic)		81,713,380
Nepheline Syenite	414,785	15,765
Salt and Brine	1,718,102	22,001
Sulphur, crude or refined	–	719,829
Non-Metallic Minerals, crude, N.E.S.	–	111,560
Sodium Sulphate	367,930	35,501
Natural Stone, basic products	–	19,603
Firebrick and similar shapes	–	31,510
Refractories, N.E.S.	–	13,308
Glass, basic products, N.E.S.	–	32,879
Portland Cement	1,464,650	79,523
Silicon Carbide, crude and grains	–	30,898
Gypsum, Lath, Wallboard and basic products	–	13,920
Gypsum	4,775,755	28,716
Lime, quick and hydrated	–	17,944
Shipping Containers, glass and Parts	–	62,127

NES – Not Elsewhere Specified
Source: Statistics Canada, May 20, 1983

To date grants of $3.37 million have been offered to five companies to expand their industrial mineral operations or in the case of one company to revitalize a pink granite quarry.

OUTLOOK

Certainly the objective of the Ontario Government is to encourage self-sufficiency as much as possible in industrial minerals for our manufacturers. However the local markets are often not large enough to sustain an investment in plant so that export markets must also be sought. Let us hope that the low levels of industrial activity of the past two years are nearly over and that we can look to relatively stable demand in years to come. An enormous amount of scrambling has been going on everywhere and it appears that proximity to markets and low production costs will be the key to success for years to come.

Structural Industrial Minerals in Ontario*

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ABSTRACT

Ontario has available a full range of structural industrial minerals, including sand and gravel; stone for use in the manufacture of crushed stone, lime and cement; clay; shale; and gypsum. By far the greatest percentage of the deposits and operations are in the Paleozoic and Quaternary age materials of southern Ontario close to the markets.

In 1981 structural industrial minerals accounted for 84% of the Ontario industrial mineral production. These minerals ranged in value from $2.00 per tonne for sand and gravel to approximately $60.00 per tonne for lime and cement.

The 1981 production and values of the major structural industrial minerals are as follows (Minnes 1982):

1. Sand and gravel production was in excess of 75 million tonnes valued at $150 million, with over 2000 licenced properties in southern Ontario.
2. Crushed stone production was 35 million tonnes valued at $122 million; much of this production was concentrated along the Niagara Escarpment.
3. Cement production from seven plants producing from the Paleozoic rocks of southern Ontario was 3.6 million tonnes valued at over $200 million.
4. Lime production from nine plants, mainly producing from the Detroit River Group of Devonian age, was over 1.7 million tonnes valued at $103.5 million.
5. Gypsum production from three mines in the Salina Formation of Silurian age was 688,000 tonnes valued at $5,353,000, and was mainly used for the manufacture of wallboard.
6. Clay and shale materials production was 384 million brick equivalents valued at $59.5 million. Over half of this production was bricks produced in nine plants and the remainder was structural clay tile, drain tile etc. produced in 10 other plants.

INTRODUCTION

Ontario has abundant structural industrial minerals which include sand and gravel, crushed stone, clay, shale, gypsum and limestone and dolostone used in the manufacture of metallurgical stone, lime and cement. These materials and the products made from them are largely used in construction applications. Often these materials are used as they are found (pit-run sand and gravel), with some processing (crushing and screening to produce crushed and specification aggregate), or may be chemically or physically altered (cement, lime, gypsum, clay products). Transport cost, especially of the least valuable products such as sand and gravel, is normally greater than half of the delivered price of the material. The majority of these deposits and operations are in the Paleozoic and Quaternary materials of southern Ontario, close to the large markets of urbanized southern Ontario and the northeastern United States. The rocks of Paleozoic age include sandstone, limestone, dolostone and shale, as well as deposits of gypsum.

The Quaternary Period witnessed numerous advances of ice sheets that scoured, mixed, sorted, moved and redeposited the weathered detrital materials, forming such features as clay plains, eskers, kames, moraines and outwash plains. These deposits form the present-day sources of sand and gravel and of clay for structural uses.

In 1981, structural industrial minerals, including gypsum, accounted for 84% of the Ontario industrial mineral production by value. The range in value of the structural industrial minerals is great, ranging in 1981 from $2.00 per tonne for sand and gravel to approximately $60.00 per tonne for lime and cement.

Sand and Gravel

Sand and gravel is generally abundant in Ontario (Figure 1); however, it is a fixed-location resource which may occur in large quantities or may be scarce depending on the glacial processes that were active in the area over the past 100,000 years. Parts of Ontario have abundant natural aggregate deposits, such as the Saugeen Highlands, the Grand River glacial spillway (i.e. valley train) deposits, and the Thessalon area of northern Ontario. However, there are several areas where natural aggregate is scarce, as in the Windsor and Sarnia areas in southwestern Ontario.

The major sources of sand and gravel are generally found in the large outwash and deltaic deposits which formed during the melting back of the glacial ice masses. Several of these deposits extend for tens of kilometres.

One extensive deposit associated with the melting of

*This paper is published with the approval of E.G. Pye, Director, Ontario Geological Survey.

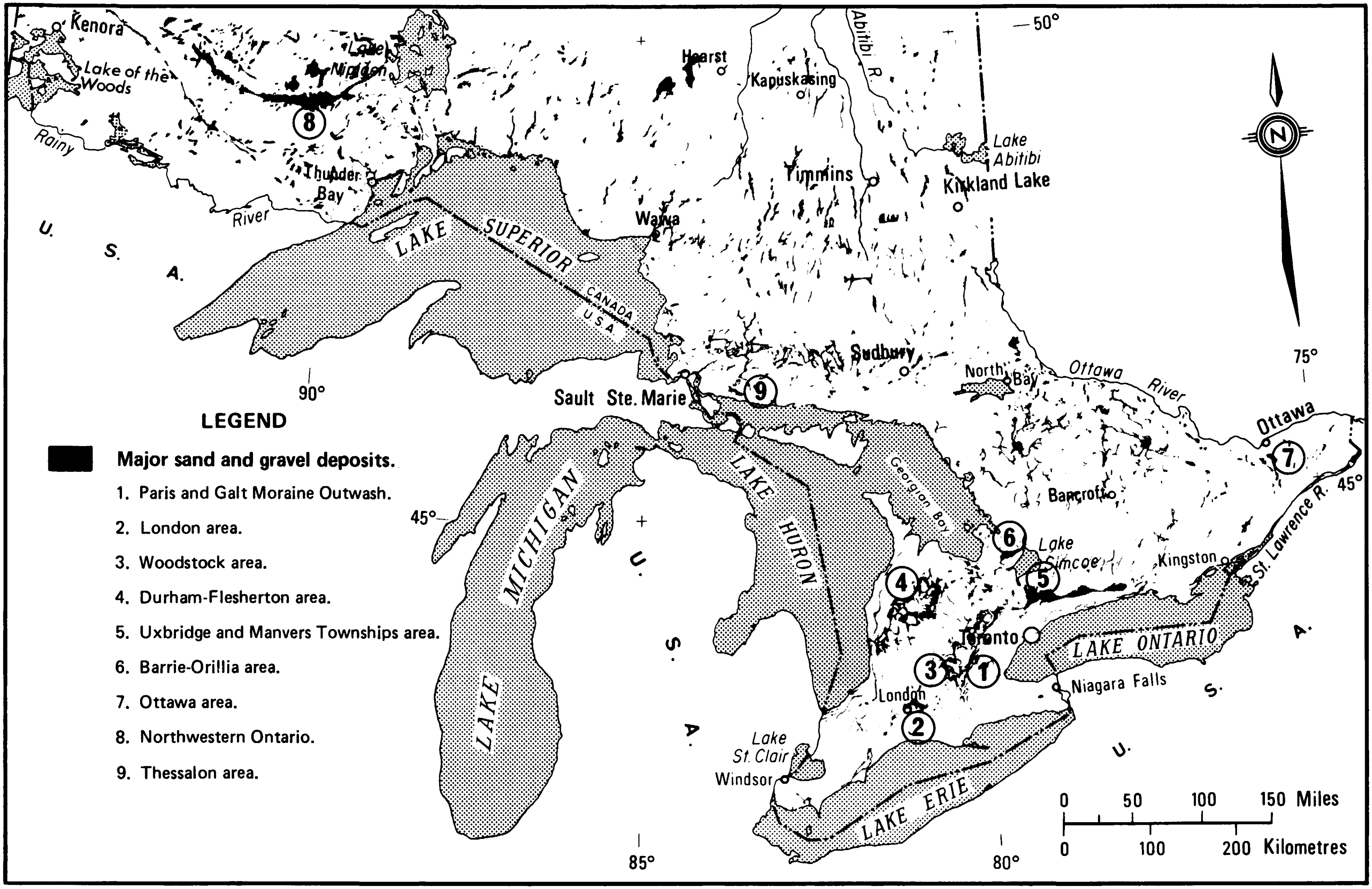

Figure 1. *Major sand and gravel deposits (south of 50° Latitude).*

the ice masses that deposited the Paris and Galt Moraines runs from the Mono Township – Town of Caledon area north of Toronto to the Brantford area. Throughout its length this deposit is actively mined. Through much of its extent, the material has a suitable grain size for processing into aggregate. There is generally a varying mixture of sedimentary, igneous, and metamorphic pebbles and sands in the deposits, with dolostone and limestone fragments predominating in this area. The mix of constituent materials is normally acceptable for use in concrete and asphalt applications. In some areas, especially near the Niagara Escarpment, these deposits contain shale and siltstone which must be removed by beneficiation to enable the material to be used for higher specification products.

Other major sand and gravel deposits occur in the London area in outwash and deltaic deposits; in the Woodstock area in outwash deposits (this area has a high chert content requiring beneficiation if used for concrete); in the Durham-Flesherton area (Saugeen Highlands) which is one of the largest remaining resource areas in the Province, consisting of outwash, esker and kame deposits; in the Uxbridge and Manvers Townships area consisting of ice-contact and outwash deposits; in the Barrie-Orillia area; in the Ottawa area consisting of modified morainic deposits; in the northwestern part of Ontario in the large morainic and outwash deposits; and along the north shore of Lake Huron, especially in the vicinity of Thessalon (Figure 1). Throughout Ontario other similarly good deposits exist.

Sand and gravel aggregate production is concentrated near the demand centres such as Ottawa, Kingston, Kitchener, Guelph, Brantford, London, Sudbury, Thunder Bay, Timmins and Sault Ste. Marie; by far the greatest concentration is in the Toronto-centred area (approximately 90 km radius around Toronto). The two major supply areas for the Toronto area are in the Town of Caledon and the Township of Uxbridge located to the northwest and northeast of Toronto, respectively.

Production of sand and gravel in 1981 exceeded 75 million tonnes with a value of over $150 million dollars. In those areas designated under *The Pits and Quarries Control Act, 1971* (in southern Ontario and around Sudbury and Sault Ste. Marie in northern Ontario) there are well over 2000 licenced pits. Numerous other pits are found in non-designated areas. Sand and gravel produced in 1981 was used mainly for road construction and lesser amounts were used for concrete, asphalt, railroad ballast, mortar sand, backfill for mines, fill, and other uses.

While there are ample resources of sand and gravel in Ontario, problems are developing in opening new extraction operations due to zoning and other restrictions. This has prompted the publication of "Aggregate Resources Inventory Reports" which will be discussed later.

Crushed Stone

Ontario has plentiful stone deposits suitable for making aggregate. The Ontario production of crushed stone in 1981 was 35 million tonnes valued at $122 million.

In southern Ontario the dolostones and limestones of Paleozoic age are located close to demand centres, and the vast majority of the crushed stone production comes from these formations in south-central and southwestern Ontario (Figure 2). The major production is from the dolostone of the Lockport-Amabel Formations, which is the caprock of the Niagara Escarpment. Major production sites on the escarpment are located between Niagara Falls and Halton Hills. The Middle Devonian limestone which extends from Fort Erie through the Woodstock and London area to Lake Huron is also of major importance; several large quarries are situated in these limestones in the Niagara Peninsula and in the Woodstock-Ingersoll area.

The Ordovician Simcoe Group limestones (especially the Bobcaygeon Formation and Gull River Formation) located between Lake Simcoe and Kingston are another important source of crushed stone. Production is also located in other Paleozoic formations; one of these is the Oxford Formation of the Beekmantown Group which is quarried in the Ottawa area.

The Precambrian bedrock areas of Ontario include rock-types such as basalt, anorthosite, granite, and granite-gneiss which in general are suitable for the production of aggregate, but there are few quarries opened in these deposits. An exception worth mentioning is the former Marmoraton iron mine, located in Marmora, where basalt (trap rock) is extracted to produce a specialty hot-laid surface course asphalt aggregate (H.L. 1 as defined by the Ontario Ministry of Transportation and Communications). Recently, blast furnace and steel slag have also been used for some projects requiring H.L. 1 aggregate. This has been supplied from slag derived from the Hamilton and Sault Ste. Marie steel mills.

The quarries producing crushed stone are generally large; at least eight have an annual production of over 1 million tonnes (excluding producers for lime and cement manufacture). In total there are a couple of hundred operating quarries in Ontario.

A full range of products from armour stone to manufactured sand and filler grade materials is also produced. Several operations also produce metallurgical flux stone in various sizes for use in the steel industry. Many quarries produce crushed stone as well as other products, often with their main product being, for example, cement, lime or metallurgical products (i.e flux or dead burned dolostone).

Cement

The cement industry in Ontario is highly developed with modern efficient plants. In 1950 cement production was 840,000 tonnes valued at $11 million. By 1981 the cement production in Ontario was 3.6 million tonnes valued at over $200 million.

The rated capacity of all plants in Ontario is 6,500,000 tonnes per year, currently operating at a utilization factor of 65%. There are five cement companies producing from limestone feed material in seven plants (Table 1). A sixth

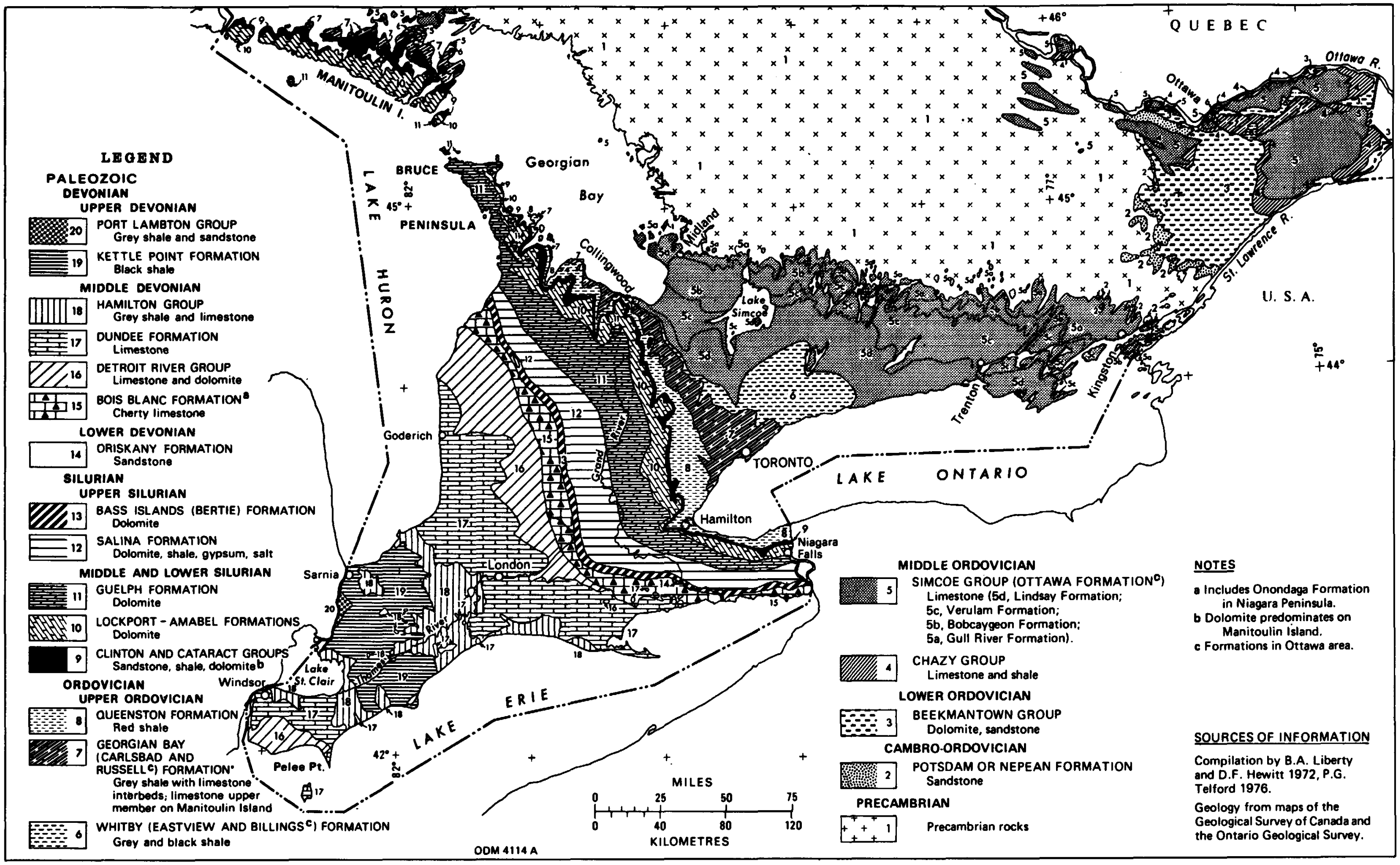

Figure 2. Bedrock geology of southern Ontario.

TABLE 1. ONTARIO CEMENT QUARRIES AND PLANTS

Company	Plant Location	Quarry Location	Process	Capacity tonnes/yr.	Sources of raw materials for mix					
					Limestone	Shale	Clay	Sand	Iron Oxide	Gypsum
Canada Cement Lafarge Ltd.	Bath	Bath	dry	1,000,000	Verulam Formation	—	local glacial till	Kingston area—Potsdam Sandstone	steel mill scale	Little Narrows, Nova Scotia
Canada Cement Lafarge Ltd.	Woodstock	Woodstock	wet	540,000	Detroit R. Group	—	local glacial clay & till	Hagers-ville—sand	Hamilton—steel mill scale	Little Narrows, Nova Scotia
Federal White Cement	Woodstock	Purchase Stone from Beachville	dry	120,000	Detroit R. Group	—	alumina slag	Midland silica	—	Newfoundland
Lake Ontario Cement Ltd.	Picton	Picton	dry	1,515,000	Lindsay Formation Verulam Formation	—	local glacial clay & till	Kingston area—sandstone; S. of Napanee—sand	Hamilton—flue dust	Little Narrows, Nova Scotia
St. Lawrence Cement Company	Clarkson	Ogden Point, Beachville	2 wet 1 dry	1,680,000	Lindsay Formation & Detroit R. Group	Georgian Bay Formation	—	—	Hamilton—steel mill scale	Nova Scotia
St. Marys Cement Limited	St. Marys	St. Marys	1 dry	935,000	Dundee Formation & Detroit R. Group	—	local glacial clay & till	—	Hamilton—steel mill scale	Little Narrows, Nova Scotia
St. Marys Cement Limited	Bowmanville	Bowmanville	wet	680,000	Lindsay Formation	Georgian Bay Formation	—	Midland—silica	Nephton—magnetite	Little Narrows, Nova Scotia
Standard Slag Cement Co.	Fruitland	—	—	150,000	blastfurnace—slag		—	—	—	—

company produces hydraulic slag cement from granulated blast furnace slag. The existing plants are located at Bath, Picton, Bowmanville, Clarkson, Woodstock (Two), St. Marys and Fruitland. These cement plants produce for the Ontario market with considerable sales to the northeastern United States especially New York and Michigan.

The raw materials used in the seven portland cement plants operating in Ontario are limestone, clay or shale, sand, iron oxide and gypsum with minor other constituents as required.

The Ontario cement industry is well situated (Figure 3) both in location to major demand areas and seaway transport to take advantage of the export potential to other provinces and the United States. One company in particular, Federal White Cement at Woodstock ships their product all over North America and the Caribbean on account of the specialized nature of their product.

Cement is used in numerous construction and building product applications such as buildings, bridges, roads, concrete block and brick, and exposed aggregate concrete panels. The greatest demand for cement comes from the ready-mixed concrete companies, who consume about five times as much cement as the next largest user, the concrete product manufacturers. Other operations using cement include highway contractors and building material dealers (E. Matten, Ontario Ministry of Natural Resources, personal communication, 1982).

The Ontario cement industry is vertically integrated with cement companies owning ready-mix, concrete product, paving and construction companies. In the large urban area of Toronto, more than half of the ready-mix business is done by cement company subsidiaries.

Some of the major products of the concrete product industry are structural beams, concrete blocks, and concrete bricks. The concrete bricks have increased in use during the past several years because of their frequent price advantage over clay bricks and the acceptance by architects and consumers especially for the antique bricks made from concrete.

The limestones used for manufacturing cement are from the Verulam Formation and the Lindsay Formation (both of the Simcoe Group, of Ordovician age) in eastern Ontario, and the Detroit River Group and Dundee Formation of Devonian age in southwestern Ontario. The Verulam and Lindsay Formations are especially suitable for the production of cement because of their high calcium values.

Canada Cement Lafarge Limited's operation at Bath, situated 25 km west of Kingston uses the Verulam Formation limestone which is a medium brown and grey, finely

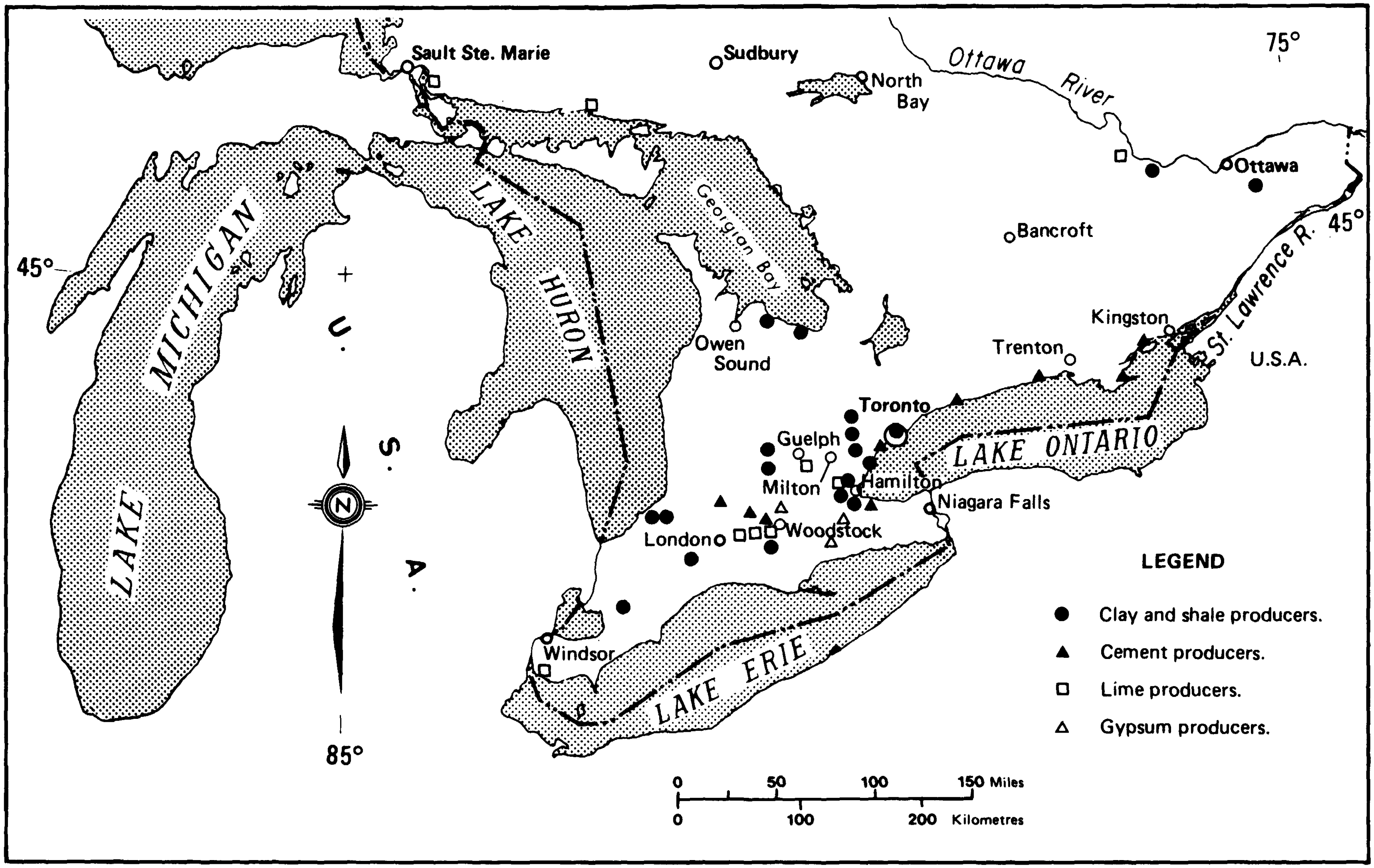

Figure 3. Major non-aggregate structural industrial mineral operations.

crystalline limestone uniformly bedded with pale to medium brown and grey bioclastic limestone and grey and brown shale (Carson 1981).

The Lindsay Formation, the youngest of the Simcoe Group, is divided into two members. The lower member is approximately 30 m thick and is a medium grey and bluish grey, finely to medium crystalline limestone in beds 3-10 cm thick with thin shaly seams and partings. The upper member is a pale to medium grey, sublithographic to finely crystalline shaly limestone (Carson 1981). The Lake Ontario Cement quarry at Picton, situated 60 km west of Kingston contains a thickness of 13 to 16 m of Lindsay Formation limestone and 13 m of Verulam Formation limestone (Hewitt and Vos 1972). The St. Lawrence Cement Company quarries the Lindsay Formation at Ogden Point, situated 30 km west of Trenton, in two lifts of 15 m each. The rock has a silica content of 11.6-13.52% and a lime content of 42.4-44.5% (Hewitt 1960). The limestone is shipped by boat to the company's plant at Clarkson to the west of Toronto. The company also purchases Detroit River Group limestone from the Woodstock area for making some specialty cement. The St. Marys Cement Company's Bowmanville quarry, situated 60 km east of Toronto operates in the Lindsay Formation; the overlying Georgian Bay Formation and glacial till are stripped away.

The Detroit River Group and overlying Dundee Formation occur in a band running from Fort Erie, situated 25 km south of Niagara Falls, through the Woodstock and London area to Lake Huron. These rocks also outcrop in the Windsor area.

The Detroit River Group includes the Lucas and Amherstburg Formations and is the basic material for the cement and high-calcium lime industry in the Woodstock to St. Marys area, some 30 km to the northwest of Woodstock. In this area the Detroit River Group consists of limestone and north of St. Marys it consists of dolostone. The facies in the Beachville area, situated 10 km west of Woodstock, consists of over 30 m of high purity calcium limestone, medium-brownish grey to tan in colour, medium crystalline to finely crystalline in texture with medium to thick beds. This rock has less than 1% combined silica, iron and alumina and less than 1-1.5% magnesia (Hewitt 1960). The Woodstock quarry of Canada Cement Lafarge Limited intersects 30 m of this rock which is overlain by up to 21-24 m of clay, till and sand overburden. The clay and till are used in the manufacture of cement.

The Dundee Formation is a medium brownish grey to medium light grey, medium crystalline to finely crystalline limestone with thick to medium beds with some shaly partings in the St. Marys area. The St. Marys Cement Company quarry in this area exposes 15 m of this rock (Hewitt 1960). At this quarry the high calcium Detroit River Group limestone is also mined.

The Standard Slag Cement Company located at Fruitland southeast of Hamilton produces a hydraulic slag cement from granulated blast furnace slag obtained from the Hamilton steel mills.

Lime

Lime was one of the original agricultural soil conditioners and building materials used; however today only about 5% of the lime produced in Ontario is used for agricultural or construction uses. The major uses today are found in iron and steel processing, pulp processing, glass manufacture, fertilizer production, uranium plants, water and sewage treatment, non-ferrous smelters, etc. Calcitic lime is also used by the chemical industry in manufacture of calcium carbide and soda ash. Ontario production of lime is from nine plants (see Figure 3) (one of which produces agricultural lime as a by-product). Most of the production is from the Devonian Detroit River Group limestone and the Silurian Guelph Formation dolostones. These formations consist of high purity stone very desirable for the production of lime. Production in 1981 was over 1.7 million tonnes valued at $103.5 million. In 1979 Ontario produced over 67% of the total Canadian lime output (Energy, Mines and Resources Canada 1980).

There are four operations producing dolomitic lime and/or dolostone flux stone, two of which are for use in associated, captive processes.

The Steetley Lime Division of Steetley Industries Limited at Dundas, near Hamilton operates three rotary kilns with feed material from the Guelph Formation dolostone and the upper part of the Eramosa Member (Lockport-Amabel Formations). This operation is ideally situated to supply the Hamilton steel mills.

Another operation is the Guelph Quarry of Guelph Dolime which mines a 12 m section of high purity Guelph dolostone. This is an older operation which dates back to the late 1800s and uses vertical kilns to process the lime. Part of this production goes to the Dofasco steel smelters (the parent company).

Chromasco Limited at Haley, situated 80 km northwest of Ottawa also produces a dolomitic lime from Precambrian marble. This is supplied for a captive process where the lime is used for the manufacture of magnesium metal and where agricultural lime is derived as a by-product.

Algoma Steel Corporation Limited also produces dolomitic lime, at Sault Ste. Marie on demand for their steel-making process from Amabel Formation dolostone quarried at the west end of Manitoulin Island. This lime is used in their own iron and steel smelters at Sault Ste. Marie.

Numerous other dolomitic lime operations existed in the past, however the decreasing demand for flux in the steel industry and dwindling sales of mortar mix have taken their toll. Previously, operations existed at Hespeler, Rockwood, Elora, Campbellville and Puslinch all situated within 25 km of Guelph in the south-central part of Ontario.

There are four operations producing high calcium lime from the Detroit River Group. Three of these are located in the Beachville area near Woodstock. These operations are Domtar Chemicals, Beachvilime Limited and the Steel Company of Canada Limited (Chemical Lime Works). The fourth company is Allied Chemical Canada Limited at Amherstburg, south of Windsor which produces lime for captive in-house use in the production of soda ash (sodium carbonate) by the Solvay process.

Two other operations in northern Ontario, the Algoma Steel Corporation Limited at Sault Ste. Marie and Reiss Lime Company of Canada Limited, at Blind River 60 km east of Sault Ste. Marie use imported stone from the Detroit River Group in Michigan to produce high calcium lime. In 1958 there were 16 lime producers, in 1962, 14 producers, by 1970 there were only 12, and today only 9 remain (Hewitt 1960; 1964a; Hewitt and Vos 1972).

Gypsum

Gypsum mining began in Ontario in 1822 along the banks of the Grand River near Paris, located 25 km east of Woodstock. The gypsum was originally mined for use in a ground form as fertilizer (land plaster) and as a calcined product in the form of "plaster of paris".

There are presently three mines (see Figure 3) producing from the Silurian age Salina Formation. In 1981 production was 688,000 tonnes valued at $5,353,000 for the raw product (Minnes 1982).

The Domtar Construction Division of Domtar Incorporated operates a mine and two wallboard plants at Caledonia, 15 km southwest of Hamilton. The No. 1 mine was continuously operated from 1905 to 1953 and the No. 2 mine has been operated since 1952. The No. 2 mine, with operations at a depth of 25 m is reached by an inclined ramp. The gypsum bed being mined is 2.5 m thick, overlain by 5 m of dolostone and up to 20 m of unconsolidated material (Guillet 1964). Mining is by room and pillar method with mobile equipment.

The Salina Formation gypsum mined at this site is fine grained, massive and white light brown or grey in colour. Interlayering of dolostone and shale is common and individual gypsum layers range from 5-10 cm thick. Domtar is the largest producer of wallboard in Ontario and its new No. 2 wallboard and plaster plant is highly automated.

The second mine and plant is that of the Canadian Gypsum Company Limited located near Hagersville, 15 km to the southwest of Caledonia. This operation commenced in 1931 and mines a 1 m thick bed at a depth of 20 to 40 m underground. Mine access is by an inclined ramp. The room and pillar mining method is used and mobile loaders and shuttle cars muck out the ore. The underground workings cover an area of 8 km^2.

The gypsum is a white, fine grained, relatively pure material with few dolomitic or shale laminae. There are two automated wallboard production lines.

The third gypsum mine is that of Westroc Industries Limited near Drumbo, situated 10 km to the northeast of Woodstock, which opened in 1978. The shaft is 140 m deep with a 3.8 m inside diameter. This shaft was drilled using a 4.5 m diameter bit. The bed being mined is at the 116 m level and has a thickness of 1.7 m with an 88% purity (Guillet 1983). The room and pillar mining method is employed with trackless equipment. The lump gypsum is transported to the company's Mississauga wallboard plant for calcining and the production of wallboard.

Over 80% of the gypsum produced in Ontario is for the manufacture of wallboard and the remainder is used as ground gypsum in cement, plaster of paris, etc. Extensive undeveloped resources of gypsum occur in northern Ontario in the Moose River Basin.

Clay and Shale

The clay and shale materials industry is extensive in Ontario; the 1981 production was 384 million brick equivalents valued at $59.5 million. Much of this production was composed of clay brick produced in nine plants with the remainder, including clay tile and drainage tile, produced in 10 other plants (see Figure 3). There are numerous clay and shale deposits in Ontario suitable for structural products and lightweight aggregate manufacture.

Ontario has widespread clay resources related to the last glaciation. Some till deposits in southwestern Ontario are also acceptable for the production of tile. In the lower Ottawa and St. Lawrence Valleys lacustrine-marine clay is widespread. Significant deposits of kaolin occur in Mesozoic strata of the southern Moose River Basin.

There was a great profusion of operations producing structural products from clay in the late 1800s and early part of the 1900s. However, these have all but disappeared to be replaced by large, shale-based operations. There are several important shale formations used by the industry.

Shale of the Georgian Bay Formation (formerly, the Meaford and Dundas Formations) is moderately soft and blue-grey to green-grey in colour. It underlies the Toronto area as far west as Streetsville, situated 10 km to the west of Toronto and persists beneath the drift along the base of the Niagara Escarpment to Georgian Bay. The Georgian Bay Formation also exists in the Ottawa area.

This shale is the principal raw material used by three brick plants and formerly for an expanded aggregate plant. It burns to a salmon red, dense, hardbody of relatively low absorption.

This rock has hard limy and sandy interlayers which form some 10-20% of exposed sections. The chemical and mineral content is relatively uniform. Lime content is variable from 3-18%, reflecting the percentage of green shale beds, which are harder, more limy and less easily broken down by weathering. Colour and porosity of the fired ware is dependent on the percentage of green shale. Carbonate content increases northward and at Owen Sound causes the shale to burn to a buff porous body. The shale is also used for pottery and artware (Guillet 1977).

Georgian Bay Formation shale is the major raw material for clay bricks made by Domtar Construction Materials at Cooksville, situated 7 km west of Toronto and Toronto Brick Company Limited in the Don Valley of Toronto. The shale has also been used for expanded aggregate by Domtar. This crushed, sintered aggregate product made in a rotary kiln has the trade name of "Haydite". Domtar also made a coated aggregate from Georgian Bay Formation shale (Guillet 1977).

The Queenston Formation shale is the major raw material for 10 brick and tile plants (Guillet 1977). This shale overlies the Georgian Bay Formation and is brick red in colour. It outcrops from Streetsville west to Milton and extends north and south along the lower terraces of the Niagara Escarpment. There is a small outcrop of the Queenston Formation near Ottawa which is used by Domtar Construction Materials for brick manufacture.

This formation is Upper Ordovician in age, and forms the youngest unit of the Ordovician system in Ontario. It is 180 m thick in the Hamilton area, decreasing northward. It is brick red in colour, thin to thick bedded and moderately soft. Thin green bands, parallel to the bedding and sometimes at right angles to it, have been formed by the reducing action of acidic groundwater. Green shale makes up 5-25% of sections (Guillet 1977). The weathered red soil derived from this formation has superior ceramic properties.

Shale of the Middle Devonian Hamilton Group outcrops in the area northwest of London and is used for making tile at Parkhill and Thedford near Lake Huron. It is a soft, smooth and plastic material when wet and burns to a weak red or red brown colour.

The Animikie Formation shale near Thunder Bay, in northern Ontario is a sandy non-calcareous rock containing one-third quartz. It was used in the past but is no longer used for the manufacture of clay products.

The industry uses both periodic batch kiln and continuous tunnel kilns, and most operations have continuous dryers and tunnel kilns. It takes 3.2 tonnes of clay or shale to produce 1000 bricks by methods used in Ontario.

RESOURCE PLANNING FOR STRUCTURAL INDUSTRIAL MINERALS

The urbanization of Ontario has resulted in a major increase in the production of structural industrial minerals such as sand, gravel, clay, shale, gypsum, and stone for use as crushed aggregate or building stone as well as for the production of lime and cement. Although these minerals and associated products are plentiful in Ontario, the potential for extractive development is usually greatest in urban fringe areas where land use competition is extreme. Comprehensive planning and resource management strategies are required to make the best use of available resources. To facilitate this planning, and encourage sequential land use to minimize sterilization of structural industrial mineral resources, detailed inventories of these industrial minerals are vital.

The Aggregate Resources Inventory Program was initiated to produce this information with specific reference to aggregates but also covering other structural industrial minerals. Such reports have been or are being prepared for municipalities designated under *The Pits and Quarries Control Act, 1971* to provide the municipalities and other interested parties with reliable geological information on which they may base their planning decisions.

The preparation of these reports involves the interpretation of published geological data and other data on file with other ministries and agencies, as well as additional detailed fieldwork including sampling, drilling and geophysical techniques as may be necessary.

The Aggregate Resources Inventory Report is composed of three parts. Parts I and II are common to all reports and relate to the inventory methods and the data presentation and interpretation, respectively. Part III contains a written assessment of the surficial and bedrock resources and potential uses, including background information, for the individual report area. Three maps and seven tables providing detail on the resource areas accompany the text.

The first map ("Distribution of Sand and Gravel Deposits") outlines the sand and gravel and clay deposits showing texture, thickness, depositional environment and quality constraints. The second map is derived from the first and is an interpretive map with the deposits classified into primary, secondary and tertiary significance. The primary deposits are further classified as to their relative value as a resource by a deposit number indicating ranking order of the deposit. Secondary deposits contain significant amounts of resource but are not the best areas. The tertiary areas because of low potential and difficulty of extraction are not considered to be important resource areas.

There are two sets of criteria used for the selection of resource areas. The main set includes site-specific criteria, related to the characteristics of individual deposits. These are deposit size (depth and areal extent), aggregate quality, and deposit location and setting. The other set of criteria is based on the evaluation of local resources in relation to the quality, quantity and location of resources in the demand region.

The third map portrays bedrock resources and integrates bedrock geology, bedrock topography, drift thickness and rock quality considerations. The map also displays selected bedrock resource areas at a single level of significance. Selections are based on similar resource selection criteria to those used for unconsolidated deposits. Although, the main emphasis of this map is the aggregate resource potential of the bedrock, delineation and selection are also made for areas of high potential for the manufacture of lime, cement, structural clay products, building stone and gypsum.

At the present time 67 Aggregate Resources Inventory Reports are available to the public and another 40 reports are in various stages of completion. Numerous other areas still require reports in southern Ontario, let alone the considerable workload remaining in northern Ontario. These reports have assisted our Ministry in coordinating our structural industrial mineral planning effort to achieve appropriate mineral aggregate resource planning in municipal official plans and zoning by-laws. The same reports have been used by municipalities in dozens of official plans and by-laws and are recognized as an invaluable component of the resource management and planning process. Consultants and aggregate producers similarly utilize these reports for locating potential future structural industrial mineral deposits.

APPENDIX 1 – GEOLOGY OF BEDROCK SUITABLE FOR CRUSHED STONE PRODUCTS (see Figure 2)

Bass Islands Formation (Upper Silurian)

(Includes the Bertie Formation of the Niagara Peninsula) Composition: Medium- to massive-bedded, aphanitic, brown dolostone with shaly partings. Thickness: 35 to 60 feet (11 to 18 m) near Hagersville. Uses: Quarried for crushed stone on the Niagara Peninsula at Fort Erie, Cayuga, Hagersville, and Dunnville. Los Angeles Abrasion Test: 17-35% loss; Absorption: 1.4%. Shaly parts are unsuitable for aggregate due to high soundness losses.

Bobcaygeon Formation (Middle Ordovician)

Composition: Compact, homogeneous, medium- to thin-bedded, fine-grained limestone with some argillaceous and shaly partings. Thickness: The lower unit is 40 to 72 feet (12 to 22 m) thick in the east and the remainder of the formation is 40 feet (12 m). Uses: Quarried at Kirkfield and Marysville for crushed stone. The Bobcaygeon Formation has consistently acceptable quality for granular base course materials and concrete.

Bois Blanc Formation (Lower-Middle Devonian)

Composition: Brownish grey, medium-crystalline, medium- to thin-bedded, cherty limestone, commonly fossiliferous. Limestone may be silty or sandy in places. Thickness: 9 to 200 feet (3 to 61 m). Uses: Quarried at Hagersville, Cayuga, and Port Colborne for crushed stone. High chert content makes much of the material unsuitable for concrete aggregate. Los Angeles Abrasion Test: 14-28% loss; Soundness Test: 4-10% loss; Absorption: 0.7-2.0%.

Dundee Formation (Middle Devonian)

Composition: Fine- to medium-crystalline, brownish grey, medium- to thick-bedded, dolomitic limestone with shaly partings, sandy layers, and chert in some areas. Thickness: 60 to 160 feet (18 to 49 m). Uses: Quarried near Port Dover and Pelee Island for crushed stone. Used at St. Marys for portland cement. Los Angeles Abrasion Test: 22-32% loss; Absorption: 0-4%.

Gull River Formation (Middle Ordovician)

Composition: Member A is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone with a maximum thickness of 60 feet (18 m). Members B and C are dense, aphanitic limestones with argillaceous dolostone interbeds. Uses: Quarried at Kirkfield and Uhthoff for crushed stone. The product is generally fresh and compact with good cubic-shaped factor, low clay content, low absorption, and low soundness losses. Smooth particle surfaces may cause adhesion problems for asphalt. There is some alkali reactivity in a few of the layers.

Lockport and Amabel Formations (Middle Silurian)

Composition: Amabel Formation (Waterdown to the Bruce Peninsula) is massive, fine-crystalline dolostone, with reef facies dolostone near Georgetown. Lockport Formation (lateral facies equivalent to the Amabel Formation from Waterdown to Niagara Falls) is thin- to massive-bedded, fine- to medium-grained dolostone. Thickness: Amabel Formation, maximum observed thickness of 84 feet (26 m). Lockport Formation, up to 130 feet (40 m). Uses: The Lockport and Amabel Formations have been used to produce lime, crushed stone, concrete aggregate and building stone throughout their area of occurrence, and are a resource of provincial significance. Los Angeles Abrasion Test: 21-35% loss; Soundness Test: 2.0% loss; Absorption: 0.4-1.6%.

Onondaga Formation (Middle Devonian)

(Equivalent to the Detroit River Group, with a textural change). Composition: Edgecliff Member is medium-bedded, fine- to medium-grained, dark grey cherty limestone with an estimated thickness of 25 to 30 feet (8 to 9 m). Clarence Member is massive-bedded, dark grey brown, fine-grained, very cherty limestone having an estimated thickness of 26 feet (8 m). Moorehouse Member is medium-bedded, dark grey brown or purplish brown, fine- to coarse-grained, variably cherty limestone with an estimated thickness of 15 to 25 feet (5 to 8 m). Uses: Quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne. High chert content makes much of the material unsuitable for concrete aggregate.

Ottawa Formation (Middle Ordovician)

Composition: Lower Phase (Lowville and Pamela Beds); shale, some sandstone and dolostone. Thickness: 100 feet (30 m). Middle Phase (Hull, Rockland, and Leray Beds): pure, thick-bedded, crystalline limestone. Thickness: 150

feet (46 m) near Ottawa. Upper Phase (Cobourg and Sherman Fall Beds): pure and impure crystalline limestone with few to numerous shaly partings, 450 to 475 feet (137 to 145 m) thick near Ottawa. Uses: The Leray, Rockland, and Hull Beds have been quarried extensively for crushed stone and for building stone. In addition, the Hull Beds are an excellent source of lime for cement production and agricultural uses.

Oxford Formation (Lower Ordovician)

Composition: Medium- to thick-bedded, grey dolostone, with some shaly partings. Thickness: 240 feet (73 m). Uses: Quarried for crushed stone (road and concrete aggregate) at Ottawa, Brockville, and Smiths Falls.

APPENDIX 2 – GEOLOGY OF BEDROCK SUITABLE FOR LIME AND CEMENT PRODUCTION AND OTHER CHEMICAL USES (see Figures 2 and 3)

Detroit River Group (Middle Devonian)

(Equivalent to the Onondaga Formation in the Niagara Peninsula, with a textural change) Composition: Near Beachville, the group consists of medium- to microcrystalline, medium-bedded, high-purity limestone. It grades northwards near St. Marys to soft, evenly bedded, fine-grained dolostone with bituminous laminae. Massive, porous, reef facies material also occurs to the north (Formosa Reef Limestone). Thickness: 100 feet (30 m) at Beachville, 350 feet (107 m) at Clinton. Uses: The most important source of high-purity limestone in Ontario is the Lucas Formation of the Detroit River Group at Beachville. Detroit River limestone produces much of Ontario's lime and cement. The Anderdon Member of the Lucas Formation is quarried at Amherstburg for crushed stone.

Grenville Marble (Precambrian)

Composition: Recrystallized, fine- to coarse-grained white limestone and dolostone, usually of high chemical purity. Uses: Lime production, but also in small amounts for terrazzo chips, poultry grit, decorative stone, and building stone.

Guelph Formation (Middle Silurian)

Composition: Aphanitic to medium-crystalline, thick-bedded, soft, porous dolostone, characterized in places by extensive vuggy, porous reefal facies dolostone of high chemical purity. The Guelph Formation and the underlying Amabel Formation have a combined thickness of 200 feet (61 m) on the Niagara Peninsula and more than 400 feet (122 m) on the Bruce Peninsula. Uses: The main use is for dolomitic lime in the construction industry. The formation is quarried near Hamilton and Guelph.

Lindsay Formation (Middle Ordovician)

Composition: Lower Member is fine-crystalline, rubbly, nodular-weathering limestone. Upper Member is grey calcareous claystone with shaly partings and bioclastic layers. The rock is "soft" and weathers to rubble. Both members are characterized by low dolomite content and by numerous clayey partings. Uses: Quarried at Picton, Ogden Point and Bowmanville for cement. The formation is generally unsuitable for crushed stone, concrete aggregate, or granular base course.

Verulam Formation (Middle Ordovician)

Composition: Fossiliferous, pure to argillaceous limestone and interbedded calcareous shale. The rock is not resistant to erosion and commonly weathers to rubble. Thickness: 200 to 300 feet (61 to 91 m). Uses: Quarried at Picton, Ogden Point, and Mara Township for cement. The formation is unsuitable for crushed stone due to clay impurities, many clayey interbeds, and low abrasion resistance, high soundness losses and poor freeze and thaw resistance.

APPENDIX 3 – GEOLOGY OF BEDROCK SUITABLE FOR BRICK AND TILE MANUFACTURE (see Figures 2 and 3)

Georgian Bay Formation (Upper Ordovician)

(Formerly known as the Meaford-Dundas and Blue Mountain shales in the Toronto and Bruce Peninsula areas) Composition: Soft, fissile, blue-grey shale with limey or sandy lenses in a few places. Thickness: 640 feet (195 m) at Toronto. Uses: Several producers in Metro Toronto and Cooksville produce brick and structural tile. Lightweight aggregate has been produced at Streetsville by heat expansion of the shale.

Hamilton Group (Middle Devonian)

Composition: Grey shale with interbeds of crystalline and cherty limestone. The group has six formations, but only the Arkona is of commercial value. It is a soft, light grey, calcareous shale which is plastic and easily worked when wet. Thickness: 80 to 300 feet (24 to 91 m). The Arkona Formation has a thickness of 14 to 121 feet (4 to 37 m). Uses: The Arkona Formation is extracted at Thedford and near Arkona for production of drainage tile.

Queenston Formation (Upper Ordovician)

Composition: Red, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding. Thickness: 400 to 500 feet (122 to 152 m). Uses: There are several large shale pits developed in the Queenston Formation in the Toronto-Hamilton region and one at Russell, near Ottawa. All produce brick for construction. The Queenston Formation is the most important source material for brick manufacture in the Province.

APPENDIX 4 – BEDROCK SUITABLE FOR OTHER INDUSTRIAL PRODUCTS (see Figure 2)

Nepean (Potsdam) Formation (Cambro-Ordovician)

Composition: Creamy, coarse-grained, silica sandstone. Uses: Quarried throughout its area of outcrop for building stone, decorative stone, abrasives, and for glass making.

Salina Formation (Upper Silurian)

Composition: Grey and red shale, brown dolomite, and, in places, salt, anhydrite, and gypsum. The formation consists predominantly of evaporite deposits with up to eight members identified. Uses: Gypsum is mined at Hagersville, Caledonia, and Drumbo. Salt is mined at Goderich and is produced from brine wells at Amherstburg, Windsor, and Sarnia.

Whitby Formation (Upper Ordovician)

(Formerly known as Collingwood Shale near Toronto) Composition: Brown to black fissile shale. Uses: Quarried at Bowmanville for use in cement production. Testing indicates that the Whitby Formation may produce satisfactory lightweight expanded aggregate.

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Mineral Aggregates in Ontario Legislation, Policy and Rehabilitation

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ABSTRACT

The past decade has seen the Government of Ontario become increasingly involved in the management of the Province's mineral aggregate resources. Initially this involvement concentrated on the control and regulation of the aggregate industry by means of legislation known as the *Pits and Quarries Control Act*. Passed in 1971, the intent of the Act was to regulate the operation of pits and quarries and provide for rehabilitation. In 1975, the inadequacies of the Act prompted the establishment of the Ontario Mineral Aggregate Working Party to examine the situation and suggest alternatives. The findings of the working party indicated that, not only was new legislation required, but a provincial framework for the planning of mineral aggregate resources was also necessary. Subsequently, the Ontario Ministry of Natural Resources has developed two separate, but complementary programs in an aggregate resource management strategy for the Province of Ontario: legislation and planning policy. The proposed *Aggregates Act* will replace the *Pits and Quarries Control Act*, providing for the regulation and control of pit and quarry operations, including rehabilitation, through a licensing process. The planning policy provides direction to municipalities for the planning of mineral aggregate resources and the aggregate industry, primarily through the municipal planning process under the provincial *Planning Act*. However, the management of a resource does not stop with the adoption and enforcement of appropriate legislation and policy. The Province through the Ministry of Natural Resources has been providing leadership by funding internal and external research on rehabilitation of all types. This research is to assist the government, industry and the public in understanding what rehabilitation is and how it is done. The rehabilitation research will be described in detail in the paper. To provide efficient and wise management of Ontario's mineral aggregates, the Province has also undertaken aggregate demand studies, resource inventories, transportation studies and public education programs. This research should prove useful to any jurisdiction, be it another province or state, responsible for any aspect of the aggregate industry.

INTRODUCTION

The Government of Ontario has been involved in the management of the Province's mineral aggregate resources for many years. It has been an involvement born of necessity. Ontario, especially southern Ontario, represents the highest demand area for mineral aggregate of any region in Canada. In 1980, for example, 120 million tonnes of mineral aggregate or 14 tonnes per capita were used in the Province (Ontario Ministry of Natural Resources 1980). The majority of this tonnage was produced and consumed in the southern part of Ontario, in the vicinity of the Great Lakes, where 88% of the Province's 8.5 million people reside. As shown in Figure 1, 19 of the 23 Ontario cities with a population greater than 50,000 are located in the southern part of the Province. Metropolitan Toronto, and the surrounding regional municipalities of Peel, York and Durham constitute the largest market for sand, gravel and crushed stone in Ontario (Figures 2 and 3), consuming approximately 28 million tonnes per year (Ontario Ministry of Natural Resources 1982).

The proximity of this resource to its market is a major economic asset, but this proximity has also created social and physical complications of its own. The Government of Ontario's involvement with the mineral aggregate industry has evolved from these complications. This paper examines the Province's continuing and necessary role in the management of this most vital resource. Discussion centres on mineral aggregate resource management in the 1980s, and the challenges confronting both government and industry. The basic provincial management tools of legislation and policy are examined, along with the Province's work in the area of rehabilitation.

BACKGROUND

History of Aggregate Extraction

In the 1950s, Ontario along with the rest of western world experienced an unprecedented surge in economic growth, a growth that was to be accompanied by vigorous construction activity and consequently an increased demand for aggregates. To achieve economy of scale and to cope with sophisticated marketing techniques, large corporations

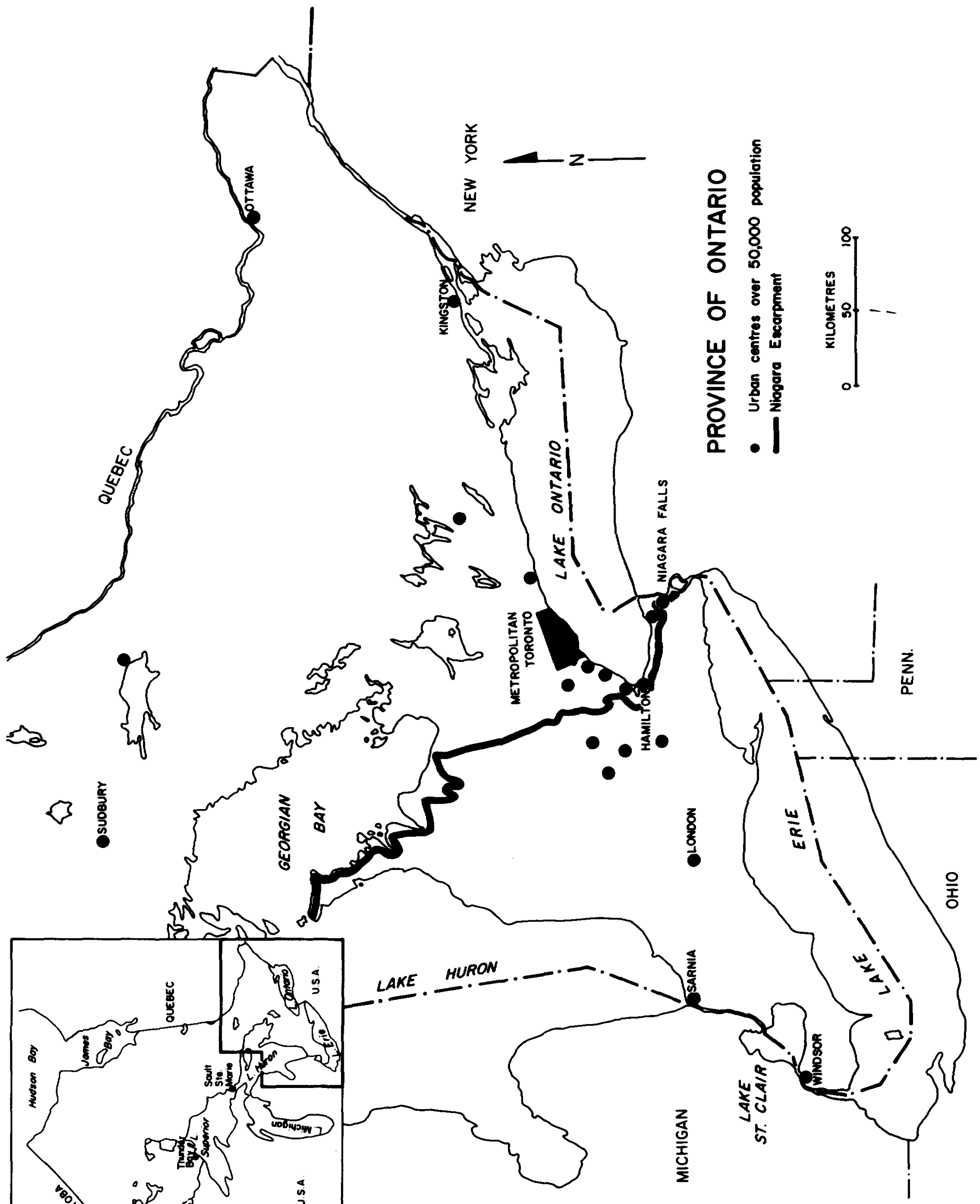

Figure 1. Province of Ontario showing urban centres with over 50,000 population.

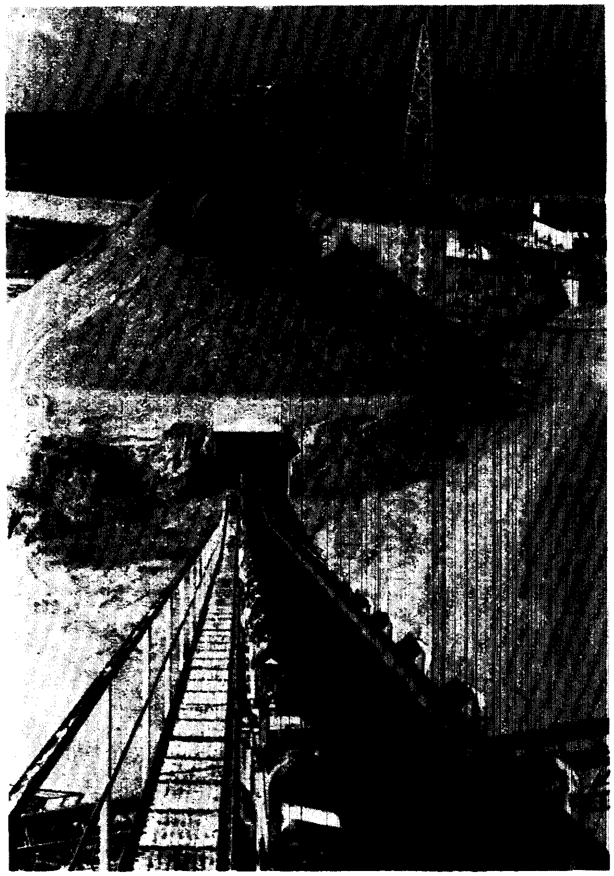

Figure 2. *Sand and gravel operation of Custom Aggregates, in Puslinch Township, west of Toronto.*

Figure 3. *Typical quarry operation at the Nelson Aggregate Company's Oneida Quarry near Hagersville, Ontario.*

and even multinational corporations joined the ranks, some producing as much as 5 million tonnes annually, at their various sites across the Province.

Increasing environmental concern in the mid-1960s saw the focussing of attention on the effect of these operations on the natural environment. No meaningful provincial regulations existed at this time to effectively control such operations. As a consequence some aggregate producers ran their operations in complete disregard for the environment, the rights of neighbouring landowners or their obligations as good corporate citizens.

Since the 1960s, this problem has been compounded by an increasingly non-farm rural population. As the number of exurbanites increased, so did their effectiveness as an irritant to the aggregate industry. Responding to this pressure from exurbanites, many local municipalities enacted by-laws effectively prohibiting expansion of existing operations and the starting of new operations. By the late 1960s industry recognized the possibility of a shortage crisis and requested government to take remedial action, preferably in the form of legislation. The Provincial Government responded by passing the *Pits and Quarries Control Act* in 1971 (Yundt and Messerschmidt 1979).

The Pits and Quarries Control Act

The *Pits and Quarries Control Act* was intended to provide rules and regulations that would accelerate rehabilitation and minimize the environmental impact of pit and quarry operations, while still providing for the aggregate requirements of the Province to be met within the Province. The Act is enforced by the Minister of Natural Resources.

The *Pits and Quarries Control Act* and its regulations control the operation and rehabilitation of pits and quarries in municipalities of Ontario that have been designated by the Lieutenant Governor in Council by regulation. This Act now applies to those areas shown on Figure 4. This covers most of southern Ontario and the Sudbury and Sault Ste. Marie areas of northern Ontario. The designations correspond to the higher production areas (Figure 5) and more urbanized areas (see Figure 1) of Ontario. There are currently 2500 licensed pits and quarries in the designated area.

Under the terms of the Act, a licence application must be accompanied by a site plan which includes, among other things, progressive and ultimate pit development and

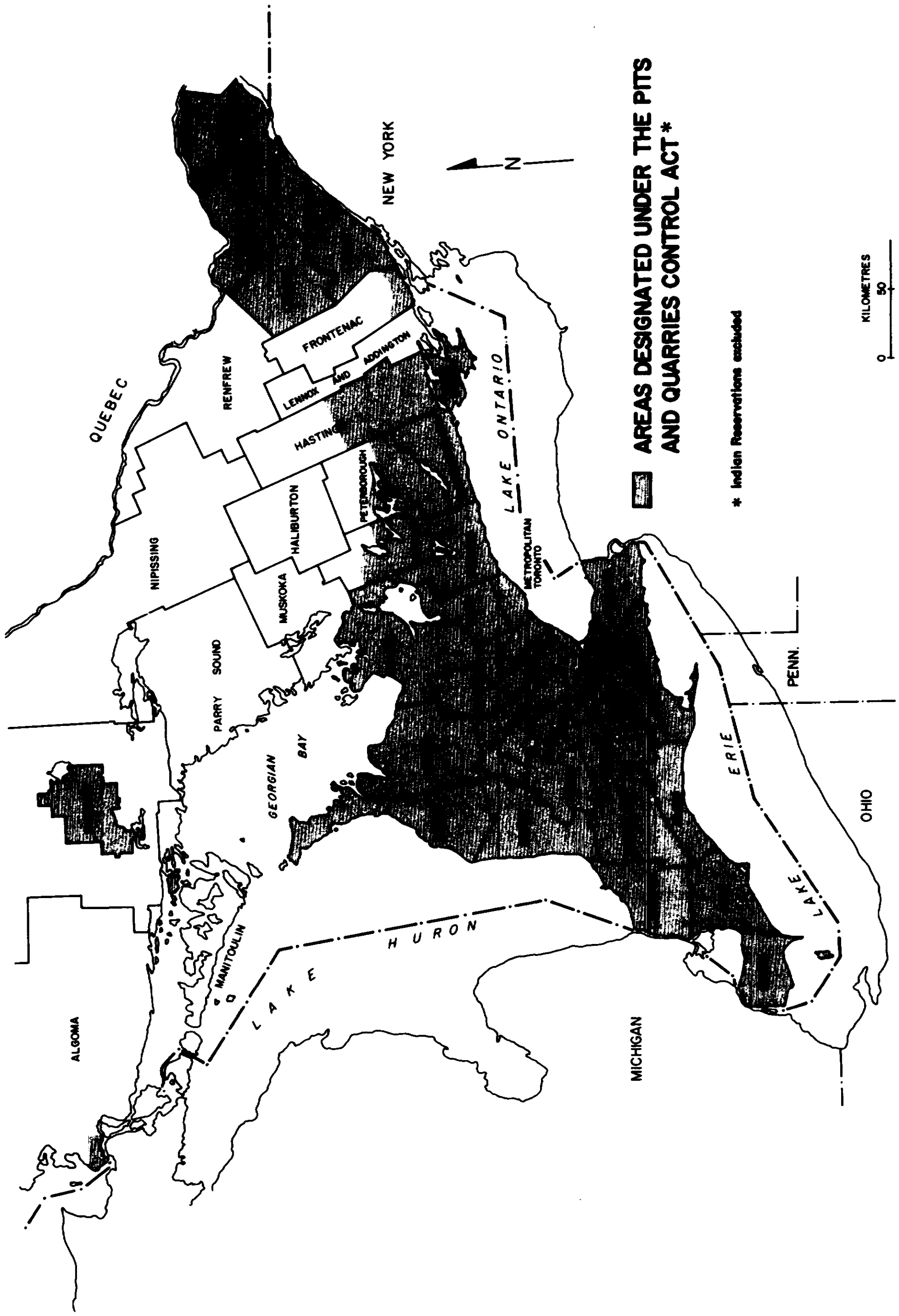

Figure 4. *Areas designated under the Pits and Quarries Control Act.*

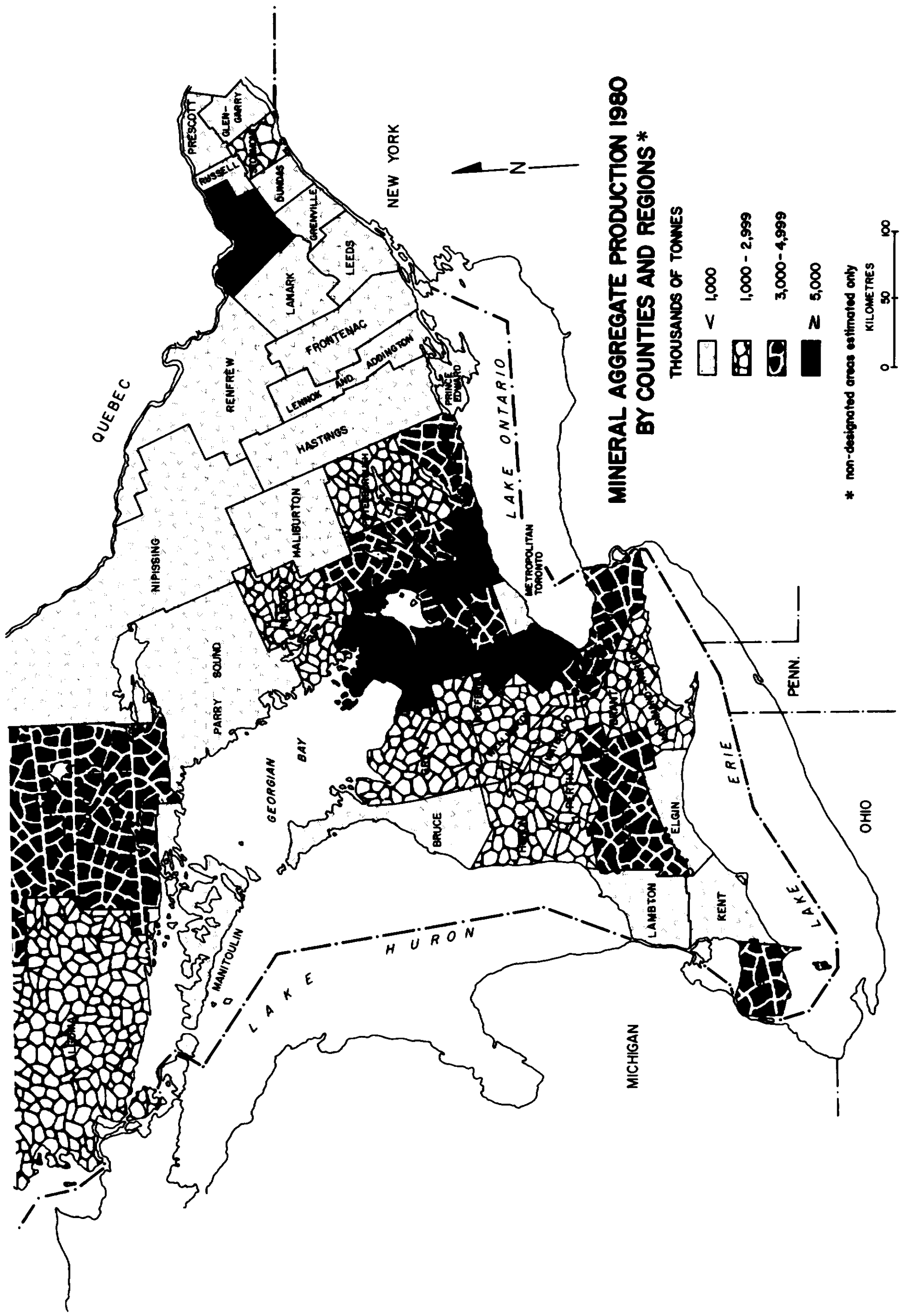

Figure 5. *Mineral aggregate production in counties and regions of Ontario for 1980.*

rehabilitation. Somewhat less information is required for an operation producing less than 15,000 tonnes per year. This division was applied to protect the small businessman and to maintain the competitive nature of the industry.

An objection by anyone affected by the issuance of a licence requires the Minister to refer the matter to the Ontario Municipal Board, a quasi-judicial tribunal. The Minister may also refer the matter to the Board on his own, if he feels a hearing is warranted. A drawback to the licensing process is the length of time it takes for the necessary approvals. Two to five years and considerable sums of money are required to take an application before the Ontario Municipal Board.

With respect to rehabilitation, the regulations under the *Pits and Quarries Control Act* require a security deposit of 8¢ per tonne of material removed from the property be paid to the Province. Payment into the fund must continue until such time as the licensee has a minimum of $1,000 on deposit per hectare of land requiring rehabilitation. Any surplus over and above the minimum amount required may then be claimed for expenses incurred in the rehabilitation of the site. If rehabilitation is not undertaken, payment must continue to a maximum of $3,000 per hectare requiring rehabilitation. It is, therefore, to the aggregate producer's economic advantage to undertake progressive rehabilitation to reduce the number of disturbed hectares and thus, maintain his security deposit at a minimum. Once rehabilitation is completed, any surplus remaining in the security deposit is refunded to the producer. If rehabilitation is not undertaken or not completed to the Ministry's satisfaction, the producer forfeits the money remaining in the account. This money is then used to rehabilitate the site.

ONTARIO MINERAL AGGREGATES IN THE 1980s

Towards a Mineral Aggregate Resource Management Policy

The past 11 years have demonstrated that there are many inadequacies in the *Pits and Quarries Control Act*. This is not to say that the *Pits and Quarries Control Act* has been an ineffective mechanism for the control and regulation of the aggregate industry in the Province. The past decade has seen the Province of Ontario achieve objectives, in the regulation of aggregate operations, that have taken European countries 30 years to achieve. Research has indicated that since passage of the Act in 1971, the amount of rehabilitation has increased by 100% in the high production areas surrounding Toronto (Coates and Scott 1979), and the quality of this rehabilitation is improving annually. A recent study conducted at the University of Guelph (Mackintosh and Mozuraitis 1982) concluded that between 60% and 70% of all agricultural rehabilitation has been successful based on pre-and post-extractive soil capability classes; an impressive fact considering the industry's previous lack of experience in this area.

The weaknesses of the present Act became apparent over a period of years following problems in administration and enforcement. As a result, the Ontario Mineral Aggregate Working Party was appointed by the Provincial Government in December, 1975, to examine the operations of the industry and the concerns of the municipalities. This method of formulating policy was a new concept to the Ministry of Natural Resources because all concerned parties were involved throughout the entire process. The fourteen members of the working party were selected to represent those groups most concerned with the problems associated with pits and quarries: regional and municipal councillors and staff; concerned ministries; industry; and special interest groups such as the Niagara Escarpment Commission and the Conservation Council of Ontario.

The working party published its report, "A Mineral Aggregate Resource Management Policy for Ontario" in January of 1977 (Ontario Mineral Aggregate Working Party 1977). The report contained 64 recommendations for new policy and legislation (Yundt and Messerschmidt 1979).

Cabinet reviewed the report and indicated that, not only was new legislation required, but that a provincial framework for the planning of mineral aggregate resources and the extractive industry was also necessary. Subsequently, the Ministry of Natural Resources has developed two separate, but complementary programs in an aggregate resource management strategy for the Province of Ontario: legislation and planning policy. The proposed *Aggregates Act*, not unlike the *Pits and Quarries Control Act*, provides for the regulation and control of pit and quarry operations, including rehabilitation, through a licensing process. The planning policy provides direction to local municipalities for the planning of mineral aggregate resources and the aggregate industry, primarily through the municipal planning process under the provincial *Planning Act*.

Legislation

The new legislation is designed to eliminate the weaknesses inherent in the *Pits and Quarries Control Act*. To be known as the *Aggregates Act*, it is expected to replace the present Act in 1983.

The *Aggregates Act* provides for:

1. *Remuneration to Municipalities*. Over the years, local municipalities have maintained that they should be compensated for costs resulting from aggregate operations. The working party reviewed the problem and recommended that municipalities be compensated. This provision will be in the new Act. The annual licence fee under the new Act will be 6¢ per tonne with 4¢ going to the local municipality, 1/2¢ to the region or county, 1/2¢ to an abandoned pit and quarry rehabilitation fund and 1¢ to the Province.

2. *Municipal Liaison*. The *Pits and Quarries Control Act* does not require the Ministry to liaise with municipalities with regard to applications for a licence to operate a pit or quarry. The *Aggregates Act* will generally require consultation with municipalities and a review of site plans every five years.

3. Rehabilitation of Abandoned Pits and Quarries. The present Act has no provisions to deal with the rehabilitation of abandoned pits and quarries. The *Aggregates Act* will require that 1/2¢ of the annual 6¢ per tonne licence fee be set aside in a fund for the rehabilitation of abandoned pits and quarries.

4. Progressive Rehabilitation. Progressive rehabilitation will become mandatory where it is possible so more rehabilitation in total will occur.

Planning Policy

A new "Mineral Aggregate Resource Planning Policy" has recently been released and it is the other major component of the Government's strategy for aggregate resource management. To understand how this fits in with and complements the *Aggregates Act,* it will be useful if a brief background to the development of this policy is given.

Although potential mineral aggregate resources exist in many parts of Ontario, a reduction in the availability of these resources is occurring in certain areas of the Province. The reduction of near market supplies is becoming serious and is not wholly connected with the depletion of these mineral aggregate resources. Incompatible land uses (e.g. housing, institutions, etc.) occurring over or adjacent to deposits have effectively eliminated some mineral aggregate resources, while restrictive planning, legislation and other controls have also made the establishment and operation of pits and quarries difficult.

Unlike the control and regulation of pit and quarry operations, the planning of aggregate resources is beyond the jurisdiction of the *Pits and Quarries Control Act* and the proposed *Aggregates Act.* Local municipalities have major land use planning and management powers on private lands in Ontario. This role is basically delegated to local municipalities by means of the *Planning Act* and the *Municipal Act.* The fundamental tools used to implement mineral aggregate policy at the local level are the official plan and zoning by-law.

Development of this policy began in 1979 and has evolved over the past four years with the benefit of full participation from all concerned parties. The major components of the policy can be summarized as follows:

To formally recognize the importance to the Province of mineral aggregate resources;

To protect existing pits and quarries through municipal official plans and zoning by-laws;

To protect adequate mineral aggregate resources through official plans and zoning by-laws to allow options on future extraction to remain open to meet long term needs;

To require official plans to provide a method and criteria for establishing new pits and quarries;

To permit wayside pits and quarries without requiring an official plan amendment, and generally, without re-zoning;

To require rehabilitation policies in official plans;

To establish the role of Provincial Ministries with regard to mineral aggregate planning and management; and

To establish how the policies will be implemented.

RESEARCH AND REHABILITATION

The management of a resource does not stop with the adoption and enforcement of appropriate legislation and policy. Additional information is required if the proposed *Aggregates Act* and Mineral Aggregate Resource Planning Policy are to be implemented successfully. The Ministry of Natural Resources fully realizes this, and has undertaken a number of programs considered necessary for the efficient and wise management of Ontario's mineral aggregate resources. These include aggregate demand studies; aggregate resource inventories; transportation studies; rehabilitation research; and educational programs.

Rehabilitation is perhaps the single most important factor in gaining public acceptance of the aggregate industry. Extractive operations are rarely compatible with the surrounding landscape, with the result that they are quite visible to the public. This visibility is heightened by the fact that pits and quarries are generally located on the fringes of the more urbanized areas of the Province.

The less visible the industry, the more compatible it will be to its surroundings and the more it will demonstrate the operator's willingness to fit within the community framework. Consequently, the Ministry of Natural Resources has been promoting rehabilitation since passage of the *Pits and Quarries Control Act* in 1971. Rehabilitation satisfies two important objectives. It returns extractive sites to an after-use compatible with the surrounding landscape and makes more land available for other high priority land use requirements in urban fringe areas where land is at a premium. In these high demand areas, rehabilitated land can often be incorporated into the overall land use pattern in a short time period, thus making rehabilitation highly desirable.

The benefits of rehabilitation have been recognized by the aggregate industry for a number of years. Many excellent rehabilitation projects have been completed by conscientious operators eager to improve their public image (Figure 6). These projects range from housing estates and golf courses (Figure 7) to agriculture, the most challenging of after-uses. Unfortunately, not all operators view rehabilitation as a necessary and important part of the aggregate industry's total operation. However, with the 8¢ per tonne rehabilitation security, these attitudes towards rehabilitation are changing quickly.

Progressive rehabilitation will become mandatory under the proposed *Aggregates Act* and should lead to a further reduction in the total land area disturbed by extractive operations. Many aggregate producers already practice progressive rehabilitation simply because it is less costly in the long term. The equipment is on the site and can be used alternately for extraction and rehabilitation. In fact, an efficient and well planned progressive

Figure 6. *Cutting grass in the early stages of rehabilitation of the Standard Aggregates site at Paris, Ontario. In later years the land was used for corn production.*

Figure 7. *Steed and Evans Limited have rehabilitated this former pit to a first class golf course and a fishing pond with trout at Fonthill, Ontario.*

rehabilitation program will allow for the simultaneous use of equipment. Overburden and topsoil can be stripped from the active area and replaced on the area being rehabilitated, in one operation. This not only reduces the amount of overburden and topsoil that must be stockpiled, but also minimizes the active site area, thus, reducing its visibility.

The Ministry of Natural Resources, however, is not only interested in increasing the quantity of rehabilitation work undertaken. It is also, equally concerned with the quality of that work. To this end, the Ministry has actively pursued a research program to assist aggregate producers in their rehabilitation efforts. This program was initiated in 1970, with the publication of "A Guide to Site Development and Rehabilitation of Pits and Quarries" (Bauer 1970). This report introduced Ontario's aggregate producers to the advantages and techniques of rehabilitation.

Since that time, the Ministry has continued its investigations into the complexities of rehabilitation. In 1975, a report on the use of trees, shrubs, grasses and legumes in pit and quarry rehabilitation, entitled "Vegetation for the Rehabilitation of Pits and Quarries" (Ontario Ministry of Natural Resources 1975), was released. Another report published in 1979 reviewed the quality and quantity of rehabilitation that had taken place since passage of the *Pits and Quarries Control Act* in 1971 (Coates and Scott 1979). In the same year, a comprehensive study entitled "Trees and Shrubs for the Improvement and Rehabilitation of Pits and Quarries in Ontario" was also released (Lowe 1980). The Ministry has since published another study in the same series entitled "Agriculture and the Aggregate Industry" (Mackintosh and Mozuraitis 1982). Conducted at the University of Guelph, this study determined the procedures and techniques necessary for the successful rehabilitation of extracted sand and gravel lands to productive agriculture (Figure 8).

Several brochures have also been prepared for use by the general public. "From Pits to Playgrounds" (Yundt and Augaitis 1979) is a publication intended to make the public aware of just how many former sand, gravel and clay pits, in Metropolitan Toronto, have been rehabilitated. The report is presented in the form of a tour guide to enable citizens to observe, first hand, what can be accomplished through rehabilitation. Over 60 sites are listed, all of which have been rehabilitated to a variety of uses, including recreational areas, residential estates, commercial malls and industrial parks. A similar educational brochure (Ontario Ministry of Natural Resources 1980) briefly describes the state of the art of pit and quarry rehabilitation in Ontario, the legislation controlling the aggregate industry, and the importance of the industry to the Province's economy.

Since the success of any mineral aggregate management program depends on the actions and attitudes of the aggregate industry, municipalities, municipal associations and other groups, the Ministry of Natural Resources continually works to establish a close liaison with these groups. Recent efforts in this area have involved tours of extractive operations for local municipal and government officials to demonstrate the problems and characteristics of the aggregate industry. As well, tours of rehabilitated sites have been organized for various municipal associations, to show that the rehabilitation of pits and quarries can be successful, if approached in the proper manner. These tours are essential to an understanding of the

Figure 8. *This wayside pit has been rehabilitated to agriculture in Burford Township. Here an early crop of clover will help restore the land by replacing nitrogen.*

aggregate industry. They allow municipal, provincial and federal officials as well as the public an opportunity to acquire first-hand knowledge of this vital industry, including operating practices, rehabilitation techniques and the actual use, and consequently the importance of Ontario's aggregate resources.

The Ministry of Natural Resources is committed to ensuring full and progressive rehabilitation of all licensed and abandoned sites in the designated areas of the Province. The proposed *Aggregates Act* is designed to ensure such end results. However, the regulations under the Act are not so severe as to stifle competitiveness or to drastically inflate consumer prices.

CONCLUSIONS

The Province of Ontario, through its Ministry of Natural Resources has been seriously working toward a comprehensive mineral aggregate resource management strategy for well over a decade. A great deal has been accomplished, but the Ministry fully realizes that there is a long way to go to achieve the ambitious goals of resource management/protection and environmental care/rehabilitation, embodied in the proposed *Aggregates Act* and the Mineral Aggregate Resource Planning Policy.

To summarize, the Province of Ontario's efforts have been concentrated on controlling and regulating the aggregate industry by means of legislation over the past decade. Only during the past four years have efforts been directed towards protecting this non-renewable resource by means of a mineral aggregate resource planning policy. Hence, the emergence of the Ministry's dual approach to mineral aggregate resource management: legislation, and planning policy. The proposed *Aggregates Act* and the Mineral Aggregate Resource Planning Policy will provide the Province of Ontario with one of the most advanced mineral aggregate management strategies in Canada, if not in North America. It is anticipated that when implemented, this approach will prove to be a most effective mechanism for controlling the aggregate industry and preserving the Province's aggregate resources for the future.

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Talc — The "Unique" Industrial Mineral

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ABSTRACT

Talc is unique among the industrial minerals. The term *talc* is often used to describe a broad range of products with large differences in purity, particle size distribution and characteristics. The geology of the talc ore and methods of processing are responsible for wide variations between talc products. These differences are reviewed and discussed.

The use of talc as an industrial mineral requires some knowledge of the various behaviour characteristics. The science of talc behaviour is in its infancy and much research is required before we can fully understand its behaviour. However, this paper will attempt to review and discuss talc's unique properties and the present major applications.

INTRODUCTION

The talc industry forms an increasingly complex web of varying interactions among producers, consumers, and alternative industrial minerals. The consuming industries of this single industrial mineral represent one of the most diverse and intriguing sectors of the world of industrial minerals.

Talc can compete with a number of other mineral substitutes depending on desired end product properties. With the wide range of talc grades available and the unique properties of these talcs, the growth and diversity of talc markets show exciting future trends. Presently talc is used in ceramics and refractories, paints, pulp and paper, plastics, cosmetics, rubber, pharmaceuticals, building products, insecticide carriers, and has numerous other minor uses.

The most characteristic properties of the mineral talc are its lack of abrasiveness, its chemical inertness, hydrophobic/organophilic nature, and high brightness. While these properties are common to all talcs, talc is the only industrial mineral known to possess this unique combination of properties. Varying geological conditions during mineralization, the host (or parent) rock in the deposit area, and the method of processing result in differences that make certain talcs more desirable than others for specific applications.

The type and amount of associated minerals influence the choice of mining and processing methods employed, dictate or limit market applications, and influence the finished product properties and behaviour. A limited number of talc deposits exist in which talc purity can be controlled by selective mining. These deposits contain low levels of associated minerals which are beneficial in specific applications and limited markets. Concurrently, the selling price will vary dependent upon product quality. Other deposits exist in which contaminant type and levels are detrimental to product properties, dictating additional beneficiation. Methods commonly employed include magnetic separation, flotation, classification and heavy media separation. Products from these types of processing are typically in the high purity range and possess more desirable properties. These products find expanded applications for both present and future markets. They sell for higher prices because of the higher processing costs.

Talc properties can also be influenced by the amount of grinding. Talc products are usually broken into categories determined by the degree of grind. A coarse grind talc is usually a +200 mesh (74 micrometres) or +325 mesh (44 micrometres) product. Intermediate grinds are usually -325 mesh and fine or ultrafine grind products have a greater distribution of particles in the -400 mesh (37 micrometre) range. The extra energy required to produce the finer grinds also produces an increase in the material selling price.

GEOLOGY OF TALC

Talc is generally formed by one of two mineralization processes: (1) hydrothermal alteration of ultrabasic rocks and low grade thermal metamorphism of siliceous dolomites; (2) steatization of serpentine resulting in the conversion of serpentine to talc, chlorite, and carbonate (Deer et al. 1966).

Typically, the talcs of northern Ontario are formed by the alteration of extrusive olivine-rich komatiites resulting in talc-magnesite ore bodies (Kretschmar and Kretschmar 1982).

TALC STRUCTURE

Talc is a sheet silicate consisting of brucite (magnesium hydroxide) core sandwiched between tetrahedral silicate layers (Figure 1). The single crystals are very thin, with

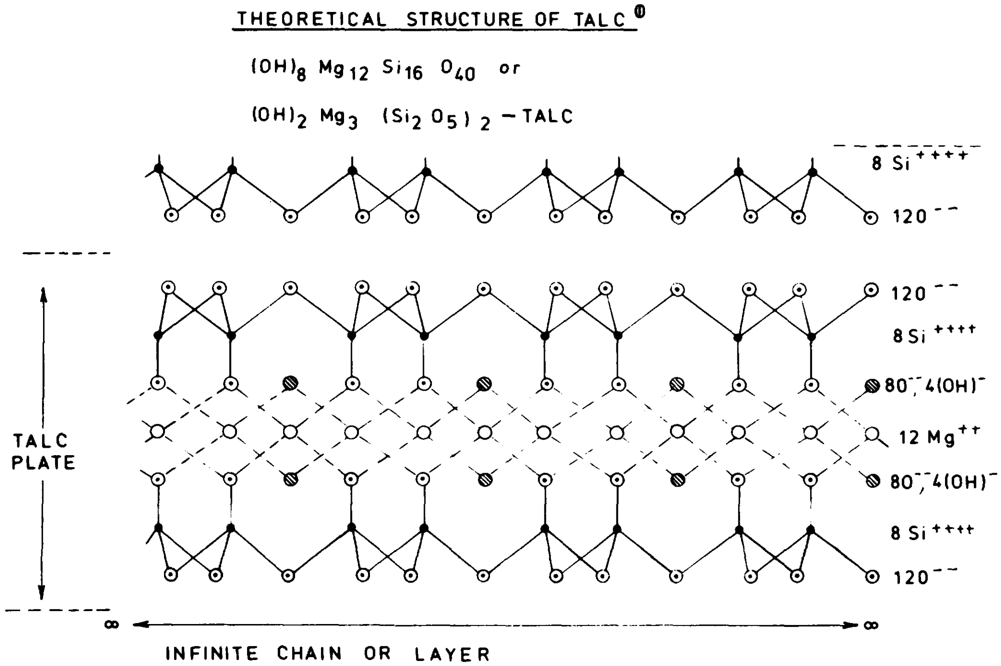

Figure 1. *Theoretical structure of talc (Bragg 1975).*

monolayer thickness in the order of 6.8 angstroms. The talc sheets stretch out in an infinite layer with crystal diameters being unique to the specific deposit. The talc sheets are stacked on top of one another such that in even the finest grinds of micronized talc, we see up to hundreds of sheets or stacks. The sheets are electrically neutral and held together by weak van der Waal's forces. Delamination occurs very easily with crystal cleavage along the (001) plane, giving talc its characteristic slip or greasy feel.

The theoretical chemical composition of pure talc is shown by the formula $3MgO.4SiO_2.H_2O$ and is made up of 63.5% SiO_2, 31.7% MgO, and 4.8% H_2O. Most talcs found in nature have varying amounts of ionic substitution normally occurring in the octahedral brucite layer. Typical impurities replacing magnesium atoms are iron, nickel, and/or manganese. As well as substitutions of atoms in the crystal lattice, commercial talcs are usually associated with varying amounts of accessory minerals dependent upon the deposit geology. Examples are magnesite, dolomite, chlorite and calcite. Talc products are usually classified into two grades dependent on purity. Industrial grades of talc may contain as little as 30% actual talc and still be referred to as *talc.* High purity grades typically contain more than 95% talc.

Structurally crude talc may occur as foliated, massive, or cryptocrystalline admixtures with carbonate rock.

"UNIQUE" PROPERTIES OF TALC

One of the unique properties that sets talc apart from all other industrial minerals is its softness. On the Mohs scale of mineral hardness ranging from one to ten, talc is numbered one and is the standard of softness. Massive or steatite talc rock is so soft that a fingernail will scratch it.

Industrial talcs show an abrasive character considerably higher than high purity talcs due to the varying levels of accessory mineral contaminants. High purity talcs however, exhibit an almost total lack of abrasiveness.

A second unique property that distinguishes talc from all other industrial minerals is its hydrophobic/organophilic character. Talc is the only known industrial mineral which will preferentially adsorb organics from aqueous media (organophilicity). Its renowned water repelling properties (hydrophobicity) have caused it to be used to help prevent diaper rash of infants for centuries. However, these properties can be altered by the use of surface treatments making talc an attractive filler or extender in both oil- and water-based systems.

The unique chemical inertness of talc allows it to be used in many formulations in which chemical interaction would be detrimental. This property is a result of the metal atoms being locked in both the sandwich structure and the crystal lattice. Additionally, the surfaces of the crystals are electrically neutral and unaffected by acids or bases.

As well as the above properties, talc also exhibits excellent dielectric behaviour and very low thermal conductivity. It has a low thermal expansion and shrinkage factor.

MARKETS AND APPLICATIONS

As a result of the unique combination of properties exhibited by talc, the diversity of applications is enormous. The largest consumer of talc is the ceramic industry; however, this is not a major market for high purity talc. The major benefits of talc in ceramics include reduced mold shrinkage, increased greenware strength, and improved dewatering rates of sanitary-ware bodies. The normally low iron content present in ceramic talcs results in a neutral-coloured fired body. The low coefficient of thermal expansion is the major property that must be exhibited by a ceramic talc.

In the paint industry, the second largest consumer, talc is used as a filler and extender for very expensive white pigments such as titanium dioxide as well as other synthetic white pigments. Talc is used as an anti-sheen agent in flat wall paints of either oil or water base. The preferential orientation of the talc platelets reduces the light scattering in the paint film. The uniformity of grind and consistency of colour are key requirements of a talc product for the paint industry.

While the consumption tonnage of both the pulp and paper and the plastics industries are comparable today, the trend for future growth appears to weigh heavily towards the plastics industry. The filling of plastics is an excellent growth market for talc. Talc increases the tensile, flexural, and hardness properties while decreasing the deflection temperature, mold shrinkage, and coefficient of linear thermal expansion. High purity talcs with their reduced abrasion factor are beginning to replace the industrial talc usage in polymers as the cost of injection and extrusion dies increase. The talc filler is effective in a range from 15 to 40% by weight of polymer. The particle size distribution of plastics fillers should be in a narrow range to minimize the adsorption of processing additives or stabilizers. The primary economic advantage is in the extension of the very expensive polymer with talc.

A strong stable market for talc has continued to exist over the past quarter century. The use of talc in the pulp and paper industry has a diversity of uses ranging from organic deposit control to high brightness extenders and fillers. The unique organophilic properties of talc have found a niche in the control of oleoresinous and tramp organic contaminants (commonly referred to as pitch) in the pulp and paper-making processes. The trend toward closed water systems resulting from environmental and governmental concerns has stimulated the demand for high purity ultrafine grind talc products. The use of talc has allowed continuous operation of these closed water systems without the concurrent build-up of pitch. The unique organophilic nature and chemical inertness of talc allow it to adsorb the undesirable pitch. This minimizes pitch deposition and chemical build-up, thereby increasing product quality and reducing downtime (Parmentier 1979). Additionally, the talc-pitch entities are carried with the final product increasing production yield. A typical example is a paper mill producing an average 600 tons/day: a 1% addition of talc will save 6 tons of fibre. These benefits result in conservation of our woodland resources, reduction of environmental impact, and increased productivity and product quality.

The cosmetic industry has long been aware of talc's unique properties of softness, slippery feel, hydrophobic character and inert nature (Grexa and Parmentier 1979). Only the highest purity talcs are acceptable to the cosmetic market. Talc finds extensive use in baby and body powder formulations, dry spray deodorants, facial makeup, eyeshadow, and foot sprays.

SUMMARY

The unique properties of talc have been reviewed with reference to variations in purity, grind, structure, and its wide application in the marketplace. An understanding of talc properties as described is necessary for the potential user to make an intelligent and effective selection for a specific application.

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Steep Rock Calcite — a Division of Steep Rock Resources Inc.

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ABSTRACT

Steep Rock Resources Inc. owns a calcite quarry property at Tatlock, Ontario, and a calcite manufacturing plant at Perth, Ontario. The Tatlock marble deposit forms part of an extensive series of carbonate rocks of the Grenville geological Province in the Precambrian Shield of Southeastern Ontario. The deposit is very unusual, if not unique, in the Grenville area in its combination of characteristics of large size, whiteness, high calcium content, low magnesium and silica contents, and scarcity of accessory minerals.

A major expansion of the fine grind products capacity of the plant was undertaken in 1982 and this is expected to be on stream by mid 1983. The expansion will provide important operating benefits at the plant: it will provide greater flexibility as to the product mix and will reduce dependence upon the single grinding mill presently operating at the plant.

The expanded facility will consist of primary and secondary crushers, a rotary dryer, a screenhouse producing a range of screen separator grade products, an air-swept Raymond Mill, and a pebble mill with integrated air classifiers, product storage bins, bulk, semi-bulk, and bagged product shipping capabilities, road and rail access, and a substantial product warehouse. The expansion was designed to be compatible with a move into ultrafine calcite production, and is capable of supplying the anticipated sales growth within its market area during the next 5 years.

Products are exceptionally white, with good chemistry, low abrasion, and consistent quality. Markets range, according to product particle size, from pre-cast concrete aggregate to fillers for coatings, plastic pipe, and compounds.

INTRODUCTION

Steep Rock Resources Inc., with a long and distinguished history as an independent Canadian producer of iron ore products, became an operating industrial minerals company in December, 1980. This occurred through the purchase of a calcite operation at Perth, Ontario, from William R. Barnes Company Limited. This paper will describe Steep Rock's calcite plant with emphasis on the recently completed expansion of the fine and medium-fine grinding facility.

DESCRIPTION OF PLANT

Perth is located roughly midway between Toronto and Montreal and is accessible by Highway 7 and by CP Rail.

The Perth plant is essentially an operation in which white marble is crushed, dried, screened, dry ground and air classified into a wide range of products, from white garden stone chips to white fillers and extenders used in paint, plastic and joint compounds.

At the time that Steep Rock acquired this operation, in December 1980, the main elements of the plant were a primary crusher, two screenhouses, a rotary drier, a fine grinding section containing a 66-inch diameter Raymond Mill, air classifiers, bagging and bulk load out facilities and a warehouse.

Screenhouse No. 1 is the primary dimension stone circuit in which -2 inch stone is screened into sized products for use in decorative landscape chips, pre-cast concrete and roofing stone. The oil fired rotary drier is between the two screenhouses. All the stone used to produce screen separator grades, or finer grades, passes through the rotary drier. Surface moisture is removed at this stage, facilitating screening, transporting through the plant, and fine grinding. Feed to the rotary drier is usually -3/4 inch stone. Surface dried products from the drier enter Screenhouse No. 2 where grades from 6 mesh down to 200 mesh are separated by screening. Surplus stone feed and 12-40 mesh material goes on to feed the roller mill.

Up to the time of the recent plant expansion the fine grind operation consisted of a Raymond Mill and integrated air classifiers in which four separate products were segregated with particle topsizes of 76, 44, 25 and 15 micrometres (microns) respectively. While there was some flexibility to produce these products in various proportions, generally, this system had a limited capacity to produce the finest sized and highest value products. It also had the inherent weakness of total dependence on a single piece of grinding equipment, the Raymond Mill.

DESCRIPTION OF THE TATLOCK QUARRY

The Perth plant is supplied with feed from Steep Rock's quarry at Tatlock. This is located approximately 24 miles north of the plant and is accessible via Highway 511. The quarry property consists of 790 acres, part of which is held in fee simple with the balance being a number of unpatented mining claims. It lies in an extensive series of carbonate rocks in the Grenville Province of the Precambrian Shield of southeastern Ontario. Usually coarsely crystalline with various colours (white, grey, blue, green), marble deposits in the Grenville area are often dolomitic to some degree and variable in their chemical and mineral composition.

The zone of marble contained within this property has an exceptional combination of large size, dazzling whiteness, high calcium, low magnesium and silica, and a scarcity of other impurities. Proven reserves exceed 7 million tons with strong indications of additional tonnages, which will permit over 25 years of production at estimated rates. The property held protects the possible extension of the ore zone for 3,000 feet to the north and 1,000 feet to the south. The brightness of the ground product is 95-97, an unusually high value. Quarrying, crushing, screening and trucking of this material to the Perth plant is carried out by a local contractor in a summer-season operation.

Steep Rock also holds a number of additional mineral claims in the vicinity of Perth containing large marble deposits which have not yet been explored in detail. Collectively, these mineral properties together with those at Tatlock have the potential to support larger scale production rates in the future.

REASONS FOR THE PLANT EXPANSION

Sales of fine grind products from the Perth plant had almost reached production capacity in the spring of 1982 when the decision was made to undertake the expansion project. The target date for completion and commissioning was early 1983 in order to catch the usual heavy surge of seasonal sales expected in the first half of the year. In addition to providing for continued sales growth of fine and medium-fine grind products the expansion also has introduced some needed flexibility of operation by allowing, within reasonable limits, matching of individual product quantities with actual sales.

The pre-expansion production of fine grind and medium-fine grind products came entirely from a single grinding machine, the 66 inch Raymond Mill. Any interruption in the operation of this machine completely stopped the manufacture of the plant's most important product lines. The expansion removed this total dependency on the Raymond Mill as the new mill can be fed directly from Screenhouse No. 2, operating in parallel with the Raymond Mill. The Raymond Mill, as it was being used before the expansion, was operating at the very limit of its capabilities, producing very fine products at a very low rate. In the expanded plant it will generally produce a much coarser product at a much higher and more efficient rate for further grinding in the pebble mill.

DESCRIPTION OF THE PLANT EXPANSION

The plant expansion consists essentially of a pebble mill with an integrated air separator, two new high efficiency air classifiers, a major new bulk load-out facility with seven mass flow bins and a truck scale, dust collection systems, a pneumatic conveyor system, enlarged bagging system, a new 2000 KVA electrical sub-station, and a central operation control room. This equipment is contained in part within the existing plant buildings, and in part within a major new steel frame building attached to the northwest side of the older Raymond Mill building.

The pebble mill is a 10 foot by 84 inch Koppers-Hardinge unit with ceramic liners and pebble charge. A converted ball mill is one of the few major pieces of used equipment in the expansion. The classifier which is integrated with the mill is a Koppers-Hardinge Gyrotor Air Classifier utilizing a 250 H.P. main fan motor. Product from the Gyrotor is further classified in two "Micro-Sizer" high efficiency air classifiers.

The six new bulk product storage bins are contained in the new bin rack. Each of these is a mass flow bin, has a capacity of 120 short tons and can feed the bagging operation through the pneumatic conveying system. Truck loading, as with a number of other material transfer operations, is accomplished with a combination of screw conveyors and air slides.

The plant expansion provides a doubling of fine and medium fine grinding capacity, and allows Steep Rock to satisfy projected market demand for these products for several years. Although fully integrated with the present plant, the expansion is capable of operating independently when required. The flexibility of the plant is thus enhanced considerably.

The process is controlled from a central control room with many of the functions automated but under full control of the operator. With the expansion, plant operators can within reason manipulate the product mix in response to fluctuations in market demand. This is an important aspect of the expansion and other plant and process modifications.

The pebble mill system will derive its feed sources from the Raymond Mill circuit, and from granular product produced in the No. 2 Screenhouse. This will allow the Raymond Mill to operate much more efficiently than previously, producing a coarser product.

Use of open conveyor belts or screw conveyors has been minimized where possible. Pneumatic conveying or airslides are used extensively to transport material in the plant. Bagging operations have been centralized and could be automated at a future date.

A new 2000 KVA sub-station has been installed. This provides ample capacity to feed the load which has been added and for further plant additions.

The expansion has been designed to be fully compatible with a possible further future plant development in mind: a move into the production of ultrafine calcite products.

DESCRIPTION OF PRODUCTS

The Perth operation produces three types of product: dimension stone, screenhouse products, and fine and medium-fine grind products.

Dimension stone products are the coarsest in size and the lowest in value of these three categories, ranging from 1-1/4 by 5/8 inch down to -1/8 inch size. Typical uses for this material are decorative landscape chips and driveway stone, terrazzo chips, poultry grit and white block manufacturing.

Screenhouse products have finer particle sizes, ranging from 12 mesh by 40 mesh to 40 mesh by 200 mesh. Typical uses here include animal feed, stucco mix, cultured marble, floor tile and ashtray sand.

Fine and medium-fine grind products have the smallest particle size and highest value of the three categories. The coarsest medium-fine grind product is 20% +325 mesh. The finest of the present fine grind products has a particle top size of 15 micrometres (microns). These products are used as fillers in paint, plastics, rubber, joint compounds, adhesives and other industrial products. It is in this application, as a filler that Perth calcite products find their greatest importance. The exceptional qualities of the Tatlock marble which contribute to its success as a filler are its chemical purity, uniformity, low abrasivity, stable pH, good grindability and most important of all, its high standards of colour or brightness. The Tatlock deposit is the most northerly, and by far the whitest naturally occurring calcite deposit in operation in North America.

FUTURE DEVELOPMENTS

Up to the present time, sales of dry ground calcite products in the medium-fine and fine sizes have been the most vigorously expanding segment of the Perth plant's business. This growth is expected to continue, utilizing the new capacity which is presently being commissioned.

One exciting area of new business for the future is the development of ultrafine calcite products at Perth. Present technology suggests that these would be wet ground products. They would also be beneficiated to high standards of purity, perhaps by flotation methods. Particle sizes would be one step finer than our present fine grind products, with top sizes in the range of 5 micrometres, 90% less than 2 micrometres, and an average particle size of 1 micrometre.

The decision to develop these products would be market related, and would likely be triggered by a decision by paper makers in the plant's market area to switch to alkaline sizing, so permitting the use of calcite fillers instead of the presently used, and much more costly, china clay fillers. Steep Rock has the financial means, and the mineral resource potential to make this development move at the appropriate time. Steep Rock is alert for other profitable business development opportunities which might arise for the Calcite Division, and in other industrial minerals, and hopes to grow into a large scale producer with all of the efficiencies and product support services that will be possible.

Geology, Mining and Processing of Nepheline Syenite

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ABSTRACT

Nepheline syenite is a silica-deficient crystalline rock consisting of nepheline, microcline and albite with varying amounts of mafic and accessory minerals. Typically, the crude ore contains the following proportion of minerals: albite 54%, microcline 20%, nepheline 22%, and mafics 4%.

Nepheline syenite in the Nephton area outcrops in a northeast-trending area 8 km long by up to 2.5 km wide. The deposit has been the subject of several studies to determine its origin. It has been referred to as an intrusive stock, a metasomatic deposit, an intrusive sill and a metamorphic-metasomatic body. The body is divided into six zones distinguished by their mineralogy: muscovite zone, muscovite-magnetite zone, biotite-muscovite zone, biotite zone, hornblende zone and a pink syenite zone. Within the nepheline syenite, there are mafic bodies which may represent basic rocks that have been less altered by metasomatism, metamorphosed basic dikes, or stoped blocks of metasediments. The most prominent structural features are the northeast-trending folds which have been modified by later northwest-trending folds.

Indusmin Limited mines nepheline syenite from two open pits in the Blue Mountain deposit. Proven ore reserves are 18 million tonnes which at the current rate of production will sustain operations for forty years. Additional ore reserves are known which will provide ore for many years to come.

The processing of nepheline syenite involves drying and crushing the ore through several stages to produce sand size grades. Fines are removed by air classification; iron is removed by stages of low and high intensity magnetic separation and screened to sand size for glass customers. Sand is ground in pebble mills and air classified to produce products for the ceramic, paint and plastics extender fields. The quality control program plays an important role in this operation. This program operates on three levels, namely, ore grade control, process control and quality assurance.

INTRODUCTION

Indusmin Limited, a subsidiary of Falconbridge Limited, has two silica operations in Ontario and Quebec, a feldspar/mica/silica operation in North Carolina, two aggregate quarries near Toronto, a steel casting division at Orillia, Ontario, and a nepheline syenite operation at Nephton, Ontario. This paper describes the geology, mining and processing of nepheline syenite.

Initial interest in the area resulted from prospecting in the 1890s and in 1912 tests were made to attempt to extract alumina from finely ground nepheline syenite. In 1932-1933, W. Morrison staked most of the area known as Blue Mountain Ridge in Peterborough County. He interested H.R. Deeth in the glass and ceramic application potential of this property. A company called Canadian Nepheline Limited, the forerunner to the present Indusmin Limited complex, began mining operations in 1936 and established a 50 tons per day mill at the rail point in Lakefield, Ontario. A subsidiary company, American Nepheline Corporation was formed in 1937 to process the crude ore in Rochester, New York. The ore was barged from Nephton to Lakefield where it was transferred to railcars and shipped to Cobourg, Ontario, and then to Rochester via the railcar ferry. In 1946, a mill was established at Nephton and two fine-grinding mills were installed at Lakefield. In 1951, all of the milling process was consolidated at Nephton and in 1954, the Canadian Pacific Railway completed a spur line into Nephton from Havelock. A new mill was built in 1956 at a rated capacity of 600 tons per day. Several stages of expansion have provided our present capacity of 550,000 tonnes per year of finished product.

The mining operation is located 200 km northeast of Toronto in Methuen Township, Peterborough County, Ontario.

Transportation of the products is by railroad and trucks to customers in Canada and the United States and via ships from bulk warehousing facilities in Montreal to Europe and Australia.

GENERAL GEOLOGY

The stratified bedrock formations in Methuen Township are Precambrian metavolcanics and metasediments and Paleozoic limestone. The oldest intrusive rocks cutting the metavolcanics and metasediments are diorite and gabbro. The two largest intrusions are the Horse Lake and Twin Lakes diorites. The nepheline syenite cuts and replaces para-amphibolite, paragneiss and marble and is intruded by pink syenite. The youngest intrusive rocks in the area are granite, with the largest being the Methuen granite.

PREVIOUS GEOLOGICAL WORK

The earliest work done on the Blue Mountain nepheline syenite was by W.G. Miller (1899) and by Adams and Barlow (1910). In 1939, M. L. Keith defined two major mineral zones and interpreted the deposit as an intrusive stock.

In 1951, D. R. Derry suggested that the deposit was of a non-intrusive origin and had been formed by a process of "nephelinization" of a pre-existing sedimentary formation. He believed that the foliation was due to the original bedding of the formation, recrystallized as a result of folding.

In 1960, D. F. Hewitt documented 12 areas which he regarded as evidence of an intrusive origin for the deposit. Hewitt stated that the foliation and lineation observed in the nepheline syenite represented a secondary metamorphic fabric.

In 1962, G. R. Guillet concluded that the body had an intrusive origin, based on studies of solid inclusions in the felsic minerals of the nepheline syenite. J.G. Payne completed a petrographic and geochemical study of the deposit in 1966 and concluded, "it is an intrusive sill into metasediments, and was fractionated during formation into several zones, distinguished by chemistry, mineralogy and texture". According to Payne, the prominent foliation had been developed by fractional crystallization and the sill had been folded into its present shape during the Grenville Orogeny, but the texture and mineral composition of the sill had been only slightly modified by the metamorphism of the orogeny.

MINERALOGY AND PETROLOGY

Nepheline syenite is a silica-deficient, crystalline rock consisting of nepheline, microcline and albite with varying amounts of mafic and accessory minerals. Typically, the crude ore contains the following percentages of minerals:

Albite:	Na_2O, Al_2O_3, $6(SiO_2)$	54%
Microcline:	K_2O, Al_2O_3, $6(SiO_2)$	20%
Nepheline:	$(Na,K)_2O$, Al_2O_3, $2(SiO_2)$	22%
Mafic minerals:		4%
Total		100%

Nepheline Syenite

Payne (1966) outlined six mineralogical zones (Table 1) which are detailed as follows.

Muscovite Zone. The muscovite zone outcrops at the southwest end of the deposit, and consists of fine-grained rock with poorly developed foliation. The mineral grains are generally anhedral with interlocking borders.

Muscovite-Magnetite Zone. This zone outcrops at the northwest end of the deposit and south of the Cabin Ridge Pit. The zone consists of fine- to medium-grained, light grey rock. The mineral grains have irregular, interlocking borders, and the replacement of albite by microcline is distinctive. The main accessory minerals are muscovite, magnetite and calcite.

Biotite-Muscovite Zone. This zone occurs along the flanks of the biotite zones adjacent to the contact with the metasediments and the Methuen granite. The zone consists of fine-grained, dark grey rock with irregular, penetrating grain boundaries. Biotite inclusions are linearly oriented in the nepheline grains, and the feldspars contain many calcite, cancrinite, magnetite and mica inclusions. Magnetite is found in small quantities and is interstitial to feldspars, surrounded by a muscovite rim. There is a prominent foliation outlined by biotite.

Biotite Zone. The biotite zone occurs in the upper part of the deposit and is the zone from which most of the current mining is done. The zone consists of light grey, medium-

TABLE 1. MINERALOGICAL COMPOSITIONS OF MINERALOGICAL ZONES IN THE BLUE MOUNTAIN NEPHELINE SYENITE BODY (AFTER PAYNE 1966).

	Muscovite Zone	Muscovite Magnetite Zone	Biotite Muscovite Zone	Biotite Zone	Hornblende Zone	Pink Syenite Zone
Albite	51.4	58.6	54.4	52.0	48.4	64.9
Microcline	19.0	18.2	18.6	18.9	22.7	20.7
Nepheline	25.5	19.7	19.9	24.1	24.9	0.5
Biotite	0.1	0.4	4.3	2.2	0.2	5.0
Muscovite	3.3	1.8	1.7	0.7	0.0	7.1
Magnetite	0.5	1.1	0.2	0.5	0.4	0.1
Hornblende	0.0	0.0	0.0	0.0	3.0	0.0
Pyroxene	0.0	0.0	0.0	0.0	0.2	0.0
Garnet	0.0	0.0	0.0	0.0	0.2	0.0
Calcite	0.1	0.1	0.5	0.1	0.0	0.7
No. of Sections	9	27	25	69	69	14

grained rock, in which magnetite and biotite are the predominant mafic minerals. Biotite is often bleached to a light green color. The foliation is prominent near the borders of the zone and it is poorly developed at the center. Mafic-depleted haloes around magnetite grains are found primarily in this zone. Calcite is a minor accessory mineral which occurs interstitially to magnetite and biotite. The feldspars usually have strong, interlocking borders with nepheline.

Hornblende Zone. The hornblende zone outcrops in the central part of the deposit. It is a grey, medium-grained rock characterized by the presence of hornblende, garnet and magnetite. The nepheline and feldspars have slightly interlocking boundaries. The foliation is prominent and is outlined by the parallel alignment of hornblende. Garnet is common towards the center of this zone.

Pink Syenite Zone. The pink syenite zone occurs along the contacts with country rocks. It is a fine-grained pink rock composed essentially of albite, microcline, muscovite and biotite with only a minor amount of nepheline.

Mafic Bodies and Amphibolite

There are a number of mafic bands within the nepheline syenite deposit. They are more commonly found in the biotite and hornblende zones and may form concordant sheets up to 300 m in length and a few metres wide.

Payne (1966) identified four types of mafic zones (Table 2).

Derry (1951) and Phipps (1955) believed that the mafic rocks were the remnants of basic dikes and sills which had been less altered during the process of nephelinization. Hewitt (1960) suggested that these bands represented sedimentary inclusions, metamorphosed basic dikes or biotite shear zones. Guillet (1962) and Payne (1966) believed that these rocks were stoped blocks of metasediments.

Pegmatite Zone

Nepheline-bearing pegmatites are common in the biotite zone and less so in the hornblende and muscovite zones. There are two types of pegmatites. The first contains nepheline, albite and microcline. The second type is similar to the first but also contains pyrite, pyrrhotite, tourmaline, sodalite, cancrinite and muscovite.

STRUCTURE

Derry and Phipps (1957) believed that the nepheline syenite replaced a series of folded metasediments while Keith (1939), Hewitt (1960), and Guillet (1962) believed that a series of folded metasediments had been intruded by a nepheline syenite stock. The most prominent structural feature of the deposit is the northeast-trending Cabin Ridge anticline and Grassy Lake syncline. Cross-folding has produced reversals in the direction of the plunge.

Structural measurements from detailed drilling and mapping of the orebodies indicate that the foliation is conformable to the folding of the stoped metasediments.

MINING

The nepheline syenite outcrops in a northeast-trending area 8 km long by up to 2.5 km wide. Indusmin Limited mines from two open pits in the Blue Mountain deposit.

Proven ore reserves are 18 million tonnes which at the current rate of production will sustain operations for forty years. Additional reserves are known, but not yet diamond drilled, which should provide ore for many years to come. The ore, which is mined at the rate of 2,000 tonnes per day, is blended from two open pits to provide the mill with a consistent mill feed. Production drilling is done by air

TABLE 2. MINERALOGICAL COMPOSITIONS OF ZONES IN MAFIC BODIES AND AMPHIBOLITE (AFTER PAYNE 1966).

	Amphibolite	Pyroxene Amphibolite	Feather and Biotite Amphibolite	C.M.B.A. Gneiss
Plagioclase	31.9	30.6	50.1	55.0
Microcline	0.2	0.0	7.6	10.0
Biotite	2.0	0.9	5.1	25.0
Calcite	0.2	0.0	0.4	5.0
Hornblende	51.5	23.2	24.5	1.0
Pyroxene	0.1	34.3	4.6	0.0
Garnet	1.6	10.9	1.7	2.0
Magnetite	0.3	0.0	0.4	0.1
Sphere	0.0	0.5	0.8	0.5
Quartz	6.7	0.0	3.4	0.0
Plagioclase Comp. (percent An)	20-50	20-50	10-30	5-20
No. of Sections	2	4	5	6

driven mobile drills which develop the 12 m high benches. Analyses of the drill cuttings are made prior to blasting the 12,000-15,000 tonne shots. The 5.5 cubic metre loaders and four 32 tonne haulage trucks load and haul the material to the crushing plant or to waste disposal depending on quality.

PROCESSING

The blended ore from the open pits is reduced to -5 cm in a jaw crusher and a cone crusher. The ore is then dried to 0% moisture content in two parallel oil-fired rotary driers. The ore is further reduced in the tertiary crushing circuit using two cone crushers or an impact crusher. The -4 +30 mesh ore from the tertiary crushing circuit is reduced to -30 mesh, using two stages of rolls crushers.

The -30 mesh fraction is passed over magnetic separators to reduce the iron from 2% to 0.7% Fe_2O_3 and produce a saleable magnetite concentrate. The -30 mesh material is then passed through air classifiers to remove the -200 mesh fines. These fines are treated in a high intensity magnetic separation circuit.

The -30 +200 mesh fraction is treated in a high intensity magnetic separation circuit. Magnetic and para-magnetic minerals are removed from the sand by high intensity magnetic separation conducted at field strengths of 1500, 12,500 and 13,500 gauss at the top, middle and bottom rotors of the separator. The separator waste is re-treated in a high intensity magnetic separation circuit where a -40 mesh high iron sand is produced. The secondary milling circuit receives its feed from retreated +30 mesh and +40 mesh oversize fractions.

The pebble mills operate in closed circuit with air classifiers. The pebble mills are lined with jasper and the grinding media is either jasper or high density alumina balls. The product from the pebble mill classifiers is either A-200 or A-270 which is used in the ceramic industry. These two grades are further classified in high speed classifiers to provide products for the paint extender pigment and plastic filler market.

QUALITY CONTROL

Quality control starts in the open pit operations and continues throughout the milling operations through to the shipment of the finished products. The quality control program proceeds on three levels, namely, ore grade control, process control and quality assurance.

The quality of the ore in the open pits is initially determined from the analysis of diamond drill core. Samples from the drill core are subjected to chemical analysis and microscopic examination. The secondary phase of ore grade control deals with the analysis of drill cuttings sampled from the production drill holes. The samples from the diamond drilling and drill cuttings are processed in a pilot plant which duplicates the milling process. The data obtained from the drill cuttings are correlated with the diamond drill results and are also used to calculate the blending ratios in the mining operation.

Information from the process control program is used to monitor the alkali, alumina, and fired colour of the ore blend from the open pits and to assist in controlling the iron content and particle size of the products within the mill.

The final level of the program, quality assurance, pertains to the analysis of representative shipment samples.

SUMMARY

The glass industry is, by far, the largest user of nepheline syenite. In this industry, nepheline syenite is the primary source of alumina and also provides silica and alkali.

Alumina increases the viscosity of the melt and improves the resistance of the finished glass to surface attack. The secondary mill products, i.e. A-200, A-270 and A-400 are sold to the ceramic industry. The nepheline syenite acts as a vitrifying and fluxing agent, binding together the other constituents and reducing the firing time and temperature of sanitary-ware, porcelain and whiteware products.

The extender and filler markets represent the smallest, yet a growing market area. The Minex 4, Minex 7 and Minex 10 grades are used in paint, rubber and plastic filler applications.

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Lime in Ontario

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ABSTRACT

Ontario is the largest producer of lime among the Canadian provinces. Of the nearly 1.9 million tonnes produced in the Province in 1981, the bulk came from the producers quarrying the Detroit River limestone deposit in the Beachville area. Domtar Chemicals/Lime Division operates the largest of the three lime plants in the area.

The high-calcium limestone of the Detroit River Group occurs in medium to thick flat-lying beds of varying physical characteristics. Stylolites, corals and football-like stromatoporoids occur abundantly in the formation. The brownish-grey to tan stone varies from medium crystalline to a micro crystalline texture of high chemical purity. Average composition of the quarried stone exceeds 98% calcium carbonate. Moderate to high depths of overburden cover the stone in the area. The quarried face is about 70 feet high. The depth of quarrying is limited by the underlying Bois Blanc Formation which is characterized by high levels of silica and magnesium carbonate, rendering it unsuitable for lime production.

The Detroit River limestone is characterized by narrow bands of chemical impurities at specific levels in the formation. These impurities play an important role in the quarrying and processing methods as they have a bearing on the ultimate uses of the products of the operation.

The high-calcium stone is quarried, crushed and screened, and used primarily as feed to the lime plant which has both vertical and rotary kilns. Part of the resulting quicklime production is used to make hydrated lime. Because of the high quality of the stone, a variety of specially-sized limestone products is also produced.

Six gas-fired vertical (or shaft) kilns at 75 tonnes per day each and three rotary kilns (two at 250 tonnes per day and one at 550 tonnes per day) constitute the main calcining capacity at Domtar's Beachville plant. The vertical kilns burn limestone 4-6 inches in size charged from skip hoists. The rotary kilns are fed with smaller limestone ranging in size from 1/4 to 2 inches. Due to varying fuel costs, comparative experience with combinations of different fuels (gas, coal, bunker) is continually being explored. The rotary kilns have the advantage of more complete utilization of all stone sizes, greater production per man hour and better control of temperature and feed resulting in better control of product quality.

Markets for lime are myriad. The metallurgical industry is the largest single market for lime from Beachville. Recent developments in hot metal de-sulphurization have augmented this sector. Other predominant areas include mining, pulp and paper and water treatment. Recent potential developments include liming of lakes and the removal of sulphur dioxide (SO_2) from hydrocarbon fuels or from stack gases by either wet or dry scrubbing.

A pulverized limestone plant produces a range of dry screened products used for glass manufacture, fillers, soil conditioners, fertilizers and feeds.

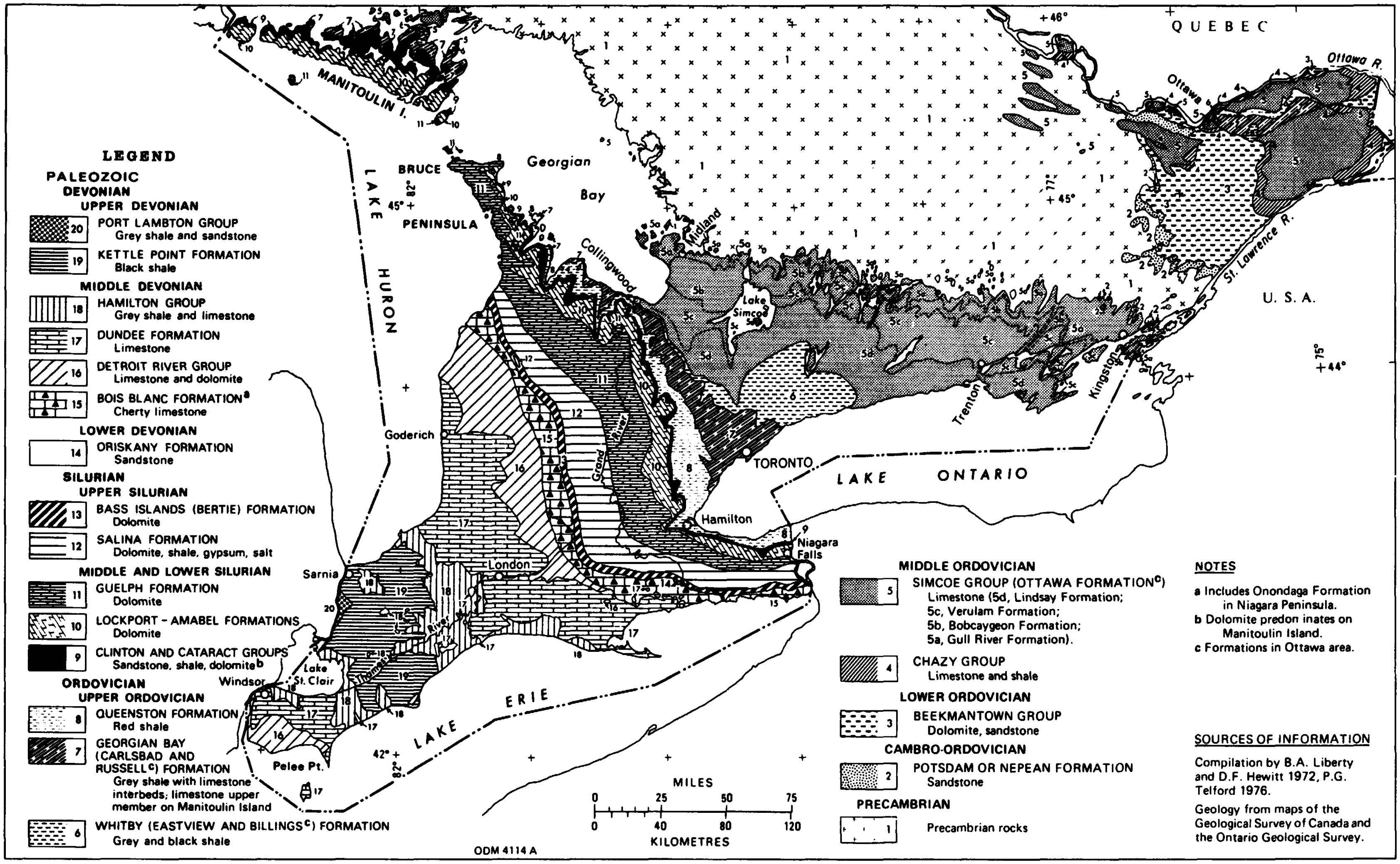
INTRODUCTION

Ontario is the largest producer of lime among the Canadian provinces, accounting for 65% of the Canadian total production of just over 2 million tonnes. There are at present nine operating lime plants in the Province of which six produce high-calcium lime and three produce dolomitic lime. Of these, six produce mainly for captive use.

Three of the main producing facilities for high-calcium lime which constitute about 70% of the total production are located in the valley of the Thames River between the Town of Ingersoll and Beachville, a village which calls itself the "Lime Capital" with some justification.

GEOLOGY

In the Beachville area, along the river, is exposed limestone of the Middle Devonian Detroit River Group. Figure 1 shows the various bedrock formations in southwestern Ontario where Beachville is located, the Detroit River Group occurring as a band varying in width from a few miles to nearly 25 miles and stretching from Lake Huron, north of Goderich, southeasterly to Lake Erie. The banded distribution of this and other Paleozoic formations in southwestern Ontario is the result of the shallow westward dip of the strata towards the centre of a dished structure referred to as the Michigan Basin. The various formations outcrop in narrow to moderately wide bands, terminating to the east at the Niagara Escarpment. The sedimentary formations in the area are near the eastern edge of the Michigan Basin, which is centred on the lower Michigan Penninsula. The Detroit River Group also outcrops in other areas to the southwest and is an important source of high purity limestone at Amherstburg along the Detroit River and in northern Michigan. Figure 2 shows the Michigan Basin and



55 **Figure 1.** *Bedrock geology of southern Ontario (from Uyeno et al. 1982).*

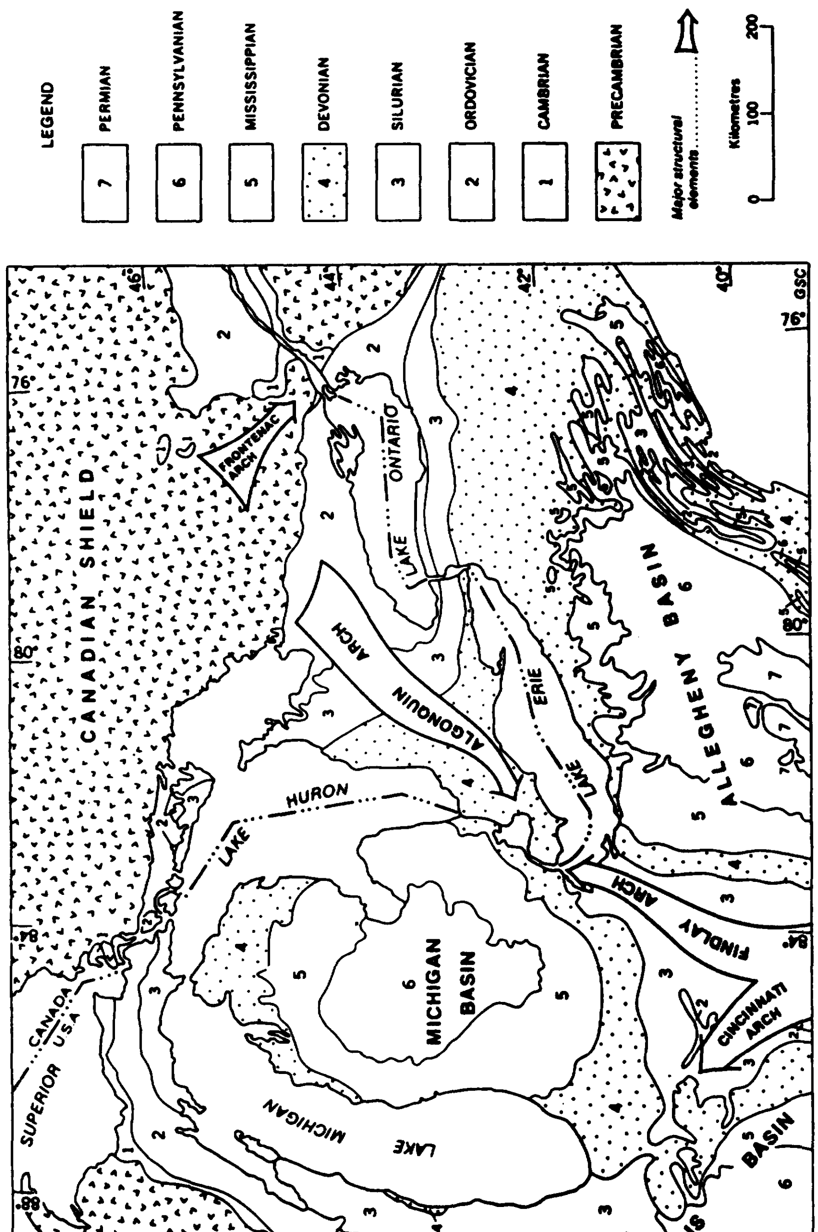


Figure 2. Geological map of the Great Lakes region of Canada and the United States (from Uyeno et al. 1982).

its relation to other geological features in the Great Lakes region.

Recent studies have further characterized the Detroit River limestone. Uyeno *et al.* (1982) gave the following description: "The Detroit River Group consists of the Amherstburg Formation and the overlying Lucas Formation .... Excellent exposures of the Lucas Formation occur in quarries near Amherstburg, Ingersoll (Beachville area) and St. Marys .... The Anderdon Member (of the Lucas Formation) is quarried extensively near Ingersoll and Amherstburg and is a very high purity limestone. In the Ingersoll area where quarrying has exposed a virtually complete section of the unit, the Anderdon Member is about 39.5 m thick."

Hewitt (1960) has described the limestone in the Beachville area: "The 110 feet (34 m) of Detroit River limestone is characterized by its high purity and averages less than 1 percent combined silica, iron and alumina, and less than 1-1.5 percent magnesia. This limestone is the thickest, most uniform and purest high-calcium limestone available in Ontario and is an important stone source for the production of chemical lime."

Geology of the Domtar Quarry

Domtar Chemicals Group/Lime Division is the most easterly of the three lime producers operating in the area. Because of the dip of the strata the full thickness of Detroit River stone is reduced to about 75 feet (25m) in the Domtar quarry. To quote Hewitt further, "Eastward in the (Domtar) quarry the thickness of high-purity stone diminishes. The lower contact of high-purity stone is placed at a well marked chemical unconformity where the magnesia content exceeds 2 percent and the silica content exceeds 1 percent. There is no marked lithologic break but chert generally appears in the upper part of the Bois Blanc formation which underlies the Detroit River limestone. The limestone dips southwest at the rate of 30 feet per mile in the Thames River valley at Beachville."

Hewitt (1960) illustrated the characteristics of the quarry face as shown in Figure 3 and described the limestone as follows: "The Detroit River limestone is medium brownish grey-weathering; medium crystalline to micro crystalline; medium to thick-bedded with abundant styolites, corals and 'football-like' stromatoporoids. Black bituminous partings are present."

Chemical analyses reported by Hewitt are reproduced in Table 1. This diamond drill hole which was drilled to the east of the quarry intersected only 50 feet of Detroit River stone. The marked change in limestone purity in the Bois Blanc is well illustrated in the data. Figure 4 is a quarry section as drawn by our company geologist showing certain defined features. As the quarrying has moved away from the Thames River, the depth of overburden has increased substantially. At the top of the quarry face we find 30 feet or more of high-purity stone overlying 5-15 feet of a layer of somewhat lower purity, characterized only by an increase in $MgCO_3$ content. Below this is about 10 feet

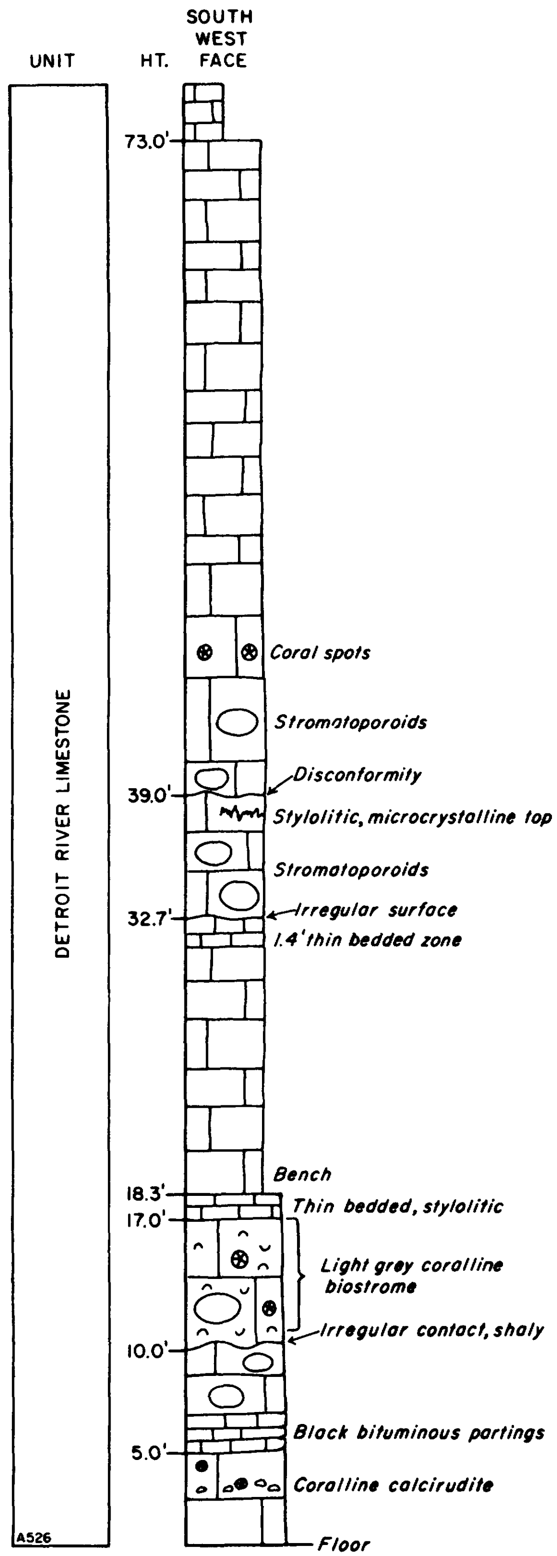


Figure 3. *Representative stratigraphic section of Domtar quarry at Beachville (from Hewitt 1960).*

TABLE 1. CHEMICAL ANALYSES OF DIAMOND DRILL CORE FROM DOMTAR QUARRY AT BEACHVILLE (HEWITT 1960, FROM COMPANY DATA).

	Depth feet	L.O.I. percent	SiO_2, R_2O_3 + Insolubles percent	CaO percent	MgO percent	SO_3 percent	Total percent
Overburden	0- 23						
Detroit River Limestone	23- 26	43.66	0.41	55.20	0.32	0.04	99.63
23-73(?) feet	26- 28	43.85	0.68	54.80	0.18	0.02	99.53
total 50 feet	28- 35	43.77	0.37	55.00	0.32	0.03	99.49
	35- 40	43.85	0.39	55.00	0.16	0.04	99.44
	40- 45	43.44	0.88	54.30	0.83	0.06	99.51
	45- 50	43.79	0.74	54.00	0.96	0.06	99.55
	50- 55	43.79	0.48	55.00	0.30	0.04	99.61
	55- 60	43.35	0.57	55.40	0.21	0.06	99.59
	60- 65	44.01	0.48	54.80	0.25	0.04	99.58
	65- 70	44.24	0.50	54.10	1.02	0.05	99.91
	70- 75	44.00	1.11	53.20	1.61	0.07	99.99
Bois Blanc Formation	75- 80	42.12	5.25	50.65	1.81	0.09	99.92
73(?)-127 feet	80- 85	42.95	3.63	50.10	3.24	0.09	100.01
(bottom of hole)	85- 90	41.97	6.64	47.00	4.41	0.08	100.10
total 54 feet	90- 95	42.20	6.08	47.40	4.35	0.05	100.08
	95-100	42.45	4.90	51.05	1.54	0.10	100.04
	100-105	40.22	9.66	48.50	1.63	0.05	100.06
	105-110	40.09	9.84	49.10	0.96	0.03	100.02
	110-115	38.96	12.29	47.40	1.25	0.04	99.94
	115-120	36.54	17.75	44.30	1.44	0.07	100.10
	120-125	36.55	18.16	44.30	0.94	0.06	100.01
	125-127	25.21	42.85	30.50	1.26	0.04	99.96
			Average Chemical Analyses				
Detroit River (52 feet)		43.80	0.61	54.58	0.59	0.05	99.63
Bois Blanc (52 feet)		40.41	9.42	47.98	2.16	0.07	100.04

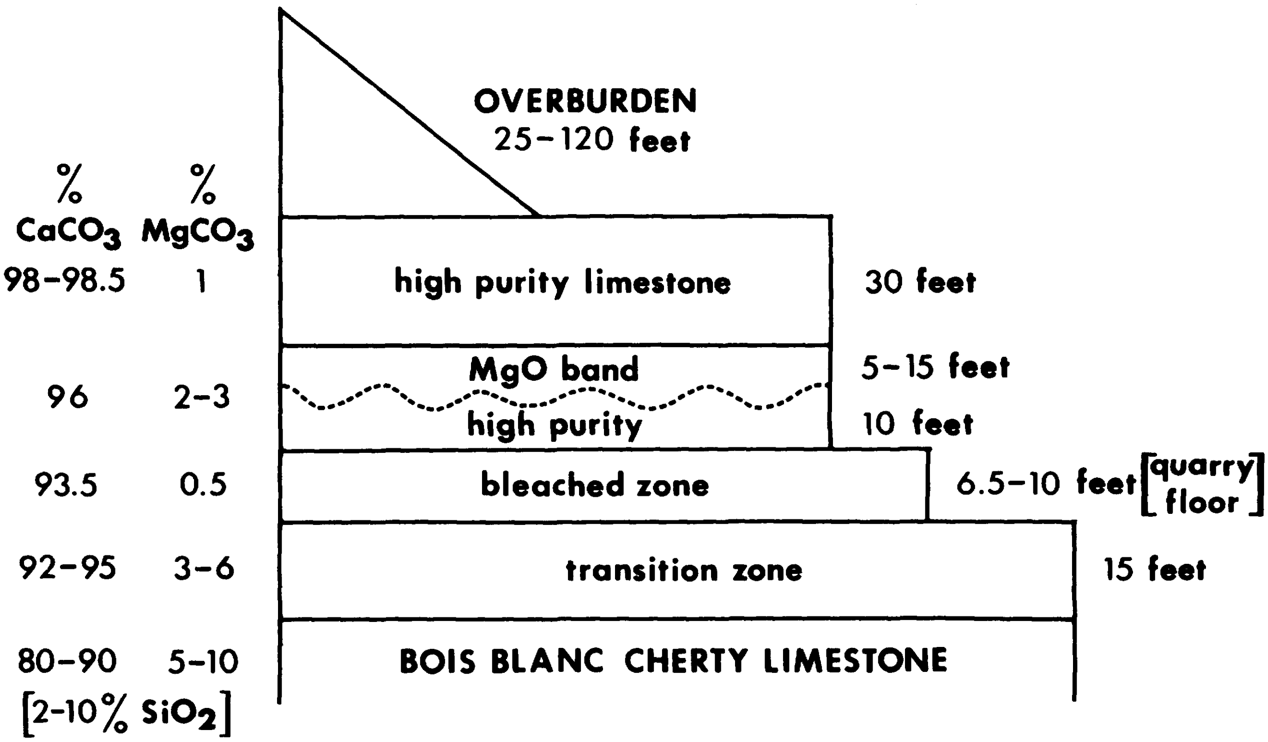


Figure 4. *Schematic section of Domtar quarry at Beachville, showing extractive units (prepared by company geologist).*

of high purity stone and then a very thin but well defined pyrite zone where grains of pyrite can commonly be seen scattered through the limestone matrix. Below the pyrite zone is 6-10 feet of very high purity limestone referred to as the bleached zone because of its lighter colour. The bottom of the bleached zone is the normal quarry floor. Below the bleached zone is about 15 feet of limestone referred to as the transition zone and characterized by increasing $MgCO_3$ content. Below that is the Bois Blanc cherty limestone, in which there are further increases in $MgCO_3$ and SiO_2.

MINING AND PROCESSING AT THE DOMTAR QUARRY

The 60-70 foot face is drilled and blasted in one lift. Broken stone is loaded in trucks and hauled about l km to a primary crusher. The crushed stone goes through a screening and recrushing operation to provide various sizes for the lime-making operation. Stone from 1/4 to 2-1/2 inches (5-50 mm) in four specific fractions is used as feed to three rotary kilns. Stone 4 to 6 inches (100-150 mm) is used as feed to four vertical kilns. Rated production of lime is 1500 tonnes per day making this the largest lime facility in Canada.

Most of the lime produced is screened to give pebble lime, the most popular form for most applications. Some finer sizes of lime are also produced. Most of the lime is shipped in bulk form – trucks or rail cars – but some of the finer material is bagged. Some of the quicklime is also used for production of hydrated lime where two hydrators adequately supply market requirements.

A stone processing plant is also part of the operation, producing several sizes of high-purity limestone for particular applications ranging from a nominal 4 X 8 mesh (2-6 mm) down to a product which is essentially 100% -100 mesh (150 micrometres).

USES OF LIME

In an industry with a 2000-year history, quicklime can only be described as a mature product. However, it has a substantial and continuing position in the market place. In terms of tonnage, lime ranks second to sulphuric acid as the largest chemical product from the standpoint of both shipments and consumption (National Lime Association 1981).

The versatile properties and multiple end uses of lime have sustained continuous growth over the years. As construction markets for mortar and plaster declined during this century, uses in steel manufacture rose. Currently, as growth in steel consumption dwindles, potential environmental uses for lime in water and sewage treatment and flue gas de-sulphurization have emerged.

Because lime is an extractive industry, it is fully integrated backwards. Fuel, power and explosives are purchased supplies with fuel being the major cost item. Thus, total manufacturing costs are affected mainly by the cost of energy as the manufacture of a tonne of lime requires from 5.5 to 8.5 million BTU's depending on the process used and its efficiency.

The served market for Domtar's Beachville Lime Plant is composed of Ontario and parts of the States of Michigan and New York. Quicklime and hydrated lime shipments are fairly evenly distributed amongst these areas.

Domtar's main served industry is steel which accounts for a major portion (60%) of the plant's quicklime shipments. In steel manufacture lime acts as a flux in purifying steel during the "heat" by promoting fusion of the slag and assisting in the removal of phosphorus, silica, and sulphur as calcium phosphates, silicates, and sulphides in the slag that is tapped off the molten metal (Boynton 1980). Most steel plants that desulphurize the hot metal externally in torpedo cars or ladles following the blast furnace and before charging into the BOF (Basic Oxygen Furnace) also require quicklime or lime-based calcium carbide and magnesium metal as the sulphur scavenger (National Lime Association 1981). Other served markets for Domtar's quicklime include mining, sewage and water treatment and chemical applications with approximately equal product distribution (10-12%) among these sectors.

Increasingly, lime is being employed to abate air pollution by de-sulphurizing stack gases at utility and industrial plants burning coal and high sulphur oil. In addition to removing up to 98% of the sulphur, lime also absorbs about 50% of the nitrogen oxides, and concomitantly greatly reduces particulate emissions (National Lime Association 1981).

The main markets for products from Domtar's stone processing plant are the glass, fertilizer and feed industries. In glass manufacture, a sand-sized high purity limestone is used as a basic raw ingredient along with silica sand and soda ash. For fertilizer, a fine high purity limestone (-200 mesh) is a prime ingredient in the production of di-calcium phosphate. Other uses for fine limestone are as a filler in construction material products (shingles, coating etc.). One of the oldest and still significant uses of limestone is as a plant nutrient and neutralizer of acid soils.

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The Role of Industrial Minerals in Canada from a Policy Point of View

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ABSTRACT

Of all the non-fuel minerals, the industrial minerals sector is the most complex and as such, it offers the greatest challenges and opportunities. Industrial minerals are and will continue to be directly associated with virtually every activity of human life e.g. eating, dressing, housing, transportation, arts, etc. However, these essential ingredients of human activity are largely ignored mainly because of the numerous stages of transformation involved in making them suitable for final consumption. Unlike the metals which are easily recognizable in consumer goods, industrial minerals are hidden in compounds that often entirely mask their origin.

Industrial minerals play another important role in the life of Canadians: for example, they accounted for about one-third ($5 billion) of the value of total mineral production (excluding fuels) in 1981. They account for even more in terms of transportation volumes.

Another reason why the industry fails to attract the attention it deserves, is that only a few industrial minerals can be referred to as "major internationally traded commodities". Only potash, asbestos, sulphur, and phosphate rock could be classified in that category. For example, the first three account for almost 90% of all Canadian exports of industrial minerals. In fact, Canada is the world's largest exporter of these three minerals, a ranking which tends to dwarf the importance of other industrial minerals.

Canada currently relies on imports for all of its phosphate rock requirements. This reliance is not a concern for the federal government but relatively new information on the potential of major phosphate deposits in northern Ontario points to future opportunities for development of a fully integrated fertilizer industry in Canada. Phosphate rock imports currently represent a deficit of some $150 million in our balance of trade.

Phosphate rock is only one example where opportunities to develop Canadian capacity in industrial minerals is evident. Such opportunities to replace imports and possibly to develop export-oriented industries do exist in other industrial minerals but they are less evident. In that context, the Mineral Policy Sector of Energy, Mines and Resources Canada has undertaken initiatives to promote the industrial minerals sector.

First, junior mining taxation has been highlighted in the Mineral Policy Review as an area for action; an inter-governmental task force has examined ways in which tax systems could be changed so that junior mines could benefit from certain tax write-offs. Many such operations exist in the industrial minerals sector and are unable to benefit from these write-offs as they have no other source of income.

The second initiative was undertaken last year by the Industrial Minerals Division. The division, with the assistance of industry, is preparing a compilation of uses and required specifications for industrial minerals. This will be followed by a detailed examination of our supply base. It is expected that the results will assist existing and potential producers of industrial minerals in identifying market opportunities, and users in identifying potential sources of supply.

These are modest initiatives, but, along with those undertaken by various provincial governments, they will help enhance the potential of Canadian industrial mineral resources.

INTRODUCTION

The major issues concerning industrial minerals, that are of direct interest to the Mineral Policy Sector of Energy, Mines and Resources Canada, include public health, the environment, international trade problems and, last but not least, the recession and its implications for the construction materials industry. But first, I would like to mention a few facts that illustrate the importance of industrial minerals.

Traditionally, industrial or non-metallic minerals have failed to receive the attention they deserve in comparison to other materials (for example the non-ferrous metals). In that regard, my own organization, the Mineral Policy Sector is also guilty. This is due to a number of factors.

First, many industrial minerals, because of their bulky nature, are limited to a regional role. Only a few enter international trade, which is an area where the federal government traditionally focuses its attention.

Secondly, industrial minerals do not enjoy the glamour or high visibility of metals, not only because they are usually low-priced and bulky, but because they are not subject to speculative trading.

A final reason is that the industrial minerals industry is extremely complex and only a few specialists understand it well.

As a result of all these factors, there is limited information available on these minerals, and the industry is not the subject of a great deal of public and political attention.

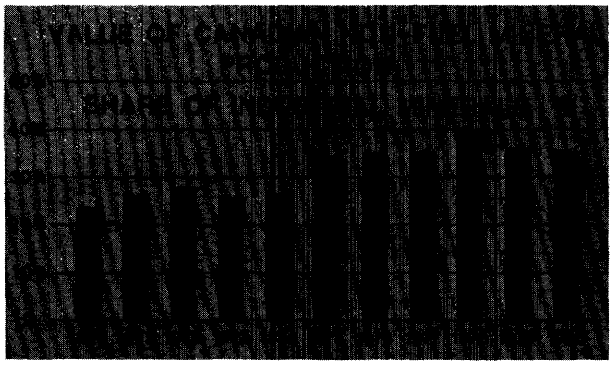

Figure 1. Industrial minerals' share of value of Canadian non-fuel mineral production, 1970-1980.

Most readers will surely agree that industrial minerals deserve additional attention because they represent more than 30% of the value of Canadian non-fuel mineral production (Figure 1), and that percentage seems to be growing. In money terms, this was equivalent to about $4.7 billion in 1981. The industry (both mining and manufacturing) normally employs about 75,000 Canadians and there are over 4,000 corporations involved in industrial minerals.

These minerals are present in massive quantities in our daily lives (Figure 2). For example, the annual per capita consumption of stone in North America is about 5 tonnes. This compares to 23 pounds of copper or 12 pounds of zinc consumed by each person each year.

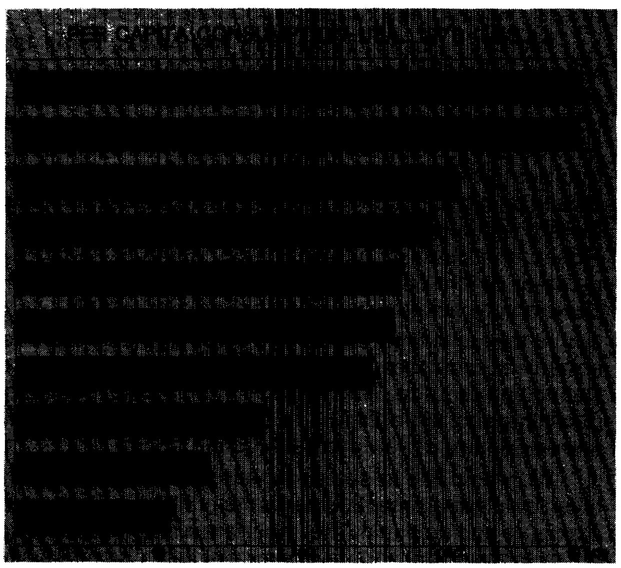

Figure 2. USA per capita consumption of industrial minerals and non-ferrous metals.

As I have mentioned, only a few major industrial minerals play a substantive role in our international trade. Even so, our country accounts for over 50% of US imports of lime, asbestos, potash, nepheline syenite, sand and gravel, crushed stone, gypsum, sodium sulphate and sulphur.

PUBLIC HEALTH AND ENVIRONMENTAL CONCERNS

Asbestos

Let me now turn to the issue of public health. One major industrial mineral that is seriously affected by that issue will come quickly to your mind; that is asbestos. Until the 1970s, asbestos production in Canada enjoyed nearly continuous growth and about 95% of production was sold on world markets. But demand has been falling since 1979 (Figure 3) when production was 1.5 million tonnes valued at more than $600 million. Last year, Canadian production was only 822,000 tonnes valued at $403 million because of depressed economic conditions worldwide and a shift towards substitutes.

This shift has accelerated in recent years because of adverse publicity about the health effects of exposure to asbestos. This publicity was often based on a misleading interpretation of medical facts and an exaggeration of the problem. It is true that severe problems occurred as a result of past high exposure levels but these are conditions that no longer exist in the environment or the work place.

The Government of Canada believes that asbestos can be used safely. Moreover, employees, and the public in general, can be protected from the risks associated with exposure to asbestos dust by suitable product design and enforcement of appropriate regulations.

Officials of my own department of Energy, Mines and Resources Canada and also Industry, Trade and Commerce have been particularly active in initiatives to protect the asbestos industry from the effects of unwarranted adverse publicity and unfair treatment of asbestos in certain key markets. Our departments are working in close consultation with provincial governments and were instrumental in convening the first World Symposium on Asbestos last year, as well as in the establishment of the Canadian Asbestos Information Centre in Montreal. Moreover, the Government has made representations in key markets, particularly in Western European countries that have adopted or are about to adopt unduly restrictive regulations. These regulations are often nothing less than a de facto ban of asbestos products.

As you will note from the production curve (see Figure 3), the performance of the asbestos industry has been rather dismal since 1979. It is very difficult to forecast what the future holds for Canadian asbestos production, as the

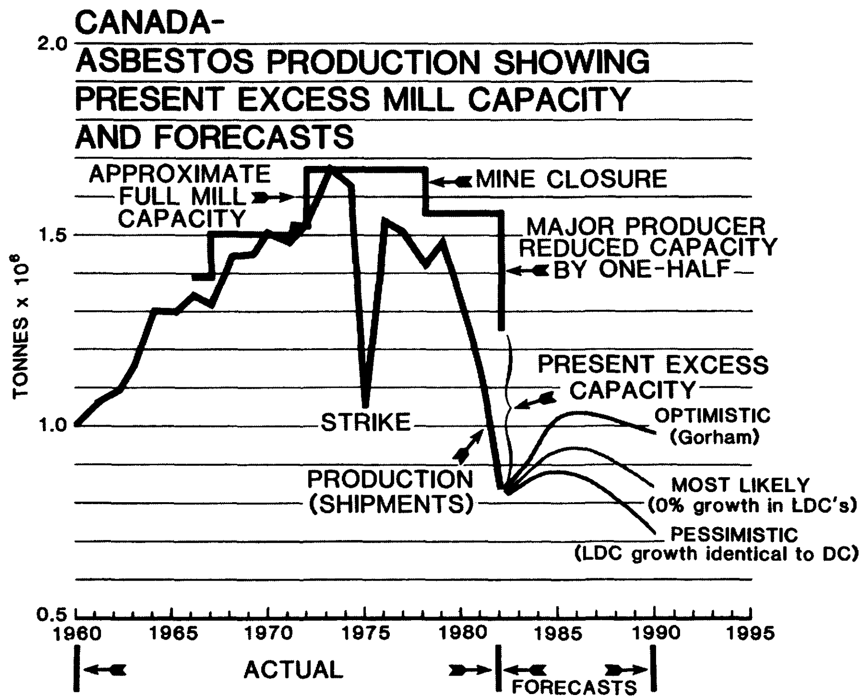

***Figure 3.** Canadian asbestos production showing present excess mill capacity and forecasts.*

move toward substitutes is accelerating. It is almost impossible to define what percentage of the deterioration is due to substitution as opposed to the recession. For that answer we have to wait till the economy recovers. However, if we assume that control-type legislation rather than total banning will dominate the regulatory approach worldwide, the most likely scenario for growth in Canadian production will range between 0 and 0.5% per year over the next 10 years.

In Canada, federal and provincial governments have adopted stringent regulations to control the exposure to asbestos.

In general, governments have regulations in place which limit exposure to asbestos in the workplace to realistic and safe levels. The Government of Canada, together with the majority of provincial governments, endorses the view that workers and the general public can be protected from the risks associated with exposure to asbestos dust. According to available evidence, this can be done through suitable product design, as well as through enforcement of appropriate regulations in occupational health and environmental control.

Sulphur

Sulphur is another major industrial mineral that has been affected by environmental issues although not in the same fashion as asbestos. Only about 10 years ago, sulphur was seen by many as a nuisance by-product of natural gas, and a great deal of effort went into research to find new uses for it. Prices were as low as $1-2 per ton. Practically no one really knew what to do with sulphur, and stockpiles of 21 million tonnes were accumulated, mainly in Alberta.

Eventually, demand for sulphur improved to a point where prices went as high as $100 per tonne and Canada emerged as the world's leading exporter. Some of our customers are even upset about the level of recent sulphur prices. I will address that issue separately below.

Without claiming that we are visionaries, we in the Mineral Policy Sector are proud of the fact that we have always (even 10 years ago) considered sulphur a precious commodity. We felt it should not be regarded as a waste by-product to be disposed of at any price. And our forecast was right (for once). We still believe that sulphur prices should be high enough to promote its capture at smelters, thereby reducing sulphur dioxide emissions and acid rain. Indeed, the price of sulphuric acid, which is partly dependent on the price of sulphur, is a key determinant in decisions by smelters to build acid recovery plants.

At the same time, the current sulphur price ensures a sizeable source of export revenues (Figure 4) for a scarce Canadian resource. The availability of sulphur has been declining and will continue to decline as a result of the sweeter nature of new gas sources in Canada.

We would like to see consistency in the approaches taken by all governments towards the problems of asbestos exposure and acid rain. The importance and use of public policy in the social and environmental fields is continually increasing. Unless consistent approaches are taken, such policies could be increasingly used as instruments for

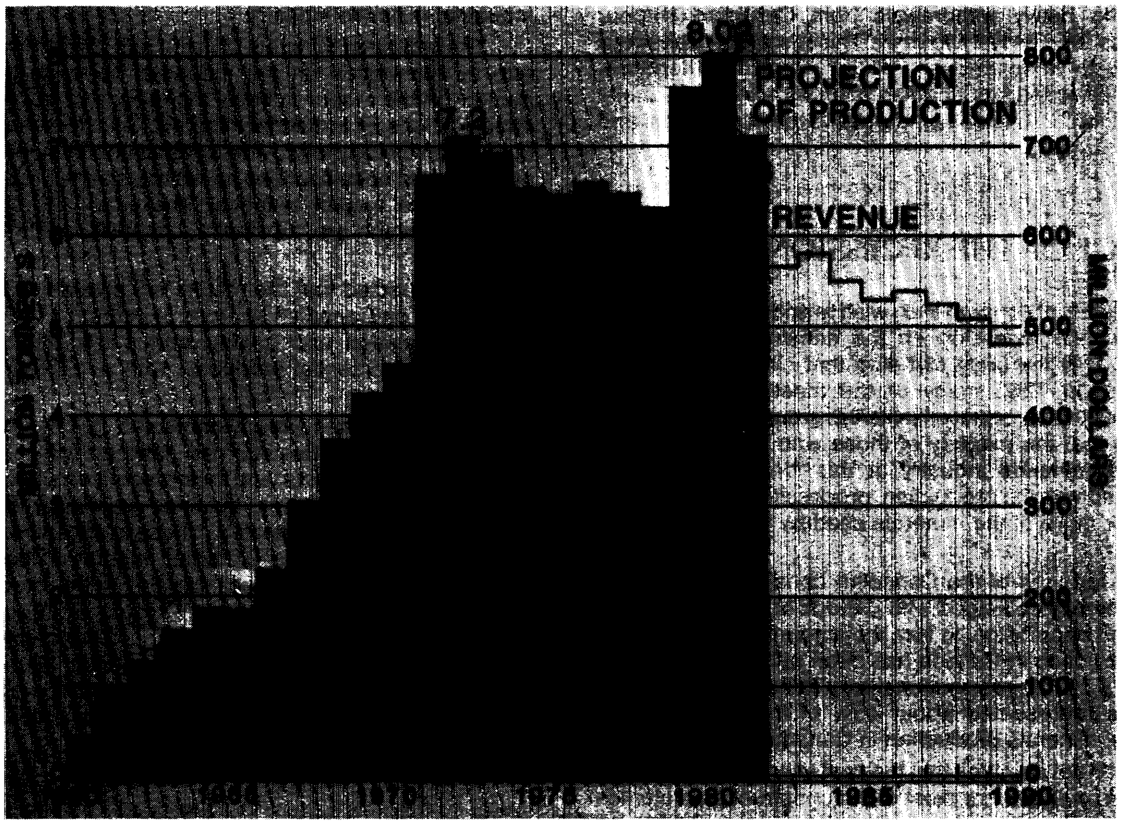

Figure 4. Canadian elemental sulphur production and forecasts.

economic protectionism rather than for safeguarding public health and safety.

INTERNATIONAL TRADE

The next issue that I would like to address is that of the new international trade environment. Several nations are undergoing severe problems of excessive indebtedness. Most of these are developing country exporters of raw materials in competition with Canada. The resulting liquidity crisis is leading to arrangements such as barter or counter-trade deals and clearing accounts between importing and exporting nations.

Potash and sulphur exports to Brazil are good examples of the type of problems that will confront Canadian exporters of minerals in an increasing number of markets. Poland, with a debt in excess of $1.5 billion towards Brazil, has insisted on repaying Brazil with exports of coal, sulphur and ice-breakers. Brazil has accumulated a sizeable trade surplus with East Germany over recent years. To correct this imbalance, preferential financing and trading arrangements between Brazil and East Germany have been implemented to favour imports of East German potash. Thus, the Canadian shares of the Brazilian market for sulphur and potash are jeopardized by factors having little to do with normal market forces. The federal government, in consultation with industry and provincial governments, has been working actively to preserve the Canadian share of the Brazilian market but this may not be sufficient. At the moment, Canadian companies are not heavily involved in barter trade. The ever increasing popularity of this form of trade may call for serious examination of policies or mechanisms required by Canada to respond to this development.

Morocco is another area of concern with respect to Canadian sulphur trade. Morocco is a very important market for Canadian sulphur, using it to manufacture phosphate fertilizers. However, the price of these fertilizers, a major source of revenue for Morocco, has declined seriously and Moroccan importers have been putting pressure on Canadian suppliers to reduce the price of sulphur. Alleging that Canada has behaved in such a manner as to keep prices at high levels, the Moroccans have refused to perform on contracted tonnages from Canada.

We have responded to Moroccan allegations by pointing out that Canada has been sensitive to its international obligations by exporting more than it has produced, leading to heavy withdrawals from Canadian sulphur stockpiles over the last two years. This is scarcely behaviour designed to keep prices artificially high. Furthermore, supplies provided by Canadian sources are exceptionally secure compared to some sources in the Middle East and Eastern Europe.

IMPACT OF THE RECESSION

The last issue of concern that I wish to address is that of the impact of the recession on the construction materials industry. It is my understanding that since the Forum's beginning in 1965 many of the meetings have been focused on the construction materials group of commodities. I believe that the majority of those who represented the industrial minerals industry at this forum are, in fact, associated with the production, processing and marketing of one or more of the minerals used by the construction industry.

The fortunes of the Canadian construction industry have generally coincided with periods of economic prosperity and depression. In fact, the amount of money spent on construction in Canada has been rather consistent at 16.0 to 16.5% of gross national expenditure. Construction materials represented about 43% of the total value of industrial minerals production in Canada in 1982.

I need not point out that the past year has been one of the worst on record for most of the construction materials industries. The Canadian portland cement industry, for example, operated at only slightly more than 50% of its rated capacity.

As an aside, I should mention that the Canadian industry has exported cement and clinker to neighbouring American states in significant quantities in recent years. One particular issue that has our portland cement industry concerned is the inclusion of a "buy American" clause in recent legislation — the United States Surface Transportation Assistance Act — which is designed to fund the upgrading of the nation's highway systems. The prospect of such a barrier to free trade is clearly of concern also to the Canadian Government.

Turning back to the economic situation, traditional indicators are not encouraging for the immediate future. None of the construction material producers is expecting any remarkable recovery in 1983. Canadian housing starts could increase to approximately 150,000, but this is still far below the 1976 record level of 273,000. The Canadian Construction Association predicts slow recovery in the non-residential building sector through the next two years and only about 4% real growth in the heavy construction sector through 1984. Capital investment projections by major Canadian companies for 1983 and beyond were reduced by 8% during 1982. However, it is expected that measures announced in the recent federal budget will stimulate activity in the construction sector in particular.

Before closing, I will mention an initiative recently undertaken by the Mineral Policy Sector of Energy, Mines and Resources Canada that we hope will assist the industrial minerals industry.

The Industrial Minerals Division has identified a major gap in information on the industrial minerals industry, namely on the resource base, the uses, and the required specifications for industrial minerals. So, it has decided to embark on a study to provide a global compilation of uses and required specifications as well as an accurate knowledge of the market potential. The study will cover all industries which are substantial consumers of industrial minerals.

It is expected that the results will provide users with information on Canadian sources of industrial minerals in terms of location and quality, and it will also provide producers or potential producers with valuable information on markets.

The Division has already contacted close to 100 user companies in industries such as glass, abrasives, refractories and clay products, and their response has been very encouraging. The survey obtained positive responses from 85% of those contacted. These companies, representing over 95% of the Canadian market in these four sectors, have offered to collaborate in the study. The Division has begun compiling the results from questionnaires that were sent to plants in April. Other segments of the industrial minerals processing industry will be dealt with in subsequent phases of the study. We believe this will be a useful study and are grateful for the cooperation of the industry in it.

CONCLUSIONS

The health of the industrial minerals industry is closely linked to general economic conditions.

Investment spending is still sluggish as a result of low operating rates and profit levels, but recent budget proposals and changes in economic indicators seem to indicate that while the recovery may be slow, the bottom has been reached and we are now on an upward curve.

In spite of these encouraging signals, much effort is still required in designing and implementing programs to assist the mineral industry to recover after the recession. If these efforts from all levels of government and from the private sector are successful, they will ensure that our industry is in a position to take full advantage of the recovery while adjusting to structural changes in a way that will improve its long-term competitive position.

Aggregates — The Often Maligned and Often Forgotten Industrial Mineral

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ABSTRACT

Aggregate resources, consisting of sand, gravel, stone, crushed stone or ballast materials, represent a considerable percentage of the overall tonnage of industrial mineral production.

This paper will review the status of aggregate production with respect to total mineral production and with respect to other industrial minerals in Canada with emphasis on the Province of Newfoundland.

The necessity of aggregate production and the importance of interaction of the granular resource manager with other resource agencies (i.e. agriculture, forestry, etc.) and with municipal planners will be discussed.

The need of aggregate production is related to consumer demand as dictated by domestic, institutional, and industrial growth. Transportation costs figure substantially and the results of restrictive land use policies are borne ultimately by the consumer in terms of higher priced aggregates.

INTRODUCTION

Mineral aggregates are defined as "any of several hard, inert, construction materials such as sand, gravel, slag, crushed stone or other mineral material or combinations thereof". Fragments of various sizes or combinations of sizes may be mixed with a cementing or bituminous material to form concrete, asphalt, mortar, plaster, etc., or may be used alone as in railroad ballast or in various manufacturing processes (such as fluxing). These uses may be extended to include aggregates used in road construction (for subgrade fill or ballast and sub-base, base and asphaltic gravels, crushed stone, etc.), bridge construction (e.g., concrete aggregates), and domestic and industrial construction (e.g., fill or ballast used in site preparation, driveway and parking lot aggregates, concrete aggregates in foundations, etc.).

Not all materials are suitable for aggregates. For example, too much or too little fine material (silt/clay) in aggregates used in road construction can cause instability, such as slumping or flowage in the case of too much fine material, or the loss of compaction properties in the case of too little fine material. Too much fine material in concrete or asphalt aggregates interferes with the bonding process between the aggregate and the bituminous or cementing agent. The presence of deleterious substances such as clay/silt coatings or manganese or iron oxide staining on mineral aggregates or a prevalence of certain friable or blade-shaped particles is generally undesirable either because of bonding problems with the cementing agent or because the particles may continue to break down and deteriorate over time.

This paper reviews the status of mineral aggregate production with respect to total mineral production and with respect to other construction minerals in Canada, with emphasis on the Province of Newfoundland.

The necessity of continued aggregate production and the importance of interaction of the granular resource manager with other resource agencies (e.g., agriculture, forestry, etc.) and with municipal planners is also discussed.

SOURCE OF AGGREGATES

Mineral aggregates include unconsolidated surficial materials, consolidated bedrock materials and by-products of industrial processes.

Unconsolidated aggregates may be derived from (a) naturally sorted waterlain sediments such as glaciofluvial, fluvial, lacustrine or marine deposits of sand and gravel, (b) glacially eroded and transported materials such as glacial till, and (c) material derived as products of mass wastage or weathering (e.g., felsenmeer, colluvium, etc.).

The preferred deposits for most uses such as road gravel, concrete and asphaltic mixtures are the naturally washed and sorted deposits that have a low silt/clay content and an appropriate blend of the various size fractions. Extraction of these materials is generally relatively inexpensive and, depending upon the quality of the aggregate and the end use, it requires little or no processing. In the absence of naturally sorted aggregates, glacial till deposits with a somewhat higher silt/clay content are often considered for use after processing (e.g., washing, crushing or screening).

If neither of the above is available near an area of need, bedrock materials provide a reasonable though more expensive alternative. Aggregates derived from consolidated bedrock sources require a substantially larger amount of work to "win" the aggregate from the ground, such as drilling, blasting, crushing, etc., before a product is ready for market. Depending upon the bedrock type and the amount of fines generated by crushing, washing may also be required.

The final category of mineral aggregates is tied directly to manufacturing or industrial processes, for example, the production of aggregates from waste slag derived from a smelter operation.

The glacial history of Newfoundland and Labrador is such that most of the naturally occurring waterlain deposits of sand and gravel are rather restricted in distribution. This distribution often does not coincide with the areas of demand; therefore, materials such as glacial till, colluvium, felsenmeer and bedrock figure prominently in the mineral aggregate industry of the Province.

NECESSITY OF MINERAL AGGREGATE PRODUCTION

Most mineral aggregate usage in Newfoundland and Labrador is in road construction and maintenance programs. These materials vary from ballast used for subgrade construction (usually consisting of the poorer quality sand, gravel, glacial till or bedrock materials) to the better quality gravels used for sub-base, base and surface course construction. The better quality mineral aggregates are often mixed with bituminous materials or cement for asphalt or concrete pavements. Lesser amounts of aggregates are used in concrete curb and bridge construction associated with road building.

Other major uses are related to large scale or megaprojects such as the hydroelectric developments at Churchill Falls, Upper Salmon River and Cat Arm. Future megaprojects will probably include the offshore production of hydrocarbons from the Hibernia oilfield. Activities will include the construction of onshore supply and service bases; the onshore and nearshore construction of concrete production platforms, each requiring up to 500,000 tonnes of aggregates and 150,000 tonnes of cement; and the offshore construction of berms or islands to fend off the icebergs that frequent the area.

Smaller quantities of mineral aggregates are consumed in small-scale construction projects (e.g., office, warehouse, industrial, etc.) and in residential construction.

Aggregates are, therefore, an essential, nonrenewable resource. The resource is nonrenewable since aggregate reserves are finite in quantity, and although some materials may be recycled, the desire for more or bigger and better roads and additional industrial and residential construction will continue to deplete existing reserves.

COMPETING LAND USES IN AREAS OF AGGREGATE POTENTIAL

Most of the better quality unconsolidated aggregates were deposited by glacial or proglacial rivers, streams and lakes and marine waters. These deposits are often in terraces parallel to existing rivers or in areas that were once the bottoms or shorelines of proglacial lakes, streams or coastlines. These areas are generally flat lying and well drained as a result of the mode of deposition and the porosity of the underlying material.

Overlapping demands for use of these areas are common since many of their depositional features have created soils suitable for both forestry and agricultural purposes. The limited nature and distribution of high quality aggregate resource areas and the lack of higher class agricultural soils (no class 1 or 2 soils) in Newfoundland and Labrador has meant that aggregate, agriculture and forestry industries are often competing for the same piece of real estate. Various uses that might be spread over a number of soil classes in other provinces must be accommodated in a very narrow range of soil classes in Newfoundland. For example, soils that would be considered unproductive or marginal agricultural lands in other parts of Canada represent the best of Newfoundland's arable lands.

The problems of a suitable land base are further complicated by the dearth of flat, well drained lands suitable for residential, industrial or other community needs. As a result, agricultural and forestry lands and the areas of mineral aggregate potential are coming under increasing pressure as communities grow and expand.

Recreational requirements (parks, cottage developments, wilderness or nature preserves, etc.) further threaten access to aggregate resources, and wildlife concerns (caribou and moose management areas, etc.) put added pressures to limit extractive operations in some of these areas. In some instances, aggregate extraction has threatened areas of archeological significance, particularly in coastal areas known to have been frequented by the Dorset Eskimo and Archaic Indian (400 B.C. to 700 A.D.) cultures.

AGGREGATE RESOURCE MAPPING — A TOOL IN LAND USE PLANNING IN NEWFOUNDLAND AND LABRADOR

The Newfoundland Department of Mines and Energy has been actively involved in mineral aggregate resource mapping since 1974. In 1977, under the Canada/Newfoundland Mineral Development Subsidiary Agreement, it embarked on a program to map, sample and test the aggregate resources within a 6 km wide corridor parallel to all transportation routes (forestry access roads excluded) in Newfoundland and Labrador (Figures 1 and 2). The corridor was expanded to include an area of 8 to 80 km radius (not shown on figures) around municipal areas and to include areas of ongoing major developments, such as the Upper Salmon River and Cat Arm hydroelectric projects, and proposed developments such as the Lower Churchill hydro-electric development, the Gull Island – Strait of Bell Isle power transmission line, the trans-Labrador (Freedom) highway, and a proposed road for the Kitts-Michelin uranium mine development northeast of

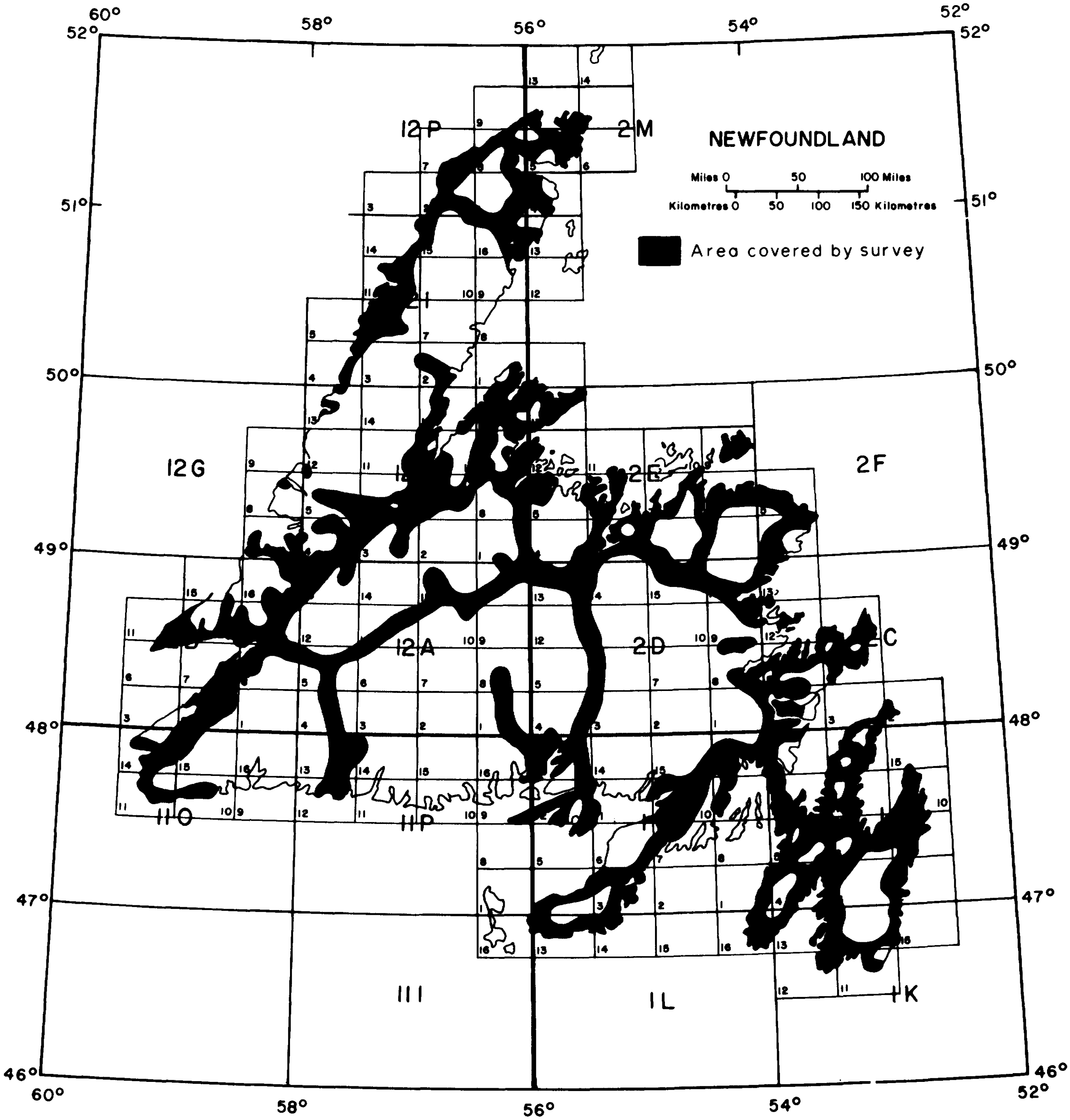

Figure 1. Newfoundland inventory of aggregate resource mapping.

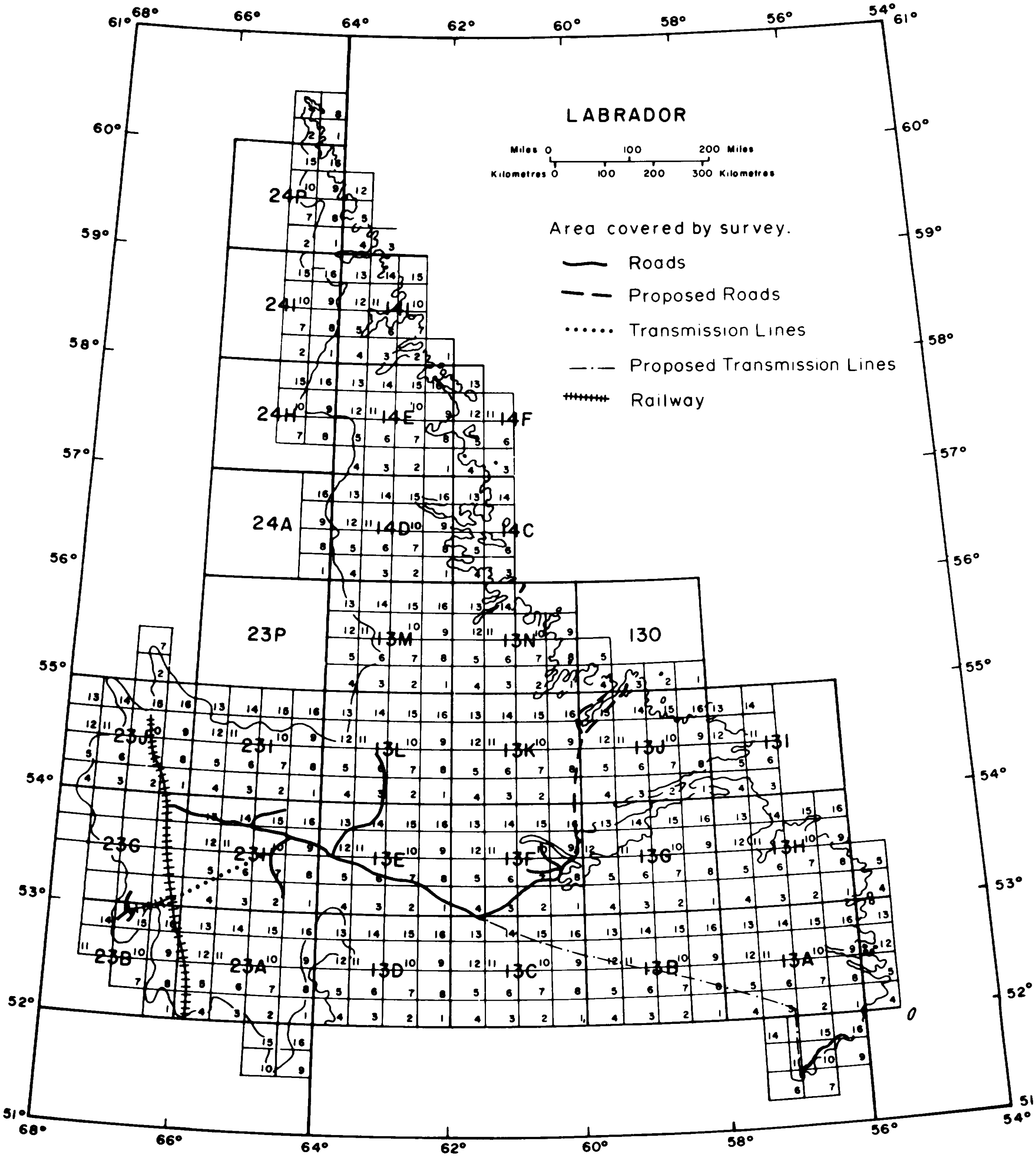

Figure 2. Labrador inventory of aggregate resource mapping.

SPECIMEN LEGEND

1	*Areas known to contain usable granular materials. Probability of locating economic deposits is moderate to high. May include active or inactive pits and quarries*
‹‹‹‹‹‹‹	*Eskers - Sinuous ridges of granular materials, moderate to high potential for locating economic deposits*
1b	*Areas known to contain granular materials of predominantly sand size. High potential for economic sand exploitation, low to moderate potential for other coarser granular type materials*
2	*Areas containing thin or discontinuous or nearly depleted usable granular materials. May also include areas where extent of thicker deposits could not be determined by field investigation. Probability of locating usable deposits is moderate to low*
3	*Areas that may contain usable granular materials but deposits not substantiated by field investigation. Probability of locating usable deposits is low to moderate*
4	*Areas of possible usable materials of nongranular composition, e.g., sandy tills, colluvial or weathered bedrock materials generally containing less than 10 to 15% silt/clay that may be beneficiated for higher grade uses*
	Areas having no known potential for location and production of granular materials

NOTE: *Classification criteria do not include conflicting land uses for routine purposes*

Figure 3. *Classification of zones of aggregate potential.*

Goose Bay. Recently, the program has been expanded to include mapping in 1983 of a coastal strip of southeastern Labrador.

The Inventory of Aggregate Resources program has covered parts of approximately one hundred and eighty 1:50,000-scale map areas, and collected and tested approximately 10,000 samples of sand, gravel, glacial till, silt, clay, etc., in both Newfoundland and Labrador. All areas of aggregate potential within the study areas, as outlined from aerial photography and surficial geological mapping, are zoned (zones 1 to 4, Figure 3) for aggregate resource potential. Investigations and testing include field and laboratory particle-size analyses (for proportions of gravel, sand, silt and clay), moisture content determinations, and an analysis of pebble lithologies to determine petrographic numbers (modified from CSA Standard A23.2, 1973).

The resultant data (e.g., zones of aggregate potential, sample localities by sample type and sample number) have recently been released (Kirby *et al.* 1983) as a series of twenty-nine 1:250,000-scale, four-colour maps.

This aggregate resource information, since the start of mapping, has been made available to land planning agencies such as the Crown Lands Division of the Department of Forest Resources and Lands, the planning office of the Department of Municipal Affairs, the Department of Rural, Agricultural and Northern Development, and other resource or development agencies. The Department of Mines and Energy is working closely with each of these agencies in identifying areas of potential jurisdictional overlap in an attempt to prevent potential land-use conflicts.

The Departments of Forestry and Agriculture have agreed with the Department of Mines and Energy about the necessity of long-term planning for the preservation of areas suitable for extractive purposes. The aim is to develop plans and policies that enable each department to achieve most of its goals.

For instance, by joint agreement of the Department of Forest Resources and Lands and the Department of Mines and Energy, extraction will occur in silviculture (thinning, controlled burns, fertilizing and planting) areas only if no other aggregate resource is locally available. In some cases, silviculture projects were identified in areas with a potential for extraction in the 5 to 15 year range. Plans for replanting, etc., these areas were either modified or dropped in recognition of the necessity of aggregate extraction.

In the case of the Department of Agriculture, it is inevitable that some of the better agricultural land coincides with the better sand and gravel deposits. Lands under agricultural production are subjected to extraction normally only as a last resort. In areas of identified higher aggregate potential, agriculture may be a permitted interim land use but farm buildings may not be allowed. Where no other alternative is available, extraction in areas of agricultural capability is allowed and mining proceeds in a planned manner that will return the land to as near its former capability as possible.

Of prime importance in the case of extraction in areas of forestry and agriculture potential is the preservation of existing topsoil materials, the grading of the pit or quarry area, and the respreading of topsoil materials. During the planning phases of a quarry operation, it is important that a close working relationship be established between the regulatory agency, other agencies with a vested interest (e.g., forestry, agriculture, etc.) and the pit or quarry operator.

The Municipal Planning Office of the Department of Municipal Affairs now contacts the Department of Mines and Energy during municipal plan development regarding areas to be zoned "extractive". In these areas, detailed aggregate assessment (including test pitting with a backhoe) and a detailed plan (scale 1:5,000 or 1:12,500) of the reserves is made. Aggregate reserves are evaluated in relation to existing land uses and proposed community expansion, and the better quality deposits are recommended for zoning as "mineral extractive". Mapping and test pitting at the more detailed level are necessary to enable the selection of prime targets for aggregate resource development and to identify areas of lesser potential that may be used for other municipal purposes.

Municipal plans are not final until officially adopted by the municipality, so the cooperation of the community council is also essential. In this regard, we have recently succeeded in having the Kippens town council, in western Newfoundland, adopt a plan that recognizes a number of areas as aggregate reserves. Several other municipal plans that include extractive designations are currently being prepared for submission for municipal council approval.

The Province of Newfoundland still has available an abundance of Crown Lands. This land is administered by the Crown Lands Division of the Department of Forest Resources and Lands in consultation with other resource and administrative agencies. The Crown Lands Division is currently producing Land Use Plans and Maps (scale 1:50,000). Zones of aggregate potential are identified on these maps and other land uses are not permitted; land grants or leases may not be issued in areas of aggregate potential without prior referral to the Department of Mines and Energy for comment.

The establishment of the importance of Aggregate Resource Zones and the process of attaining a working relationship with other resource and planning agencies have been evolving over a five-year period. Persistence, understanding and tolerance have been important traits during this process.

MINERAL PRODUCTION* 1960 TO 1982

Canadian Mineral Production

The total value of mineral production in Canada (Figure 4, Table 1) has increased from $2,492,509,981 in 1960 to about $33,081,908,000 in 1982. Metals have increased in value 5-fold, non-metals 10-fold, and structural materials 5-fold over this period. Structural materials in the early 1960s represented nearly 13% of the total value of mineral production. The relative value of structural material production has steadily declined with respect to other minerals and, in 1982, represented only 3% of the value of mineral production in Canada. This relative decline in value is a reflection of the stability in the price of structural materials (i.e., a pricing structure that is linked directly to the cost of production and transportation, free from external pricing influences). Structural materials remain a low-cost, high-volume material and the proximity of these materials to the market or demand area keeps transportation costs relatively low compared to other minerals.

Newfoundland Mineral Production

The total value of mineral production in Newfoundland (Figure 5, Table 2) has increased from $86,637,123 in 1960 to $1,030,263,000 in 1981. In 1982, the value of production dropped dramatically to $625,913,000**. Between 1960 and 1981 the value of metals had increased 12-fold, non-metals 25-fold and structural materials only 3-fold. In the early 1960s, structural materials represented 6% of the value of Newfoundland's mineral production but by 1981 this value had dropped to 1.7%. In 1982, this percentage rebounded to 2.6%, an indication that the demand for construction materials had not decreased as much as the demand for metals and non-metals. The value of metals production in Newfoundland dropped by 38% and non-metals by 63% between 1981 and 1982, whereas the value of structural materials dropped by only 6% for the same period.

Structural Materials Production

Structural materials consist of sand, gravel, stone, clay, cement and lime. Sand, gravel, and stone (mineral aggregates) represented an average of 51% (fluctuating between 46 and 54%) of the value of production (Figure 6, Table 3) of all Canadian structural materials for the period 1960 to 1982. This consistency is a reflection of the

*All figures are derived from Statistics Canada published figures but, since many small aggregate operators do not file appropriate returns, these figures may be considered as minimum figures for sand, gravel and stone production.

**As of April 1, 1983.

TABLE 1. VALUE OF MINERAL PRODUCTION IN CANADA, 1960-1982. ALL FIGURES ARE FROM STATISTICS CANADA; 1982 FIGURES ARE ESTIMATED.

YEAR	METALS	NONMETALS	STRUCTURAL MATERIALS	TOTAL MINERALS
1960	1,406,558,061	197,505,783	322,594,308	2,492,509,981
1961	1,387,159,036	210,467,786	331,345,763	2,582,300,387
1962	1,496,433,950	214,453,009	353,166,833	2,844,986,179
1963	1,510,403,586	253,549,943	379,011,116	3,051,392,732
1964	1,701,648,538	284,497,000	403,058,324	3,387,971,534
1965	1,907,575,899	327,238,901	433,161,904	3,744,470,821
1966	1,984,372,572	363,387,717	474,108,899	3,972,480,919
1967	2,285,279,477	406,269,252	448,197,382	4,398,670,853
1968	2,492,599,647	446,922,191	439,563,425	4,722,248,677
1969	2,377,523,395	450,188,745	442,841,663	4,735,953,872
1970	3,073,344,135	480,537,626	450,446,081	5,722,058,591
1971	2,940,287,001	500,826,829	512,478,366	5,968,002,192
1972	2,952,412,514	513,488,411	571,328,810	6,404,783,556
1973	3,850,072,222	614,523,120	674,200,788	8,365,937,888
1974	4,820,674,603	895,891,586	835,176,705	11,753,465,894
1975	4,793,853,123	939,180,016	958,982,041	13,345,370,180
1976	5,314,585,005	1,162,351,587	1,106,794,474	15,692,843,066
1977	5,987,885,986	1,362,468,079	1,249,362,040	18,472,528,105
1978	5,697,571,000	1,477,877,000	1,508,048,000	20,261,053,000
1979	7,950,959,000	1,867,677,000	1,646,005,000	26,081,356,000
1980	9,096,956,000	2,532,361,000	1,668,577,000	31,841,758,000
1981	8,683,794,000	2,706,596,000	1,769,152,000	32,340,807,000
1982	7,035,214,000	2,154,003,000	1,573,073,000	33,081,908,000

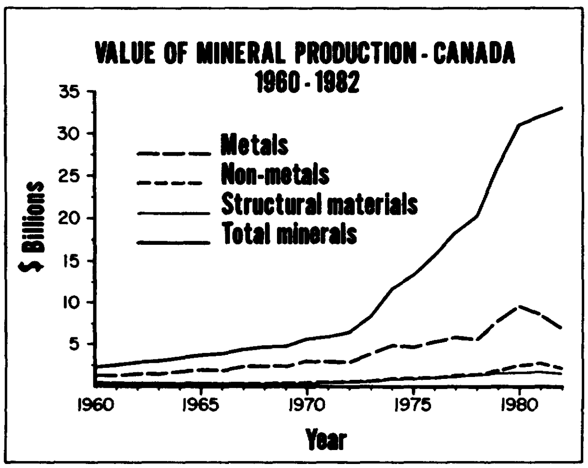

Figure 4. Value of mineral production in Canada, 1960-1982.

TABLE 2. VALUE OF MINERAL PRODUCTION IN NEWFOUNDLAND AND LABRADOR, 1960-1982. ALL FIGURES ARE FROM STATISTICS CANADA; 1982 FIGURES ARE ESTIMATED.

YEAR	METALS	NONMETALS	STRUCTURAL MATERIALS	TOTAL MINERALS
1960	78,925,679	2,225,362	5,486,082	86,637,123
1961	83,883,928	2,457,555	5,277,226	91,618,709
1962	93,283,793	2,497,958	6,077,209	101,858,960
1963	123,664,870	6,538,913	7,044,558	137,248,341
1964	166,169,266	9,995,362	5,988,028	182,152,656
1965	188,172,863	13,043,166	6,341,598	207,557,627
1966	225,338,474	12,973,669	5,707,943	244,020,086
1967	246,911,563	14,122,548	5,331,038	266,365,149
1968	286,729,864	16,177,364	6,804,761	309,711,994
1969	235,096,050	15,742,263	6,097,624	256,935,937
1970	327,078,458	18,455,678	7,726,682	353,260,818
1971	316,423,850	17,591,712	9,415,716	343,431,278
1972	261,012,538	19,319,798	10,326,724	290,659,060
1973	335,830,447	25,324,894	13,350,411	374,506,252
1974	407,354,373	25,972,153	15,232,375	448,558,901
1975	512,262,430	21,004,800	17,691,223	550,958,453
1976	688,662,120	40,577,517	15,789,201	745,028,838
1977	810,087,007	42,104,433	14,954,118	867,145,558
1978	634,404,000	24,731,000	15,893,000	675,028,000
1979	1,054,271,000	44,175,000	26,074,000	1,124,520,000
1980	968,539,000	51,139,000	15,975,000	1,035,653,000
1981	955,427,000	57,187,000	17,649,000	1,030,263,000
1982	593,713,000	15,637,000	16,563,000	625,913,000

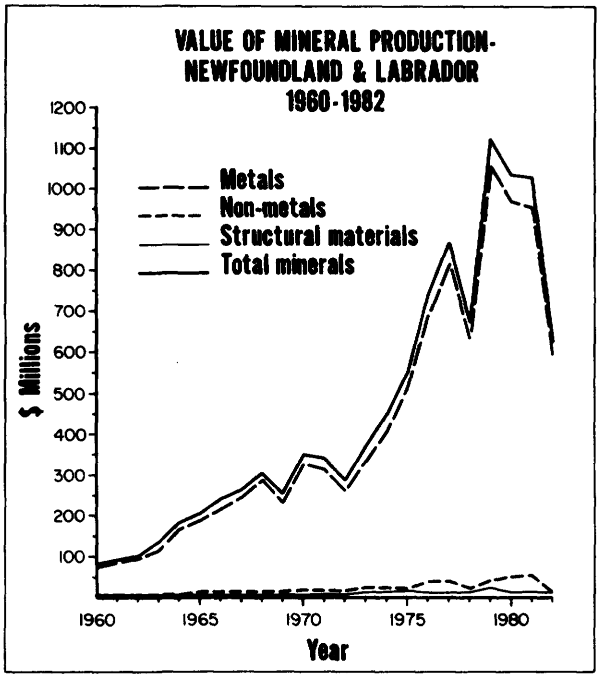

Figure 5. Value of mineral production in Newfoundland and Labrador, 1960-1982.

TABLE 3. VALUE OF STRUCTURAL MATERIAL PRODUCTION IN CANADA, 1960-1982. ALL FIGURES ARE FROM STATISTICS CANADA; 1982 FIGURES ARE ESTIMATED.

YEAR	CLAY	CEMENT	SAND AND GRAVEL	STONE	TOTAL STRUCTURAL MATERIALS
1960	38,226,538	93,261,473	111,163,886	60,640,621	322,594,308
1961	36,982,948	103,923,644	104,654,132	66,567,668	331,345,763
1962	37,816,878	113,233,726	118,603,283	65,866,358	353,166,833
1963	38,154,294	118,614,926	123,854,254	79,883,419	379,011,116
1964	40,830,585	130,704,220	125,232,132	86,882,683	403,058,324
1965	42,837,582	141,523,169	133,819,824	94,847,021	433,161,904
1966	42,956,085	156,300,622	151,525,102	104,987,366	474,108,899
1967	44,356,825	143,150,284	143,706,843	100,416,233	448,197,382
1968	48,721,444	148,210,428	129,500,553	95,658,075	439,563,425
1969	51,165,915	162,091,044	122,159,146	88,186,262	442,841,663
1970	51,791,258	155,739,761	133,558,000	87,975,750	450,446,081
1971	48,583,262	191,244,394	152,628,000	96,537,073	512,478,366
1972	52,556,655	210,685,000	178,100,000	103,326,155	571,328,810
1973	61,170,321	240,560,991	213,437,316	128,692,603	674,200,788
1974	69,073,936	281,957,923	263,984,793	177,207,078	835,176,705
1975	78,423,273	331,523,582	305,180,621	202,724,040	958,982,041
1976	98,457,781	381,614,093	334,414,078	230,638,462	1,106,794,474
1977	103,360,945	420,085,858	364,881,204	296,567,310	1,249,362,040
1978	109,635,000	572,590,000	416,860,000	332,744,000	1,508,048,000
1979	121,526,000	653,877,000	457,120,000	330,708,000	1,646,005,000
1980	108,453,000	581,372,000	508,364,000	341,156,000	1,668,577,000
1981	119,116,000	665,936,000	518,166,000	312,060,000	1,769,152,000
1982	94,656,000	610,387,000	464,221,000	254,948,000	1,573,073,000

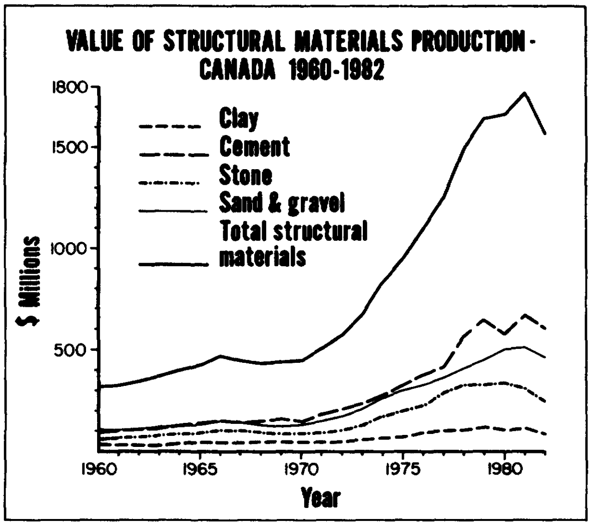

Figure 6. Value of structural materials production in Canada, 1960-1982.

TABLE 4. VALUE OF STRUCTURAL MATERIAL PRODUCTION IN NEWFOUNDLAND AND LABRADOR, 1960-1982. ALL FIGURES ARE FROM STATISTICS CANADA; 1982 FIGURES ARE ESTIMATED.

YEAR	CLAY	CEMENT	SAND AND GRAVEL	STONE	TOTAL STRUCTURAL MATERIALS
1960	83,435	1,688,664	3,069,395	644,588	5,486,082
1961	75,890	1,789,980	2,777,393	633,963	5,277,226
1962	142,000	1,985,524	3,504,594	445,091	6,077,209
1963	92,120	1,848,347	4,276,626	827,465	7,044,558
1964	99,038	1,833,743	3,501,694	553,553	5,988,028
1965	72,717	1,987,220	3,785,071	496,550	6,341,598
1966	172,700	1,632,982	3,584,261	318,000	5,707,943
1967	199,570	1,744,284	3,086,688	300,496	5,331,038
1968	152,200	1,922,695	3,632,018	1,097,848	6,804,761
1969	120,280	1,896,229	3,742,412	338,703	6,097,624
1970	37,304	2,875,978	4,474,000	282,600	7,726,682
1971	79,605	2,932,090	5,827,000	577,021	9,415,716
1972	256,814	2,709,000	6,829,000	531,910	10,326,724
1973	260,000	3,748,371	8,370,503	971,537	13,350,411
1974	436,000	4,024,604	8,727,772	2,043,999	15,232,375
1975	536,149	4,678,129	9,587,488	2,889,457	17,691,223
1976	568,647	5,250,927	8,686,713	1,282,914	15,789,201
1977	550,000	5,175,463	7,022,954	2,205,701	14,954,118
1978	592,000	5,685,000	7,452,000	2,164,000	15,893,000
1979	659,000	6,784,000	15,709,000	2,923,000	26,074,000
1980	806,000	6,415,000	6,066,000	2,688,000	15,975,000
1981	921,000	5,580,000	9,074,000	2,074,000	17,649,000
1982	821,000	4,304,000	9,380,000	2,058,000	16,563,000

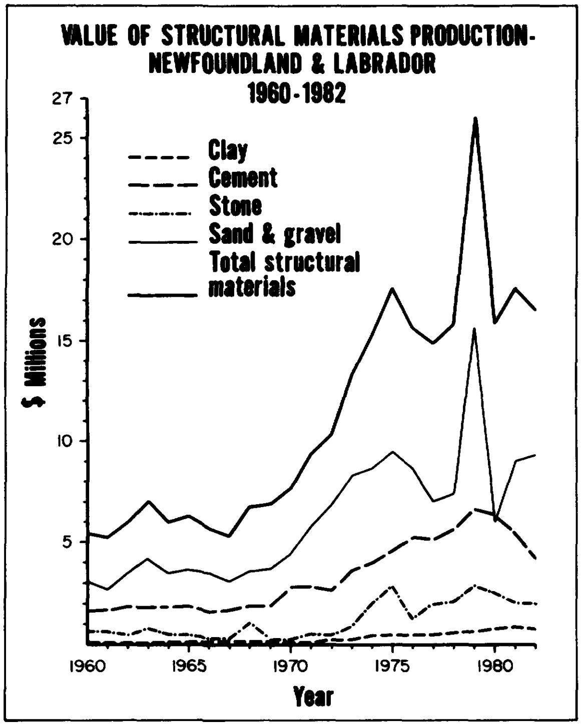

Figure 7. Value of structural materials production in Newfoundland and Labrador, 1960-1982.

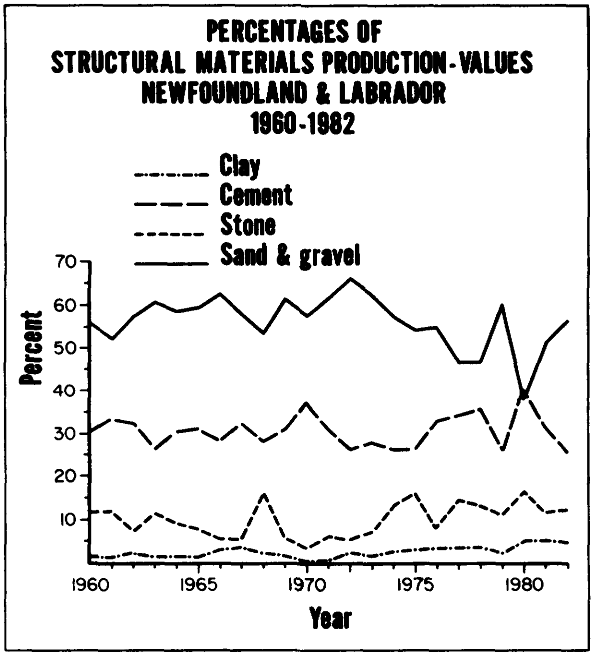

Figure 8. Percentages of structural materials production values, Newfoundland and Labrador, 1960-1982.

constant demand of a variety of construction activities. In Newfoundland for the same period, the value of sand, gravel and stone production (Figure 7, Table 4) averaged 67% and ranged between 55 and 72% (Figure 8) of the total value of Newfoundland structural material production.

The difference in the average percentages of sand, gravel and stone production (versus other structural materials) for the Province of Newfoundland (67%) compared to Canada (51%) is a reflection of the lesser amounts of clay, cement and lime production in Newfoundland compared to the rest of Canada. For example, there are only one brick plant and one cement plant, but no lime production in Newfoundland and Labrador.

A review for the period 1960 to 1982 (Figure 9) indicates that, on average, Canadians used the equivalent of 14 tonnes of sand, gravel and stone per capita per year or 332 tonnes per person over the 23 year period. In Newfoundland and Labrador during the same period, 221 tonnes per person or an average of 10 tonnes per capita per year was consumed. Most mineral aggregates are used in road construction; therefore, it appears that road construction in Newfoundland and Labrador is much less than the national average.

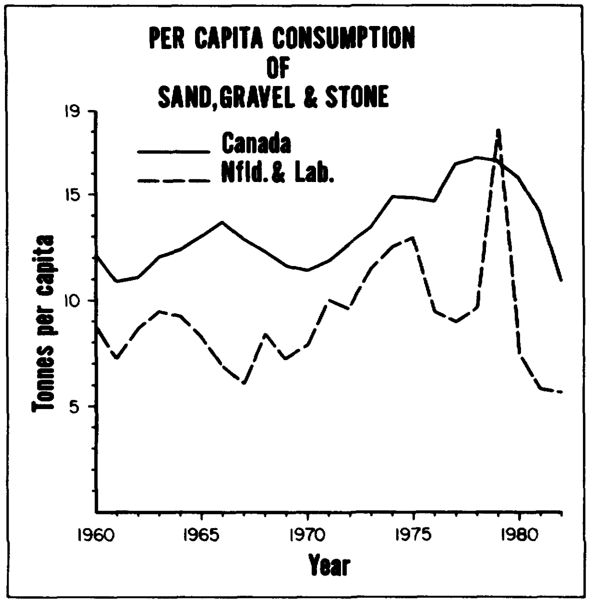

Figure 9. Per capita consumption of sand, gravel and stone in Canada, Newfoundland and Labrador, 1960-1982.

Comparison of Mineral vs. Mineral Aggregate Production

The impact of mineral aggregate extraction in the Province of Newfoundland, as in the rest of Canada, tends to be overshadowed by the value of production of other mineral commodities. The largest single mineral producer in Newfoundland and Labrador is the Iron Ore Company of Canada. Iron ore from the Labrador City, Wabush, and Knob Lake areas of Labrador represented an average of 81% of the tonnage and 87% of the value of mineral production in the Province (Table 5) between 1979 and 1982. Structural materials represented 2% of the value, but 16.5% of the tonnage of mineral production for this same period. If iron ore production is removed from the statistics of mineral production for the years 1979 to 1982, structural materials represented 16% of the value of production but, more significantly, represented 86.5% of the tonnage of mineral production in Newfoundland and Labrador.

For the 1960 to 1982 period, sand, gravel and stone represented on average 98% of the tonnage and 66% of the value of structural material production in Newfoundland and Labrador (Figure 10). The impact of sand, gravel and stone production should, therefore, not be underrated.

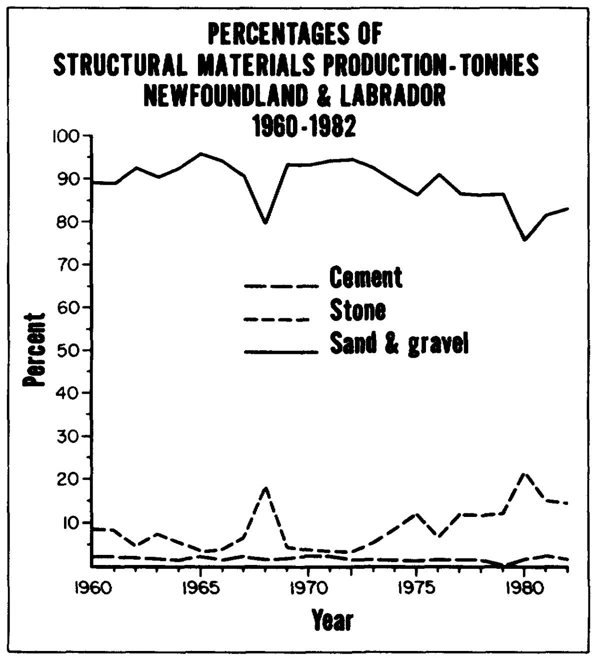

Figure 10. Percentages of structural materials production tonnes, Newfoundland and Labrador, 1960-1982.

TABLE 5. PROPORTIONS OF TONNAGE AND VALUE FOR MINERAL PRODUCTION IN NEWFOUNDLAND AND LABRADOR, 1979-1982.

	TOTAL MINERAL PRODUCTION				MINERAL PRODUCTION LESS IRON		
Year	Iron Ore	Other Metals	Nonmetals	Structural	Other Metals	Nonmetals	Structural
1979 Tonnage (%)	72.75	0.16	2.21	24.88	0.60	8.11	91.29
Value (%)	85.72	8.03	3.93	2.32	56.25	27.51	16.24
1980 Tonnage (%)	82.88	0.18	2.38	14.56	1.05	13.91	85.05
Value (%)	86.47	7.05	4.94	1.54	52.09	36.50	11.40
1981 Tonnage (%)	86.05	0.16	2.40	11.38	1.17	17.23	81.60
Value (%)	88.66	6.02	3.84	1.48	53.12	33.84	13.04
1982 Tonnage (%)	82.45	0.14	1.98	15.43	0.79	11.29	87.92
Value (%)	89.23	5.63	2.50	2.65	52.24	23.20	24.57
Average 1979-1982							
Tonnage (%)	81.03	0.16	2.24	16.5	0.90	12.64	86.47
Value (%)	87.52	6.68	3.80	2.00	51.92	30.26	16.31

ECONOMICS OF THE NEWFOUNDLAND MINERAL AGGREGATE INDUSTRY

An economic study (Carter 1981) of the mineral aggregate industry in Newfoundland and Labrador employed an economic methodology that linked the demand for mineral aggregates to the level and mix of the construction activities which collectively consume most of the aggregates produced. This involved the calculation of technical aggregate usage coefficients which relate the consumption of aggregates to a certain expenditure on a particular type of construction. These coefficients were estimated using information obtained for the year 1977. Forecasting the demand for aggregates involved forecasting the (constant dollar) levels of the construction activities which consume aggregates, and the application of the derived usage coefficients to translate expected construction expenditures into aggregate requirements.

The major results and conclusions of that study may be summarized as follows:

1. The mineral aggregate industry in Newfoundland and Labrador appears to be very competitive. No particular firm accounts for more than a small share of total provincial production.

2. The cost of producing mineral aggregates is site specific and depends on factors such as the type of aggregate produced, the scale of operations, and the type of equipment and methods used. The most significant factors influencing the price of mineral aggregates are capital equipment and labor costs, which accounted for 76.7% of the cost of production in 1977.

3. In general, producers establish the pit or quarry price of aggregates on a cost-plus basis. The average price of sand and gravel aggregate was $3.30 per tonne in 1977, and the price of crushed stone aggregate averaged $4.15 per tonne. In 1982, the price is estimated to have been about $3.38 per tonne for sand and gravel and $4.20 per tonne for stone.

4. The aggregate industry in Newfoundland and Labrador is relatively undercapitalized compared to the industries of several other provinces in Canada. Labor costs account for a significantly greater proportion of the costs of production than elsewhere, and labor productivity is significantly lower. Economics of scale are restricted by the dispersed and low-volume market in Newfoundland.

5. The demand for mineral aggregates is mainly derived from the demand for construction. The characteristic instability in the level and mix of construction in Newfoundland causes wide swings in the demand for construction aggregate, and contributes to keeping the aggregate industry in a constant state of uncertainty.

6. The annual demand for mineral aggregate in the province was forecasted to increase 154% from a forecasted level of 8,263,000 tonnes in 1978 to 20,904,000 tonnes in the year 2002 (Figure 11). The demand for aggregate over the period 1978-2002 was forecasted to total 346,738,000 tonnes (Figure 12).

7. Mineral aggregate is a relatively low unit value mineral commodity. Transport costs represent a high proportion of the delivered or market price. The average (truck) haul distance (in 1977) was 14 km (60 km hauls are not uncommon), and the cost of transporting aggregate that distance represented 28% of the average delivered price. The high transport cost limits competition in a particular market area and influences the locational decision of individual firms and the locational pattern of the industry.

8. Trucks will be the dominant mode of transporting aggregates in the future. It is extremely unlikely that, under present circumstances, there will be any significant movement of aggregates by rail, as there are no economic savings associated with rail transport in the Province of Newfoundland.

9. Enforcement of more stringent and specific regulations concerning the rehabilitation and restoration of aggregate production sites is considered to be a method of partially internalizing some of the external costs of the aggregate industry.

10. Prohibiting aggregate operations through restrictive zoning and land-use planning reduces the supply and increases the cost of producing and transporting aggregates. Ensuring maximum access is essential to ensure an adequate supply at reasonable cost in the future.

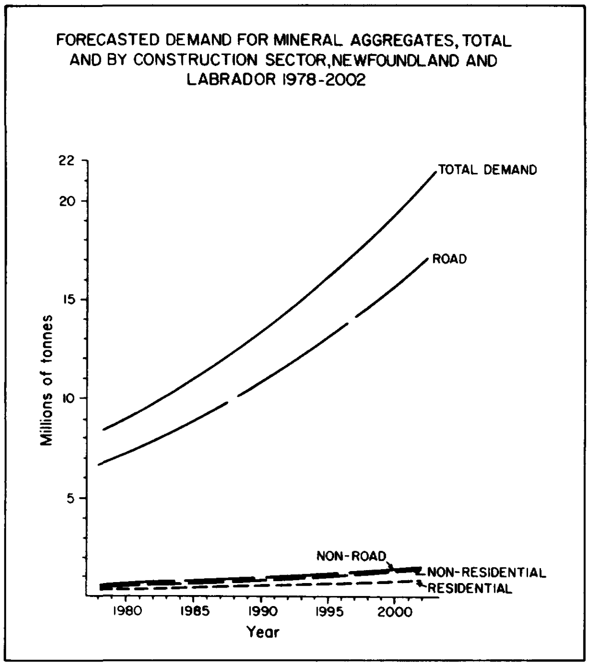

Figure 11. Forecasted demand for mineral aggregates, total and by construction sector, Newfoundland and Labrador, 1978-2002.

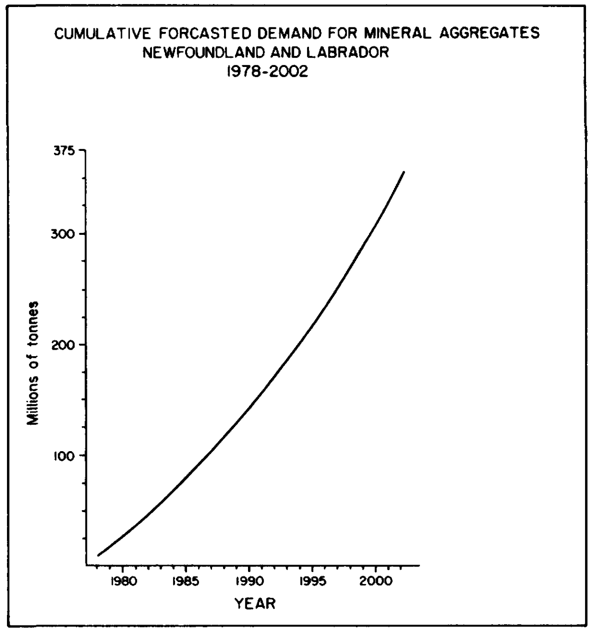

Figure 12. Cumulative forecasted demand for mineral aggregates, Newfoundland and Labrador, 1978-2002.

LEGISLATION

The extraction of quarry materials in Newfoundland and Labrador is controlled under the *Quarry Materials Act, 1976*. This Act is administered by the Department of Mines and Energy and applies to all Crown Lands and to those lands granted after 1952 (i.e., all grants issued after 1952 reserved the quarry materials rights onto the Crown). Some earlier mineral concessions (e.g., Reid Lots) included the quarry materials but implementation of the *Mineral Holdings Impost Act* since 1978 has resulted in the mineral rights (including quarry rights) of many of these long-term concession areas reverting to the Crown.

The current *Quarry Materials Act*, although in need of some amendments, is interpreted to be broad enough to allow for the implementation of adequate measures (e.g., via quarry permits and quarry leases) to protect the environment and surrounding land uses, and to successfully administer a policy of aggregate resource management and pit and quarry restoration. For short-term or new operations, these policies include (a) a two-week referral process upon application for a quarry permit, (b) specific guidelines for the development of a pit or quarry under a one-year permit, and (c) site reclamation upon completion of quarry activity. For longer term or continuing operations, or in areas of sensitivity or comprehensive quarry development as determined or designated by the Department of Mines and Energy, quarry leases for 5 to 20 years may be granted. Since 1982, all leases have been subject to the submission of two or more detailed quarry development plans prepared by the qualified surveyor in a predevelopment, syndevelopment (phases during life of operation) and postdevelopment format similar to plans used in the Province of Ontario.

Since the 1982 implementation of these quarry lease requirements and at the time of this writing, ten firms have either submitted completed questionnaires, written text and the appropriate plans, or were engaged in either obtaining geotechnical assessments (for resource reserve calculations) or the preparation of surveys and plans. To date, there have not been any major problems or complaints. The mineral aggregate industry, we believe, has itself realized the need for a governmental monitor that will apply a reasonable set of uniform guidelines on the industry for pit and quarry development. In addition, there are benefits of dealing primarily with one agency of government rather than a multitude, particularly when that agency is also responsible for the management of the resource. The resource manager fulfills a double role. He can ensure that pit and quarry operations are carried out in an environmentally acceptable fashion (permits or leases can be withdrawn or withheld or charges laid for violations), ensuring the protection of, or at least minimizing impact on the environment and its inhabitants. He can also present a good case based on the availability of the resource, and present the facts concerning state-of-the-art pit and quarry reclamation. He is, therefore, able to encourage an open-minded approach to pit and quarry development in areas of reserves that might otherwise have been sterilized by conflicting land-use designations or by restrictive zoning policies.

CONCLUSIONS

Mineral aggregates are a nonrenewable, finite resource. Aggregates produced from poorer quality materials often require processing, as do materials produced from bedrock sources. The cost of production is much higher in the latter case than for the better grades of naturally occurring unconsolidated materials.

Most aggregates used in Newfoundland are consumed in road construction, although significant amounts are consumed in megaprojects related to hydro-electric developments or, in the future, other major developments such as offshore oil production. Lesser amounts are used in domestic and industrial construction. The competition for land areas for agriculture, forestry, municipal growth and aggregate resources requires the recognition of aggregate extraction as a primary land use. Proper resource mapping and planning of extraction together with the interaction of the mineral aggregate resource manager with other resource and municipal planning agencies can lead to a multiple or sequential land-use design.

Mineral aggregates have escalated in price less rapidly than other mineral commodities over the past 23 years. Production is generally affected less by major recessions in the economy than are other mineral commodities. Canadians have annually consumed an average of 14 tonnes of sand, gravel and stone per capita since 1960, while the comparable lack of road construction in the Province of Newfoundland has resulted in a per capita consumption of only 10 tonnes per annum.

In Newfoundland and Labrador, structural materials have represented l6% of the value and 86.5% of the tonnage of mineral production (excluding iron ore) since 1979. Sand, gravel and stone represent 66.5% of the value of 98% of the tonnage of structural material production for this period.

In Newfoundland and Labrador, labour accounts for a significant portion of the cost of production in an industry of which the product sales are dependent on the demand for construction. The forecasted demand for aggregates in Newfoundland and Labrador is expected to exceed 20 million tonnes per year by the year 2002.

It is the role of the mineral aggregate resource manager to ensure maximum access to aggregate reserves to guarantee an adequate supply at a reasonable cost in the future. Restrictive land use planning or municipal zoning reduces the supply and increases the cost of producing and transporting aggregates. Any added costs are ultimately borne by the consumer or the taxpayer.

ACKNOWLEDGEMENTS

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Gypsum in Atlantic Canada

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ABSTRACT

Gypsum has been mined in Atlantic Canada for over 200 years and has been exported to markets as distant as New Zealand and Great Britain, but principally to the eastern seaboard of the United States.

Gypsum is not classified as a mineral in Nova Scotia and has always been considered as a substance originally granted to the surface owner. For this reason most initial producers were small family-owned enterprises, however for the past century these have been consolidated into larger companies. The export of this commodity created a need for dependable transportation that resulted in the development of company owned shipping fleets.

Gypsum is mined from a sequence of marine evaporites in the Windsor Group of Upper Mississippian age. The geologic structure of several of the deposits is extremely complex. During the past 20 years, ongoing studies, initiated by the industry, have been concentrated on the Windsor Group. Academic studies have been vigorously pursued by R.G. Moore, Acadia University, at Wolfville, and in recent years personnel from the Nova Scotia Department of Mines and Energy have also been actively engaged in these studies. All of the quarries are stratigraphically located in the lower part of the Windsor Group.

All gypsum being produced in Atlantic Canada is being quarried by modern, large size mobile equipment, and processed by large capacity crushers and high speed ship loading facilities. Up to 500,000 m^3 of glacial overburden is being stripped annually and 2.3 million tonnes of gypsum is produced from the largest quarry. There are a total of six operations producing gypsum for wallboard and plaster manufacture, one in Newfoundland and five in Nova Scotia. A small quarry is being operated in New Brunswick producing gypsum for a portland cement plant. Production of gypsum in Atlantic Canada totalled 5.7 million tonnes in 1980 valued at $30.7 million. This represented about 30% of North American production with most of it being exported.

The industry has a number of concerns about government policies, particularly taxation and the potential threat of displacement with byproduct gypsum and imports of cheaper foreign natural gypsum.

INTRODUCTION

In a review of the mining history of Canada the contribution of the gypsum industry tends to be overlooked. Together with coal, which has been mined on Cape Breton Island, Nova Scotia, since 1720, gypsum from the Atlantic provinces has been an export commodity from this region to international markets for over 200 years. Proximity to the seacoast and the economic transportation afforded by coastal vessels contributed to the development of the industry and remains as the most important factor in the continuing growth of the industry in eastern Canada. This paper concentrates on the gypsum industry in Nova Scotia since the magnitude of these operations both historically and presently greatly exceed those of Newfoundland and New Brunswick.

The history of the gypsum industry contains little or no reference to the "romance" generally associated with the discovery and development of many of the metal mining camps of the United States and Canada. Over the past 20 years one of the authors (W.L.L.) has had an opportunity to search land titles, review and collect old documents and memorabilia connected with the industry in the Windsor and Cape Breton areas of Nova Scotia and Hillsborough, New Brunswick. From the notes collected during this period it is obvious that political histrionics and patronage, secretive transactions and power struggles to monopolize not only control of the gypsum deposits but also the markets were entrenched operating techniques well established before the twentieth century. The details of the gypsum industry in Nova Scotia between 1850 and 1900 could well replace or add a chapter to Rickard's "Romance of Mining".

HISTORY

Gypsum Ownership

Gypsum has had a rather unique status in Nova Scotia since it has never been classified under the statutes as a mineral. In Nova Scotia, all minerals are considered to be the property of the Crown.

Prior to 1826 certain minerals were reserved to the Crown but the specific minerals reserved varied from land grant to land grant. Most commonly included were coal, precious metals, copper and lead. In 1826 King George IV granted to his brother the Duke of York the rights to all minerals in Nova Scotia not previously granted. The Duke of York, in order to reduce his personal debts, immediately conveyed to a group of his creditors, who had formed together as the General Mining Association, a lease valid for 60 years to all minerals in the province not being actively worked. At that time the principal mining industry other than coal was gypsum which was being shipped from numerous locations in Nova Scotia from small, family operated quarries. Although this lease effectively eliminated all mining except by consent of the Mining Association, it is unclear if or to what extent this hindered the gypsum trade.

Several proposed mining projects were rejected by the Mining Association and increasing pressure was directed toward the government of the day to secure a repeal of this lease. In 1856 a delegation was dispatched to petition Parliament in London for relief from the terms of the lease. Upon their return to Nova Scotia, the legislative assembly in 1858 introduced a bill effectively repealing the reservations of the grant of 1826. After the usual performances characteristic of politicians, recorded in the debates of 1858, the bill was passed and appears as chapter 1 of the Statutes of 1858. The net effect of these statutes and subsequent amendments was to establish that Crown grants were deemed to have excluded all minerals *except* limestone, plaster (gypsum) and other building materials.

The Windsor area of Nova Scotia was the birthplace of the gypsum mining industry in North America with the first recorded shipments having occurred prior to the American Revolution. Although undocumented, it is likely that shipments began about the time of the first British Crown grants in 1759 following the expulsion of the Acadians in 1755.

Shortly thereafter property records indicate that gypsum was recognized as a commercial commodity and the numerous small family businesses soon became consolidated into large companies. One of the first documented consolidations of gypsum holdings was recorded in 1818 with the purchase of a property for £230. This parcel of land and gypsum rights were sold in 1879 for $3000, gypsum rights only were sold in 1906 to the J.B. King and Company for $3000, and in 1912, the surface owner received an additional $400 for the privilege of carrying out any activity that might disrupt the surface in connection with the gypsum mining.

In deference to the General Mining Association's lease of 1826 one of the earliest reservations and transfers of gypsum holdings and quarries was by will probated at Windsor in 1835. This separation of gypsum from the surface ownership requires that in many locations title abstracts have to be developed for both the surface and gypsum for a period of more than two centuries.

Under British common law, ownership of the gypsum conveys to the owner the legal right in perpetuity to mine the gypsum without being required to purchase the surface or to reimburse the surface owner for damages. Although the law and historical records of original purchase price support this right, convincing the current surface owner of this right is, to say the least, difficult. As outlined above the same property has often been purchased for its gypsum two or three times in the past and it will require purchase again in the future.

Development of the Industry

In the latter half of the nineteenth century the gypsum industry became consolidated in the hands of perhaps a dozen or so fairly large producers, most of whom were partially owned by or under contract to plaster manufacturers located along the eastern seaboard of the United States or in the Montreal area.

The first mining operation at Hillsborough, New Brunswick, producing gypsum for export to a specific manufacturer began in 1847. In 1854 this operation was sold and enlarged, and the first calcining mill was constructed by the Albert Manufacturing Company.

In 1876 a branch line of the Intercolonial Railway (now CNR) was constructed to Hillsborough. This permitted shipment of products to the Canadian market for the first time.

In the year 1882 modernization of the gypsum industry in Nova Scotia began with the arrival of the first locomotive at Windsor and the construction of an extensive narrow gauge railway for transporting the gypsum from the quarries to the docksite. Rail haulage in the quarries continued until 1960.

The first plaster mill in Nova Scotia, which incidentally remains in operation today, was constructed in Windsor in 1888.

In 1891 the Gypsum Packet Company was incorporated at Windsor specifically as a gypsum transportation company.

The second calcining mill in Nova Scotia was constructed by the Great Northern Gypsum Company in 1907 at Cheticamp located on the west coast of Cape Breton Island. By 1912 this mill had two 10-ton kettles, but the mill operated sporadically before being permanently closed by Atlantic Gypsum Products Limited in 1926.

Overburden stripping as we know it commenced in the Windsor area in 1909 with two Marion steam shovels being used to load mud into small narrow gauge railcars.

The Hillsborough plaster mill which was destroyed by fire in 1911 was rebuilt and enlarged to a capacity of 1000 barrels of plaster per day in 1912. Plaster production ceased in 1975. Despite later improvements most of these facilities remained intact until the plant closed in 1980.

The third plaster mill in Nova Scotia was constructed by Iona Gypsum Company Limited at Grassy Cove near Iona, Cape Breton Island, in 1914. Prior to its closure in 1933 this plant produced up to 10,000 tons of plaster per year and shipped products to points as distant as western Canada and New Zealand.

In 1922 a jaw crusher was installed at Windsor at about the same time that the conversion to jackhammer drilling from hand drilling for blasting was instituted. This crusher is now the primary crusher at the Miller's Creek facilities of the Windsor Plant.

Two names are synonymous with the gypsum industry in Windsor during the period 1860-1924: E.W. Dimock, a Windsor native, and J.B. King of New York. The Wentworth Gypsum Company Limited was established and operated by Dimock and J.B. King and Company was named for and controlled by the grand nephew of an American pioneer in gypsum calcining.

In 1924 Canadian Gypsum Company Limited acquired the assets of both of these two companies. In 1962 these were transferred to Fundy Gypsum Company Limited. Drilling techniques continued to be improved and by 1928 two well rigs drilling 4-inch holes to depths of up to 60 feet were being used in one of the large white rock quarries (Cole 1930).

Just prior to 1930, two large reinforced-concrete silos equipped with ship loading conveyors were constructed at the Hillsborough docksite on the Peticodiac River. It is believed that these silos, which are still standing, were the first structures erected using the continuously poured slip-ring method of construction in eastern Canada.

In 1930 the first wallboard plant in eastern Canada was constructed at the existing Hillsborough, New Brunswick, manufacturing facilities when Canadian Gypsum Company acquired the plant. The calcining capacity was increased with some of the equipment transferred from the old Iona mill.

In 1935 the Victoria Gypsum Company erected a crushing and shipping plant at Little Narrows, Cape Breton Island, and commenced production. Rock from the crusher was conveyed by belt to a storage shed and dock located on the shore of the Bras d'Or Lake. Ocean going ships could also be loaded directly from the quarry by conveyor. With only minor alterations this same system remains in operation today.

Canadian Gypsum Company Limited completed construction of a storage shed with a high-speed ship loading capacity at Hantsport in 1947.

Newfoundland became a producer of gypsum products in 1952 with the development by the Newfoundland Government of a deposit at Flat Bay and the simultaneous construction of a board plant near Cornerbrook.

A high-volume quarry was placed in production near Milford, Nova Scotia, by National Gypsum (Canada) Limited in 1955.

The most recent major changes in the gypsum industry in Atlantic Canada occurred in 1962 when Flintkote commenced shipments from a loading dock located near the Flat Bay, Newfoundland, deposit. During the same year Georgia Pacific Corporation commenced gypsum mining in Nova Scotia from a new quarry located at River Denys, Cape Breton Island.

Transportation

In the early days of gypsum mining in Nova Scotia small sailing schooners were used to transport gypsum to customers along the east coast of the United States. The Minas Basin area, during the nineteenth century, was known worldwide as a major shipbuilding region. Many of these newly constructed vessels being delivered to American buyers carried a gypsum cargo on their maiden voyage to the east coast. Many coastal sailing vessels carried a gypsum cargo south and returned with a cargo of coal, sugar, rum or other goods. Commonly the ship captains acted as their own gypsum brokers, negotiating the best price possible from a manufacturer.

Entry of American interests directly into the gypsum trade in Windsor in 1891 spawned the construction of the first sailing fleet of three- and four-masted schooners solely for the purpose of transporting gypsum from Windsor to the east coast. This fleet of five sailing vessels of 600 to 700 ton capacity was soon converted to barges and towed down the coast by the first large ocean-going tug which went into service in 1898. In the 1930s a new fleet of coal-fired ships of 5000 ton capacity was placed in service. These vessels were lost in government service during World War II and were replaced in the 1950s by a five-ship fleet of oil-fired vessels of 11,000 tonne capacity. Replacement of these vessels by a new fleet of 14,500 tonne capacity ships commenced in 1975.

Possibly the first self-powered diesel gypsum ore carrier may have been a recommissioned barque, the MV Daniel Monro, which operated between Windsor and New York from about 1915 to 1930.

Currently all of the large gypsum companies in eastern Canada ship gypsum principally in vessels which are either owned by the company or are on long term charter. Occasionally transportation is by customer-owned or spot-chartered vessels. Ship capacity can be a maximum of about 36,000 tonnes because ship drafts are limited to about 10 m either at the loading facility or the receiving port.

STRATIGRAPHY

Windsor Group in Nova Scotia

The gypsum industry in the Atlantic provinces quarries its ore from the Carboniferous Windsor Group. The strata have been correlated with the Visean of England by Bell (1929) and with the Mississippian Chesterian of the mid-American continent. According to Geldsetzer (1978) the older part of the Windsor Group also correlates with the Upper Meramecian of the same area based on Bell's (1929) macrofaunal and Mamet's (1970) microfaunal work. The Windsor Group outcrops in several areas of the Atlantic provinces (Figure 1) and underlies the continental shelf.

The group name was derived from the gypsiferous strata (Figure 2) near Windsor, Nova Scotia. The Windsor Series was defined by Bell (1929) as a group of soft marine sedimentary rocks that underlie the lowlands about the Avon River and its tributaries. In this area it is underlain by sandstone and shales of the Cheverie Formation, Horton Group, and overlain by a sandstone of possible Pennsylvanian age. Bell estimated the series as being 470 m thick and composed of 20% sulphate, 25% calcareous beds and 55% red shale. On the basis of macrofauna he divided the series into five subzones designated A through E (see Figure 2). The A subzone basal limestone was thought to be unfossiliferous *until* Schenk (1967) noted a facies in the A subzone limestone at Hillsborough, New Brunswick,

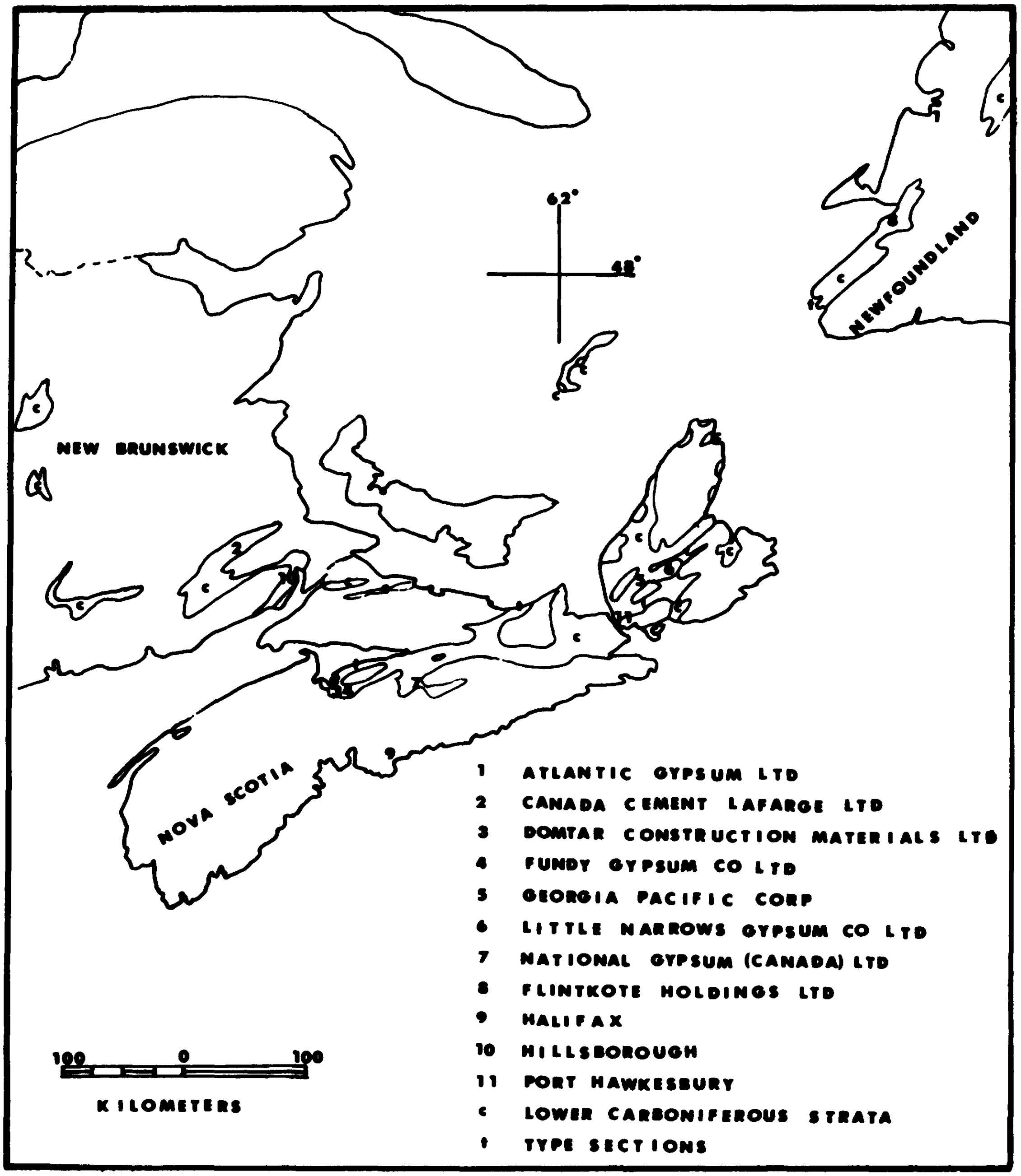

Figure 1. *Map of the Atlantic provinces showing outcrop distribution of the Windsor Group in Atlantic Canada and location of producing mining companies.*

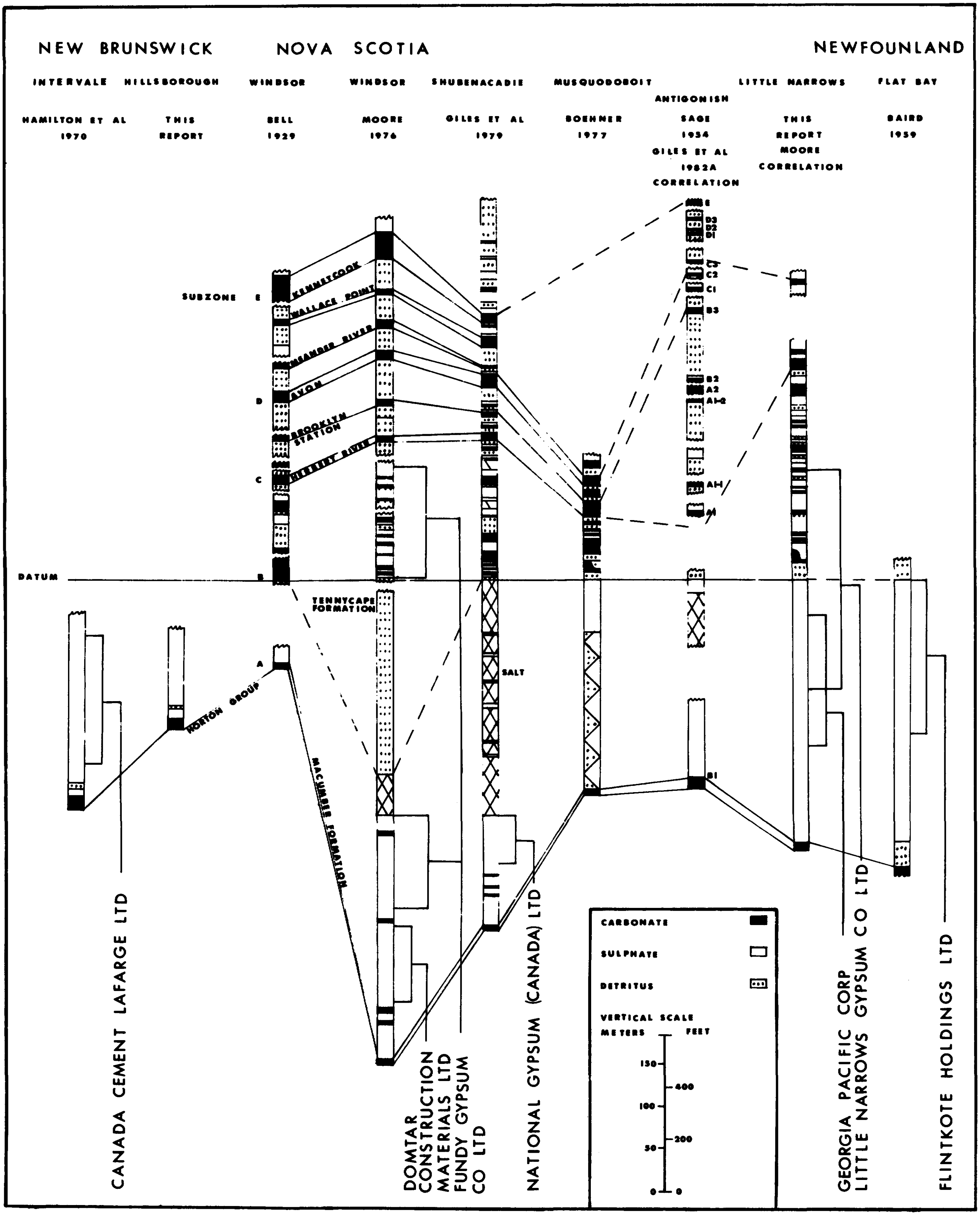

Figure 2. *Stratigraphic correlation in Atlantic Canada of the Windsor Group A, B, and C subzones with the mining horizon indicated for each producer.*

which contained abundant fossils. Giles *et al.* (1979) working on A subzone fauna at Gays River, Nova Scotia, found that the A subzone limestone is distinguishable from the B subzone because the ratio of brachiopods to pelecypods is much higher in the B subzone. The B subzone, according to Bell was characterized by *Diodoceras avonensis* and *Composita dawsoni*. Moore and Ryan (1976) however noted that they are also found in the E subzone. Giles *et al.* (1979) observed *Diodoceras avonensis* in the A subzone. The C subzone was characterized by *Dibunophyllum lambii*. The D subzone was characterized by *Productus semicubiculus* and only the E subzone contained *Caninia dawsoni* and *Chonetes politus*.

Kelley (1958) found the upper and lower contacts of the Windsor Series to be diachronous and suggested that the sequence should be mapped as a lithostratigraphic unit, i.e. Group, rather than as a biostratigraphic unit. He noted in 1967 that Poole *et al.* (1964) had redefined the Windsor Group as partly or wholly a marine sequence of strata that overlies the Horton Group or overlaps pre-Carboniferous rocks. This designation now excluded clastic rocks which contain no marine interbeds, although they may be the same age as marine strata in other areas. Giles and Boehner (1979) used a more restrictive definition based on age and lithology in which they defined the Windsor Group as strata between and including the uppermost and lowermost marine limestones of Visean age. This could be confusing if a gypsum bed or siltstone lying above the presently recognized uppermost marine limestone changes laterally into a marine carbonate. This could also result in some marine strata being placed in a different group although its lateral marine facies is in the Windsor Group.

Macumber Formation

The name Macumber Formation was proposed by Weeks (1948) for a 5 m thick, well bedded, grey to buff, fine-grained limestone conformably overlying the sandstone and sandy shale of the Cheverie Formation. The type section is at the inactive Macumber manganese mine at Cheverie, Nova Scotia. The limestone is equivalent to Bell's (1929) basal limestone.

Tennycape Formation

The name Tennycape Formation was proposed by Weeks (1948) for a formation of soft red fine sandy shales overlying the lowermost sulphate bed of the Windsor Group on the Tennycape River, Nova Scotia. It was estimated to be about 180 m thick and was thought to be overlain by gypsum.

Ardness Formation

Williams (1914) named a limestone and siltstone sequence at Arisaig, Nova Scotia, the Ardness Formation. Sage (1954) noted that this formation is part of the Windsor Group. Giles (1981) indicated that it correlates with Bell's D and E subzones.

Members

Moore (1967) described the lithology of several limestones in the Windsor area. They are generally thicker than the undescribed limestones below them. They range from 2 to 41 m thick, whereas the other limestones are generally less than 4 m thick.

The Herbert River Limestone was defined as that part of Bell's (1929) type section designated as g and h of Section 5 subzone C. It is 6 to 12 m thick.

The Brooklyn Station Limestone member has its type section near Brooklyn, Hants County, Nova Scotia and is equivalent to q and r Section 3 of Bell's C subzone. The Shubenacadie Limestone member was on the Shubenacadie River and was considered to be correlative with the Brooklyn Station member. It is 2 to 8.5 m thick.

The Avon Limestone was first named by Hartt in 1867 according to Moore (1967). Its type section was thought to be similar to Bell's d and i units in the D subzone. It is 7.6 to 18 m thick.

The 7.6 to 12 m thick Meander River member has its type section on the Meander River near Windsor, Nova Scotia. Moore (1967) thought the lower part of it was similar to unit n of Bell's Section 9 subzone D.

The type section of the Wallace Point member which is 4.5 m thick was Bell's a and b units of Section 10 subzone E.

According to Moore (1967) the Kennetcook Limestone as previously described by Hartt in 1867 was applied to more than one limestone. Bell defined the Kennetcook Limestone as units e to h of Section 10 subzone E and Moore used the same location to describe this member which is 30 to 41 m thick.

Windsor Group in New Brunswick

In New Brunswick Wright (1922) placed the gypsiferous rocks south of Moncton in the Hillsborough Series. He noted that the fauna were similar to those in Hartt's (1867) Windsor limestone, i.e. Bell's (1929) Miller limestone. Norman (1941) put the lower part of the Hillsborough Formation in the Moncton Group and the upper evaporites in the Windsor Series.

Windsor Group in Newfoundland

Bell (1948) described a gypsum, limestone and siltstone section along the southwestern Newfoundland coast and named it the Codroy Group. In addition to noting that some fauna were similar to the C and D subzones in the Windsor Group in Nova Scotia, he also observed that the Ship Cove limestone at the base of the group was similar to the basal limestone at Windsor, Nova Scotia. Sage (1954) illustrated a tentative correlation of the Ship Cove – Fishells sections with the Windsor strata in the Antigonish, Nova Scotia, area.

Informal Names and Correlation

In recent years many informal names have been used in Nova Scotia for formations and members in different areas. A formal name according to the Code of Stratigraphic Nomenclature in Krumbein and Sloss (1963) requires publication in a scientific medium and a definition that includes statement of intention to designate a formal unit, selection of a name, definition of the unit in the type area with specific location of the type section, distinguishing characteristics, definition of boundaries and contact relationships, dimensions and shape and as far as possible geologic age and correlation. Several of the following formation names are expected to become formal in the near future.

The Watering Brook Formation, Green Oaks Formation (Giles and Boehner 1979), Murphy Road Formation (Giles 1981), Churchville Formation (Giles 1982), Hood Island Formation (Boehner and Giles 1982) and Uist Formation (Boehner 1982) all occupy a stratigraphic horizon similar in whole or in part to Bell's (1929) C, D and E subzones and to Moore's (1967) formal members. The MacDonald Road Formation (Giles and Boehner 1979) Miller Creek and Wentworth Formations (Moore 1976), Forbes Lake Formation (Giles 1982), Elderbank Formation (Giles and Boehner 1982b), the Addington Formation, Wallace Brook Formation and Lakevale Formations (Boehner and Giles 1982) and the Enon and Loch Lomond Formations (Boehner 1982) occur at a stratigraphic horizon similar to Bell's (1929) B subzone. The Vinland Formation (Moore and Ryan 1976), Carrolls Corner Formation and Stewiacke Formation (Giles and Boehner 1979), White Quarry Formation (Giles 1981), the Bridgeville Formation (Giles 1982) and Meaghers Grant and Gleason Brook Formations (Boehner 1977) occupy the interval in whole or in part between the Macumber limestone and Bell's B subzone. The Gays River Formation (Boehner 1977) and Holmes Brook Formation (Giles 1982) occupy a stratigraphic position similar to the Macumber Formation.

It is unfortunate that so many new formational names have been proposed in Nova Scotia because they are unnecessary from the point of view of either an industrial geologist or a stratigrapher.

Geologists of the New Brunswick Department of Natural Resources have recently concluded that the Windsor Group strata in that province are correlative with equivalent units in Nova Scotia and that established formation names will be retained (R.G. Moore, Acadia University, personal communication). It has also been concluded that the Ship Cove limestone in Newfoundland is correlative with the basal Macumber limestone of Nova Scotia. Moore has also demonstrated that the Herbert River Limestone, Bell's C subzone, can be recognized and correlated throughout the Atlantic provinces and Magdellan Islands, Quebec.

In addition the authors have recognized that several members in both the Miller's Creek Formation and Little Narrows Formation (unpublished company reports) are present in two distinct facies.

Based on the foregoing it seems reasonable to suggest that many of those formation names are actually synonyms for formations or members that have already been formally described.

It is hoped that in the near future stratigraphic studies will be directed toward establishing correlation between various units throughout Nova Scotia. If this approach is not pursued it is essential that type sections be identified and described so that others may utilize this data.

Facies Variations

Some individual carbonate members can be correlated over 300 km, such as the Macumber Formation and Herbert River Member (Moore, personal communication) but the group as a whole has considerable variation in it. For example Boehner (1977) has shown that there is an interfingering of sulphate, sandstone, siltstone and shale in the Musquodoboit area and that the sulphate content increases toward the basin center. The base of the group also varies so that the Macumber overlies the basement in most areas but younger Windsor Group strata may locally overlie the basement rocks directly as noted by Keppie *et al.* (1978). Individual limestone members may vary considerably. At Little Narrows the carbonate at the base of Bell's (1929) B subzone can grade laterally from a 1 m thick massive unit to a 12 m thick porous, shell bank over a distance of 300 m. Boehner (1977) shows a similar variation in his 5-1 limestone in the Musquodoboit area, which occurs at the same stratigraphic level.

Baird and Cote (1964) described a type section for the Codroy Group between Stormy Point and Cape Anguille, Newfoundland, which has little sulphate at the base. To the northeast in the Flintkote Mine area at Flat Bay, Baird (1957) noted that this sulphate strata ranges from 91 to 300 m thick.

The salt content of the Windsor Group also varies considerably. Thick beds of salt are known in Bell's A subzone at Stewiacke, Nova Scotia (Giles and Boehner 1982b), Antigonish and Sussex, New Brunswick. These beds however are absent at the Wentworth, Little Narrows and Milford Quarries.

The thickness of the Windsor Group varies considerably from 900 m in the Windsor area (Moore and Ryan 1976) to 6000 m near Amherst, Nova Scotia (Howie and Barss 1974).

Although there are many variations within the Windsor Group, there is a general trend upward from a limestone at the base with a massive sulphate bed above it, to thin limestone and siltstone beds interbedded with thin sulphates toward the middle of the section, to thick limestone and siltstone beds at the top of the group.

GEOLOGIC STRUCTURE

The geologic structure is extremely variable within the Windsor Group with complexity increasing upwards in the section. Except for a few localities the structure is poorly understood.

The massive sulphate formation at the base of the group has not generally been tightly folded anywhere in the region but has undergone block faulting. In areas of minor deformation these strata exhibit a low uniform dip toward the axes of depositional basins.

In the Windsor area, Moore (personal communication) has indicated that there are extensive recumbent folds with amplitudes of 500 m or more. These recumbent folds are complexly folded into abundant synformal anticlines and antiformal synclines. This complex folding occurs above the A subzone massive sulphate (Figure 3).

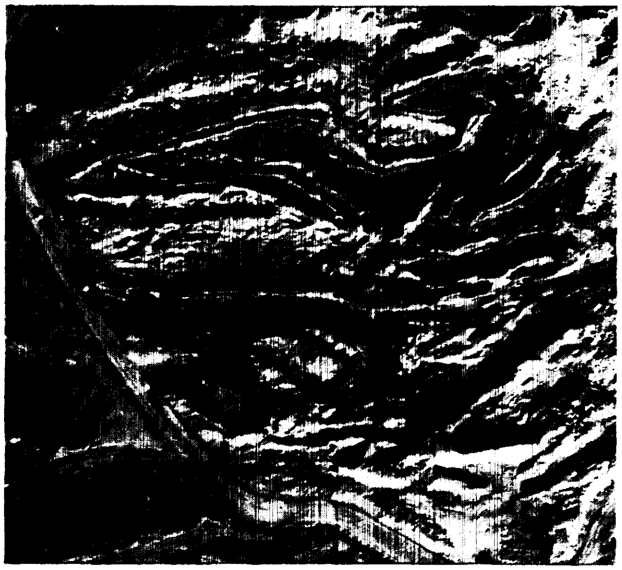

Figure 3. *Complex structure in the upper members of the Miller's Creek Formation exposed in the Miller's Creek quarry of Fundy Gypsum Company Limited.*

The structure in the Musquodoboit area has been described as a simple basin (Giles and Boehner 1982b) with only a few faults.

In the Little Narrows area, the massive A subzone sulphate is gently folded and faulted. The members of the B subzone are more deformed with some recumbent folding. Faulting occurs along the axial plane of folds which parallel the regional structural trend. Secondary folds with wavelengths of 600 to 1200 m are superimposed on the primary folds at an angle of 60 degrees. There are numerous other small localized folds and faults.

In Newfoundland, Baird and Cote (1964) have observed extensive folding and faulting in the Lower Codroy Group type section.

In New Brunswick, Hamilton and Barnette (1970) have also reported considerable folding and faulting within the Windsor Group.

Little field evidence is available to indicate that the hydration of the anhydrite to gypsum has produced structural deformation. This apparent lack of distortion due to volume expansion is difficult to explain but may be due to the removal of sulphate by circulating groundwater during the hydration process. Within the B subzone, most of the carbonate, siltstone and shale members contain secondary gypsum along bedding planes and fractures.

Keppie (1982) concluded that the folding and faulting within the Windsor Group occurred during the Hercynian stage of late Carboniferous and Permian times.

MINING INTERVALS WITHIN THE WINDSOR GROUP

Newfoundland

The quarry operated at Flat Bay, Newfoundland, is located in the Codroy Group which is probably correlative with the lower part of the Windsor Group of Nova Scotia (see Figure 2).

Nova Scotia

Currently there are four large gypsum mining operations producing gypsum in Nova Scotia. Two of these also produce anhydrite for use as a retarder in the manufacture of Portland cement and as an agricultural soil conditioner. A fifth plant produces about 7,000 tonnes of calcined plaster products annually.

Production of gypsum in Nova Scotia is confined to subzones A and B (Bell 1929) and for mining purposes the previously described stratigraphy can be generalized. The A subzone consists of up to 300 m of calcium sulphate, usually as anhydrite, light blue to grey in color, containing less than 5% disseminated carbonate, silica and clay minerals. Occasional thin (30 mm) discontinuous beds of carbonate are encountered. In areas where this formation is found at outcrop or in subcrop beneath overlying glacial deposits, the anhydrite has frequently been hydrated to gypsum. The extent of hydration ranges from a few millimetres to depths ranging up to 75 m but generally averages in the range of 10 to 20 m. The zones of deeper hydration frequently appear to be related to increased fracturing or overlying surface drainage.

Hydration of the anhydrite in the A subzone produces a high quality, dense microcrystalline white gypsum that has a spectral reflectance of 85 to 90% (MgO standard). Locally where a thin dolomite bed has become disseminated over a width of 1 to 2 m the color will deteriorate several percentage points but this gypsum can usually be utilized for specialty plaster products by blending.

Depending upon the ultimate use of the white gypsum, one or more beneficiation techniques are utilized at the mine site. If the end use of this gypsum is in wallboard manufacturing dry screening may be required to remove surface mud and field stones from fracture zones and solution channels. Gypsum content of this product will range from 88 to 92%.

Maximum gypsum purity obtained from the A subzone will range from 92 to 96% but to approach these values on a consistent basis additional beneficiation is required. Washing to remove mud may be followed by treatment in a heavy media flotation circuit to remove remnant anhydrite which is commonly co-mingled with the gypsum on the lower quarry benches. Gypsum which has been beneficiated to this degree is used in the manufacture of specialty plasters.

Gypsum from the A subzone is produced by:

Flintkote Holdings Limited, Flat Bay, Newfoundland;
Little Narrows Gypsum Company Limited, Little Narrows, Nova Scotia;
Georgia Pacific Corporation, River Denys, Nova Scotia;
National Gypsum (Canada) Limited, Milford, Nova Scotia;
Fundy Gypsum Company, Limited, Windsor, Nova Scotia; and
Domtar Construction Materials Limited, Windsor, Nova Scotia.

Gypsum is produced from the lower half of the B subzone by:

Fundy Gypsum Company Limited, Windsor, Nova Scotia; and
Little Narrows Gypsum Company Limited, Little Narrows, Nova Scotia.

In contrast to the previously described A subzone, the sulphate members in the B subzone comprise about 75% of the mining section, being interbedded with carbonate, shale and siltstone members which range from 0.3 to 5 m in thickness.

The sulphate within the B subzone is generally light to dark grey in color, predominantly with fine to medium sugary texture and has a sulphate content of 80 to 92%. Within the mining section individual sulphate members range in thickness from 1.5 to 20 m but average about 7 to 8 m.

Locally the base of the B subzone appears to represent a collapse breccia – fault zone containing blocks of sulphate up to 10 m in size, embedded in a matrix of greenish grey siltstone. This zone may represent the stratigraphic position of the A subzone salt horizon found in the subsurface at various locations in the Atlantic provinces.

As a rule the hydration in the B subzone extends to a much greater depth than in the A subzone, commonly to depths in excess of 100 m. This is no doubt due to the high permeability of the interbedded carbonate and siltstone members. Locally anhydrite occurs as lenses in the gypsum and may be encountered within a few metres of the surface. Its presence is usually confined to the central portion of the thicker gypsum members but in some cases appears to be structurally controlled.

Small amounts of soluble salts, predominantly chlorides, are scattered throughout the gypsum deposits of the B subzone. Usually the highest concentration of these salts is found adjacent to the anhydrite lenses as a halo, 2 to 3 m in width. At most of the mines, the chloride salt content of the gypsum is monitored since the manufacturing process can be adversely affected when concentrations exceed 500 grams per tonne.

MINING METHODS

Except for the Hillsborough, New Brunswick, area where underground mines were common until 1958, gypsum produced in Atlantic Canada has been quarried.

Originally quarries were developed where the gypsum was overlain by little or no overburden and were abandoned when the overburden thickness reached 2 to 3 m. The introduction of mechanized equipment allowed an increased thickness of overburden to be stripped. Today the five large producers remove up to 40 m of glacial till with the average being 10 to 20 m. Equipment used to strip this material includes 5 to 6 cubic metre loaders, 2 cubic metre shovels, 30 to 45 tonne capacity trucks, twin engine – 20 cubic metre scrapers and at one operation a dragline with a 14 cubic metre bucket.

Blast hole drilling is commonly conducted with rotary air rigs drilling 100 to 150 mm diameter holes. Percussion drills are often used if there is substantial anhydrite present. An ammonium nitrate – fuel oil mixture is commonly used for blasting. Blasts are fired using electric or fuse caps, primacord and primers. Wet holes are cleared of standing water or are loaded with traditional explosives. Five cubic metre loaders or occasionally 2 cubic metre shovels are used to load 30 to 45 tonne trucks at the face for haulage to the crushing plant.

As many as three crushers of various sizes and types are used in crushing gypsum. Crushing rates are commonly in the range of 500 to 1000 tonnes per hour. All of these large operations have a dry screening plant incorporated in the crusher system to remove mud and improve product quality.

With the exception of the Little Narrows operation all of the crushed gypsum must be transported by railway from the mine site to the ship loading facility.

The percentage of gypsum ore recovered from the gross rock mined varies from 65 to 90% depending upon the quarry and is a function of the screen size, volume of the screening required and the ratio of sulphate to non-sulphate members in the deposit.

DESCRIPTION OF INDIVIDUAL OPERATIONS

Flintkote Holdings Limited Flat Bay, Newfoundland

Since 1962, crude gypsum has been exported primarily to the east coast of the United States, principally Camden, New Jersey, and Savannah, Georgia.

Overburden averages about 10 m in thickness and a stripping ratio of about 1:1 is maintained using a 2 cubic metre shovel, 5 cubic metre front-end loader and trucks.

The gypsum is quarried from a series of benches, 9 m in height. About 650,000 tonnes is produced during an 8 month ice-free shipping season.

Impurities in the deposit are limited to occasional discontinuous pockets of limestone and siltstone. Erratic concentrations of chloride salts are frequently encountered in the main quarry in amounts up to 50 kilograms per tonne.

For a number of years all gypsum rock has been dry screened with the -50 mm fraction rejected. In an effort to reduce this screening loss a 20 mm screen size was used in 1982 with little success. Construction has begun on a washing plant to improve gypsum recovery of the -50 mm material.

The crushed rock is conveyed by means of a 10 km aerial tramline to a stockpile at the dock on Saint Georges Bay. The system consists of 245 buckets, each about 650 kg capacity and can convey about 350,000 tonnes per year. The balance of the production is delivered to the dock by 40 to 90 tonne trucks. Gypsum is shipped to both the wallboard plant and cement plant located at Humbermouth by aluminum bodied, 20 tonne capacity highway trucks.

Charter vessels of 25,000 to 30,000 tonne capacity are employed to transport the gypsum to customers. Ship loading is carried out with a movable boom belt capable of loading about half of a ship's hatches before the vessel must be moved.

Little Narrows Gypsum Company Limited
Little Narrows, Nova Scotia

In 1955, the Victoria Gypsum Company was acquired by the Little Narrows Gypsum Company Limited (see Figure 1) and production has increased from 50,000 tonnes per year during the 1935-1955 period to about 1 million tonnes annually produced during an 8 month ice-free shipping season.

Prior to 1957 all gypsum was mined from the A subzone. In 1957 production began from a new large dark gypsum deposit in the B subzone which was developed adjacent to the primary crusher, and since then most of the gypsum production at Little Narrows has come from this multi-bench quarry. In addition about 100,000 tonnes of anhydrite overlain by a thin hydrated layer of gypsum has been produced from a quarry in the A subzone (Figure 4).

About half of the gypsum and anhydrite which is produced at Little Narrows is shipped by chartered vessels to customers located along the St. Lawrence River and Lake Ontario. The balance of the gypsum and some anhydrite is shipped on company ships to customers along the east coast of the United States.

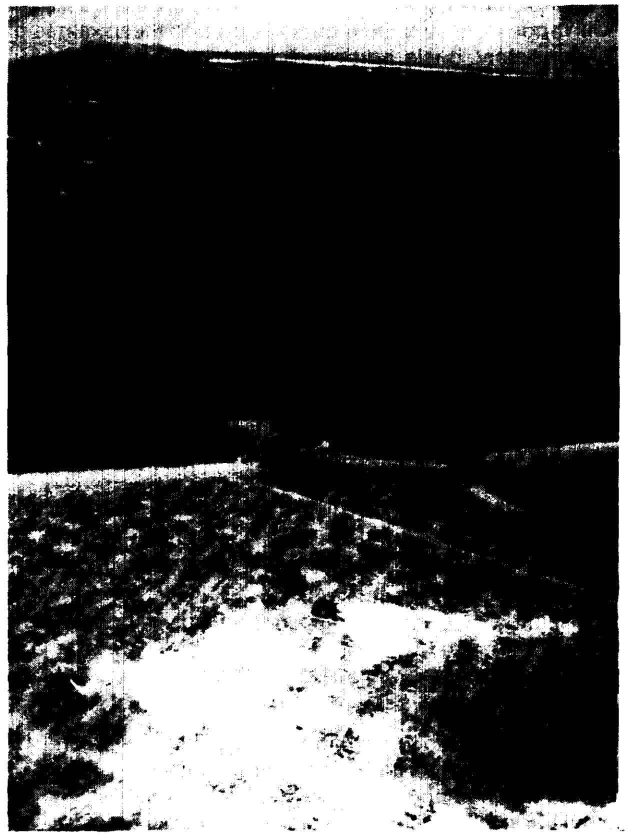

Figure 4. *Little Narrows Gypsum Company Limited's dock-site and storage shed; quarry in background.*

Georgia Pacific Corporation
River Denys, Nova Scotia

Georgia Pacific Corporation, Gypsum Division, commenced production at River Denys, Cape Breton Island (see Figure 1), in 1962. Gypsum is mined along the River Denys Valley and its tributaries, from the massive A subzone sulphate which is irregularly (10-25 m) hydrated.

The overburden averages about 17 m in thickness and is composed of glacial till with localized pockets of sand and gravel. About 1.3 million m^3 per year of stripping is carried out using a dragline equipped with a 14 cubic metre bucket.

The gypsum is drilled with a track-mounted boom drill, blasted and loaded by two 2 cubic metre shovels into 32 tonne trucks for haulage to the crusher. Annual production is about 700,000 tonnes and their recovery is the best of any of the exporting producers.

The crushed gypsum is transported from the quarry by the Canadian National Railway a distance of 32 km to the ship-loading facility located on the Canso Strait at Point Tupper. The shipping facilities occupy the site of the former Canadian National Railway ferry terminal which was employed prior to construction of the Canso Causeway joining Cape Breton Island and the mainland. A fixed discharge conveyor is used to load a new, company-owned, self-unloading vessel of about 30,000 tonnes at a rate of 2300 tons per hour.

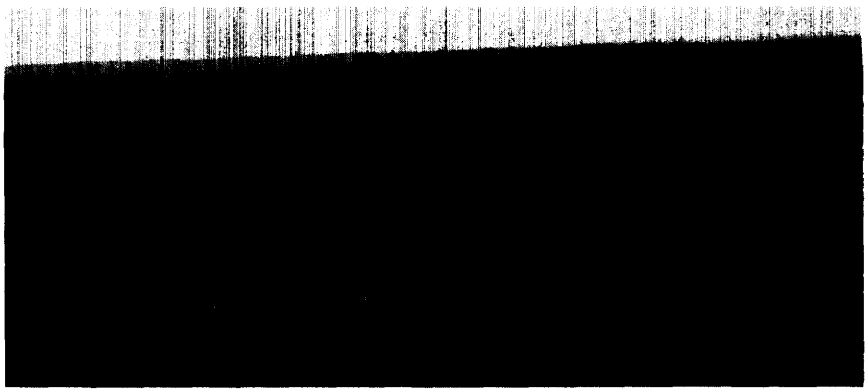

Figure 5. *National Gypsum Company (Canada) Limited's Milford, Nova Scotia, quarry; plantsite in background.*

National Gypsum (Canada) Limited Milford, Nova Scotia

National Gypsum (Canada) Limited conducted large scale quarry operations at Dingwall in northeastern Cape Breton Island for about two decades prior to commencing operations near Milford in 1955.

Unlike the other large producers, who must quarry using a multi-bench system, this quarry is operated as one bench, maintaining a face of about 25 m and a relatively smooth level floor (Figure 5).

Stratigraphically, the quarry is located in a collapse breccia – fault zone at the base of the B subzone and top of the A subzone. The deposit characteristically displays large angular blocks of high purity (90% or more) gypsum in a matrix of irregularly distributed, greenish grey to dark grey siltstone. Below the present floor of the quarry, anhydrite and its associated soluble salts become increasingly common.

About 460,000 m^3 of glacial till overburden are removed annually using 12.5 cubic metre capacity scrapers. The overburden averages about 13 m in thickness but increases locally to 30 m.

More gypsum is produced from the Milford quarry annually than from any other single gypsum quarry. Daily production can reach 13,500 tonnes whilst annual output is about 2.3 million tonnes. Productivity per man-day is far superior to other Canadian gypsum producers.

Following the crushing operation which may include dry screening to maintain quality, the gypsum is transported by Canadian National Railway to the shipping facility. A total of three unit trains, 4500 tonnes each, are railed 42 km to the Burnside docksite situated on the east side of the Bedford Basin. Charter ships, 18,000 to 27,000 tonne capacity, are loaded by movable conveyor boom from a 225,000 tonne open stockpile. Markets include Montreal as well as the east and gulf ports of the United States.

Fundy Gypsum Company Limited Windsor, Nova Scotia

At Wentworth (Dimock's Station), intermixed white gypsum and anhydrite are produced from quarries in the A subzone (Figures 2, 6) which have been in operation for at least 150 years.

Overburden stripping and mining is carried out with 5 cubic metre loaders and 32 tonne trucks.

Following crushing, the mixture of gypsum and anhydrite is washed and then treated in a heavy media (magnetite-ferrosilicon) sink/float plant to separate the two minerals. This plant, installed in 1958, was the first of its type to be installed in Canada for the beneficiation of gypsum (Figure 7).

The output from this plant undergoes screening and additional crushing prior to being transported about 16 km by Dominion Atlantic Railway (CPR) to the shipping facility at Hantsport.

All dark gypsum produced prior to 1957 was mined at Wentworth but in that year gypsum production was commenced at Miller's Creek, located about 5 km west of Wentworth. All dark gypsum mined at Windsor during the past decade has come from this facility.

The initial quarry at Miller's Creek was abandoned in 1978 and is presently being backfilled with stripping and screening waste. All gypsum is now being mined in a quarry developed over the past decade located about 1 km west of the crushing facilities. Both quarries are stratigraphically located in the multi-bedded, complexly folded B subzone (see Figures 2, 3).

Recognizing that many industrial mineral deposits present difficult geologic, hydrologic and mining problems which must be overcome, we believe that the combination of thin interbedded gypsum and waste members which have been subjected to extensive structural deformation represents the most complex large scale gypsum deposit being mined anywhere in the world. Frequently one or more stratigraphic members will be intersected three or four times in a vertical, 100 m drill hole. Geologic study has been continuously carried out at Miller's Creek for the past 22 years and has contributed substantially to the successful mining of this deposit.

The deposit is overlain by glacial till overburden up to 40 m in thickness but averaging about 15 m. Stripping is maintained at a 1:1 ratio to the mined tonnage using conventional large quarry loaders and trucks. The same

Figure 6. *Fundy Gypsum Company Limited's Windsor quarries. Foreground, White quarry and Dark quarry; middle, plant site, tailings pond near river; background, Hantsport dock.*

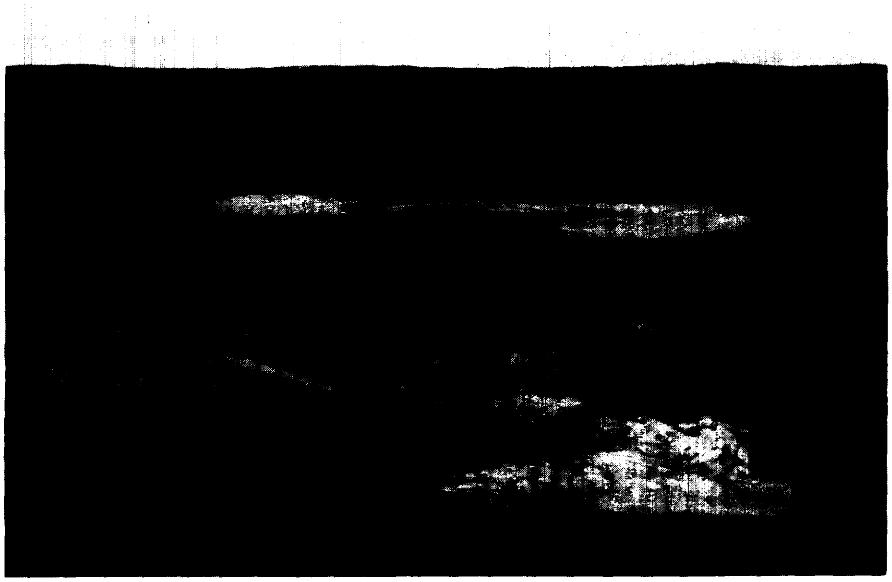

Figure 7. *Fundy Gypsum Company Limited's sink/float plant at Wentworth Creek.*

equipment fleet is used in mining the gypsum and waste units. Rock from the top two benches is dry screened in the crushing plant to remove mud and field stones. The crushed gypsum is transported about 24 km by rail to the ship loading facility located at Hantsport.

The Hantsport dock facilities near the mouth of the Avon River which empties into the southeast end of the Minas Basin consist of a 150,000 tonne enclosed storage shed equipped with two high-speed belts discharging into ships from movable booms. This facility which operates throughout the year must contend with the highest tides in the world, about 15 m variation over 6 hours. Since no provisions exist to permit vessels to remain at the dock until the next tidal cycle, ships come in on the flood tide, turn and are docked with the aid of a tug 3 hours before high water. All ships must sail no later than high water resulting in about 2 hours and 45 minutes loading time. Mixed cargoes of 11,000 or 14,500 tonnes composed of dark and white gypsum and anhydrite are loaded. The largest cargo ever loaded was 18,000 tonnes, a rate of

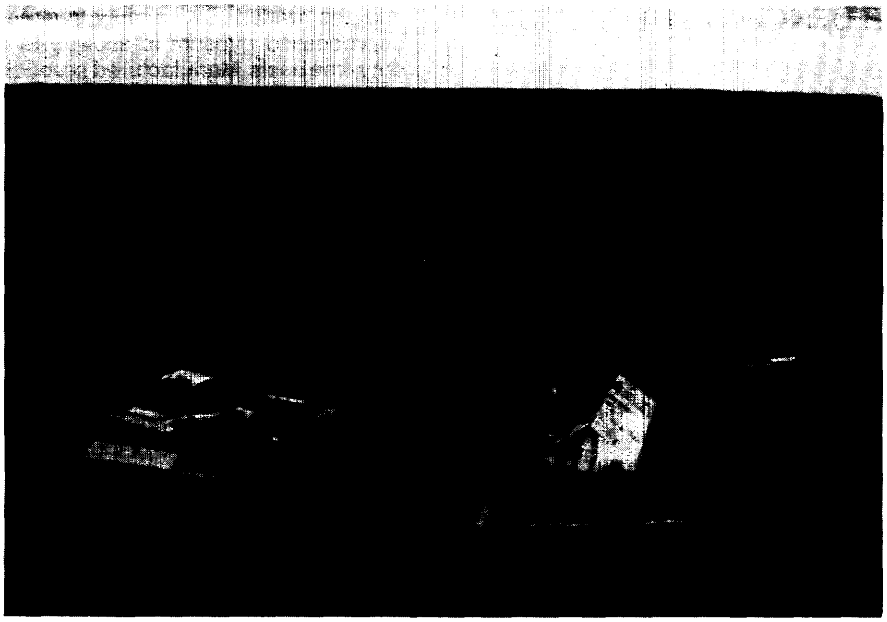

Figure 8. Fundy Gypsum Company Limited's shipping facilities at Hantsport, Nova Scotia.

6500 tonnes per hour.

About 1.4 million tonnes of dark gypsum, 90,000 tonnes of white gypsum and 120,000 tonnes of anhydrite are shipped annually from Windsor (Figure 8).

Domtar Construction Materials Limited Windsor, Nova Scotia

With the closing of Hillsborough, New Brunswick, plant in 1980 the Windsor mill became the oldest continuously operated calcining mill in Canada. Several small quarries have been operated over the past century to provide feed for this mill. For at least the past 75 years white gypsum has been mined from the A subzone. Currently about 8,000 tonnes per year is being mined near the base of the A subzone in a quarry located about 20 km east of Windsor.

Canadian Gypsum Company Limited Hillsborough, New Brunswick

Although this manufacturing plant and associated quarries ceased production in 1980, no description of the gypsum industry in Atlantic Canada would be complete without a few comments about these operations (see Figure 1).

Throughout much of its 125 year history gypsum was recovered by underground room and pillar mining with some of the rooms reaching 14 m in height. One four-level mine, closed for reasons of safety in 1930, exhibited some of the most interesting bedding features known to the authors (Jennison 1911).

In the early days horses were used in tramming ore underground, to the mill and storage shed at the docksite. This was later carried out with locomotives and from about 1958 by highway type trucks.

Three companies were at one time shipping gypsum rock principally to the New York area from three separate loading facilities on the Peticodiac River. All rock shipments ceased shortly after World War II.

The two largest operations were those of the Albert Manufacturing Company whose mines were located near the Village of Hillsborough and the Wentworth Gypsum Company quarry and mine located at Demoiselle Creek about 10 km southwest of the Village.

For many years production exceeded 100,000 tonnes of gypsum reputed to have been the whitest available.

PRODUCTION STATISTICS

Of the estimated 5.7 million tonnes of gypsum quarried in Atlantic Canada in 1980, about 85% was produced in Nova Scotia. The total value of this gypsum was $30.7 million.

Canadian exports of crude gypsum in 1980 were estimated to have been about 5 million tonnes with a value of $25.7 million. Almost all of this exported gypsum would have been produced in Atlantic Canada.

There were 11 million tons of gypsum mined in 1980 in the United States, the world's largest producer. Nova Scotia and Newfoundland combined production was 30% of the American and Canadian total in 1980.

FACTORS INFLUENCING THE GYPSUM INDUSTRY

As in any industry there are many factors which have both a positive as well as a negative impact upon the gypsum industry in Atlantic Canada.

In the industrial mineral industry it is recognized that with few exceptions these commodities owe their value as much to their geographic location as to their intrinsic value. The principal advantage possessed by the gypsum deposits of Atlantic Canada lies not in their location adjacent to centers of large population but in the fact that they are situated on or very close to the seacoast. Their fortuitous location permits gypsum to be transported relatively cheaply by large ocean going vessels to the manufacturing facilities located in market areas of high population density.

Since gypsum mining began, only three manufacturing plants have survived for more than 20 years. Of these three, the mill and board plant near Cornerbrook was constructed by the Newfoundland Government and for much of its life it has probably been a marginally economic venture. Except for short periods of very high construction activity these plants have had capacity in excess of that required for Atlantic Canada.

Nevertheless the large gypsum producers in Nova Scotia are periodically subjected to public and political pressure to construct a manufacturing facility in the province to produce wallboard for export. This pressure to manufacture locally is perhaps understandable and has resulted in at least six major studies and reports being submitted to various government agencies over the past 35 years. In 1973, following the construction of container shipping facilities at the port of Halifax, the gypsum industry prepared, at the request of the Nova Scotia Government, an extensive review of all aspects of the gypsum industry. This study included an assessment of the economics of manufacturing gypsum products locally for export using container shipping. Disregarding all other factors, the cost of shipping wallboard was about seven times more costly than shipping an equivalent tonnage of gypsum to the same market area.

Within months of this submission the Cape Breton Development Corporation commissioned a feasibility study by Peat, Marwick and Partners (1975) on the economics of gypsum manufacturing in Cape Breton. Shortly after completion of that report the Federal Department of Energy, Mines and Resources financed another study of the gypsum industry and the economics of manufacturing in Nova Scotia by Maurice Tugwell (1979), Acadia University, Wolfville, Nova Scotia. In each of these studies the final conclusions were that a gypsum plant in Nova Scotia would be uneconomic because of insufficient local markets. It would also be uneconomic for export based solely on transportation costs, without regard to several other negative effects on the existing industry. It was also noted that the present organization of the industry provided the maximum benefits possible to the people of Nova Scotia.

Another factor which contributes to the maintenance of the gypsum industry is that crushed gypsum is permitted into the United States duty-free. In a similar manner unprocessed gypsum is allowed to enter Canada on a duty-free basis. Manufactured products moving across the border in either direction are subject to duties. As might be expected there are those on both sides of our border who would like to see duties re-imposed as they were around 1896.

Weather conditions during the winter have an adverse effect on those producers mining and shipping gypsum during this period. Productivity is reduced and substantial ship loading and unloading problems are caused by wet and frozen rock.

During the past 50 years most of the gypsum produced in the Atlantic provinces has been exported to large integrated construction materials manufacturers serving markets in the Quebec and Ontario areas of Canada and to the east and gulf coasts of the United States (Figure 9). As an adjunct to their own requirements these operations have produced gypsum and anhydrite for use in the manufacture of Portland cement and as an agricultural soil conditioner particularly in the peanut industry.

Production costs which are not discussed in this paper have increased substantially over the past few years. Currently costs range from $5 to $12 per tonne and generally vary with the type of deposit, efficiency of the system, amount of beneficiation and distance of rail haul to the shipping facility. In all cases the large producers have multimillion dollar investments in mobile equipment, crushing and screening plants and ship loading facilities.

Government policies especially in the areas of taxation and gypsum ownership have caused and continue to be a cause of concern to the gypsum industry. Imposition of a Nova Scotia gypsum tax in 1952 of 6 cents per short ton (now 12 cents) directly led to the transfer of some gypsum production from Nova Scotia to Mexico and the Caribbean.

In spite of protests by the industry the *Mineral Resources Act* was altered in 1975 so that gypsum can now be unilaterally declared a Crown mineral by an Executive Order in Council. This permits for the first time the potential transfer of any or all gypsum deposits from private ownership to the Crown.

In 1982 the Legislature brought down a budget proposing that a 10% Nova Scotia Hospital Services Tax be imposed upon all goods and services purchased for the production of all nonrenewable resources. All mineral producers acting in concert were successful in having this tax reduced to 4% on anything required up to the crushing stage. For all goods and services required for production beyond this stage the Hospital Tax was increased from 8 cents to 10 cents.

Two alternative supplies of gypsum which concern producers in Atlantic Canada are by-product gypsum and cheaper foreign natural gypsum. Several million tonnes of by-product gypsum are produced annually along the east and gulf coasts of the United States. The greatest percentage of this gypsum is produced as phospho-gypsum generated in the manufacture of phosphate chemicals. To date the impurities remaining in this gypsum such as fluorine, uranium, vanadium and particularly radon elimi-

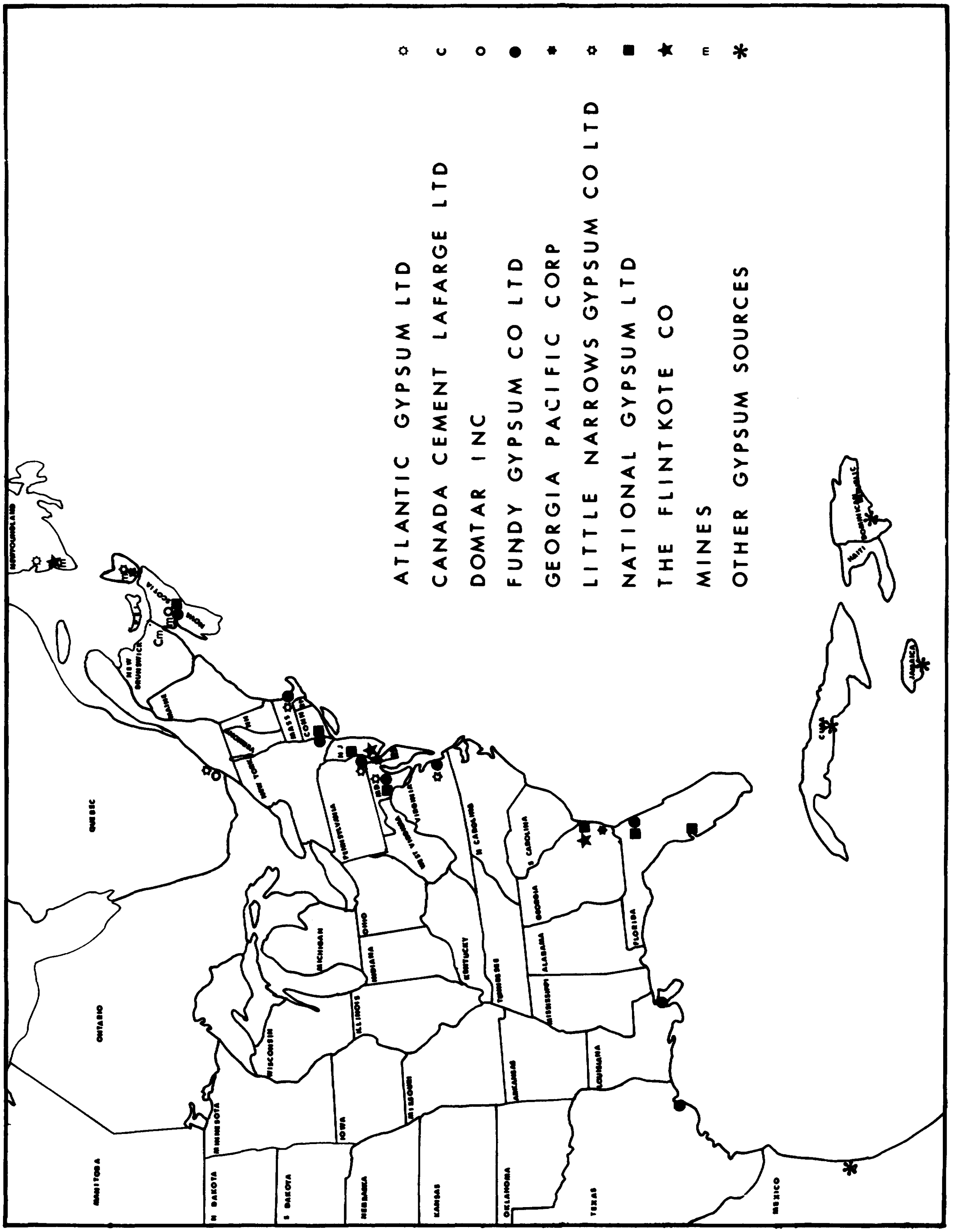

Figure 9. *Location map showing producing mine locations and the export markets supplied from these mines.*

nate this material from usage in construction in North America because of its health hazard. Lesser amounts of by-product gypsum are produced for example in the manufacture of titanium dioxide, citric acid and from sulphur dioxide in the treatment of stack gas. Impurities in some cases currently prevent the use of this gypsum in plaster and wallboard manufacture, however the technology is available to reduce these problems and some byproduct gypsum of satisfactory quality and located near existing manufacturing plants has already displaced a small amount of Nova Scotia gypsum.

A recent development in the industry has been the appearance along the east and gulf coasts of the United States of natural gypsum exported from Spain. Gypsum from this source represents a back haul cargo for the shipping industry and if it becomes established will most surely displace gypsum which is economically produced from eastern Canada.

The following point might be a pertinent comment with which to close this discussion. It has recently been reported that Spanish gypsum was being delivered to Cape Girardeau, Missouri, located about 1000 km up river from New Orleans for $9.50 per ton which is the same price paid for a shipment of Windsor gypsum delivered to Eastport, Maine, in 1815.

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Dimension Stone of Québec: Geological Aspects of Commercial Granite Deposits*

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ABSTRACT

Crystalline igneous rocks, known commercially as granite, are exploited in Québec from more than 25 quarries for building, ornamental and monumental purposes.

Québec is the main Canadian producer of construction granite, accounting for nearly 90% of total production. In the last three years, this industry has experienced an important growth due to improved marketing and use of modern equipment in rock-cutting and polishing. In 1983 a 35% sales increase is forecast.

The main rock varieties extracted are the following: porphyritic pinkish grey granite and green charnockite from Rivière-à-Pierre, mahogany brown granite and black anorthositic rock from the Lac Saint-Jean area, fine-grained pink granite from Guénette, coarse-grained brown quartz monzonite from Saint-Alexis-des-Monts. All these rock types occur in the Grenville tectonic province whereas a medium-grained, light grey granite, Devonian in age, is being extensively quarried in the southern part of the Appalachians. In the Superior province a greenish black diabase and a deep red granite are extracted.

Search for new varieties and deposits is actively being carried out by prospectors and by the Ministère de l'Énergie et des Ressources du Québec following growing demand for granitic and gabbroic rocks as dimension stone.

INTRODUCTION

Crystalline igneous rocks known commercially as granite were quarried in Québec for dimension stone as early as 1860. Granite, quartz monzonite, charnockite, diorite, gabbro, anorthosite and various gneisses are at present being extracted and milled for building, ornamental and monumental purposes. This industry is currently growing rapidly after going through various periods of decline and prosperity.

The following discussion presents a general view of the location and the geological context of commercial granite deposits as well as a description of the types of rocks exploited and their uses. It will be preceded by specifications which the products must meet before being marketed, the geological and industrial features required, and an overview of the economy of this industry in Québec.

The centres of extraction are shown on a general location map (Figure 1), and many individual quarries are located on geological maps (Figures 2-5) showing the distribution and occurrences of the different rock types. The main varieties of stone quarried are shown in Plates I-III.

Information on exact quarry locations, names of operators and prices can be obtained from the APGQ (Association des Producteurs de Granite du Québec), an association of fourteen building-stone producers from this province. Reports by Burton (1932), Osborne (1933, 1934) and volumes by Parks (1914) and Carr (1955) describe in detail commercial granite deposits, some of which are still being exploited today. A complete description of each active and abandoned quarry has been prepared by H.L. Jacob and R. Genest of the Ministère de l'Énergie et des Ressources du Québec; part of this information is available in publications by Avramtchev and Piché (1981, in press).

Limestone and sandstone are also quarried in Québec for construction materials; however it seemed preferable not to include this economic sector in the present paper, as it represented only 5% of the total value of production in 1982. Nor is this paper concerned with ashlar, rubble and crushed stone exploitations.

USE AND GENERAL FEATURES OF COMMERCIAL GRANITE

Nowadays, commercial granite is mainly used in the construction industry where it serves a functional as well as an important ornamental role in such uses as interior and exterior floor- and wall-covering, and exterior modular panelling in high-rise buildings. It is also marketed for monumental stone, a smaller but relatively more important sector as far as commercial value is concerned. However,

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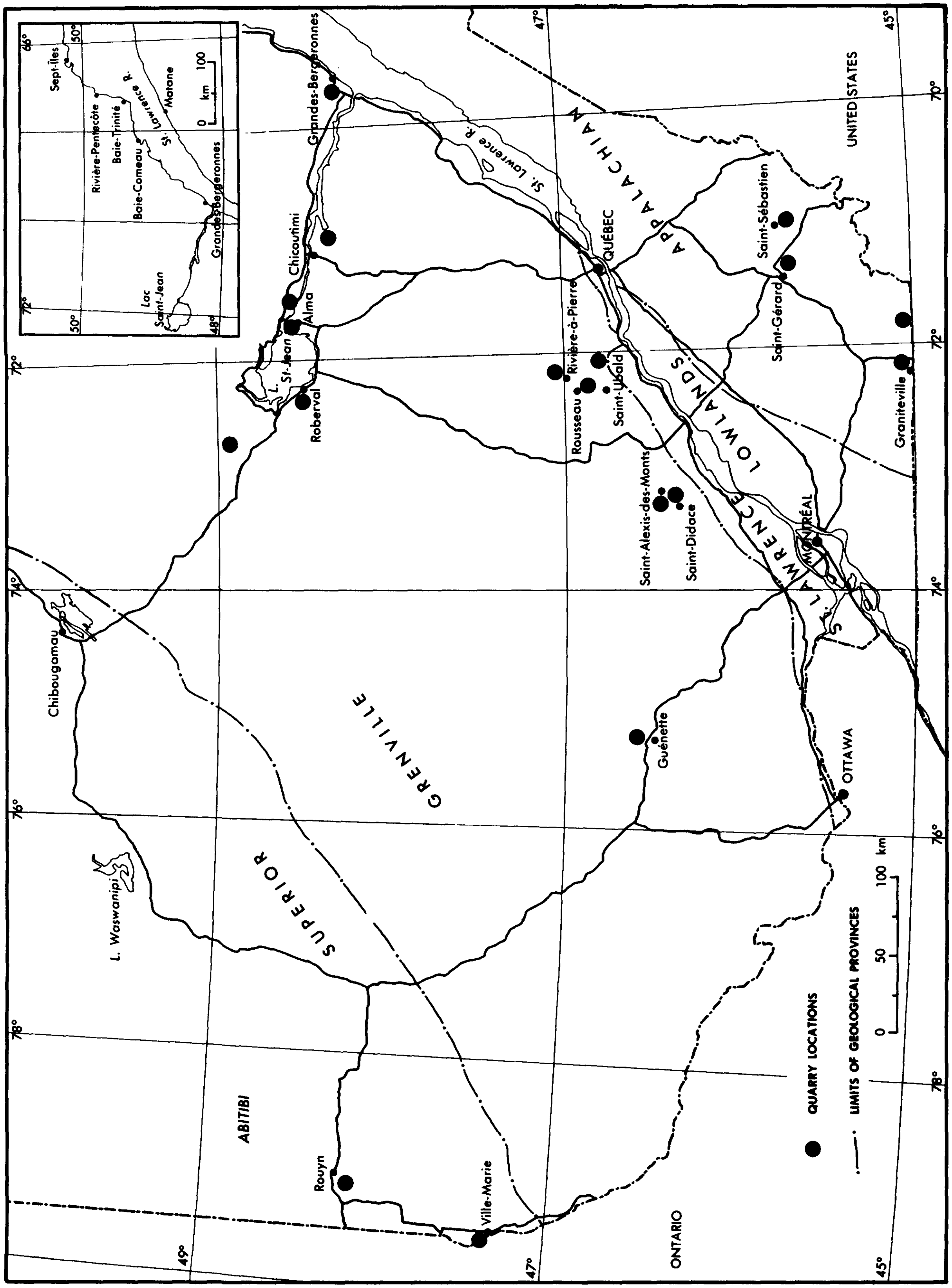


Figure 1. Location map of the main centres of extraction of commercial granite, Québec.

since the early 1960s commercial granite has almost completely been replaced by concrete in bridges, foundations, retaining walls and other similar engineering structures.

Specifications for the selection of an appropriate crystalline igneous rock for dimension stone have been established by the American Society for Testing and Materials (1980). Dimension stone must be fresh and free from seams and deleterious minerals such as sulphides that would affect the durability and appearance of the rock. For building purposes, a certain degree of natural variation is often tolerated; however, the permissible amount of mafic aggregates, veinlets and variations of colour and grain size must be specified by the client. On the other hand these features are considered as imperfections when it comes to monumental stone. In this case the rock must offer an even texture, colour and grain size, an excellent and long-lasting polish, a good contrast between carved and polished surfaces and preferably should be fine-grained.

Commercial granite marketed for building purposes must also meet rigorous physical requirements. The stone is subjected to various tests which measure absorption, density, compressive strength, modulus of rupture and abrasion resistance.

As far as quarrying is concerned, the choice of a deposit is governed by such structural features as joints, sheeting, dikes and ease of splitting. The joint pattern is particularly important as it determines the size and the quantity of recoverable blocks. The ideal pattern is a set of widely spaced orthogonal joints dipping vertically; spacing can be much closer if the stone is extracted for monuments.

Topography and accessibility are also important factors to consider as they influence extraction and transportation costs. Hillside quarries are easier to exploit than pit openings as far as waste, access and drainage are concerned. Even if a deposit offers ideal geological features, it is worthless if it is too remote from the market or simply from an access road.

PRODUCTION AND ECONOMIC ASPECTS

Québec is the most important granite-producing centre in Canada. In 1982 it accounted for 90% of the total Canadian production. Sales of Québec granite for building purposes have soared over the past three years; they increased from $9.5 million in 1979 to $18 million in 1981 and reached $25 million in 1982. Nearly 50% of the production is exported to the United States as finished products and to Italy and Japan as rough blocks.

Various factors explain the rising demand for granite. In these economically difficult times, granite is often preferred to other building materials such as concrete, ceramics and glass for its durability, low maintenance cost and superior insulating properties. Granite has also been rediscovered for its aesthetical appearance. Another factor which concerns more specifically the Québec industry, is the efforts shown by the APGQ in promoting granite on the international market.

In order to cope with the rising demand for granite, Québec producers have had to increase their production capacity and are currently modernizing their plants and building new ones. In Saint-Augustin near Québec City, a modern cutting and polishing plant for granite slabs opened in 1982; it is unique in North America in its use of the latest Italian technology.

DISTRIBUTION AND GEOLOGICAL FEATURES

Granite, monzonite, charnockite, gabbro, anorthosite and diabase are quarried in Québec for dimension stone. These rocks are from slightly deformed or undeformed massifs and, to a lesser extent, from gneissic complexes.

More than 25 quarries are being operated. They are mainly concentrated in the Grenville tectonic province and the Appalachians; as for the Superior province only three quarries are exploited (see Figure 1). A large number of varieties are found in the Grenville deposits, such as pink, pinkish grey, brown, green and black acidic or basic rocks, whereas a medium-grained, grey granite characterizes the Appalachian deposits.

The geological context of the deposits and a description of the type of rock quarried will be given for each of the above mentioned areas.

Grenville Province

More than half of the quarries exploited in Québec are found in the Grenville province. These deposits belong to Precambrian igneous and meta-igneous complexes in which granite, quartz monzonite, mangerite, charnockite, gabbro and anorthosite are often associated.

The main centres of extraction are Rivière-à-Pierre, Lac Saint-Jean and Guénette. A few quarries are also found in the Saint-Alexis-des-Monts area and in Grandes-Bergeronnes.

Rivière-à-Pierre Area

Rivière-à-Pierre is located 100 km west of Québec City. It has been a very active centre of extraction for building, monumental and curbing stone since the early 1900s. It is also an important centre as it hosts the largest and most prosperous quarry in Québec. This quarry (2A, see Figure 2) exploits a pinkish grey granite which is the main variety quarried in the area (quarries 2B, 2C). The massif is a late-tectonic intrusion and is the youngest major intrusion in the area (Pyke 1967). The rock is fresh and deleterious minerals are absent. The texture is porphyritic and the colour is imparted by coarse-grained subhedral feldspars

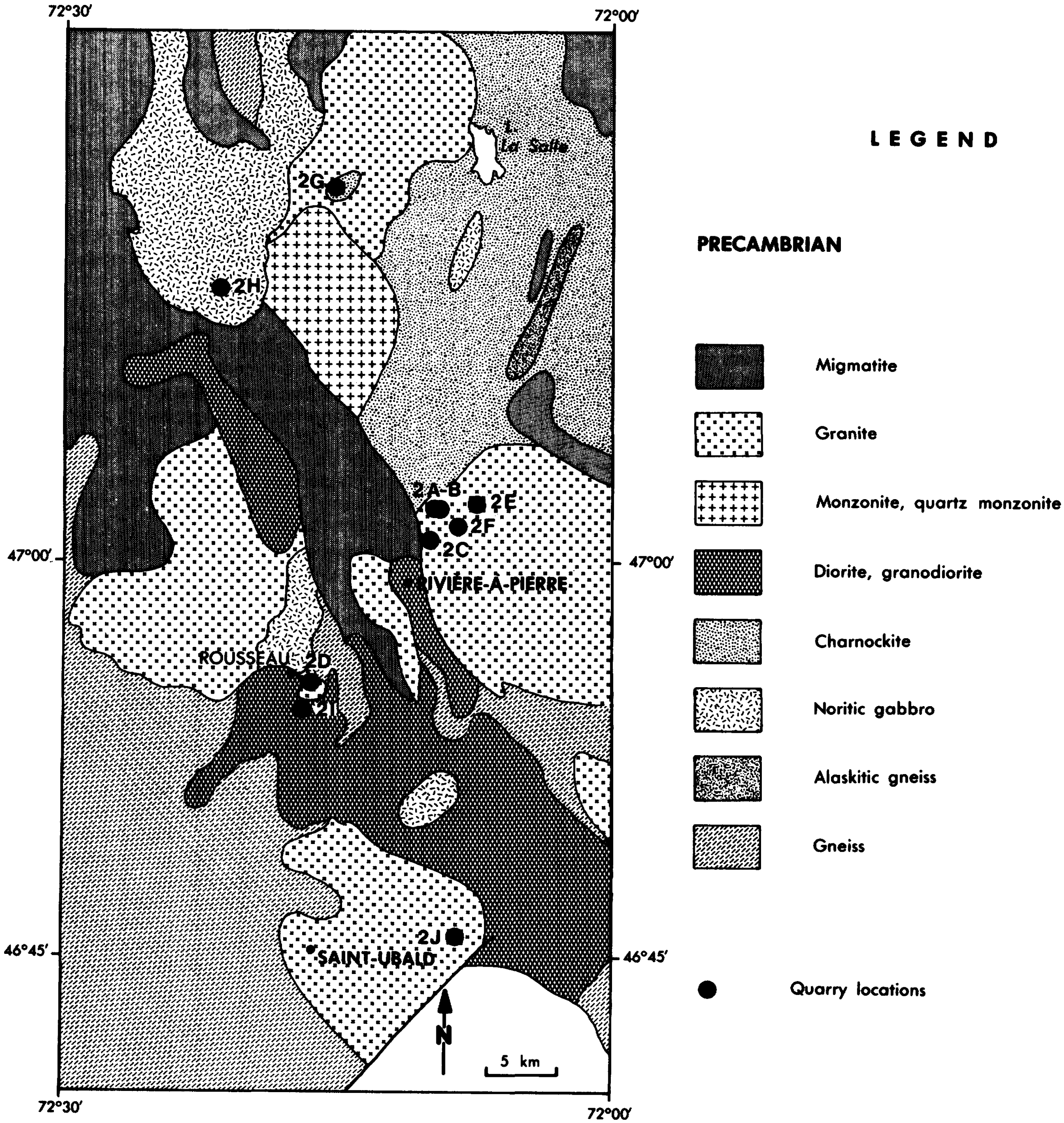


Figure 2. Geology of the Rivière-à-Pierre area, modified from Laurin and Sharma (1975).

(Plate I, No. 2). Mafic clots and a more pronounced pinkish shade are occasional features. Deposits are cut by a set of widely spaced orthogonal joints which have permitted the extraction of remarkably large blocks, up to 12 m^3 and more than 30 tons in weight. Near Rousseau, a quarry (2D) is operated in a similar but smaller intrusion where the rock is finer grained and gneissic.

Coarse-grained charnockite composed of quartz, feldspar, pyroxene and amphibole is also quarried in Rivière-à-Pierre (quarries 2E, 2F, Plate I, No. 3). This type of rock occurs locally in the granite intrusion; transition between these rock types is gradual. Problems related to colour uniformity often arise in such deposits as colour varies from deep to pale green. Some quarries even had to be abandoned because rock composition changed unpredictably from charnockitic to granitic.

An undeformed gabbro – granite – quartz monzonite – charnockite complex, occurring 30 km north of Rivière-à-Pierre, has high potential for exploitation. The granite, quartz monzonite and charnockite are similar to the rocks quarried in Rivière-à-Pierre; some outcrops offer ideal geological features for quarrying. Claims were staked in the charnockite (location 2G) during the summer of 1982 and some close attention has been paid to the gabbro. The latter is composed of fresh plagioclase, pyroxene and primary amphibole. The rock has a granular texture and the average grain size is 2 mm. It also shows layering which varies in composition from anorthositic to gabbroic, on a scale of centimetres. Compared to the granite and charnockite intrusions, joint spacing in the gabbro is much closer, thus limiting the size of extracted blocks. However, sampling and polishing tests, carried out during 1982 on one favourable outcrop (location 2H), revealed an attractive brownish black to deep burgundy colour and a uniform grain size (Plate I, No.4); this outcrop will be quarried as early as 1983.

Near Rousseau, a blue-grey dioritic gneiss is exploited for monumental and building stone (quarry 2I), and a granitic gneiss (Plate I, No.1) is extracted east of Saint-Ubald mainly for building purposes (quarry 2J). Very few quarries operate in gneisses due to problems encountered during extraction and milling: rectangular blocks as well as uniformity of colour and texture are more difficult to obtain than in massive rocks.

Lac Saint-Jean – Chicoutimi Area

Eight quarries are found in this area, located 200 km north of Québec City. The deposits are exploited from the Lac Saint-Jean anorthosite complex, the Chamouchouane and Chicoutimi quartz monzonite and the Roberval granite (Figure 3). These acidic intrusions were emplaced at the border zone of the anorthosite massif which is one of the largest in the world.

Black anorthositic rocks are quarried on both shores of the Péribonca River and near Saint-Nazaire. The rocks from these two localities differ in texture, grain size and composition.

The anorthosite from the Péribonca River quarries (3A, 3B) has a protoclastic texture and is composed mainly of black plagioclase, 5 to 15% olivine and less than 5% magnetite plus ilmenite (Plate II, No.4). Olivine is partly serpentinized and rimmed by a fine pyroxene corona (Nantel 1982). Coarsely polished surfaces show a greenish shade absent on well polished slabs. Between 1930 and 1960, quarries were operated in an anorthosite where olivine was severely altered and rimmed by complex pyroxene-amphibole coronas. The resulting green shade persisted and became even more apparent when exposed to weathering. Waste in the Péribonca River deposits can be as high as 90%. The rock is cut by undesirable 2 mm wide shear veins, filled with quartz, microcline and chlorite. These white streaks often appear once blocks are sawn. Joints are usually closely spaced. Horizontal fractures become more abundant with depth, whereas in granitic rocks, fracturing is more developed near the surface. In spite of these difficulties, quarries are operated on an almost continuous basis as this stone is much in demand for building uses and monuments.

Approximately 10 km south of Saint-Nazaire, a biotite-pyroxene bearing anorthosite is exploited for monumental stone (quarry 3C). This rock is from a small intrusion cutting an older pale grey anorthosite. The medium-grained black plagioclase occurs in laths showing a preferred orientation. The rock takes an excellent polish and the texture is appealing.

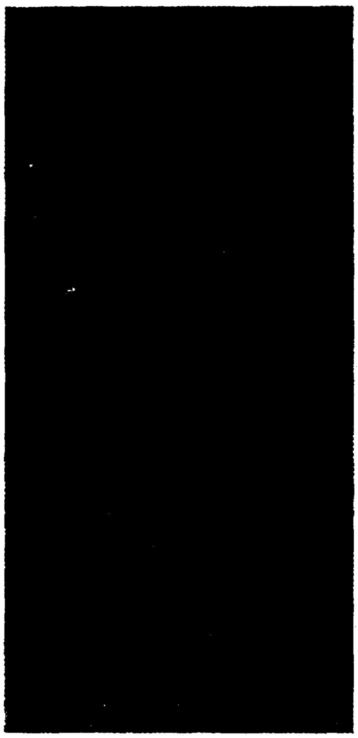
The most active quarries in the Lac Saint-Jean area, are located in the greyish pink granite of the Chicoutimi intrusion (quarries 3D, 3E) and in the mahogany brown mangerite – quartz monzonite of the Chamouchouane pluton (quarry 3F, Plate II, No.3). These quartz - orthoclase – plagioclase – hornblende – biotite rocks are slightly deformed and foliated. The colour and porphyritic texture are imparted by 3 cm long sub-tabular feldspars. Similar structure and texture are found in the Roberval granite where the rock is exploited intermittently in one quarry (3G). The main deleterious features common to these rocks are slight colour variations, aplitic or pegmatitic quartz-feldspar veins and mafic clots. The coarseness of the grain size limits their use to building material.

A fine- to medium-grained light pink granite is quarried near Alma (quarry 3H) depending on the demand. The small intrusion cuts across the anorthosite and is probably contemporaneous with the Roberval pluton (Osborne 1934). The rock is foliated and quartz-rich (35%), and the main feldspar is microcline. It is used as building stone.

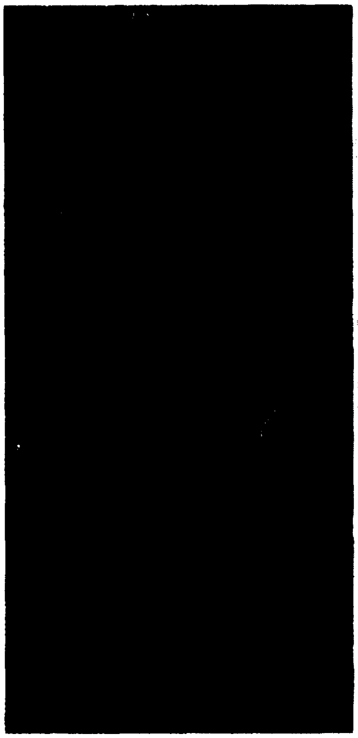
Guénette

This area (see Figure 1), which has three important quarries, has been active in the dimension stone industry since the early 1900s. The exploited rock is a fine-grained, light pink, aplitic granite (Plate III, No.2) cutting gneissic rocks of the Grenville series (Wynne-Edwards *et al.* 1966).

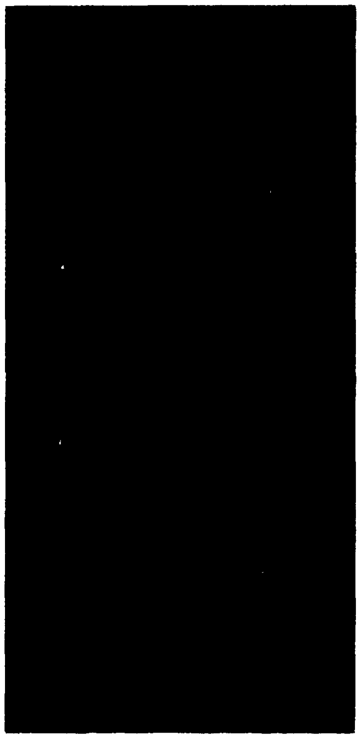
The main constituents are quartz, microcline, plagioclase, biotite and muscovite. It contains minor allanite surrounded by red hematite stains which do not harm the



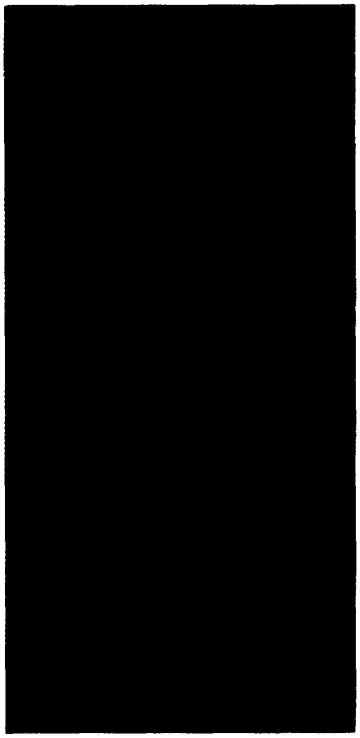
1. Pink granitic gneiss (quarry 2J).



2. Pinkish grey granite (quarries 2A, 2B).



3. Green charnockite (quarries 2E, 2F).

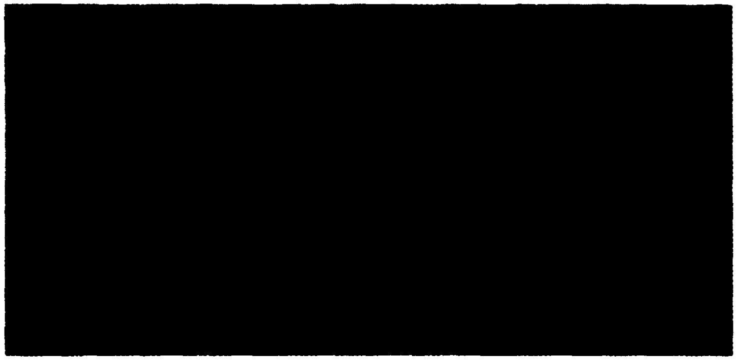


4. Brownish black gabbro (quarry 2H).

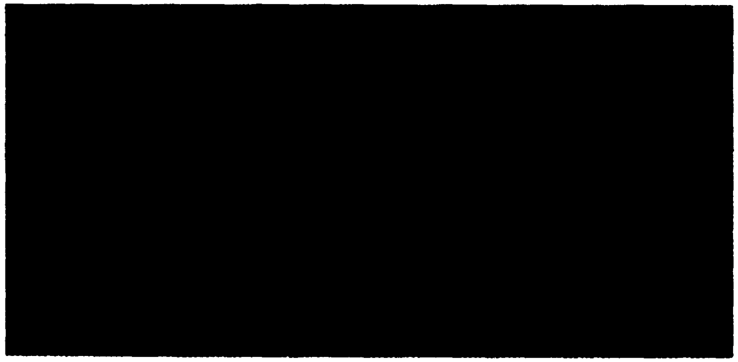
Plate I. Rocks quarried in the Rivière-à-Pierre area.

1. Light green granite (quarry 5A).

2. Grey granite (quarries 5B-5F).



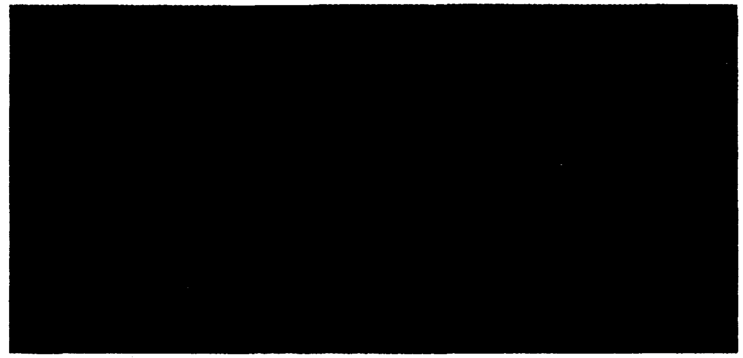
3. Mahogany brown quartz monzonite (quarry 3F).



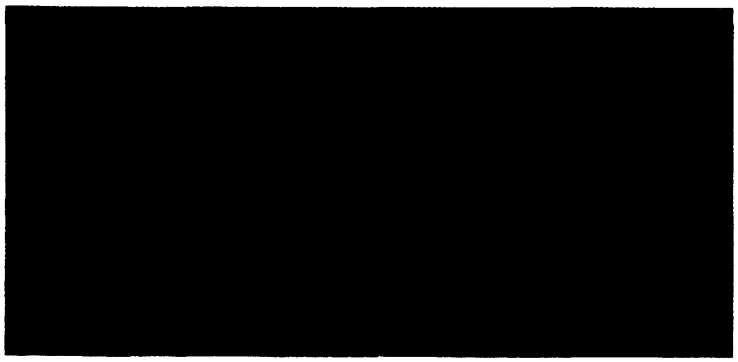
4. Black anorthosite (quarries 3A, 3B).

Plate II. *Rocks quarried in the Saint-Gérard – Saint-Sébastien area (No. 1, 2) and the Lac Saint-Jean area (No. 3, 4).*

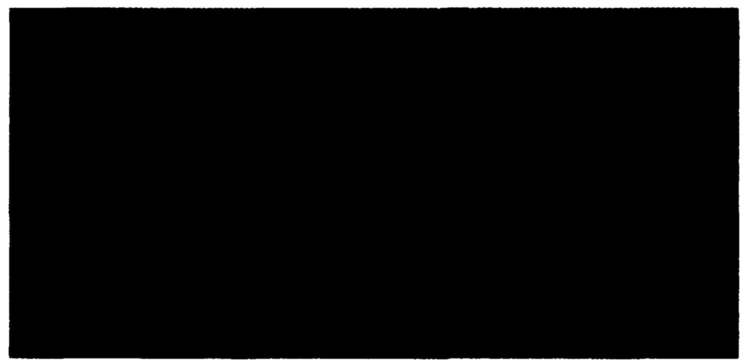
1. Pink granitic gneiss (Grandes-Bergeronnes).



2. Pink aplitic granite (Guénette).



3. Brown quartz monzonite (Saint-Alexis-des-Monts, quarry 4A).



4. Black diabase (Rouyn).

Plate III. Rocks quarried from the Grenville province (No. 1-3) and the Superior province (No. 4).

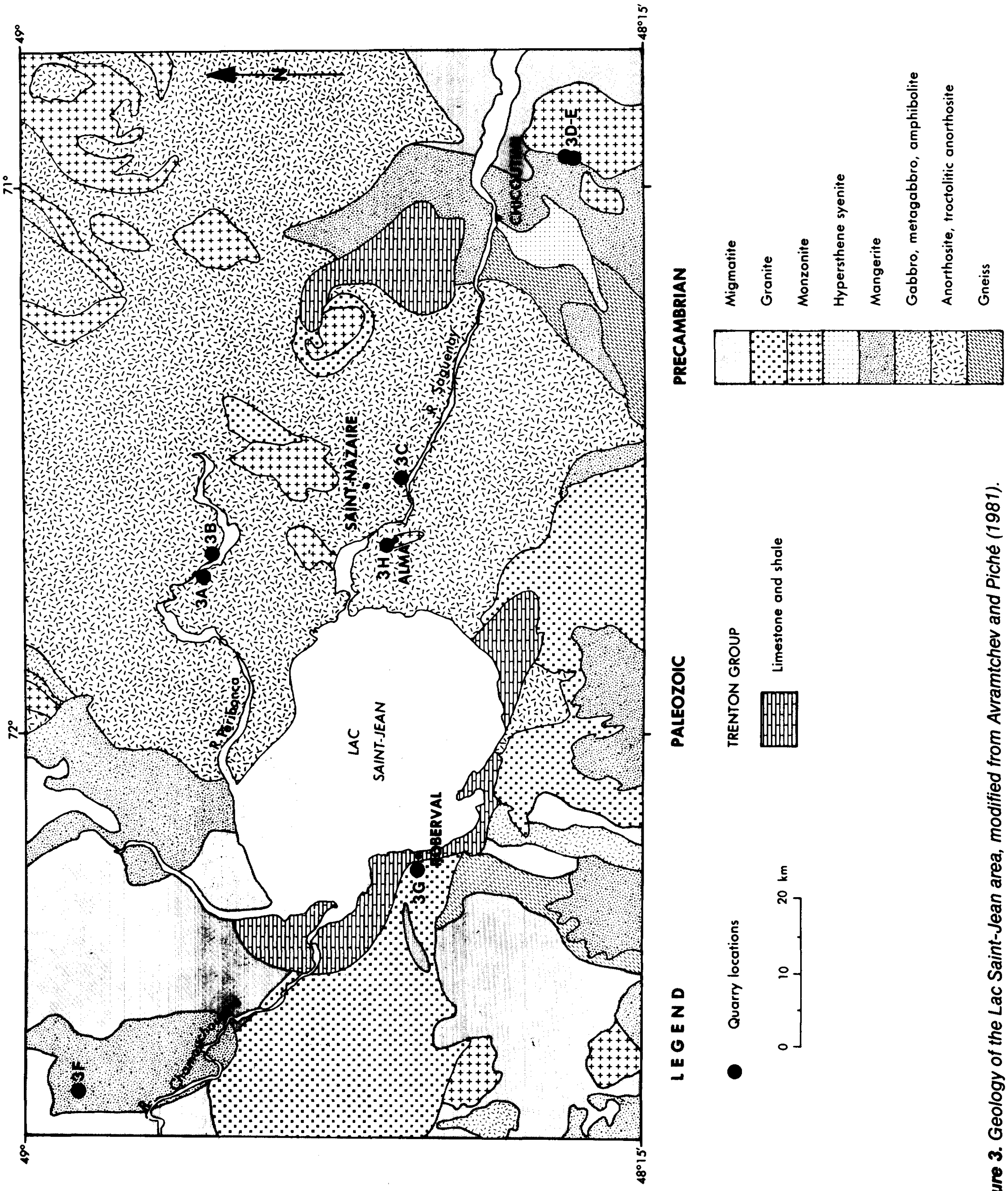


Figure 3. *Geology of the Lac Saint-Jean area, modified from Avramtchev and Piché (1981).*

appearance of the rock. Mafic clots and dikelets are responsible for high waste. However, fine grain, even texture and good contrast between carved and polished surfaces makes this stone particularly suitable for monumental purposes. The stone is very popular in the United States to which most of it is exported.

Saint-Alexis-des-Monts and Saint-Gabriel Areas

The Saint-Didace massif (Figure 4) has been the source of reddish brown and orange-brown quartz monzonite and granite for building stone since the late 1960s (Plate III, No.3). This late- or syn-Grenvillian intrusion has features similar to the Chamouchouane, Roberval, Chicoutimi and Rivière-à-Pierre plutons mentioned previously. The rock is gneissic and shows porphyritic and rapakivi textures. The colour is imparted by 2 to 5 cm tabular to ovoid crystals of potassic feldspar. The hornblende-biotite-bearing rock is fresh, and within the only two deposits actually being exploited (4A, 4B) colour and texture are uniform. The only minor defects are occasional centimetre-sized mafic aggregates. Lately, the increasing demand for this stone, because of its unique colour, has attracted new prospectors to the area.

In certain areas of the Saint-Didace massif, the rock grades into a green facies, although its texture and mineralogical composition do not differ from those of the dominant rock type (Martignole 1975). It has not yet been quarried but some interested producers have undertaken a close study of certain sites (4C).

Grandes-Bergeronnes

Only one quarry has been in operation in this locality since 1957 (see Figure 1). The rock is a homogeneous pink granitic gneiss with grain size averaging 0.5 mm (Plate III, No.1). The relatively widely spaced joints makes the stone suitable for building uses.

Superior Province

Large Archean plutons occurring in the Abitibi region (see Figure 1) of the Superior province are certainly high potential areas for commercial granite deposits, but remoteness from important markets has not encouraged the industry. Nevertheless some producers would be ready to open new quarries in rocks showing unique colour and texture. There are some small deposits in the area that have been operated on an intermittent basis for at least 50 years.

Two quarries are located near Ville-Marie on the east side of Lake Témiscamingue. The rock is a dark red, massive granite composed of quartz, microcline, oligoclase and biotite. In spite of difficulties such as high quartz content and numerous fractures, the rock is quarried mainly for its attractive deep red colour which is not found in any other Québec deposit. The stone is almost entirely marketed for monuments.

Diabase was extracted in the 1950s from a dike near Rouyn. A new quarry has been opened in 1982 in a similar type of rock, 20 km south of Rouyn, east of Lake Montbeillard. The dike is of Proterozoic age and is 40 m thick. The rock is massive and composed of white plagioclase, I to 2 mm in grain size, and dark green augite (Plate III, No.4). It is marred sporadically by white bands visible only on wet or polished surfaces. The stone is used mainly for monuments as only small blocks can be extracted from the highly fractured rock.

The Appalachians

Before quarrying became important in the Grenville province, the southern part of the Québec Appalachians was once the most important granite producing area. However, it is still an active centre of production containing approximately 12 active quarries (Figure 5).

The deposits are currently exploited in three post-Middle Devonian granite massifs intruding Siluro-Devonian sedimentary rocks. They are located in the Saint-Gérard (quarries 5A, 5B), Saint-Sébastien (quarries 5C-5F) and Graniteville areas (see Figure 1). The rock is mainly composed of grey quartz, white feldspar, biotite and muscovite with grain size ranging from 1 to 2 mm. Colour varies from light grey (Plate II, No.2) to almost white but shows a brownish or greenish shade (Plate II, No.1) in certain deposits. The main defect observed in some deposits is occasional rust stains due to pyrite. Waste is also caused by biotite aggregates. This stone, particularly popular in the 1950s in public buildings (Carr 1955), is presently used in construction and for monuments.

SEARCH FOR NEW DEPOSITS IN QUÉBEC

Intense exploration programs are currently being carried out in Québec for new deposits. In order to help producers and prospectors in their search, the Ministère de l'Énergie et des Ressources has created a program consisting of geological appraisal of various regions for dimension stone. Resident geologists of the Rouyn area located some potential sites in this district in 1981. In 1982, interesting zones were brought to the producers' attention following mapping of a part of the Lac Saint-Jean anorthosite near Alma and of an igneous complex 30 km north of Rivière-à-Pierre (the latter has been described in this paper). In 1983 the program will concentrate on the Baie-Comeau – Sept-Iles area (see Figure 1) which offers a favourable geological setting. The projects carried out so far have not only permitted location of potential deposit sites but have also led to the identification of some problems inherent in certain rock types such as close joint spacing in gabbroic and anorthositic rocks, colour variation in charnockitic rocks occurring within granite intrusions and intense fracturing in narrow dikes.

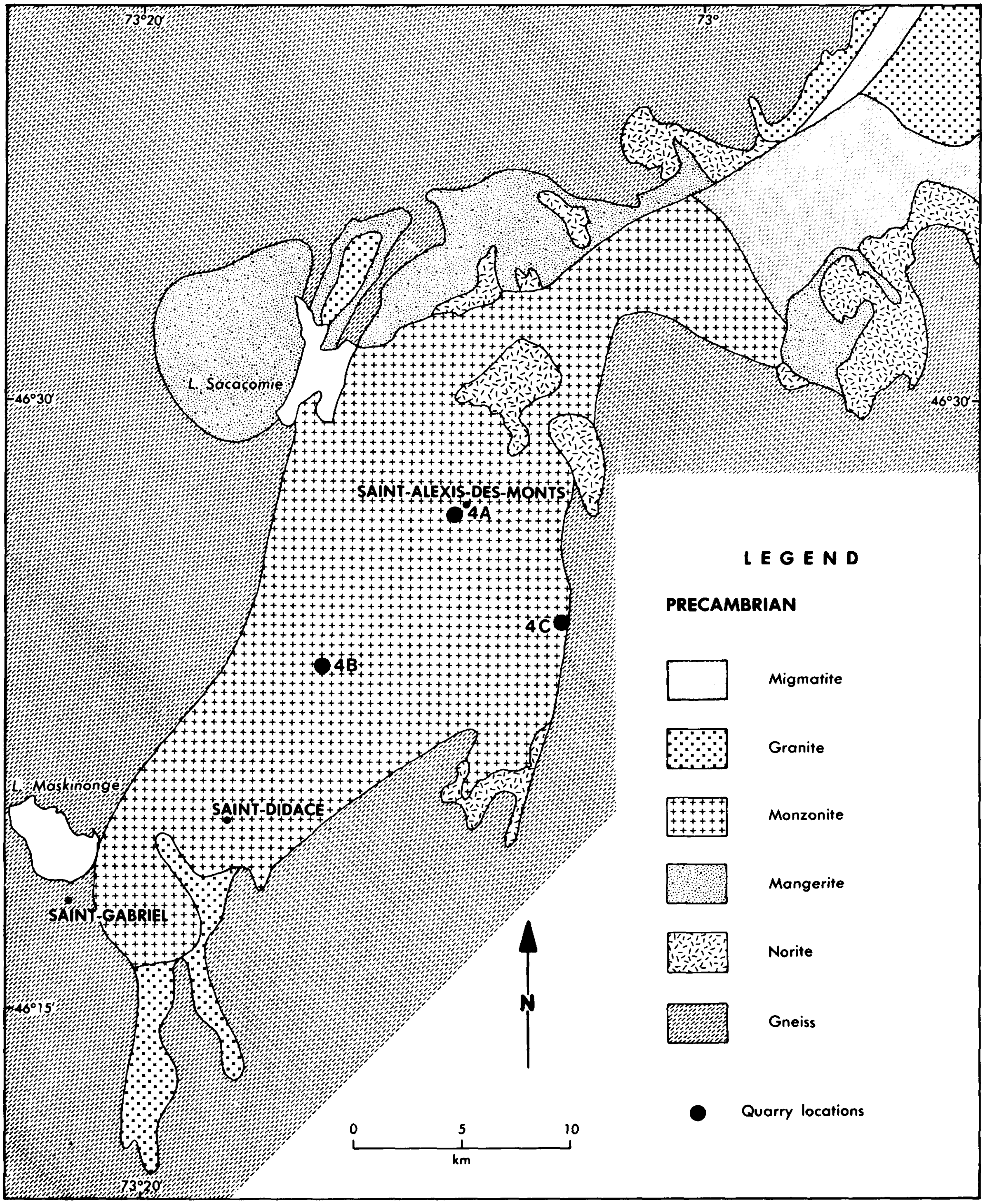


Figure 4. *Geology of the Saint-Didace massif, Saint-Alexis-des-Monts area, modified from Hocq (1969), Schimann (1971) and Martignole (1975).*

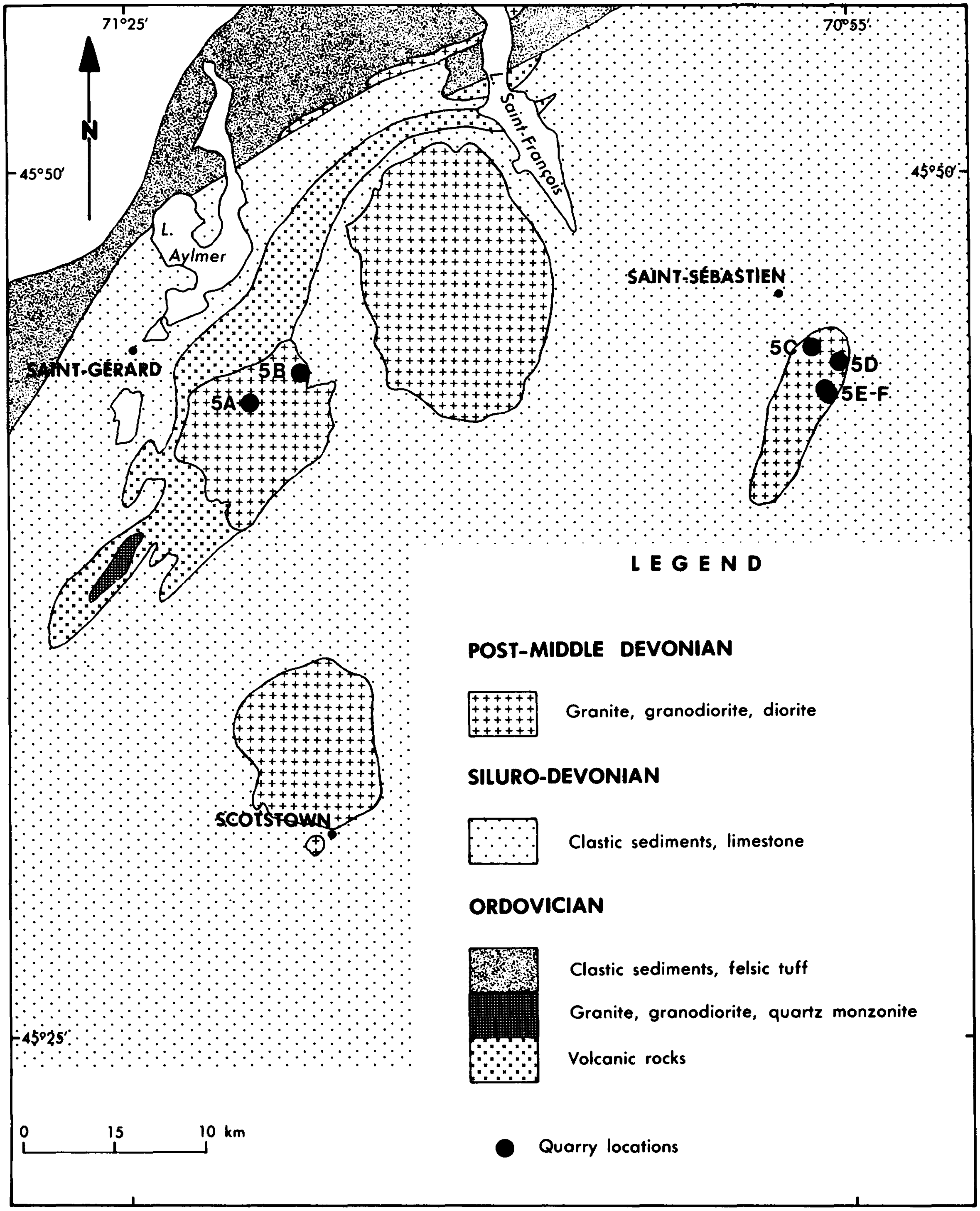


Figure 5. Geology of the Saint-Gérard and Saint-Sébastien area, modified from Harron (1976).

Selection of an area for prospecting should start with the examination of geological maps in order to locate proper rock types. Reports which accompany the maps will help in determining zones of deformation which are to be avoided, and descriptions of colour, texture and grain size will be useful for delimiting high potential areas more precisely.

The most promising regions in Québec for prospecting for commercial granite are certainly the Grenville and Superior provinces. A look at the geological setting of the various deposits being exploited in the Grenville can serve as a valuable guide for prospecting in this area; from the descriptions in this paper it can be seen that the quarries mostly belong to granite – monzonite – charnockite plutons associated with anorthosite or gabbroic massifs. Examples of similar settings are the Rivière-Pentecôte and Baie-Trinité anorthosite complexes, located on the north shore of the St. Lawrence River, east of Grandes-Bergeronnes (see Figure 1). Numerous isolated massive granite and charnockite plutons, which are widely distributed over the Grenville, could also be investigated.

As for the Superior province, search should be concentrated in the Abitibi region and more specifically in the Chibougamau, Rouyn-Noranda and Lake Waswanipi areas (see Figure 1) where large massive Archean plutons occur. The most common rock types are granite, granodiorite, quartz monzonite and tonalite. Remoteness from the most important markets highly increases the transportation cost; therefore deposits in this area would have to show ideal geological and industrial features in order to keep extraction costs as low as possible.

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Mica — Profits and Problems

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ABSTRACT

End uses for ground mica were well defined until 10 years ago. Producers were many, small and not oriented towards research and development. Growth was slow and even negative in some markets due to inroads of competitive materials, often synthetic.

Exploitation of the Bedard phlogopite mine in northern Quebec brought Martin Marietta Corporation, a billion dollar company, into the dry ground mica business. Intensive research and development led to new markets in plastics and in construction materials. Some of these new end-uses involved replacement of other industrial minerals, such as talc, calcium carbonate and short asbestos fibres. Prices for these mica products are thus in the range of $100-300 per ton. In other cases, the mica replaces part of plastics which sell for $900-2,600 per ton. The sophisticated mica products for these end-uses can be sold for $300-700 per ton.

Such prices are a far cry from the "traditional" prices of $80-130 per ton in the larger drilling mud and joint cement markets.

The new markets are small but growing rapidly. After 12 years of intensive plastics research and development, mica has become accepted by the automotive industry as the most economical reinforcing filler to be used when high temperature resistance and dimensional stability are desired properties. Ford and General Motors auto parts, that are now routinely mica-reinforced, include heater housings and seat backs/load floors. These parts replace zinc die castings and aluminum and steel sheet, at considerable savings in weight and cost. Parts that are nearing full acceptance include instrument panels, glove boxes, battery boxes and their supports, fan shrouds and inner fender liners. Here mica replaces glass fibres ($1,200-2,000 per ton) or talc ($120-200 per ton) on a cost performance basis.

Whilst highly profitable, the micas for these end-uses are fairly large flakes that must be very thin and must be surface treated to achieve optimum results. These markets require a higher degree of quality control, technical service and research and development effort than is usually given by filler manufacturers.

Like asbestos, mica must be processed with great care to prevent valuable larger sizes being degraded to the less valuable fines. This is the reverse of fillers such as calcium carbonate and talc, which are more valuable in finer sizes. The nature of the mica deposit itself also dictates the quantity of the larger flakes that can be produced. Increasing capacity for the plastics industry means increasing capacity for fines with limited markets. Finding new markets for finer micas will be the challenge of the future.

INTRODUCTION

Historically, mica has not been one of the major industrial minerals. Mica is produced in the US as a by-product from feldspar or clay production. The flotated mica is usually sold to the oil well industry, without further processing, or sold to grinders for further processing and re-sale. The amounts available have been balanced by traditional markets and there has never been sufficient surplus to warrant searches for new markets.

This situation changed with the entry of Martin Marietta Corporation and Laviolette Mining and Metallurgical Corporation into the ground mica business. This joint venture owns an orebody of more than 30 million tons of 85-90% fine flake phlogopite mica. With total world markets of less than 200,000 tons, it was obvious that new markets had to be created, to make it worthwhile opening the mine. These markets have been sought mainly in the field of plastics reinforcements and in a wide range of applications where mica has partially or totally replaced asbestos.

COMMODITY FLAKE AND GROUND MICA MARKETS

(after Johnson 1981; Zlobik 1979)

The major traditional markets for mica, dry ground and flakes (Table 1), in order of annual tonnage, are as follows.

Dry Wall Joint Cement

Mica scrap, ground -100 mesh, is used to impart smoothness and crack resistance to the 'mud' used to conceal the joints between panels of gypsum wallboard. There is no substitute for mica in this end-use. The largest producer of dry wall, US Gypsum Company Limited, has acquired mica companies to secure its mica supply.

TABLE 1. SCRAP AND FLAKE MICA PRODUCTION ON DEMAND PATTERN (THOUSAND SHORT TONS)

Production	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
World Production											
U.S.	148	153	137	132	123	129	139	134	116	133	110
Rest of World	50	100	110	100	100	110	120	120	NA	NA	NA
Total	200	250	250	230	220	240	260	250	NA	NA	NA
U.S. Demand Pattern for Ground Mica											
Roofing	19	22	10	10	3	5	7	W	W	W	–
Joint Cement	52	51	41	43	51	53	56	60	50	52	–
Surface Coating	25	33	30	21	20	24	19	17	17	18	–
Rubber	6	6	7	4	5	5	4	4	3	W	–
Other*	25	20	26	29	28	28	29	29	41	47	–
Sericite for bricks	NA	NA	NA	W	W	33	59	40	NA	NA	NA

* Mainly for oil well drilling, but includes plastics, welding rods, molded electrical insulation, textiles and decorative coating, wallpaper and agricultural products.
NA Not Available
W Withheld

Source: U.S. Bureau of Mines MCP, Minerals Facts and Problems. Mineral Industry Survey.

Oil Well Drilling Fluid-Lost Circulation Control

When a drill bit enters cracked rock, there is danger of the fluid flowing out into the formation and not returning up the annulus of the well. Since the fluid lubricates the bit, removes the drilled chips and prevents collapse of the hole, loss of circulation may cause a blow-out. Mica flakes will bridge small cracks. Flakes are added prophylactically and as a remedial measure.

Surface Coatings

Mica is used to reduce cracking, permeability to water and gases, improve weatherability and salt spray resistance and to give a smooth surface.

Rubber

Mica is used because of its lubricity at high temperatures in mold release agents for production of rubber articles. The major end-use is in formulated lubricants based on silicone fluids used in the molding of the band-plies in tires.

GROWTH TRENDS IN THE COMMODITY FLAKE AND GROUND MICA MARKETS

Dry Wall Joint Cement

There is every indication that the use of gypsum wallboard, as the primary interior finish for residential housing, will continue to grow. With housing design trending towards fewer and smaller windows, to reduce energy consumption, the area covered by gypsum board will increase commensurately. Gypsum wallboard has been a purely North American technique until recently, but this method of construction is becoming popular in western Europe and Japan. The increase in wallboard usage world-wide will be reflected in increased demand for joint cement, but with certain caveats.

1. Use of Type X (fire code) board has been growing very rapidly, but, in locations (such as furnace rooms) where the codes require two layers to get the necessary fire rating, the concealed layer is not taped, i.e. no joint cement is used.

2. Some boards are made with rounded edges so that the joins remain open and visible. These boards may be predecorated. Likewise, the demand for mica does not go hand-in-hand with joint cement production:-

   a) In the US, there has been a tendency to use less mica because the cost has become too high for this most competitive product. There has been a switch to cheaper micaceous minerals, such as sericite. The end-user would certainly use more good quality muscovite if the delivered cost was 10¢ per pound or thereabouts.

   b) European joint cement producers do not generally use mica. The walls are usually covered with a layer of wallpaper, which can then be painted or covered with decorative wallpaper. Cracks in the joint cement are thus hidden. In North America, the joints are sanded smooth, the whole gypsum wallboard area may or may not be covered with a thin coat of joint cement, followed by painting. In North American practice, the joints must be totally invisible.

   c) In the US, the mica used is muscovite of good white colour. This is because joint cement is often used as a low cost texture paint, for ceilings. In eastern Canada, tan-coloured phlogopite mica is used in joint cement, which more closely matches the colour of the wallboard than the whiter US material. Textured coatings, in Canada, do not generally contain mica. Western Canadian manufacturers, who often look south to the US for an important part of their business, tend to use imported white US muscovite.

Despite these provisos, the demand for mica for joint cement is expected to grow. I predict that the current oversupply, due to low construction starts will change to a shortfall of mica for this industry, starting in 1984-1985, because of the limited supply of US scrap mica, as by-products from feldspar and clay industries. The industries that use these minerals will not grow as fast as the gypsum wallboard industry. This shortfall has occurred at least twice in the past 15 years. I predict that the demand will be met by new suppliers who will mine for the mica alone, or will beneficiate tailings rich in mica, or will up-grade mica products that are now sold for lower priced end-uses, such as oil well drilling.

Oil Well Drilling

(after Hawley 1980)

Mica is not the only product used to prevent loss of circulation. The main competitors are cottonseed hulls, bagasse, scrap cellophane and walnut shells. Mica has one of the largest tonnages, however. Because of the general scrap nature of the competitive materials, the price of lost circulation mica is very low, of the order of $120 per ton. This reflects in the quality of 'mica' supplied which may only contain 50% true mica.

Loss of circulation is a problem in certain geological regions, e.g. Middle East and North Africa, and not in others (North Sea). Circulation also tends to be lost more often in deep wells, where the combination of the high hydrostatic pressure of the column of drilling mud, plus dynamic pressures induced during removal and replacement of the drilling string, may overcome the tensile strength of the rock and cause it to fracture.

Thus the demand for mica fluctuates depending on the regions of greatest oil exploration activity and on the depth of the holes being drilled. These factors are also largely affected by oil prices. The dropping of OPEC oil prices has severely reduced the footage of exploratory wells drilled in the USA. Footage dropped in Canada for the same reasons, and also because of Federal Government policies, perceived to be adversary by the oil industry.

There are signs that the oil price decline is over, and that oil prices will climb again, but at a controlled rate. This should stimulate exploratory drilling. But where? Drilling in the Far and Middle East means mica sales for India and China, not for Canadian and US suppliers. One can only hope that the Canadian and US Governments will act to stimulate North American exploration.

I see US and Canadian demand for oil well drilling mica growing steadily. Previous shortfalls of supply have occurred when the building industry has boomed. At such times, the major suppliers prefer to produce the more profitable joint cement mica. Knowing this, the drilling fluid supply companies have encouraged opening of low grade mica deposits, located relatively near to the main stocking points on the Gulf Coast. Colour is not a problem, nor is gritty material, if the particles are small enough not to block orifices in the drill bit. Demand for this quality mica could be as high as 100,000 tons by year 2000.

Surface Coatings

This industry wants wet ground mica of very white colour. Production of wet ground mica is difficult, expensive, and creates environmental problems, so that producers have been closing down despite the demand. Because of poor supply, and high prices of wet ground mica, paint manufacturers have been reducing the amount of mica used.

I forecast little or no growth in this area. One manufacturer of pearlescent pigments has acquired a wet ground mica producer and another has set up his own facility, using Indian scrap, to maintain their supply of good quality wet ground muscovite.

Rubber

Again wet ground mica is preferred, but most users have switched to dry ground mica, because of poor supplies of the wet ground material. Also, band ply lubricants have been developed that do not use mica. I forecast the demand to stay steady after it returns to its normal level after the recession.

HISTORY OF THE SUZORITE MICA PROJECT

(after Hawley 1981)

Carl Faessler located the original phlogopite deposit in northern Quebec in 1936 and called it *suzorite,* after Suzor Township in which it is located. In 1960, Laurent Bedard, of Laviolette Mining and Metallurgical Corporation located a richer orebody in the same region. Subsequent drilling has shown this to be an ellipsoidal mass oriented north-south, 850 m long by 270 m wide, dipping about 30° east. Reserves are estimated at 30 million tons of 85-90% phlogopite in the first 60 m of depth. The mica consists of small flakes 0.6 cm and smaller, cemented together with grains of feldspar and pyroxene.

In 1970, a joint venture was formed, with Marietta Resources International, Division of Martin Marietta Corporation, to exploit this deposit. After intensive market studies and research and development on new applications for mica, a pilot scale plant was built in Montreal. This was expanded into a small production plant at the same location. Growing demand required the building of a new plant in Boucherville, Quebec. Initial capacity was only 15,000 tons, but a series of expansions has increased this to 25,000-30,000 tons, including capacity to surface treat 6,000 tons of mica annually. Further expansions are planned, to cater to the needs of plastics and asbestos replacement users.

The facilities at Boucherville include a research and development laboratory equipped with laboratory and pilot scale surface treatment equipment; extrusion, injection molding and compression molding facilities for plastics; plus equipment for work in asbestos replacement markets. Technical service is handled by Marietta Resources' staff, from Hunt Valley, Maryland.

NEW MARKETS FOR MICA

(after Hawley 1976; Lusis 1973; Shepherd 1974)

The new markets, described below, were developed by exploiting the unique properties of mica. Table 2 compares the properties of various micas with asbestos and fibrous glass. Table 3 reviews the most important properties that mica confers when used in composites.

Plastics

Based on work at the University of Toronto and Fiberglas Canada Limited, in 1973, it was found that mica could serve as an excellent reinforcement for plastics of many types. The key was to produce mica with a high aspect ratio; that is, a large ratio of diameter to thickness. Micas that were commonly available of that time had ratios of 10-30. By ultrasonic delamination, R. T. Woodhams was able to achieve aspect ratios in the 100-300 range. At Marietta Resources International, my research and development team developed techniques to produce micas of aspect ratio 50-100. This range is sufficient for most plastic reinforcement applications.

We also found that even high aspect ratio mica was ineffective in polymers of low polarity such as polypropylene and polyethylene. Therefore, surface treatments were developed by us, in concert with coupling agent suppliers and users, such as Ford Motor Company, to produce composites of mica with polypropylene and polyethylene that showed excellent mechanical properties. Currently, these speciality mica grades are used commercially in composites with polypropylene, polyethylene, polyesters, nylon, and ABS. Work is in progress to extend the range of polymers to include PVC, newer engineering thermoplastics, and reinforced RIM (polyurethane, nylon, and polyester).

The earliest end-uses have been for large volume automotive parts such as the plastic replacement for the die-cast zinc heater valve housing on General Motors intermediate-sized cars; blow-molded seat backs/load floors for hatch back cars such as the General Motors F Cars (Firebird, Camaro), Ford ESP, and Mercury LN7; high energy distributor parts and the E-core ignition coil housing on Ford's 1.6 litre Escort and Lynx engines. Parts now coming into production or in development include instrument panels, crash pad retainers, fender liners, fan shrouds, battery trays, air conditioner fans; plus some exterior parts such as head and tail lamp assemblies, cowl vent grilles, wiper blades and front end panels.

Apart from automotive end-uses, mica composites are also used in appliances and hand tools, such as attic fans, glue guns, microwave cookware, swimming pools and boat building, loud-speaker cones and cabinets, bicycle and bucket seats.

The main contribution of mica in these composites is to increase strength and stiffness, particularly at elevated temperatures; to reduce thermal expansion and warping. High aspect ratio mica gives much greater reinforcement than is obtained from fillers such as talc and calcium carbonate, and nears that obtained with glass fibres, but at much lower cost.

Sound and Vibration Damping

Because of its high stiffness, mica damps out vibrations readily. It is used commercialy in asphalt based underbody coatings, and in plastics linings to reduce the sound level in the passenger compartment due to noise from the engine, transmission and tires.

The use of mica to produce high fidelity, low angle, speaker cones is related to the same property of mica, that of high velocity of sound within itself.

Asbestos Replacement

Mica resembles asbestos in many ways. They are both strong, stiff minerals, but mica does not have the needle-like shape that has contributed to health problems with asbestos.

Research and development at Marietta Resources International's Boucherville laboratory and elsewhere, developed many applications where mica could take over some of the functions conferred by asbestos. Asbestos is a unique mineral, so that mica must be used blended with other materials to achieve an equivalent product.

Commercial asbestos-free products which contain mica, as an essential ingredient include:

- cement pipe;
- cement sheet and shingles;
- calcium silicate boiler pipe insulation;
- calcium silicate fire-proofing sheet for marine and other uses;
- cementitious coatings;
- asphalt roof shingles;
- asphalt roofing;
- gaskets; and
- disc brake and clutch linings.

PRICING OF MICA PRODUCTS

The prices of ground and flake mica products (Table 4) relate to the degree of purity and the effort required to win and process the feedstock to an acceptable product. Processing costs increase rapidly when attempting to delaminate mica, without comminuting it, or when making the flakes fine. High technology processing, such as ultrasonic delamination may add as much as $200 per ton. Wet grinding of mica and fluid energy milling are also high cost techniques.

It is notable that mica is the most difficult mineral to comminute. The energy requirement for grinding mica is 10 times higher than that for other industrial minerals (Table 5).

TABLE 2. COMPARISON OF PHLOGOPITE WITH OTHER MICAS AND INORGANIC FIBRES

PROPERTY		SYNTHETIC FLUOROPHLOGOPITE	NATURAL MUSCOVITE	NATURAL PHLOGOPITE (SUZORITE)	CHRYSOTILE ASBESTOS	"E" GLASS FIBRES
Density	g/c^3	2.88	2.6-3.2	2.6-3.2	2.4-2.6	2.54
DO	pcf	180	160-200	160-200		
Hardness	Mohs	3-to 3.5	3-to 3.0	3-	2.5-4.0	5-7
DO	Knoop, K_{100}	120-143	100-126	95-115		
Transparency		Clear	Ruby	Amber	Opaque	Clear
Cleavage		Basal,eminent	Basal,eminent	Basal,eminent		
Crystal structure		Monoclinic	Monoclinic	Monoclinic	Monoclinic	Amor-phous
Optical axial angle, 2V	degrees	14.0 ± 0.3	38-47	0-10		
Orientation of optic plane to plane of symmetry		Parallel	Perpendicular	Parallel		
Index of refraction:						
a		1.522	1.552-1.570	1.54-1.63		
b		1.548	1.582-1.607	1.57-1.69	1.51-1.55	1.547
y		1.549	1.588-1.611	1.57-1.69		
Maximum temperature with little or no decomposition:						
	°C	1,000	500	1,000		
	°F	1,832	932	1,832		1140 (St. PT.)
Specific heat (at 25°C)		0.194	0.206-0.209	0.206-0.209	0.266	0.192
Coefficient of thermal expansion per °C perpendicular to cleavage:						
	20°C to 100°C		$15x10^{-6}$-$25x10^{-6}$	$1x10^{-6}$-$1x10^{-3}$		
	100°C to 300°C		$16x10^{-6}$-$25x10^{-6}$	$2x10^{-5}$-$2x10^{-2}$	$2.8x10^{5}$	
	300°C to 600°C		$16x10^{-6}$-$36x10^{-6}$	$1x10^{-5}$-$3x10^{-3}$		
Coefficient of thermal expansion per °C parallel to cleavage:						
	0°C-200°C	$10x10^{-6}$-$11.5x10^{-6}$	$8x10^{-6}$-$9x10^{-6}$	$13x10^{-6}$-$14.5x10^{-6}$		$5x10^{-6}$
	200°C-500°C		$10x10^{-6}12x10^{-6}$	$13x10^{-6}14.5x10^{-6}$		
Thermal conductivity perpendicular to cleavage:						
	$Cal/cm^2/sec/cm/°C$		$16x10^{-4}$	$16x10^{-4}$	$2.7x10^{-4}$	$15x10^{-4}$
	$Btu/ft^2/hr/in/°F$		4.6	4.6		
Tensile strength	psi	45,000-52,000	37,000-43,000	130,000	50,000-100,000	500,000
Modulus of elasticity	psi	$25x10^{6}$	$25x10^{6}$	$25x10^{6}$	4-$24x10^{6}$	$10.5x10^{6}$
Water of constitution	percent	None	4.5	1.01	14-18	NIL
Melting point	°C	$1,387\pm3$	Decomposes	1,405	1521	846
Crystal surface	microinches	2-4	2-4	2-4		
Radiation resistance: Maximum use temperature with $5x10^{14}$ thermal neutrons/ cm^2°C		775	500	550		
Coefficient of static friction			0.2-0.4	0.2-0.4	0.4-0.5	0.1
Specific surface	(m^2/G)			0.07 (a=115)	0.75-2.08	
Transparent Spectrum	microns		0.25-13	0.25-13		0.33-0.67
Oil Absorption	c^3/g			1.04-1.15	0.50-1.50	
Chemical resistance		Good	V. Good	Good	Poor	Medium
Water Absorption	percent		Nil	Nil	2	1
Water Solubles	percent			Nil	0.12-0.38	
Electrical Charge		Negative			Positive	
Specific resistivity	ohm cm					
At 25°C		10^{12}-10^{16}	10^{12}-10^{16}	10^{10}-10^{13}	10^{4}-10^{6}(50% R.H.)	
at 550°C		10^{12}	10^{11}			
Dielectric strength (1-3 mils thick)	v/mil	6,000-3,000	6,000-3,000	4,200-2,100		1,400
Dielectric constant at 1 Mc		6.5	6.5-9.0	5.0-6.0	33.7 (60 H_z)	5.8
Dissipation factor at 25°C						
60 cycles	tan△		0.0008-0.0009			
1 Mc	tan△	0.0002	0.0002	0.004-0.070		
Loss factor at 1 Mc	tan△	0.0013	0.0013	0.020-0.042		.001
Dissipation factor at 1 Mc						
200°C		0.0002-0.0008				
300°C		0.0004-0.0030				

TABLE 3. PROPERTIES CONFERRED BY HIGH ASPECT RATIO MICA FLAKES WHEN USED IN COMPOSITES WITH ORGANIC AND INORGANIC MATRICES

Property of Composite	Effect of Mica in Composites	Rating of Effects of Mica With Other Materials (Reinforcements & Matrices)
STRENGTH	REINFORCES, i.e. INCREASES TENSILE & FLEXURAL STRENGTH	1.5-2 times better than asbestos in composites. 0.3-0.8 compared with glass fibers, in composites. 10-30 times stronger than polymer matrices.
STIFFNESS	Increase modulus of composites	
	a) reduces deflection under load of rigid polymers.	1.12-2.25 times better than asbestos. 2.5 times better than glass fibers.
	b) increases noise & vibration absorption of semi-rigid polymers.	2-3 times better than clay or other fillers.
	c) INCREASES HEAT DEFLECTION TEMPERATURES.	2.0 times better than unfilled P.P. 1.4 times better than talc in P.P. composites. 0.8 compared with glass fibers, in P.P. composites.
DIMENSIONAL STABILITY	a) REDUCES WARPING ON COOLING OR HEATING.	Better than virgin or fiber reinforced polymer (more isotropic).
	b) reduces shrinkage & cracking	Adhesion of epoxies & polyesters is improved by addition of mica; JOINT CEMENT & COATINGS CRACK LESS.
	c) REDUCES DIMENSIONAL CHANGE DURING HUMIDITY CYCLING.	Improves properties of asbestos-free cement sheet & shingle.
Heat Stability	a) Does not produce volatiles; or/	Asbestos starts to lose its 12-15% water at 250°C.
	volume or other changes up to 1300°C (phlogopite & biotite)	E glass fibers melt above 615°C.
	b) combined water is 3%; released uniformly above 1000°C. (phlogopite & biotite)	Vermiculite loses 6-12% water & puffs up above 270°C. (Muscovite mica may delaminate when heated).
Thermal Expansion	Reduces thermal expansion of polymer to the same level as aluminum.	1/4 – 1/8 of that of P.P. 2 times that of glass fibers. 8 times that of asbestos.
THERMAL CONDUCTIVITY	AIDS FLUXING, DISSIPATION & DISTRIBUTION OF PROCESS HEAT. REDUCES PROCESSING TIME OF THERMOPLASTICS.	4 times that of P.P. 0.78 times that of asbestos fibers. Equal to that of glass fibers.
Specific Heat	Less heat is required to reach processing temperatures. Energy is saved.	0.5 times that of P.P. 0.78 times that of asbestos fibers. Equal to that of glass fibers.
Chemical Resistance	a) Improves chemical resistance; withstands all except strong acids.	Glass is attacked by weak acids and alkalis. Asbestos is attacked by weak acids.
	b) Reduces water absorption.	Much better than asbestos or glass, when used in composites.
Permeability	Air permeability is reduced by a factor of 3 in mica/P.E composites, due to fish scale effect.	Protects oxygen sensitive foods such as milk, orange juice, butter, when used in composites.
	Gasoline penetration of PE is reduced to ½ by incorporation of mica.	Avoids secondary treatment of PE with SO_2 for fuel tanks.
Lubricity	a) LOWERS COEFFICIENT OF FRICTION.	Friction modifier for asbestos-free brake linings. Dry lubricant powders & oil suspensions.
	b) Reduces wear in bearings.	Nickel plate, containing mica, integrated during plating process.
	c) Reduces screw & tool wear in thermoplastics.	Mica is much softer than glass fibers, however it does increase the hardness of the polymer matrix.

Electrical Properties	Improves electrical properties	Dielectric strength; 3 times better than glass. Dielectric constant; 1/6th of asbestos. Resistivity, 1 million times better than asbestos.
Ultra Violet Absorption	Increases resistance to U.V light (especially phlogopite which absorbs 80% of incident U.V light).	Muscovite mica is semi-transparent to U.V.
Refractive Index	Has little effect on hiding power due to low index.	Mica is usually not white, but the color is readily disguised by strong pigments.
Micro-wave Absorption	Can be used to reinforce micro-wave cook-ware, due to low absorption of mica.	Other fillers absorb radiation & heat-up, melting the polymer.
Nucleation	a) Promotes uniform cell structure, gives lower density; improves blowing agent yield in micro-cellular thermoplastics (e.g. H.D.P.E.) – reduces cost. b) Modifies spherulite structure (e.g. PP) improves mechanical properties.	Other fillers do not act as nucleating agents.

TABLE 4. PRICING OF MICA

Grade/End-Use	**Price Range US $/ton**
Sericite/Brick Manufacture	$ 3-4
Crude Ore/Drilling Fluid	85-120
-100 Mesh/Joint Cement	100-220
-325 Mesh Dry Ground/Paint and Rubber	200-300
Wet Ground/Paint and Rubber	300-400
Untreated/Plastics	200-300
Treated/Plastics	500-600

TABLE 5. WORK REQUIRED FOR SIZE REDUCTION OF INDUSTRIAL MINERALS (AFTER PERRY 1973)

Mineral	**Work Index***
Barite	6.24
Clay	7.10
Dolomite	11.31
Feldspar	11.67
Gypsum	8.16
Limestone	11.61
Quartz	12.77
Graphite	45.03
MICA	134.50

**Work Index* is the work required to reduce a unit weight from a theoretically infinite size to 80% passing 100 micrometres (microns).

REQUIREMENTS OF THE HIGH TECHNOLOGY MARKETS

In order to service the high technology markets, the mica supplier must make considerable commitments in the service sector, that are not required in commodity markets. These sectors are:

1. Research and Development.
2. Quality Control.
3. Technical Service.
4. Inventory.

Production requirements also become more severe and include:

5. Purification.
6. Production Flexibility.
7. Surface Treatment.
8. Product Uniformity.

Research and Development

The supplier must develop an in-depth understanding of the end-user's problems. Then mica grades must be developed, together with any necessary treatments of the mineral, to meet the end-user's needs. The research department must also develop ways to feed and meter mica into a mixture and ways to handle and use the composite that the end-user will take. Often the end-user does not buy the mica directly from the mica supplier, but buys it blended, with a polymer or other binder from a compounder.

The researcher must be aware of subtle differences in grades of polymer and binder, and be prepared to make specific recommendations and unravel problems when they occur.

Quality Control

When mica forms an ingredient of a material used to make a high performance product, produced in large quantities, such as an automotive part, uniform quality is essential. The supplier must select a specification that he can produce without variation and ensure that he meets it. The quality control measures that are generally used in the industrial minerals industry are adequate, but the frequency of testing must be increased. When surface treatments are used, special tests of great sensitivity must be used. Variables are so many that often the best quality control test is to compound the treated mica with polymer and make test bars.

Technical Service

The mica supplier to high technology end-users must supply in-depth information on his products: how to use them, their advantages and limitations, environmental concerns, food and drug suitability, etc. This information must be communicated on the packaging, in specifications sheets, technical bulletins and by presentations before knowledgeable people, at conferences and seminars. The technical service representative must troubleshoot not only problems of the mica itself, but those of the associated materials and methods of manufacture that are used. He must communicate, to the mica research and development and production personnel, the customers' needs, likes and dislikes, in order to create products and packaging that better serve the market.

Inventory

To meet the requirements of the end-user, the mica supplier to the high technology market must make a wide range of grades and keep inventory of each to give instant delivery. It may be necessary to stock a grade in packaging of different sizes, e.g. 50 pounds and 25 kg, to meet the end-user's requirements.

Purification

The degree of purity required for these new markets is often much higher than the mica industry is used to. Mica, from feldspar or clay production, often contains quantities of these minerals and others, especially quartz, magnetite, spinel, and garnet. Quartz is especially undesirable because it is singled out as a health hazard. Also, quartz and the other hard minerals will cause extreme wear in plastics tooling. Polymers rate much softer than talc on the Moh scale, and mica is 3.0-3.5. Minerals of 6 or higher can destroy tooling costing $250,000 in very rapid order. At the other end of the scale, fine filler particles like clay will create dust problems, increase polymer viscosity unduly, reduce mechanical properties and may add undesired degree of water vapour pick-up to the mica.

The presence of heavy metal may also make the mica unsuitable for use in food application.

Production Flexibility

These new markets for mica have by no means stabilized. The mica producer must have enough flexibility in his production facility to vary the grade mix to accommodate changing needs. It is, of course, feasible, though energy-consuming, to make fine flakes from large and thin flakes from thick, but the reverse is much more difficult.

In general, the mica supplier has more chance to produce purer and better delaminated grades, if the flake he starts with is large. A problem with by-product mica is that the ore is ground finely to extract the primary mineral, so that the by-product mica is usually of small size, 30 mesh or smaller. The new markets for mica are usually for larger flakes than are generally available from by-product micas, and the grades are more tightly sized.

Surface Treatments

Apart from size gradation and degree of delamination, the supplier must be able to produce a wide range of surface treatments in small and large lots. Often these involve the use of solvents that can produce hazardous vapours in the plant and disposal problem for the vapours.

Product Uniformity

It is difficult to maintain product uniformity at the same time as production flexibility. Changing the grade mix to meet the market demands, involves changing the circulating load to equipment units. This can change their efficiency and affects the tightness of size gradation and selection by aspect ratio.

SUMMARY AND CONCLUSION

The mica industry, like most others, is down now, but certainly not out. With the development of new, high technology markets, the flake and ground mica industry is undergoing a re-birth. Only those producers who experience a re-birth of attitudes will survive. The new markets require 21st century ideas on products and services, and will need large investments of time, money and talent as the entry fee.

I already see a feed-back situation developing. The ready availability, in quantity, of superior grades of mica is provoking new ideas for their use. This in turn spurs the development of other, still better grades of mica. The market potential is attracting new competitors, who are adding their own ideas and products. This is good. The industry they are competing in will grow bigger because of it.

I predict with confidence, that the largest markets for mica in 10 years time will not be those of old, nor even those we have discussed today. I expect those new markets to be at least as large as those for talc and possibly as large as those for calcium carbonate; my estimate is in the range of 250,000 to 1,500,000 tons annually by the year 2000. Markets this large will require major commitments by existing and new entrants into the business of producing high quality mica flake products.

ACKNOWLEDGEMENT

This paper is dedicated to the memory of Laurent Bedard, without whose faith and energy, none of this would have happened.

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The Quebec and Ontario Silica Operations of Indusmin Limited

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ABSTRACT

The major production of high-purity silica products in Quebec and Ontario has been provided for many years by Indusmin's operations at St. Canut and Midland respectively.

A pure silica-cemented flat-lying sandstone of the late Cambrian Potsdam Formation is mined and processed at St. Canut near Montreal. Approximately 85% of product sales are for glass and silicon carbide manufacture, and the remaining finer-sized products are used in the construction industry.

The Midland plant on Georgian Bay in Ontario processes ore shipped 120 miles from the mine on Badgeley Island near Killarney. The silica deposit is an almost vertically-dipping series of orthoquartzites of the Precambrian Bar River Formation. Lump products from crushing on Badgeley Island are sold directly to US and Canadian ferro-silicon manufacturers, and the minus 2-inch material is transported to Midland for production annually of up to 500,000 tons of glass, ceramic and construction material grades.

QUEBEC SILICA OPERATION

Quebec's leading silica producer, Indusmin Limited, has been supplying silica-consuming industries since 1965. The plant and quarry are located near the village of St. Canut, which is only 35 miles north of the major Montreal market area. The silica deposit being mined is in the Potsdam Sandstone Formation and has been in nearly continuous production since the late 1920s.

The Potsdam Formation covers approximately 750 square miles of southwestern Quebec and southeastern Ontario (Figure 1) and is believed to be the equivalent of the type formation of late Cambrian age at Potsdam, New York. The late Cambrian was noted for the formation of great thicknesses of dolomitic beds. The exception to this was in the northern part of the late Cambrian seas, where a sandy facies, the Potsdam Sandstone, was laid down around the flanks of the old Adirondack highlands.

There are two distinct facies of the Potsdam Sandstone in the St. Canut area. A shaly deep-water facies is represented by a thick series of maroon argillaceous

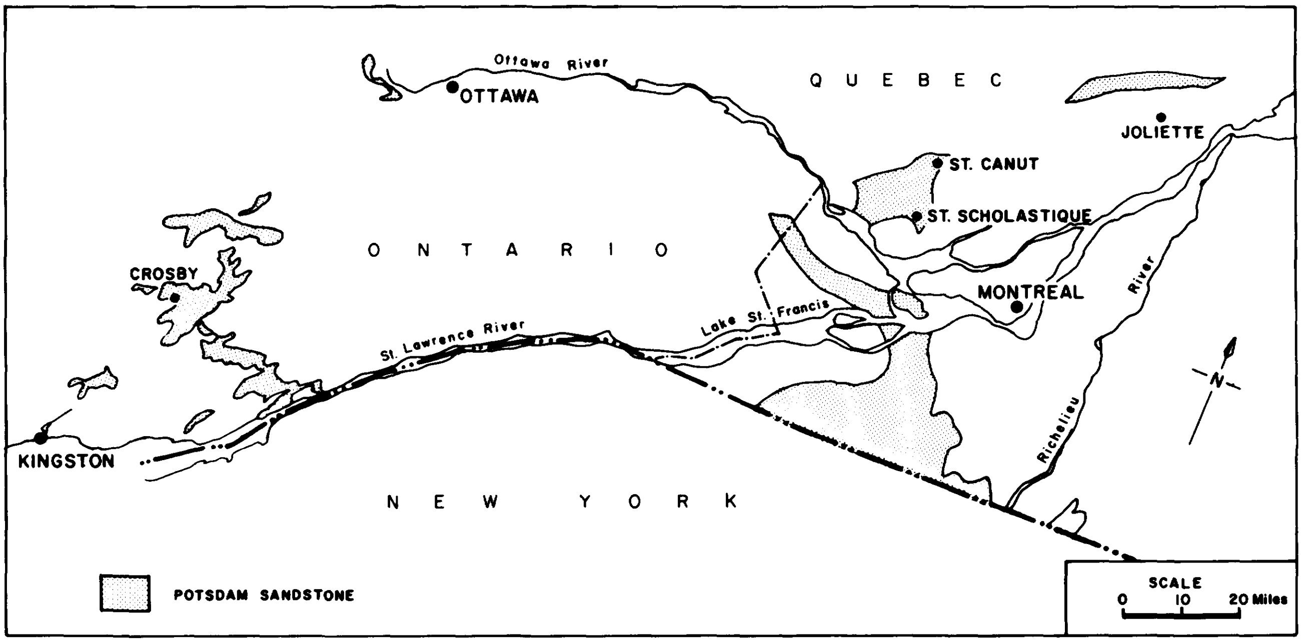

Figure 1. Distribution map of Potsdam sandstone in Ontario and southern Quebec.

sandstone. Due to a change in the depositional environment, this series is overlain by a shallow-water facies of pure quartzitic sandstone.

The purity of the upper unit appears to have resulted from the natural refining processes of wave action and off-shore currents. These high-purity sandstones are usually limited in thickness, averaging 50 feet at St. Canut and less than 40 feet on Indusmin's Crosby, Ontario property. The exception is Indusmin's Ste. Scholastique property near St. Canut, where diamond drilling indicates a depth in excess of 200 feet.

At St. Canut the beds vary from about 6 inches to 6 feet in thickness. Features such as ripple marks, cross-bedding and rain-drop prints are common. The beds have been subjected to local faulting, but there is no evidence of folding or regional metamorphism. One unusual feature is the apparent lack of any significant concentration of heavy minerals. No fossils have been found in the sandstone, although tracks of what is believed to be a trilobite have been identified. The texture of the sandstone is remarkably uniform, with quartz grains being medium to fine-grained and sub-angular to rounded. It consists of 98% silica or more, and is made up of white to light grey quartzitic sandstone, with pyrite as the main iron oxide contaminant. In areas of faulting and fracturing, which have provided access to circulating groundwater, yellow-brown to buff sandstone is encountered.

The circulating groundwater has partially leached out some of the cementing media and has altered the pyrite to limonite. This sandstone is consequently more friable than the white type. Layers of clay and shale are occasionally encountered, but they are lenticular in form and are very localised in occurrence.

There are a variety of cementing materials which largely determine the potential value of the rock as a commercial source of silica. The silica-cemented sandstones of 96% silica or better are the potential economic deposits. The most common cementing material at St. Canut is silica, with lesser amounts of calcite, limonite, hematite, pyrite and clay minerals. The removal of the cementing materials from the sandstone by the process of grinding, attrition scrubbing, flotation and magnetic separation produces silica products to meet most of the major industrial applications.

The largest consumers of industrial silica in the Montreal area are the manufacturers of glass, silicon carbide, ferro-silicon, and concrete autoclave products. Most of these consumers demand delivery of a product that is uniform in composition and controlled to rigid chemical and physical specifications.

The silica reserves at St. Canut at the end of 1982 stood at 15 million tons. The sandstone is drilled on an 8 foot by 10 foot pattern using 3 inch diameter holes. The cuttings from the production drilling are collected and analysed to assist the grade control of mill feed.

The quarried material is loaded by front-end loaders on to trucks for transport to the mill. The rock is first reduced to -1 inch size by a two-stage crushing circuit and dried. A sand product is prepared in impact crushers in closed circuit with screens. The fines are removed by air classification. Part of the sand is further treated by flotation and magnetic separation to produce a high-grade glass sand. A separate section of the plant prepares finely-ground materials in ball mills for use in the ceramic and concrete block industries. Eighteen products ranging from -10 to -325 mesh size are produced at the St. Canut plant at the present time.

The silica sand produced for glass and silicon carbide manufacture accounts for about 85% of the sales tonnage and is marketed in Quebec. The finer-sized products, used in the construction industry as fillers in tiles, asbestos-cement pipe, concrete blocks and bricks, are sold in Quebec and Ontario.

ONTARIO SILICA OPERATION

After acquisition of the Quebec silica operation was completed, Indusmin commenced an exploration program in 1966 to find a silica deposit in Ontario to supply the Ontario market. This program concentrated on the Lorraine and Bar River Formations in the Killarney area of Georgian Bay, and in 1967 the Badgeley Island deposit was discovered. This deposit is in the Precambrian Bar River Formation, part of the Cobalt Group of the Huronian Supergroup. The quarry on Badgeley Island is 4 miles by water west of the village of Killarney and the plant, located in the town of Midland, is 120 miles by water south of the Badgeley Island quarry. This operation has been supplying a large part of Ontario's silica market since 1970.

The Bar River quartzite, which is approximately 3,000 feet in thickness, was formed at the close of Cobalt time. It consists of a lower unit of white quartzite, approximately 1,200 feet thick, and an upper unit of interbedded quartzite, argillite and siltstone, approximately 1,800 feet in thickness.

The outcrop of the quartzite formation on Badgeley Island is 5,000 feet long by 1,000 feet wide. The ore zone within this formation is part of the lower member of the Bar River sandstone, and is 2,500 feet long by 500 feet wide. It is in conformable contact with the Gordon Lake Formation to the northeast and in unconformable contact with the Lindsay Formation to the northwest and southwest. To the southeast it is in unconformable contact with the Killarney granitic intrusion (Figure 2).

The original sandstone was part of a shallow-water facies similar to the Potsdam Formation. Ripple marks and cross-bedding are common. The beds are 6 inches to 3 feet in thickness, strike N70E, and dip almost vertically or steeply to the south. It is fine to medium-grained, white to buff yellow quartzite. There are no fossils and no significant heavy minerals.

There has been no major faulting in this section of the Bar River Formation, but folding has been extensive and the beds are now vertical to overturned. There are two amphibolitic dikes of pre-Killarney-intrusion age cutting the orebody; one cuts the orebody 800 feet east of its western limit, and the second forms the western limit. Only minor contamination has been introduced into the surrounding quartzite by these dikes.

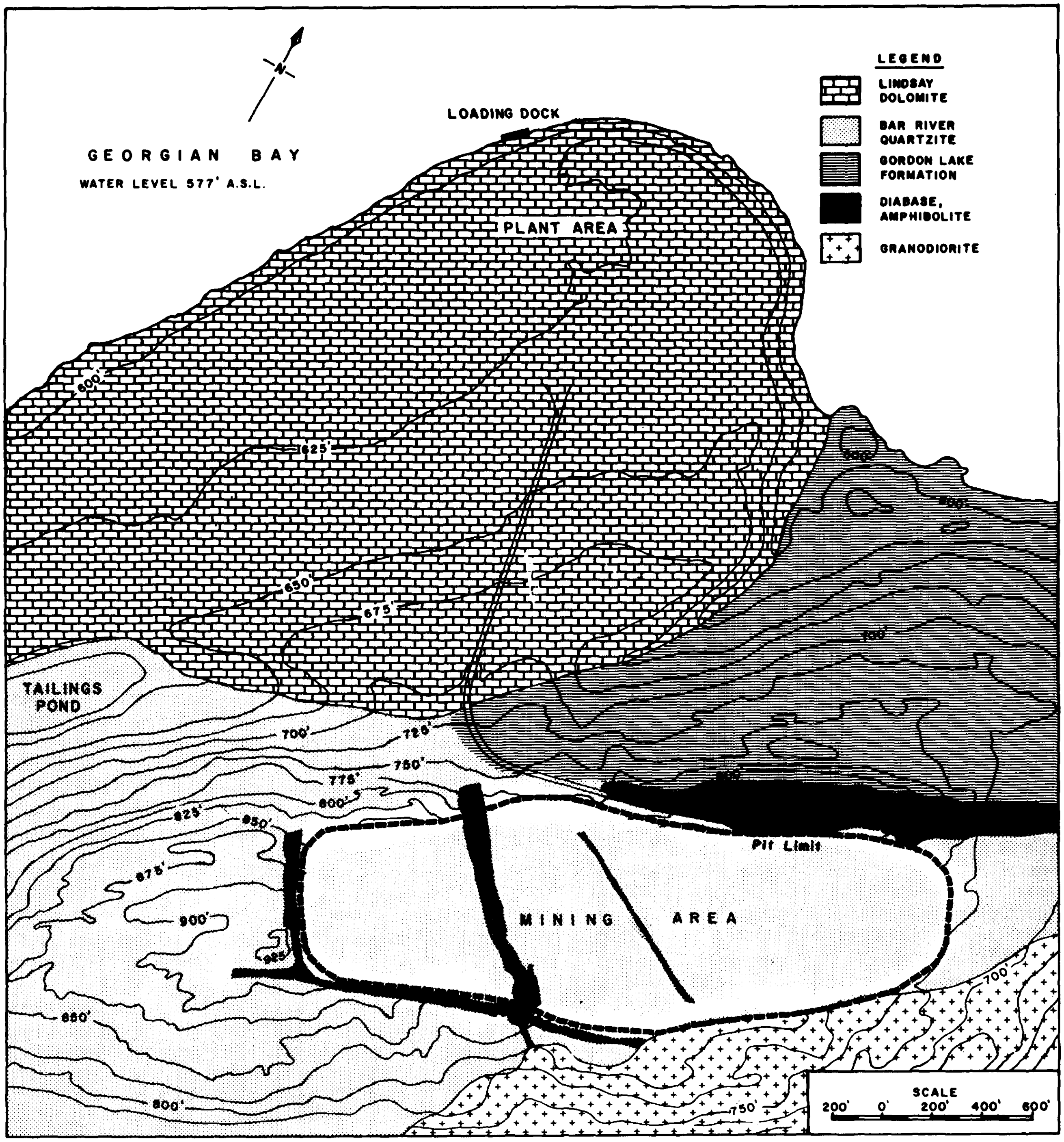

Figure 2. Location and geological map of Indusmin's silica operations on Badgeley Island, Georgian Bay, Ontario.

The most significant factor affecting this quartzite was contact metamorphism. The original sandstone was probably made up of pure silica grains, with almost pure silica cement and with only minor feldspathic grains and kaolin. There were also probably occasional thin beds of clay or shale present. The Killarney batholithic intrusion recrystallized the sandstone into pure quartzite with minor mica content. The clay or shale beds were altered to sericitic schist. Minor iron oxide was probably introduced contemporaneously along bedding planes and fractures.

The main contaminants in the Badgeley quarry are alumina, iron, and titanium. These contaminants are associated with sericite seams and, to a lesser degree, with thin amphibolitic dikes and iron-stained fractures. These seams, dikes and fractures can be segregated visually from the ore-grade material. A quality control program of production drill-hole sample analysis is used to assist visual control of ore delivered to the crusher.

Indusmin is Ontario's largest producer of high-purity silica with a capacity of approximately 700,000 tons of washed material from primary crushing and screening at Badgeley Island. Mining and crushing operations at this location are restricted to the shipping season on the Great Lakes, normally from April to late November.

Primary 2 inch by 4 inch lump products from Badgeley Island are shipped directly to manufacturers of ferrosilicon, and the minus 2-inch material is shipped to the grinding plant at Midland for further processing.

At Midland, stockpiling facilities allow a year-round operation with a capacity of 500,000 tons. The material delivered from Badgeley Island is dried, crushed, and then ground in a primary ball mill. Subsequent screening and air classification produces sand for glass, insulation fiberglass and the construction industry. The fines are ground further in pebble or steel ball mills to produce silica-flour grades for ceramics, reinforcing fiberglass, abrasive and concrete products.

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The Silica Resources of Manitoba

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ABSTRACT

Silica deposits in Manitoba span the range of geological time from Precambrian to Recent. Although only two deposits are presently being worked, the Ordovician Winnipeg sandstone by Steel Brothers, and a Precambrian meta-arkose by Manasan Quarries (for flux at Thompson), there have been other deposits worked for silica in all areas of the Province.

The silica deposits of Manitoba have been investigated and catalogued according to their ages and potential uses. The high priority Winnipeg and Swan River sandstones have potential for the glass and other "high spec" industries. The quartzites of the Churchill area and the quartz from some of the pegmatite bodies in the southeastern part of the Province have some potential as sources of lump silica for uses requiring a less pure and larger grain size product. Lastly, the Pleistocene sands from various areas have been used for such diverse products as moulding and traction sands and for glass manufacturing.

A brief description of the more promising occurrences is given along with examples of the chemical and sieve analyses.

INTRODUCTION

Ever since the white cliffs of Winnipeg sandstone were noticed by early explorers on Lake Winnipeg, there has been interest in silica in Manitoba. Over the years since Tyrrell and Dowling's report (1893) silica deposits have been worked to obtain silica for uses ranging from railroad traction sand to glass.

At present, two deposits are being worked for silica in the Province. Steel Brothers Canada Limited mines high purity Winnipeg sandstone at Black Island in Lake Winnipeg, whereas Inco Limited uses quartzite from the Manasan Quarry near Thompson. Pleistocene deposits are worked intermittently for silica sand to feed the cement plants in Winnipeg.

A two-year study of the silica resources of Manitoba by the Manitoba Department of Energy and Mines has delineated several additional potential sources of silica. The Winnipeg sandstone outcrops to the east of Lake Winnipeg in an area where hundreds of millions of tonnes with more than 95% silica material is easily available. To the west, the Swan River Formation has potential for development as a producer of both silica and kaolin, whereas the quartzites near Churchill could be used for processes requiring lump silica.

PLEISTOCENE (AND RECENT) DEPOSITS

In general, the Pleistocene and Recent sand deposits of Manitoba are too impure to be considered as potential sources of silica. Their silica content ranges from 60% or lower, up to a high of about 90% (Table 1). The higher silica sands are all either directly down ice from the Winnipeg Formation subcrop or are recent beaches directly derived from Winnipeg sandstone. In areas removed from the Winnipeg sandstone outcrop belt, sands tend to be diluted with either feldspar and heavy minerals (near the Precambrian influence of the east) or with carbonate minerals (to the west).

Examples of chemical and sieve analyses are given in Tables 1 and 2. The analyses show that the chemical and physical properties of these sands would make extensive treatment necessary to upgrade any sand into a saleable product. One area that does have potential for silica production is Beausejour, where silica sand has previously been produced for feed to a local glass plant.

Beausejour Area

The Beausejour area is situated in southeastern Manitoba approximately 40 km east of Winnipeg. The subgroup belt of the Winnipeg Formation passes just 8 km to the east of the area. The ice direction is from the northwest (Nielsen 1981) and the sand in this area is likely derived almost exclusively from the Winnipeg sands. The deposit was mined and used to feed an adjoining glass plant until 1913. Since that time the sand has been used periodically by the cement plants in Winnipeg. The Beausejour sand is composed largely of well rounded, fine grained sand. The grain size distribution is typical of Pleistocene glaciofluvial deposits with a slightly lower clay-silt content. As exposed in the banks of the pit within the town of Beausejour, there is little apparent variation in either grain size or chemical composition. Samples from pits to the north and west of the town also show similar compositions (Watson 1981).

TABLE 1. PARTIAL CHEMICAL ANALYSES OF SAMPLES FROM SILICA DEPOSITS

Sample No.	Location	SiO_2	Al_2O_3	Fe_2O	FeO	CaO	MgO	CO_2
			Pleistocene Sands					
P-1	Gull Lake	86.4	6.22	0.54	0.33	1.81	0.35	0.85
P-2	Albert Beach	89.2	4.21	0.46	0.19	2.01	0.28	1.29
P-3	Libau East	89.0	4.19	0.35	0.23	2.14	0.23	1.22
P-4	Beausejour	89.3	3.62	0.88	–	2.88	0.51	2.00
P-5	Richer	75.5	9.6	1.6	–	3.2	0.8	1.2
			Swan River Sands					
SR-1	Tudale Neepawa Well	89.35	5.98	0.47	0.13	0.03	0.18	0.48
SR-2*	Pine River	99.57	0.55	0.03	–	–	–	0.18
SR-3	L. Winnipegosis	94.55	2.46	0.13	0.01	0.18	0.07	0.33
			Winnipeg Formation Sands					
W-1	Black Island	97.8	0.68	1.42	–	–	–	–
W-2	Seymourville	98.65	0.36	0.06	0.10	0.05	0.06	0.17
W-3	Waskada Well	97.75	0.54	0.19	0.06	0.16	0.16	0.39
W-4**	Black Island	99.588	0.219	0.020	–	0.018	0.037	–
			Churchill Quartzites					
C-1	Churchill	88.65	5.70	1.65	0.02	0.07	0.23	0.3
C-2	Churchill	90.9	4.66	1.88	0.16	0.03	0.21	0.15
C-3	Churchill	97.2	1.27	0.68	0.12	0.01	0.02	0.14

* Washed sample
** Processed sand

TABLE 2. SIEVE ANALYSES OF SILICA SANDS

Sample No.		Percentage Retained on Canadian standard mesh 20	40	50	70	100	200	PAN
			Pleistocene Sands					
P-1	Gull Lake	0.3	5.3	11.1	26.2	12.8	6.9	2.4
P-2	Albert Beach	0.5	4.7	8.0	49.3	25.2	11.4	0.9
P-3	Libau East	0.0	0.1	5.2	61.0	26.6	6.8	0.3
P-4	Beausejour	4.9	19.3	28.3	25.4	12.8	6.9	2.4
P-5	Richer	0.0	0.5	0.5	0.8	6.4	86.9	4.9
			Swan River Formation Sands					
SR-2	Pine River	0.6	0.2	0.3	3.4	33.8	54.8	6.8
SR-4	Swan River	0.0	9.5	21.1	26.7	33.0	9.3	0.4
			Winnipeg Formation Sands					
W-1	Black Island	0.1	12.2	20.2	26.9	20.8	17.4	2.5
W-2	Seymourville	0.1	14.1	33.5	34.2	12.8	5.2	1.0
W-4	Punk Island	0.0	1.0	8.0	75.4	12.2	3.0	0.5

Chemically, the sand is slightly too low in silica to be considered for use by a modern glass plant. In addition, the iron content is too high for production of all but dark green/brown glass. In some other applications such as foundry sand, the iron content is not as critical and may not be a deterring factor. Aside from iron-bearing minerals, the other impurities are mainly feldspar, micas and carbonate grains. The sand contains about 2% heavy minerals, mainly hornblende along with magnetite and garnet. It is unlikely that the cost of separating these from the silica would be compensated for by the convenient location, i.e., the sand from such locations as Swan River and the Lake Winnipeg (Winnipeg Formation) area is of such high quality that transportation costs are less than processing costs for up-grading the impure sands.

Since these sands are of a glaciofluvial origin and consist of large morainal deposits, their extent could only be determined by extensive drilling to determine both area and thickness. Some information regarding extent could be obtained from water-well data, but as no composition is known, reserves and grade cannot be given. Nevertheless, there are many tonnes of this type of material in the Beausejour-Grand Beach area.

SWAN RIVER FORMATION

Sands of the Cretaceous Swan River Formation outcrop along the Swan and Pine Rivers in western Manitoba. The most complete descriptions of the formation are given by Venour (1957) and McNeil and Caldwell (1981).

Interest in the Swan River Formation was initially for lignite and kaolin associated with the sands. The first examination of the area for these commodities was made in 1916 by Johnston (1917). Since that time various properties have been tested both by private holders and different levels of government. In several other areas of the

Province, Cretaceous channels filled with similar mixtures of kaolin, lignite and silica sand have also been the subject of investigation. Unlike the Winnipeg sandstone which is markedly uniform in composition and texture throughout its range, the Swan River sands vary in grain size and composition not only from location to location, but also from bed to bed at the same outcrop. Venour (1957) classed the sands generally as fine grained; however, some of his samples are much coarser in size. The heavy mineral suites in different locations and beds also show some variation as documented by McCartney (1928). This and the varying amounts of kaolin and lignite indicate that the Swan River Formation has had a much more varied depositional history than the Winnipeg Formation. Owing to this varied history, it is difficult to make generalized predictions about the sand potential of a particular area.

Swan River Deposit

The occurrence of "pure quartz sands" in the Swan River area was first noted by Tyrrell (1892). In 1916, after the area had been settled and railways and roads established, the deposits were examined by Johnston (1917) who collected samples for testing by the Geological Survey laboratory in Ottawa. They concluded that the clays would be suitable for sewer pipe, brick and stove linings while the silica would be classed as a grade 4 sand. A sample of sand from the same area was tested by Freeman (1936) and was reported to be "the most refractory of all (naturally bonded) moulding sands tested from the western provinces".

The sands outcrop along the banks of the Swan and Roaring Rivers, east and northeast of Swan River. The outcrop areas vary from year to year as the river banks are undercut and slumping occurs. The section, as examined in July, 1982, was:

overburden	clay and organic soil	0.8 m
Swan River Formation	white, loose sand	3.0 m
	dark grey sand with pyrite nodules	0.2 m
	white to grey sand	2.4 m
	rubble at base	3.0 m

The same sequence was exposed in two bends of the river about 0.75 km apart. The sands are white, unconsolidated, and mixed with kaolin. The bedding is nearly horizontal and noticeable because of changes in the grain size and apparent amount of kaolin. In one exposure the beds were underlain by a bed of pyrite nodules and carbonaceous shale. In total, approximately 7 m of the section was exposed along 750 m of river bank. Data from water wells drilled in the area indicate that the layer of "white silica sand" (terminology from Water Well Drillers Reports, Manitoba Department of Natural Resources, Water Resources Division), is fairly widespread in its occurrence but variable in thickness.

Chemical and physical analyses of sand from several locations on the Swan River are given in Tables 1 and 2. The sand can be screened to remove most of the impurities. The kaolin is fine enough to be washed out, whereas the shale and lignite can be screened out as a coarse fraction. After washing, the sand compares favourably in composition with Winnipeg sand.

Pine River

The Swan River Formation is poorly exposed in the Pine River valley. The river has cut a channel almost 2 m deep throughout most of its length and slumped overburden covers the banks in most places.

Interest in this area started in the 1930s after silica sand, lignite and kaolin were discovered in hand-dug wells. Various companies have held quarry permits and done testing on the sand since that time.

Like the outcrop area at Swan River, the exposure at Pine River is limited. As before, some information is available from drillers' reports on the distribution of the sand but there are no figures that would enable an accurate estimate of tonnage and grade to be presented at this time.

Sylvan, Winnipeg and Other Outliers

In the areas of Fisher Branch – Sylvan, St. Andrews and several other parts of the Province, there appear to be channels cut into the older rocks and infilled with Cretaceous sediments similar to the Swan River Formation.

At Sylvan several wells were put down and examined for their lignite potential. The channel was further delineated by a series of geophysical surveys and drilling. The silica sand and kaolin at these sites is also similar in occurrence to the material at Swan River.

Unfortunately, these channel occurrences do not outcrop. They have all been found either in wells or during excavations of some sort. During the 1981 and 1982 field seasons none of the pits that have been put into these channels, i.e., at Sylvan, were drained or in any condition to be examined. The extent of the channels and their depth can be determined from the drilling reports, but the silica content and distribution is unknown because of a lack of samples.

WINNIPEG FORMATION

The Ordovician Winnipeg Formation is a series of interbedded sand and shale beds outcropping along the west side of Lake Winnipeg and dipping to the west at about 1.9 m/km. In the east it is the basal unit lying on the weathered Precambrian surface, whereas to the west in the subsurface it is underlain by the Cambrian Deadwood Formation. The ratio of sand to shale as well as the total thickness of the formation varies from place to place. A more complete description of the outcrop of the formation was given by Genik (1952).

The Winnipeg sandstone is a mature almost pure quartz sand. It varies from a loosely cemented, friable sand in the vicinity of Lake Winnipeg to a hard well cemented sandstone as seen in cores from wells in the southwest. The silica content varies from 70 to +95% with the major impurity being alumina (present as kaolin). Minor amounts of pyrite and shale are present in different areas.

The Winnipeg sandstone is currently being mined on Black Island by Steel Brothers Canada Limited.

The sand as mined could be used for most of the present applications for silica sand. The kaolin impurity is easily washed out, as well as the iron and few heavy minerals. The roundness and sphericity make the sand ideal for sand blasting, glass sand and for foundry applications.

Black Island

The outcrops of Winnipeg sandstone on Black Island were first examined in detail by Tyrrell and Dowling (1893) during their visit in 1889-1890. Since then, these deposits have been mapped by various companies and government geologists. The first attempt at exploitation of the sand was in 1929 by the Lake Bar Sand and Gravel Company. Since that time various pits have been opened up on both shores of the island. At present the only active property is Steel Brothers' quarry on the south side of the island.

A typical section at the present face is as follows:

overburden	0.5-2m
siliceous "caps"	0.5m
silica sand – clean, white well-bedded	4m
pyrite nodule layer	2.0m
sandstone-burrows + desiccation cracks	0.5-1.0m
clean sandstone	5-6m
kaolinitic sandstone	1.5m
weathered Precambrian basement	

The majority of the sandstone is very clean, well rounded and only loosely cemented. Small amounts of kaolin and pyrite occur within the quartz. A few heavy minerals are also present. Those identified in samples collected in 1981 and 1982 include pyrite and tourmaline. A study of McCartney (1928) on the heavy minerals in these sands also identified zircon, magnetite, staurolite, and rutile. In both cases, the total amount of accessory heavy minerals is much less than 1%. No attempt was made to identify differences in heavy mineral content from various levels within the sandstone section.

The only break in the otherwise uniform sand comes about mid-point in the section. At this level there is a bed of pyritic sandstone underlain by a bed of burrowed and screened sand that contains pyrite which has infilled from above. The pyrite occurs as spherical oolites to 1 mm diameter. In the pyrite-rich layer they make up about 75% of the total rock with the remainder being quartz grains. The occurrence of the pyrite layer is fairly widespread and consistent. The layer is observed at Black Island and Manigotagan roughly in mid-section. In the test hole drilled in the City of Winnipeg by Greater Winnipeg Gas Company, the layer is observed at the same stratigraphic level but the oolites are limonite in composition. At Black Island, the pyrite-bearing layer is removed and stockpiled prior to mining the underlying sand.

Seymourville-Manigotagan Area

During the summer of 1981 a pit on P.R. 304 between the communities of Seymourville and Manigotagan, about 2 km across the channel from Black Island was examined in order to determine if it was an outcrop of the Winnipeg sandstone. The conclusion reached at that time was that it was indeed Winnipeg Formation and, therefore, worthy of further investigations. Subsequently, two diamond drill holes were put down in the area by the Mineral Resources Division. These holes penetrated 10.2 and 26.8 m, respectively, of sandstone to reach the Precambrian basement. Based on the approximate elevations of the holes and the Precambrian outcrops on the shoreline of Lake Winnipeg, estimated reserves are 600 million tonnes of silica sand over an area of 1,800 hectares.

Chemically, physically and stratigraphically the deposit is identical to the Black Island deposit (Tables 1, 2). Extraction and processing of material from this area would involve the same methods as at Steel Brothers' operation. Since the initial discovery the ground has been put under lease by the Seymourville Town Council who are presently (1982) trying to develop the deposit.

Other Areas

In addition to Black Island and the Seymourville areas, the Winnipeg Formation sandstone outcrops on several other islands in Lake Winnipeg and along the west shore from near the Hecla Island Causeway, north to Matheson Island. Several of these locations have been examined as potential sources of silica but all have several drawbacks, of which the chief ones are increasing depth of overburden and location of the sand at or below lake level.

To the west, the sands are covered by the Red River and other upper Ordovician formations. This means increased costs for removal when compared with the relatively easily quarried sand on Black Island. In addition, as the Winnipeg sandstone is so porous and is water-bearing, any attempt at mining below the water table would involve considerable pumping. Southeast of Winnipeg, at Ste. Anne, an attempt was made to mine sand from the Winnipeg Formation by using a variety of methods down a borehole. At that time (1970) methods were not available that would permit economic recovery of the sand, so the project was abandoned. Should a method be developed, however, almost any portion of the Winnipeg Formation has the potential for development as a silica sand producer.

PRECAMBRIAN

The deposits of the Precambrian are the most widespread both in type and area of occurrence. They range from the pegmatite quartz of the Bird River area to the quartzites of the Churchill area. They also range from potentially pure quartz from the same pegmatites to impure silica-rich rocks such as are being mined for flux at the Manasan Quarry near Thompson. In general, due to their age and to the degree of folding, metamorphism and alteration undergone by these rocks, their distribution is erratic and each deposit is basically an unpredictable freak of nature, unlike the sandstone-type deposits of later age that once found can be traced over vast areas.

Churchill Quartzite

The Churchill Quartzite outcrops as a series of low ridges in the vicinity of the town of Churchill and along the shore of Hudson Bay on both sides of the river.

The rocks are a series of fairly pure quartzites with silica contents as high as 95% (Table 1). The rocks are described by Schledewitz (in press). They are massive and almost featureless, and contain very few inclusions of other rocks. In some exposures to the east of Churchill, there are a few beds of coarser grained material including conglomerate. These are generally small pods that cannot be traced for any distance or correlated between exposures.

At this time no tests have been done to determine whether or not this material could be upgraded to glass specifications. However, the analyses are within the limits for silica for many other uses of lump material such as ferro-silicon, silicon carbide and fluxes.

Manasan Quarry

The Manasan Quarry of Inco Limited is one of the two active silica producers in the Province. This deposit is situated approximately 20 km southwest of Thompson. Approximately 100,000 tonnes of the material from the quarry is trucked to the smelter at Thompson where it is used as flux.

The deposit consists of a series of meta-arkoses folded into a horseshoe shape. The silica content varies but averages 80%. Minor amounts of such elements as iron, alumina, etc., can be tolerated in the smelter operation as long as the free silica content is high. Tests have not been done on this material to determine its suitability for other silica uses.

Winnipeg River – Cat Lake Area

The Winnipeg River – Cat Lake belt contains many pegmatite bodies, some of which contain appreciable amounts of quartz. The geology of these pegmatite bodies varies widely as does the amount and purity of the quartz contained within them. Very little information is available on the amount or quality of the quartz in most of the pegmatites. Two locations, however, either have been mined or have been considered potential sources of silica. The only potentially economic sources of silica are the very large pegmatites with sizeable quartz cores, such as Tanco, or smaller ones that contain a product that could be hand-picked, such as rose quartz near Birse Lake.

The geology of the Tanco pegmatite has been described by Crouse *et al.* (1979). This large body contains large tonnages of tantalite, spodumene, lepidolite and several other industrial minerals in addition to quartz. The quartz bodies are estimated to contain up to 0.7 tonnes of pure quartz. This material would need to be ground and purified by flotation or some other means. There are no plans at this time to start production.

SUMMARY

In addition to the two present producers of silica, Manitoba contains large reserves of high quality silica-rich rock. The Swan River and Winnipeg sandstones have the potential to produce hundreds of millions of tonnes of glass-grade material whereas the Churchill area quartzites have some potential as sources of lump silica. Lastly, the Tanco pegmatite, already known for its reserves of spodumene, tantalite and other industrial minerals, contains almost 1 million tonnes of recoverable pure quartz.

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Potash in Canada, with Special Emphasis on Saskatchewan Potash Deposits

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ABSTRACT

Potash was first discovered in Saskatchewan in August, 1942, in an oil well drilled south of Regina. However, because of the great depth, 2,300 m below ground, and the low grade, it was not until the 1950s that the potash industry began to develop in Saskatchewan. There are now nine conventional underground mines and one solution mine in operation in Saskatchewan.

On the Atlantic coast, two potash mines are being developed for underground mining while exploration is being carried out in several areas of the Maritimes and Newfoundland for other potash deposits.

The geology of the Saskatchewan deposits is well known from extensive exploration and development over the past 30 years. The ore reserves in Saskatchewan are estimated to be in excess of 100 billion tonnes of ore. However, these reserves are not all economically recoverable using present day technology. The Saskatchewan deposits are generally of higher grade that that mined in many other countries of the world.

The four major problems in the conventional mining of potash involve the movement of large quantities of ore; rock mechanics related to roof, floor and pillar stability; the avoidance of geological anomalies, particularly solution collapse features; and protection against mine flooding from underlying and overlying water-bearing formations.

The refining of potash is essentially a crushing and flotation process. The production of 1 tonne of product results in approximately 2 tonnes of waste salt and slimes which can only be stored in surface waste dumps at this time. Consequently, environmental engineering and monitoring is becoming an established practice in the industry.

INTRODUCTION

The term "potash" originated from the method of producing potassium carbonate in the early days. Prior to the discovery of soluble potassium salts, potassium was produced by leaching wood ashes and evaporating the solutions in large iron pots. The white residue left in the pot was called "pot ash". Potash has since become the generic term referring to various natural occurring potassium salts. In Canada, the two most common and most important potash minerals mined are sylvite (KCl) and carnallite ($KCl\ MgCl_2\ 6H_2O$). The ore of potash, sometimes called sylvinite, is a mixture of sylvite, carnallite, salt and clay minerals. In Canada it is found in evaporite basins and is a result of precipitation from saline-rich seawaters evaporating under what is considered to be arid conditions in restricted basins.

DISCOVERY OF POTASH AND ITS DEVELOPMENT

Saskatchewan

Potash was first recognized in Saskatchewan in core from an oil well drilled by Imperial Oil Limited in August, 1942, approximately 110 km south of Regina. The potash occurred at a depth of 2,330 m, too deep for conventional underground mining.

The first commercial production of potash in Saskatchewan was attempted in 1951 near Unity. Ten years later, the shaft, which had reached a depth of 558 m, was flooded. The site was sealed and abandoned in 1968 (Fuzesy 1982).

Potash Company of America was the first company to successfully complete shaft sinking and went into production in 1958. However, due to water seepage in the shaft, production was suspended and did not resume until 1965. During the period 1962-1970, eight other conventional underground mines and one solution mine were brought on-stream.

In 1975, the Saskatchewan Government set up a crown corporation, Potash Corporation of Saskatchewan (PCS), to develop a new mine at Bredenbury in the southeastern part of the Province. This project was deferred and, in its place, the Corporation purchased the mines operated by Duval, Alwinsal and Sylvite, renaming them the Cory, Lanigan and Rocanville Divisions of Potash Corporation of Saskatchewan. In addition, the Potash Corporation of Saskatchewan purchased 60% interest in the Allan Potash Mine from US Borax and Swift Canadian Company (40% interest is owned by Texasgulf, now Kidd Creek Mines) renaming it the Allan Division. A further purchase of potash reserves, located in the International Minerals and Chemical Corporation (IMC) mine at Esterhazy, was concluded with Southwest Potash (AMAX).

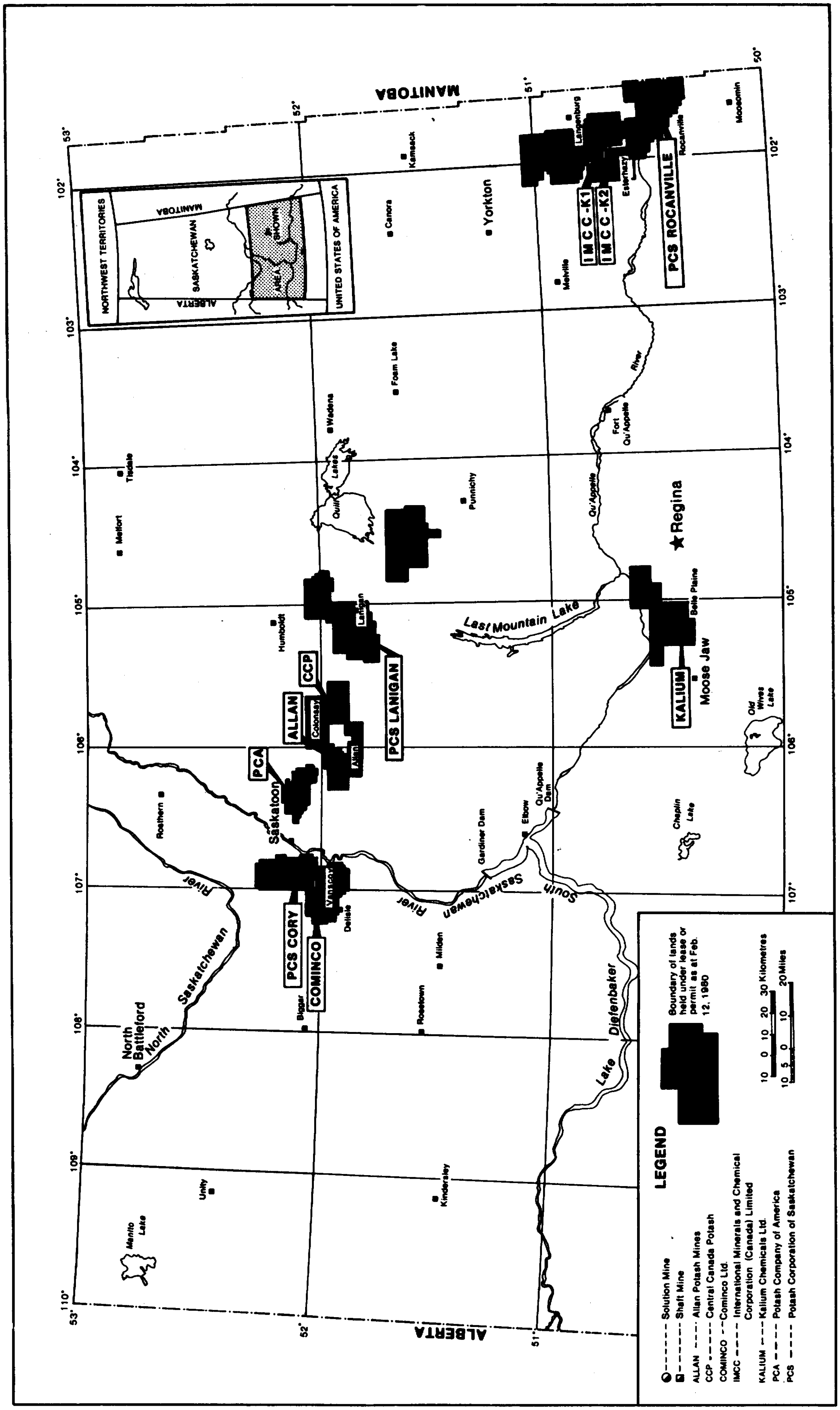

Figure 1. Potash mines, leases and permit areas in Saskatchewan (from Fuzesy 1982).

These reserves are mined by IMC for the Corporation under a production agreement. Figure 1 shows the location of the producing mines in the Province of Saskatchewan.

New Brunswick

In the early 1950s, a small salt spring was located near the town of Sussex, New Brunswick. It was not until early 1971 that an exploration well was drilled for salt near Sussex. Potash was intersected over 68 feet between 909 feet and 1,001 feet depth. In 1972, the Potash Company of America was awarded the rights to exclusive exploratory drilling in designated areas near Sussex. Favourable exploration results led to the decision in 1977 to develop a new mine. Commercial production of potash is expected in 1983.

In the same area of New Brunswick, Dennison-Potacan Potash Company is proceeding with shaft sinking to develop a second potash mine in the Province. It is expected to be in production in 1985. Exploration for a possible third mine in the Sussex area is being carried out by BP Explorations Canada Limited.

Nova Scotia

Malagash in northern Nova Scotia was the location of the first underground salt mine in Canada. It operated between the years 1919 and 1959. Potash was occasionally produced in minor amounts as a by-product of salt. Of 19 salt deposits in Nova Scotia, 12 are reported to contain potash (Boehner 1983). There are, however, no known economic

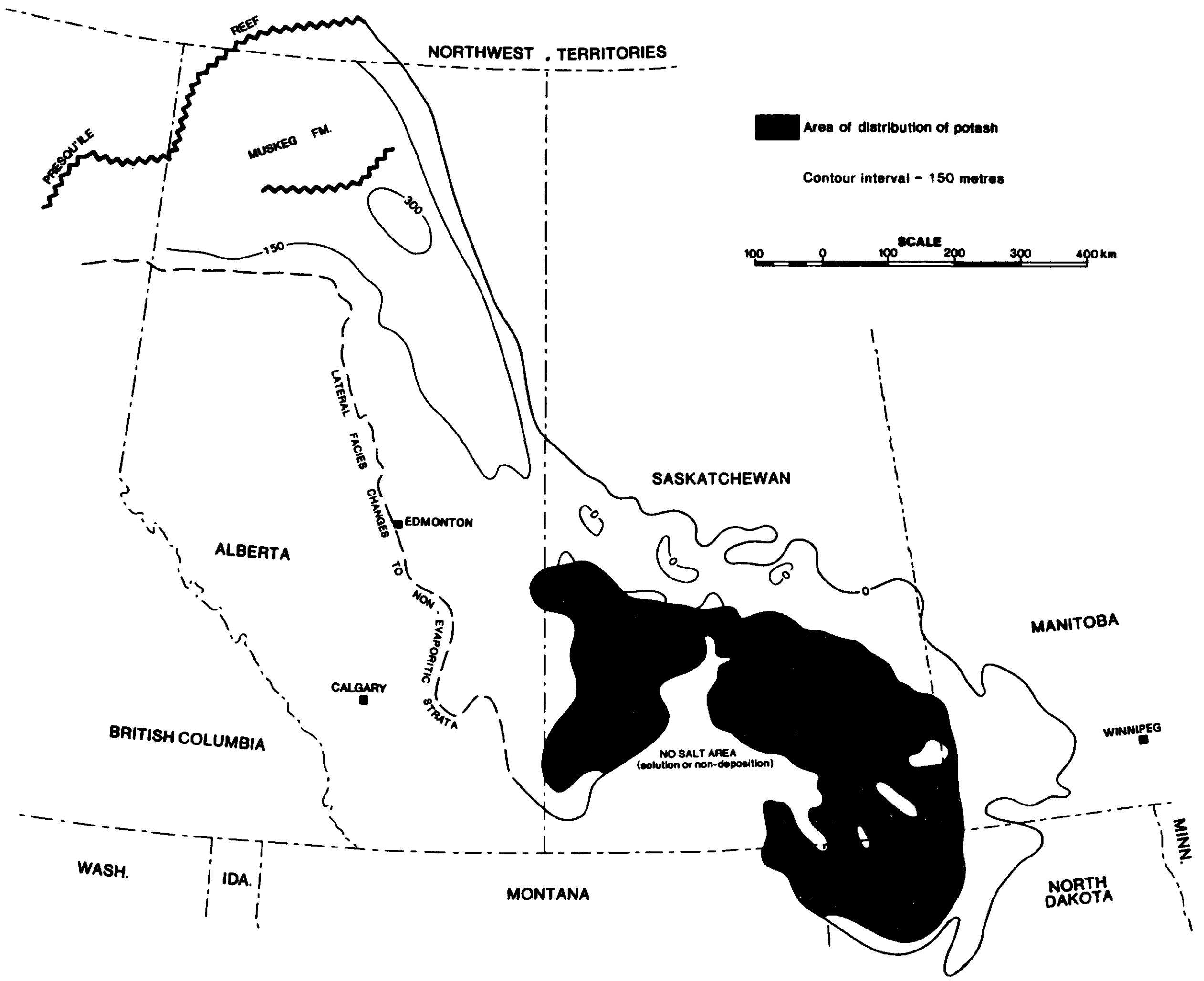

Figure 2. Area of distribution of potash in the Elk Point Basin (isopach map from Fuzesy 1982).

deposits. This is, in part, due to the lack of continuity of the potash horizons.

Newfoundland

Potash was reported in Newfoundland in 1967. Although exploration has been and is being carried out, no announcements of significant economic finds have been made to date.

GEOLOGY OF POTASH DEPOSITS

The potash deposits of Canada are of two ages. The Saskatchewan deposits are of Middle Devonian age, approximately 350 million years old, whereas the Maritime deposits are of younger, Mississippian age.

The Saskatchewan deposits occur in essentially flat-lying beds near the top of a thick sequence of halite and anhydrite, more than 200 m thick in places, known as the Prairie Evaporite. The potash occurs at a depth of approximately 1,000 m in the conventional underground mining areas of the Province. The Prairie Evaporite is in the earliest or lowest evaporite cycle of three evaporite cycles in the Middle Devonian formations of the Williston Basin. The Williston Basin is located at the southern extremity of the larger Elk Point Basin (Figures 2, 3) which extends southeasterly from northeastern Alberta, through Saskatchewan into North Dakota, southwestern Manitoba and northeastern Montana.

The Elk Point Basin is considered to have been a great dead sea in which, due to an arid climate and intense evaporation, first anhydrite and then halite beds accumulated rapidly on top of marine limestones. Insoluble material became increasingly common in the water and was deposited as thin seams or disseminated amongst the evaporite salts. As the result of continuing evaporation,

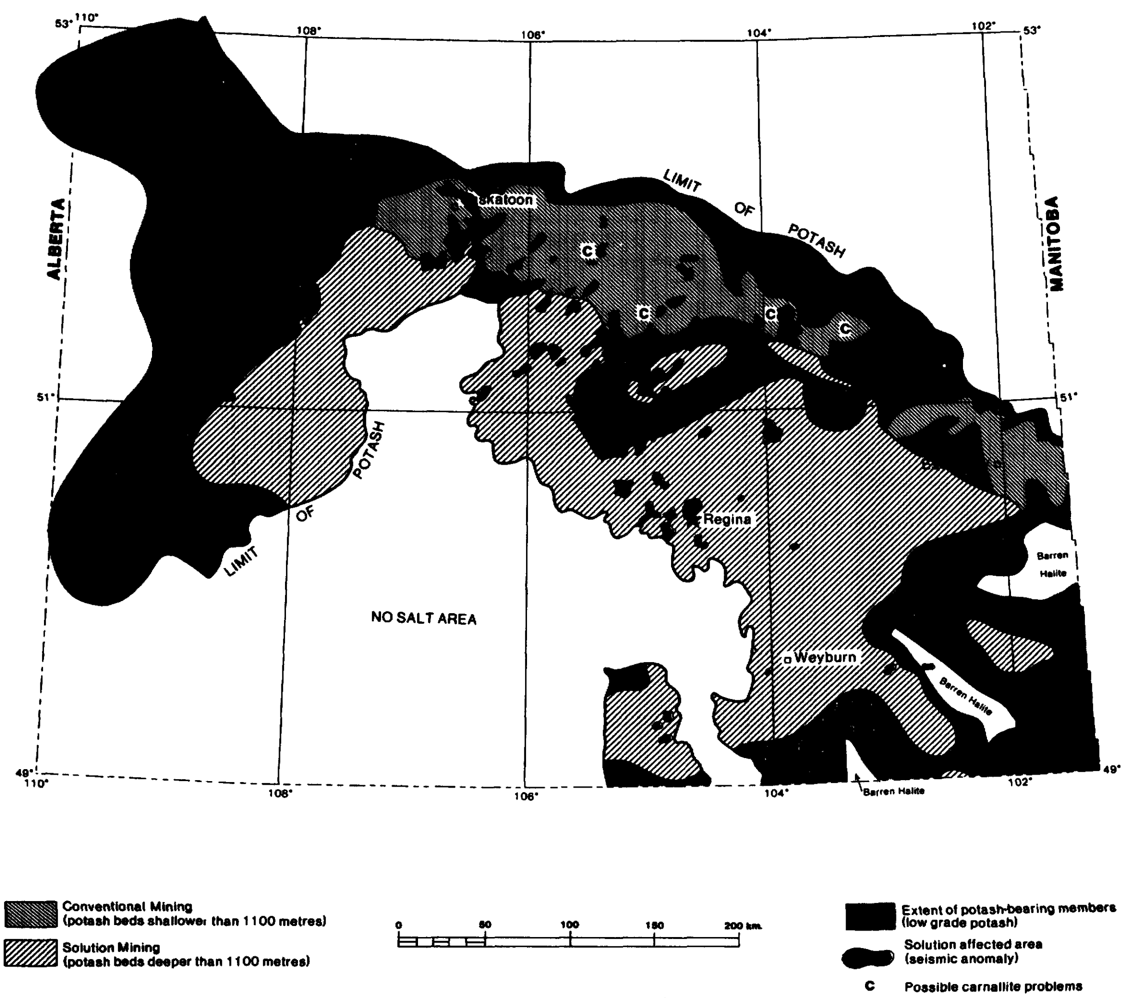

Figure 3. *Economic potential map of Saskatchewan (from Fuzesy 1982).*

potassium and magnesium collected in the Williston Basin and were deposited as potash. These salts were then sealed by muds of the incoming Dawson Bay sea (Fuzesy 1982). The sequence of muds (now clays) overlain by limestone then evaporite salt is considered to be a cycle (Figures 4, 5).

In the Maritimes, potash occurs in the Windsor Group of marine sediments within the Fundy or Magdalen Basin which extends from the Bay of Fundy to the western shore of Newfoundland and encompasses parts of southern New Brunswick, central and northern Nova Scotia and most of Prince Edward Island. The potash occurs as part of the evaporites deposited in sub-basins, within the Magdalen Basin, formed by tectonic activity in the region. The sequence of rock types is similar to that of Saskatchewan: limestones/dolomites overlain by anhydrite, halite and potash, capped by clays or clastics. As in Saskatchewan, sylvite and carnallite are the two important potash minerals, with sylvite being dominant.

The most significant difference between the Saskatchewan deposits and those of the Maritimes is the structure. Saskatchewan potash deposits are essentially flat lying with gentle undulations except where disturbed by localized anomalies. The Maritime deposits have all been subjected to folding and/or diapiric flowing. This folding has a significant effect on mining and consequently on the economics of the operation.

The other obvious significant difference is in the size of the deposits (see "Grade and Reserves").

EXPLORATION AND DEVELOPMENT

In Saskatchewan, the general areal extent and the general quality of the potash ore are known from oil exploration drilling or from previous exploration drilling specifically for potash. Consequently, detailed potash exploration can be concentrated in areas known to be favourable for economic deposits. Surface seismic surveys are utilized to determine the continuity of the Prairie Evaporite. The author's past experience with Potash Corporation of

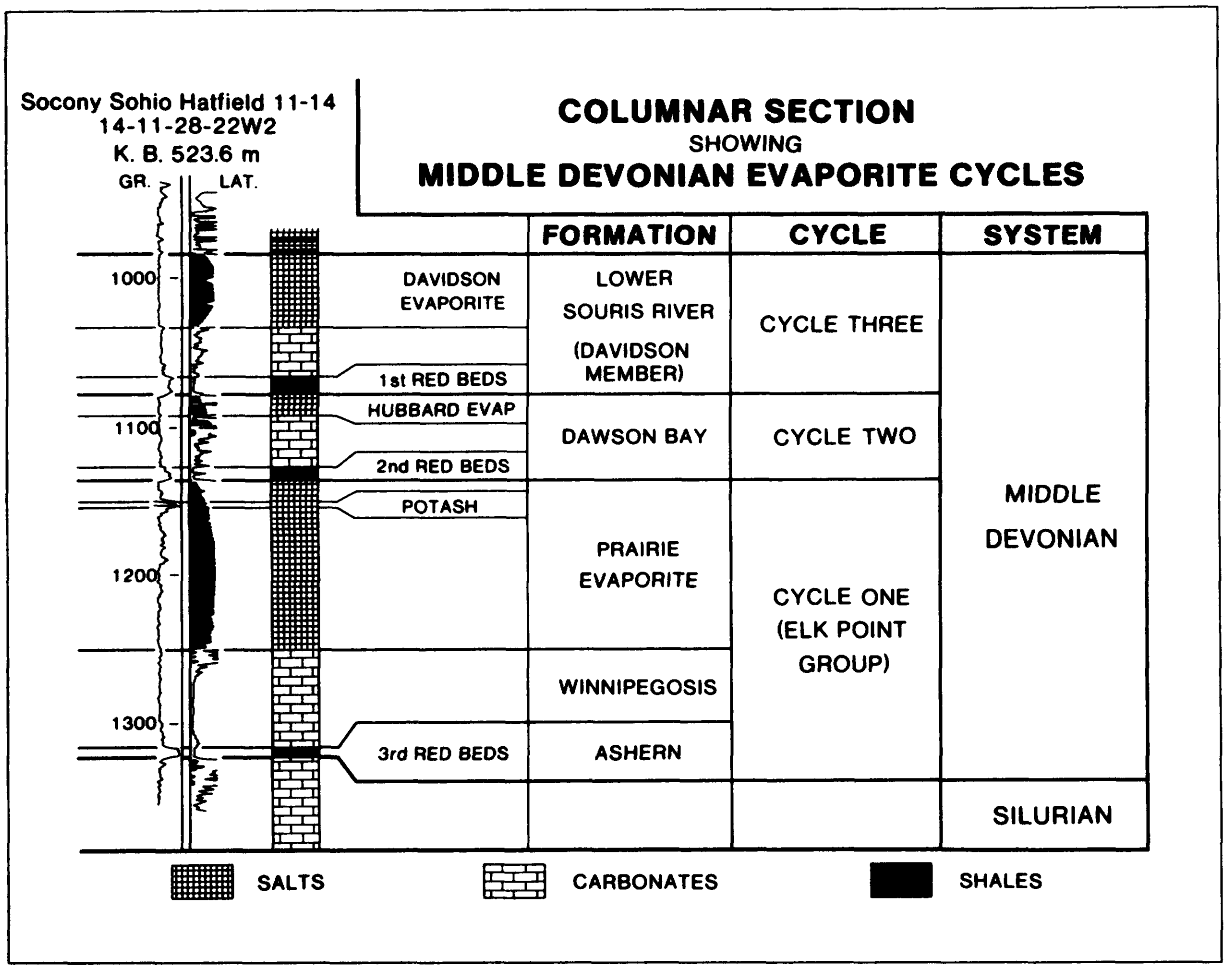

Figure 4. Columnar section showing evaporite cycles in Saskatchewan (from Fuzesy 1982).

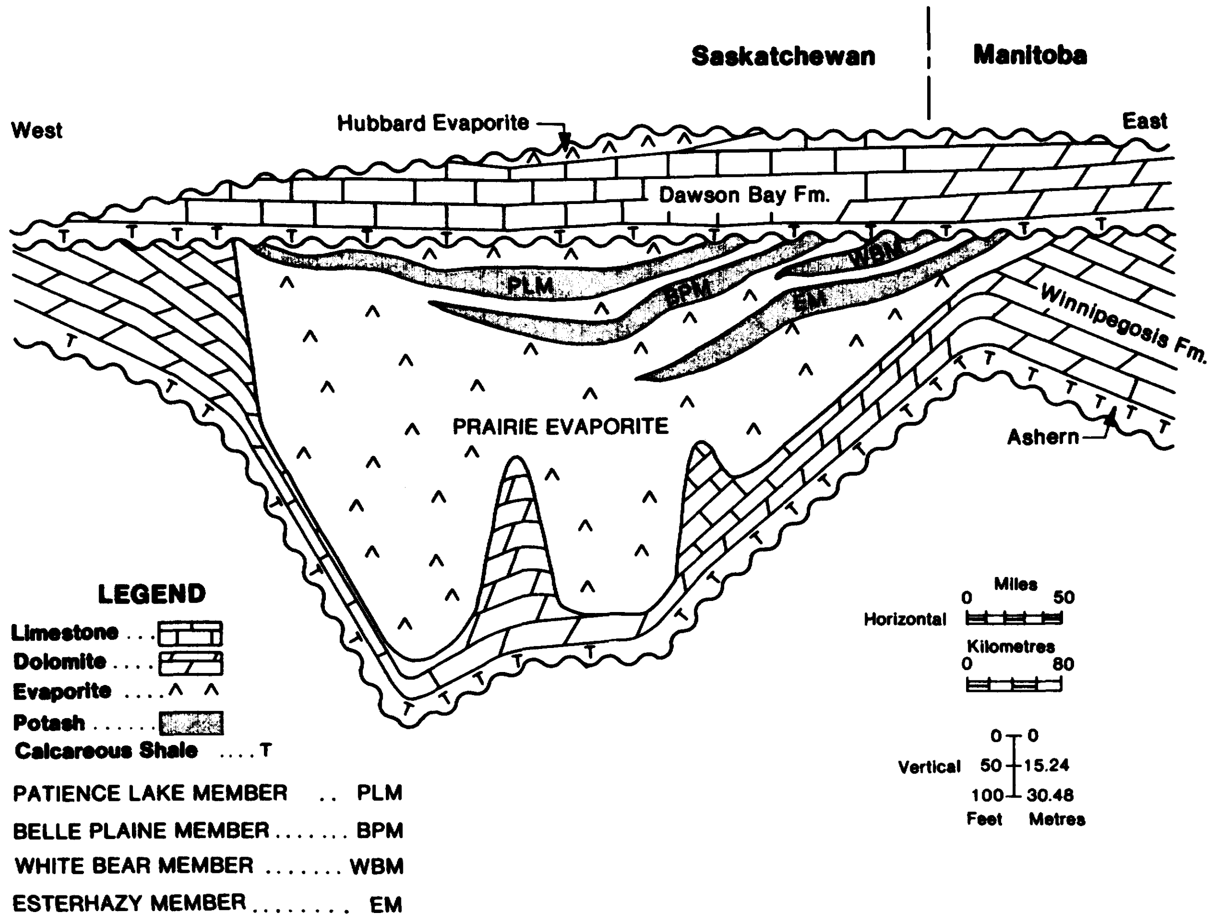

Figure 5. *Diagrammatic cross-section through the Prairie Evaporite in Saskatchewan and Manitoba (from Fuzesy 1982).*

Saskatchewan has shown that the most effective spacing for seismic survey lines is on north-south and east-west grids at 1 and 2 mile intervals for general reconnaissance, closing to ½ mile spacing for detailed work on a similar pattern of north-south and east-west intersecting lines.

The seismic survey will show the locations of anomalous areas within the Prairie Evaporite such as collapse structures, which must be avoided during mining, and seismic lows in the salt section which are areas of probable difficult mining conditions and/or poor ore grade.

Intensive exploratory drilling is not required in Saskatchewan. In conjunction with the surface seismic survey, an adequate assessment can be achieved with a density of one well per 4 to 8 square miles (4-8 sections). Standard oil well drilling techniques are used. Complete core recovery is restricted to the bottom 10 m of the Dawson Bay limestone, through the Second Red Bed and that part of the potash horizon of the Prairie Evaporite to a depth of at least 30 m below the potash. The core above and below the mining horizon is required for rock mechanics data. Although salt saturated brine has been used to core the salt and potash, the use of oil-based drilling mud is recommended for the coring program.

Upon completion of the well, a suite of logs (gamma, neutron, density and acoustic) are run using standard oil well techniques. The holes are then cement plugged through the salt section and all water-bearing formations. As a further safety precaution against water inflows into the mine workings, a 125-150 m pillar is left around each well.

In the Maritimes, because of the folded nature of the potash horizon, exploration is more dependent on core drilling. Seismic surveys cannot distinguish between salt and potash due to their similar physical properties.

Shaft Sinking

When the location of a shaft has been chosen, a pilot hole is cored from surface through the entire depth to below the potash horizon. This core provides precise data on the nature, strength and water-bearing characteristics of the rock to be penetrated. In order to prevent flooding during shaft sinking, the rock formations from surface down to beneath the last major water-bearing unit are frozen. The shaft pilot hole is not plugged as it acts as a relief for the freezing process. The shafts are lined with concrete and/or steel tubing through the water-bearing horizons. In Saskatchewan the shaft sinking process can take from three to four years to complete.

MINING

In Saskatchewan, a modified room and pillar method is used in underground mining. In the southeastern part of the Province, clay content is less than 5% and is disseminated in the ore. Although carnallite, mechanically weaker than sylvite, is present throughout the ore, the strength of the ore is such that rooms up to 1.5 km in length and up to 20 m in width are routinely cut in the mining horizon. These are separated by pillars on the order of 20 m thick.

In the Saskatoon area, clay content is greater and occurs as layers or seams within the ore horizon as well as disseminated in the ore. These seams have proven to be planes of weakness. To overcome this problem, a "stress relief" mining system was developed after extensive testing and rock mechanics studies. Basically, this method consists of mining two parallel entries in succession, followed by a centre entry. The outer or relief entries fail, normally at the clay seams, and closure of these entries relieve the pressure in the surrounding ground. The centre entry is in the stress-relieved ground and becomes stable (Haryett 1982).

The type of mining machines used were adapted from coal borers. Two rotor machines are used in the Saskatoon area, cutting openings approximately 2.5 m high and 4 m wide while producing 5.4 tonnes of ore per minute. In the Rocanville Division mine of PCS, four rotor machines cutting 2.4 by 8 m rooms are standard, producing 12.7 tonnes of ore per minute.

REFINING

The refining of potash ore to product is essentially a crushing and flotation process. The ore is finely crushed, deslimed and the potassium chloride removed by flotation. The potassium chloride is then dried and screened to provide up to four grades of potash: granular, coarse, standard and special standard. Compactors may be used to increase the production of granular and coarse grades. Chemical and soluble grades are produced from evaporation and crystallization circuits (Fuzesy 1982).

In the solution mining process, a selected pattern of cased wells is drilled from surface and a hot, weak brine is pumped into the potash beds at depth. The injected brine dissolves the sylvite and halite (and any carnallite present) and the resulting potash-rich solutions are circulated back to surface for refining by evaporation and recrystallization whereby crystals of potassium chloride are precipitated, drawn off, dried and screened (Fuzesy 1982).

GRADE AND RESERVES

The Saskatchewan potash deposits are considered to be the largest deposits of high grade ore outlined to this date. The deposits of the Soviet Union are equal or greater in size, but are not considered to be of equal grade.

The grade of ore mined in the Saskatoon area is on the order of 27% K_2O. In the southeastern part of the Province, the grade is lower, 21 to 24% K_2O, but the clay content is much less than in the Saskatoon area. The grade of ore in the New Brunswick deposits are thought to be similar to that of Saskatchewan, on the order of 20-25% K_2O.

Ore reserves in Saskatchewan are vast, on the order of tens of billions of tons of K_2O equivalent product. Canada is considered to have about one-half the total world potash resources. The US Bureau of Mines estimates 70 billion tonnes K_2O equivalent, most of this being in Saskatchewan (Fuzesy 1982). The New Brunswick deposits are smaller, but are probably sufficient for 40-50 years of production. This would place them in the order of 50 million tonnes K_2O equivalent for each deposit.

THE FUTURE

The prime use for potash is as a fertilizer. The United States is the largest consumer of Canadian potash, accounting for over 60% of production. Canadian consumption is quite small, about 5%, less than 500,000 tonnes per year K_2O equivalent.

The remaining 35% of production is exported, the largest buyers being Brazil, Japan, India, People's Republic of China and South Korea.

The present market for potash is depressed due primarily to high interest rates and surplus crops in the United States. However, as the demand for food production will increase, so will the demand for potash, an essential ingredient in the growth of food crops.

ACKNOWLEDGEMENTS

The author has made extensive use of the report "Potash in Saskatchewan" by Anne Fuzesy of the Saskatchewan Department of Energy and Mines. It is an excellent summary of the industry in Saskatchewan and is recommended as a source of greater detail on the subject of potash in the Province.

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Setting the Scene for Aggregate Resource Management in Alberta

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ABSTRACT

The Alberta Geological Survey and the Alberta Department of Energy and Natural Resources are cooperating in a comprehensive inventory of the aggregate resources of Alberta. Mapping has been completed around most of the larger urban centres, as well as in some relative wilderness areas where natural resource development is active. Three scales of information have been found most appropriate in the Province: reconnaissance (1:250,000), detailed (1:50,000), and development (1:10,000), each aimed at a different combination of resource developers, resource managers, and land use planners. Maps and reports are issued as quickly as possible, usually within a few months of field work, through an open file system at both agencies.

At the Alberta Aggregate Inventory there is a concern that the information generated is in an appropriate and informative manner for the user. Close cooperation and consultation between the two lead agencies helps in this regard, and changes in the information format have resulted from this. The most recent effort of the Inventory reflects this as a supply-demand study for the Edmonton-Lloydminster area. This is being conducted to provide resource and land use planners with an information document which is readily useable.

INTRODUCTION

The Alberta Aggregate Inventory is a joint effort of the Alberta Geological Survey of the Alberta Research Council and the Alberta Department of Energy and Natural Resources. Its purpose is to generate a full spectrum of aggregate information and to inform relevant concerned parties – both public and private, municipal and industrial – about the state of the resource in our province.

Certain basic principles have been followed since the inception of the inventory in 1976 when it became apparent that sand and gravel information was seriously deficient in the Provincial Natural Resource Data Base. A strong liaison and continuing cooperation was necessary between the two independent agencies conducting the inventory to provide information that was useful for all concerned. The satisfaction of the basic mandates of both departments are sought of course – geological research by the Alberta Geological Survey and public resource management by the Department of Energy and Natural Resources – however, the objectives of the program have always looked far beyond the goals of the individual departments.

The Alberta Aggregate Inventory is a comprehensive, province-wide inventory striving to produce quality data in the shortest time possible, for distribution to any users in the most informative manner possible. I am sure that you agree that all surveys have these same admirable goals – *but*.... It is these difficulties that all of us encounter in terms of achieving our idealistic goals that we would like to concern ourselves with in discussing the objectives and results of our inventory.

AREAS COVERED BY THE INVENTORY

Our commitment to produce a comprehensive inventory required a decision early in the program to include resources on lands not directly administered by the Province. While it may appear only natural that a resource inventory would consider all the resources, this had to be addressed since Energy and Natural Resources has a direct interest in only about 60% of the provincial land base (Figure 1). The remainder of the lands in the Province are either privately held or federally controlled, and because Alberta law holds that sand and gravel are surface resources belonging to the landowner, there is no single agency in Alberta which has total responsibility for the resource. On public lands, Energy and Natural Resources can control all aspects of resource management, development and reclamation, but the department's area of interest is almost totally in the unsettled portion of the Province. In the settled portion of the Province, where the resource management is most needed, any long-range considerations must be accomplished through the planning and zoning processes of the regional planning commissions or the counties. It is only through accepted land use plans that measures can be taken to ensure the preservation of essential aggregate resources. At this point in time, we have covered an area which contains more than 80% of the population of Alberta, and are now commencing on studies in the less populated areas.

This decision to gather information in areas outside of the administrative responsibility of the Department of Energy and Natural Resources, and to supply information

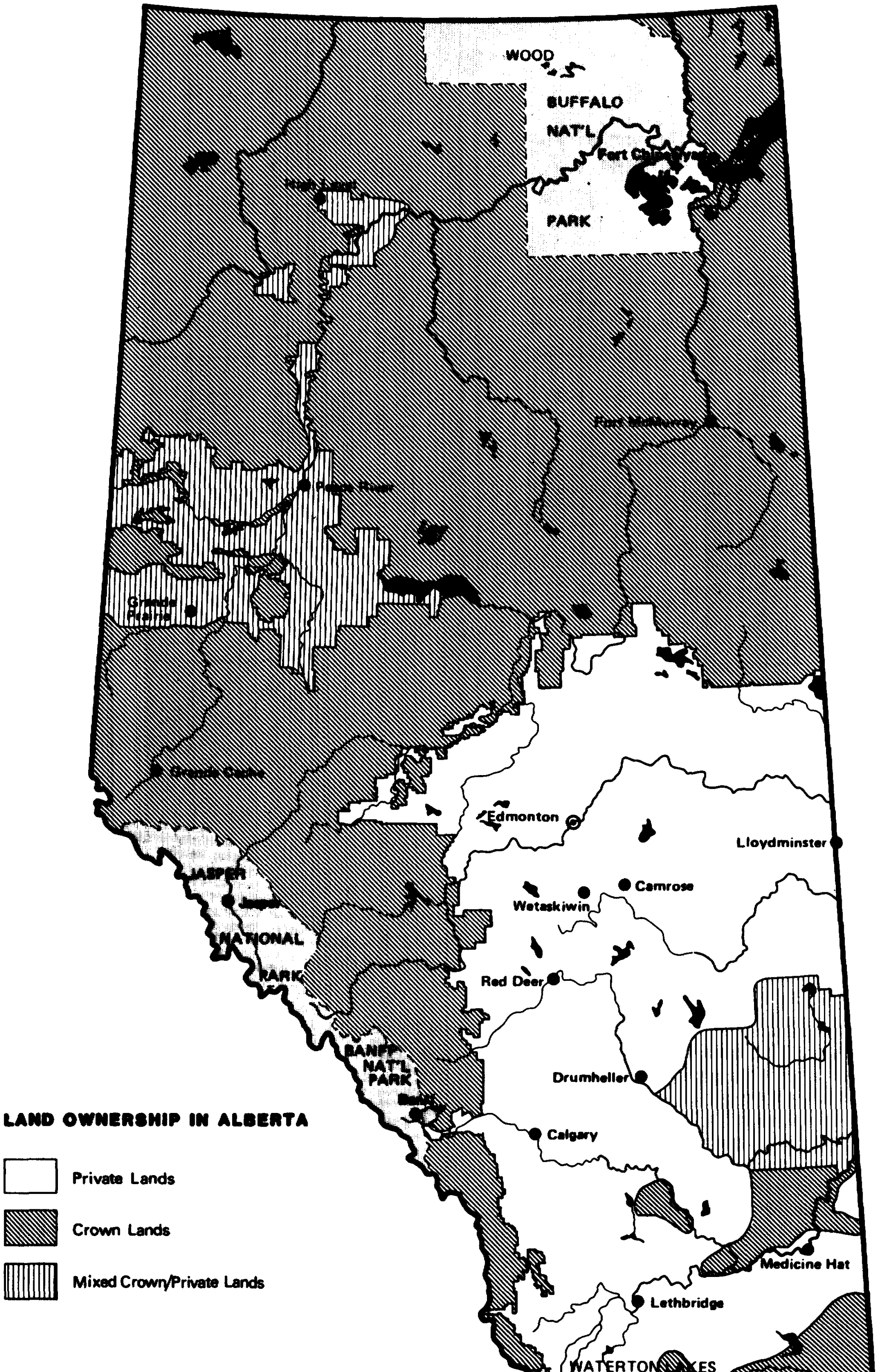

Figure 1. Land ownership in Alberta.

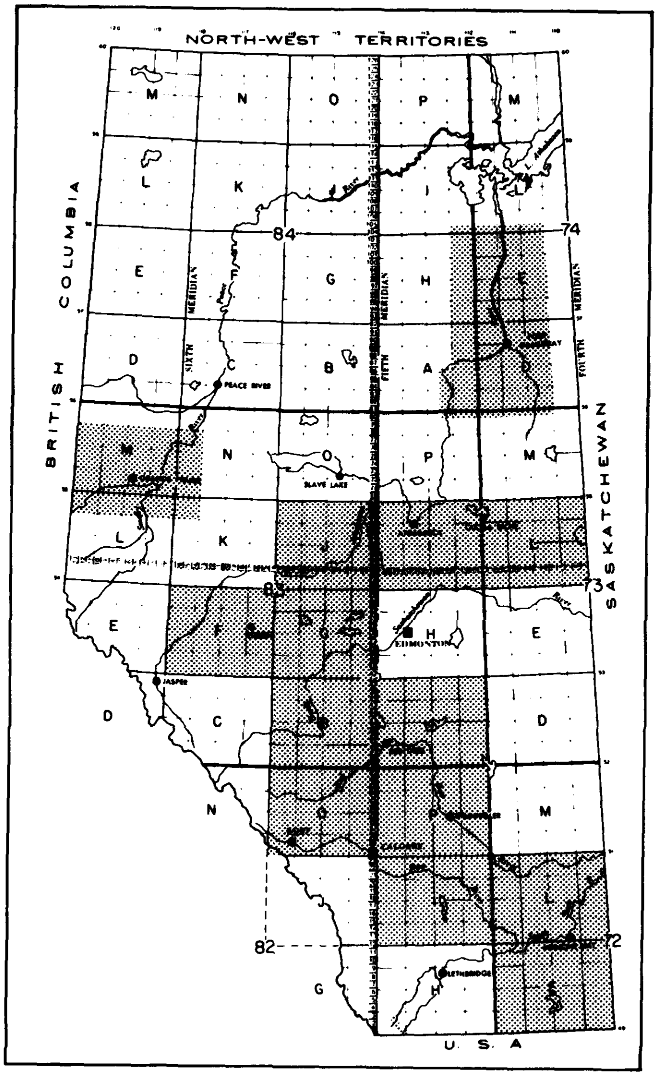

Figure 2. Areas studied for sand and gravel at reconnaissance scale (1:250,000) in 1982-1983.

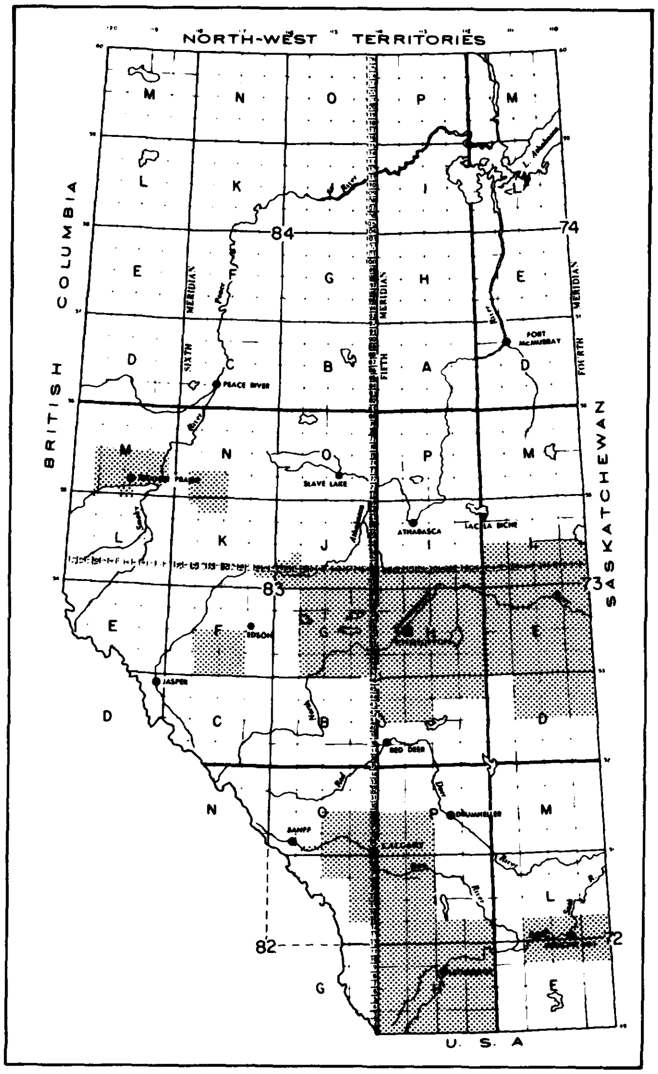

Figure 3. Areas mapped for sand and gravel at detailed scale (1:50,000) in 1982-1983.

to those concerns who do have responsibility, has required an awareness on the part of the Alberta Aggregate Inventory as to where aggregate is being used and will be required in the near future. Alberta is rare in the use of sand and gravel, in that it is not necessarily centered about the populated regions. Certain megaprojects, such as oil sands development or coal projects, require enormous amounts of aggregate in relatively unpopulated areas. In some instances, such as the Athabasca tar sands area of the Province, information has been requested of the Inventory by the Department of Energy and Natural Resources for areas proposed for mining projects. In other instances, such as the Cold Lake area, mapping studies were undertaken on the premise that possible heavy oil development in the near future would generate an immediate need for detailed aggregate information. In enough cases to justify this approach, we have found that a base level of information existing at the time of request can cut down on the amount of money involved in the study, reduce the stress associated with such a condition and reduce the time necessary to gain the information.

LEVELS OF DETAIL OF INVENTORY

Our concern for supplying quality information to a variety of users has meant that the Alberta Geological Survey conducts its field investigations at appropriate scales and at an appropriate degree of intensity necessary to supply information for the various categories of users. In Alberta we have defined that three scales of information are most appropriate and these have been employed by the Alberta Aggregate Inventory. A reconnaissance scale of informa-

TABLE 1. TYPES AND SCALES OF AGGREGATE INVENTORY

Type of Study	Reconnaissance	Detailed	Development
Scale	1:250,000	1:50,000	<1:10,000
Type of Investigation	Based on existing surficial geology maps and air photo interpretation	Detailed mapping, sampling, geophysical surveys and subsurface testing with lab testing	Grid testing and sampling at 100 m intervals or less and detailed lab analysis
Studies Completed	10	25	3
Typical Project (km^2)	15,000	4,500	0.1-1.0
Total (% Prov.)	34%	18%	
Cost			
Typical Project	3,700	125,000	10,000-100,000
Total	37,000	2,313,000	400,000
Purpose of Study	Delineate potential areas	Delineate deposits and estimate the quality and quantity of material	Prove the reserves and quality
Product	Map with simple legend	Preliminary map with extended legend followed by scientific report	Consulting report
Users	Energy and Natural Resources, Municipal Affairs, Regional Planning Commissions, Counties	Energy and Natural Resources, Transportation, Environment, Federal Departments, Regional Planning Commissions, Counties, Cities, Consulting Companies, Realtors, Oil Companies, Aggregate Companies, Private land owners	Energy and Natural Resources, Transportation, Aggregate Companies, Oil Companies Private land owners

tion (Figure 2) based on air photo interpretation and existing surficial geology maps, and supplemented by limited field work, is gathered for use by regional planning commissions and the Department of Energy and Natural Resources, for regional planning and preliminary studies. A more detailed level of information is gathered by the Alberta Geological Survey at a scale of 1:50,000 (Figure 3) and is based on detailed field mapping and subsurface testing of individual deposits. At this scale of information (detailed) individual deposits are delineated and the quality and quantity of each is assessed. This scale of information is required by the Department of Energy and Natural Resources, the Department of Municipal Affairs, regional planning commissions, counties and cities for detailed planning and zoning processes. A development scale of information is occasionally gathered by the Alberta Geological Survey through the systematic grid testing of a deposit for the extraction of the resource, and for assistance in developing a progressive rehabilitation scheme. Aggregate companies are interested in our detailed and development scale information, as are municipal planning agencies and certain public lobby groups. These various scales of information (Table 1) require various levels of budgetary support and are capable of covering considerably different areas in a given length of time. Only through liaison between the two departments involved in the Aggregate Inventory has it been possible to weigh the needs of the user and to implement this information, not only in determining areas to be studied, but also in terms of the detail warranted.

Although our inventory appears practical in that we identify our users in an attempt to have our information catered to them, it is also fair to say that we make an attempt to predict what uses our information will have in the future. In this vein, for instance, we recognize that sand and gravel, as a non-renewable resource, must be supplanted by other types of aggregate materials in the future, and that haul distances will increase drastically or construction methods themselves alter so that sand and gravel resources become less attractive even before their time of depletion. The research mandate of the Alberta Geological Survey permits investigations of such potential aggregate materials as fired shale or clay for expanded aggregate, fired till, sulphur as aggregate clasts or binding material, and the use of synthetic materials as possible substitutes for sand and gravel. Even our concern with sand and gravel takes into consideration that economic restrictions for the development of sand and gravel may vary and for this reason during the course of our mapping we do exploratory testing for deposits presently beyond the practical mining depth, or outside the quality restrictions that are presently placed on economically viable aggregate deposits. Research of this kind can be expensive and cannot always be justified in terms of immediate use. We are fortunate, in this instance, that this concept of comprehensive data collection is accepted.

PUBLICATION OF DATA

The concern for doing a comprehensive province-wide inventory and generating quality data has no impact unless this information can be provided to the user within the necessary amount of time. We are careful in our selection of areas for study that the reasons for such studies and the amount of time we have available are clearly defined. An obstacle that we have managed to circumvent at the Alberta Research Council is one that occurs at most research institutes: the length of time necessary for the writing, editing and publication of reports. The Alberta Aggregate Inventory's concern for providing information in a usable form in an appropriate length of time has resulted in the selection of an open file format for accomplishing this purpose. Open file maps are issued at both the 1:250,000 and 1:50,000 scales and contain information appropriate to each scale in an extended legend which has been designed for use by a variety of readers. All studies which are conducted produce published information before the next field season; thus research occupying the summer and late fall season is made available in published form three to six months after the final research and analysis is completed. At subsequent periods, more complete information is issued in the form of Earth Science reports with colored maps and more complete descriptions of the geological and research nature of the deposits or units.

The dissemination of information for the most effective use must not only ensure that appropriate information is supplied, but that it is supplied in an appropriate and informative manner for the user. Thus, we ensure that work performed in a given area is conducted at the scale of information necessary, that the information is supplied in an appropriate length of time, and that the type of information supplied is what the user requires. In our open file map format we have designed the legend so that it can be used by the non-technical reader (Figure 4). It contains sufficient information that the individual with more experience or background is supplied with enough information to make his own interpretations. We are very careful in this approach to define for the user that information was generated at a given scale and has a given precision, and should not be used as a source of information at a different level. We also try to make the user aware that members of the Inventory, both the Alberta Geological Survey and the Department of Energy and Natural Resources, are available to answer questions concerning our open file maps or reports or the work conducted in an area. We also feel that it is very important to get our reports or maps into the hands of the users through the most effective distribution system. All our maps and reports are placed on the publication lists of both the Alberta Geological Survey and the Alberta Department of Energy and Natural Resources. In addition, members of the Legislative Assembly in Alberta are notified when a report is issued in their area, as well as all counties and regional planning commissions. In most cases this means not only notifying those concerned, but also supplying complimentary copies of any report or map completed in their area. At this time we make ourselves readily available as consultants to help in the use of our information.

CASE STUDY

Perhaps the best way of demonstrating our concern with supplying a comprehensive and informative product is through a case example. One of the areas that was initially selected for study in 1976, when the Aggregate Inventory was originally formed, was the Canmore Corridor, an area running through the Bow Valley between Banff National Park and the western boundary of the City of Calgary. This study was begun with the intention of satisfying the need of local construction companies in finding an acceptable source of sand and gravel. An assessment of users indicated that a scale of mapping of 1:50,000 and subsequent detailed testing of deposits was required. The information gathered was assimilated by the Department of Energy and Natural Resources and resulted in an appropriate response to the contractors in the area in terms of a planning decision. The information that was gathered was filed and almost immediately was used in the development of the Policy for Resource Management of the Eastern Slopes, a policy concerned with the land management of the eastern slopes of the Rocky Mountains. For this particular purpose the same information was used in an open file map form with a specially designed legend.

During the early 1980s a different emphasis was generated in the area when Kananaskis Country (a large, provincial recreation area), the expanding boundaries of the City of Calgary, and the successful bid by Alberta to hold the 1988 Winter Olympic Games resulted in a renewed interest in the sand and gravel resources of the Canmore Corridor. Once again the information that had been gathered in a detailed manner was resurrected and quickly formed the basis for satisfying requests for information in this area. Development scale information was required as part of this request, and this was easily obtained (in the space of two weeks) to provide more specific answers in one important area of the study. This supplementary information enabled the Province to make a zoning change in its Eastern Slopes Policy, thereby providing for the long-term aggregate requirements of the area. This is but one case where cooperation and liaison between the Alberta Geological Survey and the Department of Energy and Natural Resources, and their concern for satisfying the aggregate resource dilemma, furnished appropriate and efficient responses to potentially serious problems.

AGGREGATE SUPPLY AND DEMAND

The concern for appropriate and informative information has also moved us into the realm of aggregate supply and demand. This most recent effort will provide a product less geologic in nature, but rather more suitable for planning purposes. The demand has come from county administrations and regional planning commissions who wanted a better picture of what was happening with the aggregate resources in their jurisdiction. As previously mentioned the practice of the Alberta Aggregate Inventory has been to cooperate with the municipal governments and regional planning commissions as much as possible. We have provided them with our inventory data and have offered to consult with them in any matter of interpretation of that

GENERAL COMMENTS | DEPOSIT CHARACTERISTICS

Deposit Number	Material Description	Reserves (1000 m³)		Additional Comments	Texture (%)			(%)	Overburden Thickness (m)	Deposit Thickness (m)	Deposit Area (ha)	Deposit Genesis	Additional Comments
		Gravel	Sand		Gravel	Sand	Fines	Wear					
1	Clean sand to clean sandy gravel	152,243	564,164	One of major suppliers of high quality aggregate in Edmonton region; deposit within area classified as extractive resource conservation by E.R.P.C..	20	78	2	-	15	15	4836	Fluvial	Central part of deposit contains higher % gravel (40-50% for sections, individual beds 70-80%), recoverable reserves estimated by gravel operators (1977) to be 5 million tons per quarter section of land, 74.4 million tons gravel (67.5 million MT) were estimated to underlie land assembled for gravel extraction; (1) 251.2 million tons Preglacial aggregate reported in area
2	Clean gravelly sand	900	1,950	Deformed lenses of gravel in this area are difficult to delineate and extract; area shown is approximate.	30	65	5	-	2	3	490	Glacially thrust and glaciofluvial.	Western part of area contains thrust gravel lenses with overburden cover; eastern part has meltwater channel deposits — no overburden
3	Clean sand	-	19,000	Sand ranges from fine to coarse grained; overburden may be restrictive in southern part of area.	-	97	3	-	2	8	244	Lacustrine	
4	Clean sand	29,072	109,020	Severe water table and overburden problems plus fine grained nature make development unlikely.	20	75	5	-	12	23	632	Fluvial	Part of Beverly Preglacial channel
5	Clean sand	-	1,960	Delineation of deposit approximate only — reserves and thickness may be considerably less.	-	98	2	-	2	10	20	Ice-contact	
6	Clean sandy gravel	116	80	Delineation approximate; discontinuous nature of gravel makes development difficult.	58	40	2	-	1.5	1	20	Ice-contact	May be kame or glacially thrust gravel
7	Clean sandy gravel	180	173	Gravel probably discontinuous; delineation and reserve calculations therefore approximate.	50	48	2	-	1	3	12	Glacially thrust and ice-contact	
8		-	-	No data available — potential similar to 5, 6 and 7.	-	-	-	-	-	-	12	Ice-contact	

Figure 4. *Sample 1:50,000 legend.*

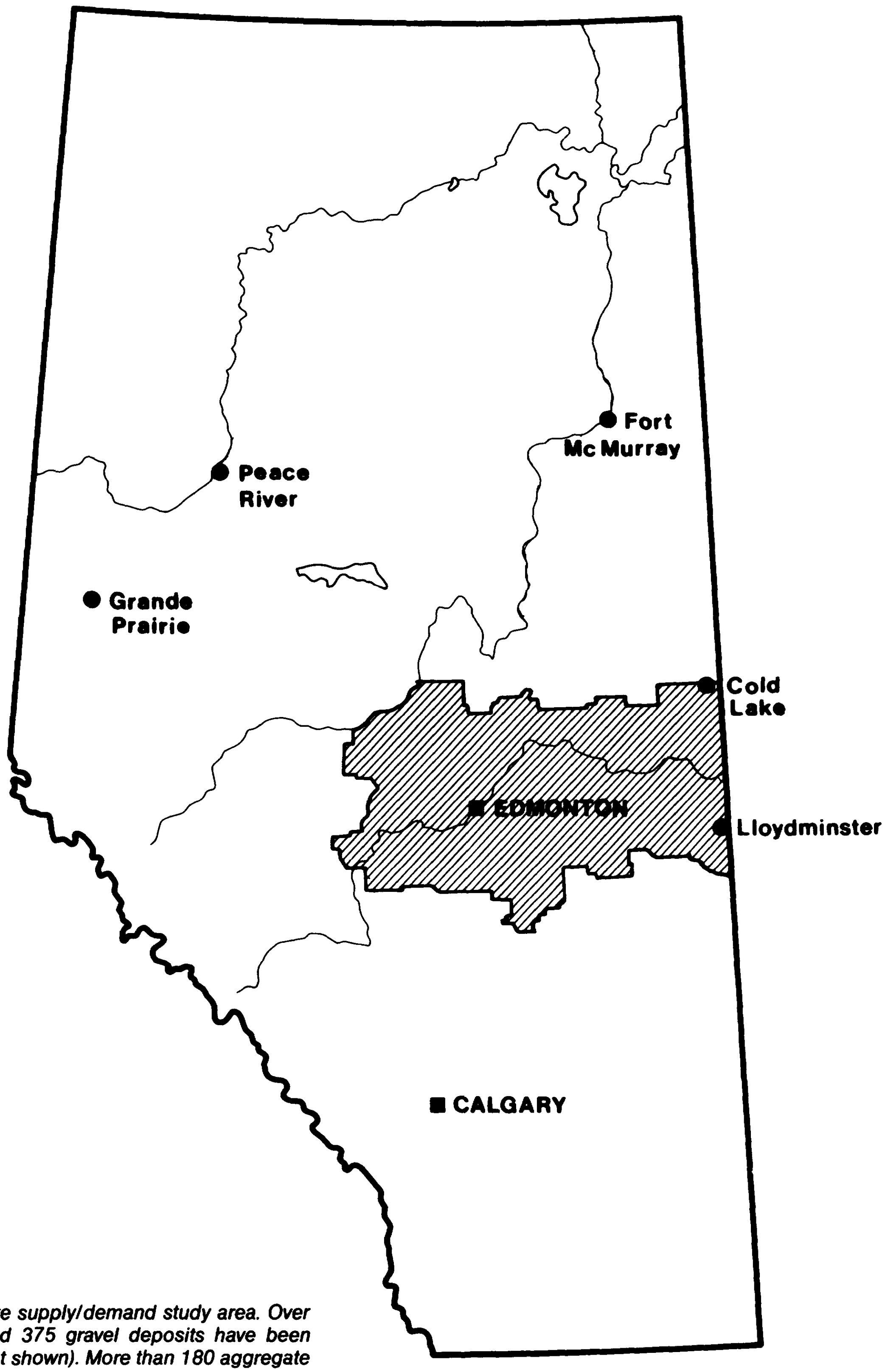

Figure 5. *The aggregate supply/demand study area. Over 170 sand deposits and 375 gravel deposits have been mapped in the area (not shown). More than 180 aggregate producers and consumers are being surveyed in this area.*

data, or aggregate resource issues where geological expertise might be of use. The Supply/Demand Study is an extension of this effort, as we are now going to provide a more subjective resource assessment for the Edmonton-Lloydminster area (Figure 5).

The Edmonton-Lloydminster Supply/Demand Study incorporates resource data from seventy-one 1:50,000 sheets or parts of sheets mapped by the Alberta Geological Survey. Over 500 sand and gravel deposits were identified in the area with total reserves of 2,670,720,000 m^3 of sand and 572,210,000 m^3 of gravel. The 1981 consumption of aggregate in the area was 11,991,000 m^3 (13.4 m^3 per capita). The distribution of the resource and the location of consumers are of critical importance, of course. The City of Edmonton for example uses about 70% of the total aggregate consumed in the study area. Fortunately over 60% of the gravel (351,828,000 m^3) occurs in close proximity to Edmonton. Information about the location and potential for use of each deposit will be conveyed to each of the 20 planning jurisdictions in the study area.

With this information in hand, the planning agencies will be able to incorporate these deposits into their plans and zoning as they find necessary to meet their objectives. This approach is different from some other authorities because Alberta is placing the responsibility for resource protection and management with the local authorities. While this approach may mean some deposits are not utilized, we feel that it is not the resonsibility of the Province to dictate to the municipalities in these land use/aggregate issues.

SUMMARY

It is the goal of the Alberta Aggregate Inventory to gather data and supply it to the municipalities for incorporation into their land use plans before critical conditions begin to occur. In Alberta, we hope to gain resource management through the communication of results, without resorting to the more costly and ineffective method of having to go through several levels of government and the larger bureaucracy of the provincial government in order to manage these resources, which have relatively small and individual market areas throughout the Province. This approach is being tested at the present time with the development of our Supply/Demand Study for a major area of the Province. Through consultation with the Alberta Geological Survey, the Department of Energy and Natural Resources and the Department of Municipal Affairs, the concerned counties in this study should be able to effectively plan for the use of their own aggregate resources. Hopefully, such communication of information to the appropriate users will provide a rational and effective way of planning for Alberta's aggregate resources.

Industrial Minerals in British Columbia Past, Present, and Future Development Potential

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ABSTRACT

Over the past 100 years, British Columbia has produced a wide variety of industrial minerals. While asbestos, gypsum, limestone, and refractory clays have become important parts of the industrial development of our province, the production of others such as building stone, bentonite or talc was rather short-lived or gradually dissipated.

Increases in population, technological progress, and shifts in the overall industrial strategy, combined with better knowledge of the local geology is bringing new mineral commodities into focus. British Columbia is becoming an important producer of silica, magnesite, and barite, with a potential to produce fluorspar, mica, and some other specialty minerals. A systematic approach in the study of individual geological units in British Columbia presents the opportunity to discover many new deposits of industrial minerals, namely ceramic and refractory clays, magnesite and perlite, as well as a variety of others.

INTRODUCTION

The purpose of this paper is to present a brief overview and to point out some opportunities in industrial minerals that we believe have good exploration and development potential in our province. The population of British Columbia is only 2.5 million and is concentrated predominantly in the lower mainland and the southernmost tip of Vancouver Island. However, a broader market area consisting of the industrial base of Puget Sound, the entire population of the Pacific Northwest (about 8 million), and adjacent areas east of the Rockies, is large enough for many lower priced, non-metallic mineral commodities. While production of some, such as limestone or gypsum, is well established, there are others which we believe deserve more attention from industry.

ASBESTOS

Despite some setbacks, asbestos in British Columbia remains very important, both in quantity and value of production (1980, 100,000 tonnes, $81.7 million; 1982, 80,000 tonnes, $70 million). Reported occurrences of asbestos in British Columbia are mainly in serpentinites. In addition to the one producing mine at Cassiar, there is a lower grade potential producer at Kutcho Creek and four other large but low grade occurrences in the southern part of the Province (Sproat Mountain, Moon Creek, J, and Ace). A newly developed prospecting tool for tracing asbestos fibre in soils should be of help in poorly exposed terrain.

Some serpentinites are also host to chromite and jade.

CHROMITE

This mineral has been reported from 31 locations clustered in ultrabasic intrusions and sills predominantly in two areas: northwest of Prince George, and west and south of Kamloops to the international border. Three sites (Scottie Creek, Mastodon, Anarchist Chrome) have reported production of small quantities in 1918, 1929, and 1957.

JADE

Occurrences of jade are also clustered. They are found for the most part in three areas: near Lillooet, in the Ogden Mountain area, and in the vicinity of Cry Lake. The largest share of production, almost 2000 tonnes, came from the Cry Lake area; about 570 tonnes were produced at Ogden Mountain, and less than 100 tonnes in the vicinity of Lillooet. A small but steady producer is the Cassiar asbestos mine where jade is a by-product. So far, most of the jade produced in British Columbia has been from alluvial boulders or from surface exposures of primary deposits.

CLAY AND SHALE

In the past, at least 26 brickyards scattered around the Province produced common brick and tile from local clays or shales. At present, only the Abbotsford plant of Clayburn Industries is active. It produces refractory bricks and other speciality goods as its main product line, and small quantities of construction bricks. The bulk of brick and tile products used in British Columbia come from Alberta or Washington State. While fireclay has been reported from Giscome Rapids and stoneware clay from the Quesnel, Prince George, and Coal River areas, the ceramic clay potential of Cretaceous-Tertiary basins in British Columbia is poorly known. Common red burning Quaternary clays of glaciomarine or glaciolacustrine origin are known from many parts of the Province. As well, bentonite was produced as a by-product of coal mining in southern British Columbia near Princeton. A Cretaceous "shale" on Saturna Island was used between 1959 and 1974 to make lightweight aggregate. Since production ceased, several other shales of the Nanaimo and Comox basins on Vancouver Island have been successfully tested for expanding properties.

TALC

Talc occurrences are numerous; many are associated with serpentinite rocks, others with schists and slaty argillites, and a few with crystalline carbonate rocks. Only two deposits have recorded production: the Eagle near Victoria from 1919 to 1935, and the Lucky Jane near Lillooet from 1916 to 1917 and 1929 to 1936. Talc from these two deposits was present as lenses in talcose schist. It was of inferior quality and was utilized in the asphalt and roofing trades. Three other properties (Gold Dollar, Gisby, and Aurum) reported trial shipments but did not go into production. While no sizeable deposit of good quality talc has been found, numerous occurrences of all genetic types indicate a good potential for its discovery.

PYROPHYLLITE

Pyrophyllite is reported in British Columbia from four different locations; in each it is an alteration product of volcanic rocks. Minor production was reported from the locality near Kyuquat on Vancouver Island in 1910 and 1911. It was used to manufacture sewer pipes and similar products in Victoria. At present, smaller tonnages mined from the deposit near Princeton are being used to make refractory brick.

MAGNESITE

Production of magnesite was renewed by the opening of Baymag Mines Company Limited's Mount Brussiloff – Eon Mountain deposit in 1982. Reported reserves of the Eon Mountain deposit are 21,265,000 tonnes of 95.7% $MgCO_3$ or 5,857,000 tonnes of 97.7% $MgCO_3$. The volume produced in 1982 from the Baymag quarry surpassed the total preceding tonnage mined in British Columbia. Magnesite was previously mined near Marysville during the early 1940s to supply the Cominco smelter in Trail.

All the economically interesting magnesite occurrences in carbonate rocks are near the Rocky Mountain Trench, both on the eastern and western sides. While some of the occurrences have sedimentary characteristics, others seem to be replacement deposits. Stratigraphically, the southern and northern occurrences are in Lower Cambrian rocks, the largest deposit (Cross River) is in Middle Cambrian carbonate rocks, and occurrences near Brisco are in Late Proterozoic rocks of the Upper Purcell Mount Nelson Group. During 1982 various European companies have shown considerable interest in this particular commodity. So far, no systematic prospecting has been carried out for magnesite.

BARITE

Barite has a 40-year production history in British Columbia. Since 1940, Mountain Minerals Company Limited, later joined by Baroid of Canada Limited and intermittently by a few other small operators, has produced barite from two replacement deposits (Spillimacheen and Mineral King near Invermere) and several vein deposits. Most of the production came from the Brisco and Parson deposits. While the producing mines are located in the southeastern part of the Province, the ever increasing market in and around the Beaufort Sea and the Mackenzie River Delta caused industry to seek alternative deposits closer to those areas. Several deposits tested in the Yukon have experienced problems with contamination of witherite and hence failed to meet API specifications. However, there are several good alternatives in northern British Columbia. Three different areas and lithologies of Devonian sedimentary formations contain significant accumulations of bedded barite. Midway and Akie River areas have barite associated with exhalites in a black shale environment; Muncho Lake has barite in carbonate host rocks. In the Akie River area the Cirque deposit, in particular, may provide barite as a by-product of silver-lead-zinc production. Midway and Muncho Lake have separate massive barite orebodies. Typical intersections from Muncho Lake are 90 m of 31.7% $BaSO_4$ and 44 m of 36.51% $BaSO_4$, or 14.8 m of 54.99% $BaSO_4$ and 9.4 m of 46.64% $BaSO_4$.

FLUORITE

The production of fluorspar in British Columbia dates back to the 1920s when the Rock Candy mine in southern British Columbia was active. This small vein-type deposit was abandoned in 1929; since then only very small tonnages produced as a by-product from the silica quarry near Oliver have been sold. There are, however, three large occurrences of economic potential, which are described below.

The Eaglet deposit is at present the only fluorspar prospect in the Province that is being actively explored. Fluorspar occurs as a stockwork with scattered veins and irregular lenses up to 20 cm wide and as impregnations in altered Proterozoic Kaza Group feldspathic gneiss over an area of 1,500 by 500 m. To date, approximately $2 million have been spent on the exploration of this property and reserves of 20.7 million tons grading 11.59% CaF_2 have been outlined. The property is located in central British Columbia, 110 km northeast of Williams Lake on the northern shore of Quesnel Lake.

The Rexspar deposit is located on the eastern side of the North Thompson River Valley 130 km north of Kamloops. The deposit is complex with high uranium and accompanying rare earth values, but fluorspar mineralization forms an independent zone adjacent to the uranium deposits. Fluorspar is present as fine-grained impregnations and it cements breccias in strongly schistose or brecciated alkali feldspar porphyry. Reported reserves are 1,200,000 tonnes of 22% CaF_2 or 500,000 tonnes of 29% CaF_2.

North of Liard River Hot Springs several small fluorspar deposits occur along the interface between limestone of the Middle Devonian Dunedin Formation and argillite of the Besa River Formation. Fluorspar is associated with witherite, barytocalcite, and barite. It is present as replacement bodies, breccia fillings, and some veins. The best intersection was 17 m of massive fluorspar.

Correlating the results obtained from the Regional Geochemical Survey (EMPR 1981) with known large occurrences, all three deposits covered by the survey (that is, Rock Candy, Rexspar, and Eaglet) produced similar size and intensity fluorine anomalies. In the twelve 1:250,000 scale map-areas covered by the survey to date, there are at least 50 similar or even larger anomalies that remain to be explained.

At present, the aluminum industry in the Pacific Northwest is importing fluorspar, mainly from Mexico.

GYPSUM

In British Columbia, gypsum has been produced from two areas: Falkland and the East Kootenays. The Falkland deposit, which was active mainly between 1913 and 1956, produced a total of 1¼ million tonnes of gypsum. Since 1949, we have seen the steady development of deposits in the Fort Steele-Windermere area and during the past 10 years they reached production volumes of 500,000-750,000 tonnes per year. In recent years Lafarge Canada took over the abandoned Falkland deposit. At greater depths it is composed mainly of anhydrite, and Lafarge Canada now produces an anhydrite/gypsum mixture for its cement plants in Kamloops and Richmond. There are two other lesser known gypsum deposits: Forget-me-not Creek near the Alberta border, and O'Connor River near the Alaska panhandle.

At present, gypsum for the Vancouver area is imported from Mexico.

SILICA

Early records on silica production in our province refer to silica flux that was used in British Columbia smelters. Such silica was not always of high purity and frequently contained some gold values.

At present, there are three different types of silica produced in British Columbia, depending on its use and application. Quartz conglomerate at Sumas Mountain near Abbotsford and a devitrified rhyolite ash at Barnhard Vale near Kamloops are quarried to provide the silica component for cement manufacturing.

Massive, Ordovician Mount Wilson (Wonah) quartzite is produced from two quarries near Golden for ferrosilicon and silicon carbide; its friable part is processed into a blasting and glass sand.

In the Kamloops area, a quartz vein near Chase is quarried for silicon carbide, and intermittently a similar vein near Armstrong has provided small tonnages of high purity silica for special uses. The largest past-producer, now almost depleted, is a pegmatitic plug at Oliver. Presently it is selling small tonnages of silica chips derived by processing the old piles of waste. International Marble and Stone Company Limited in Sirdar also produces small amounts of silica chips as stucco dash, roofing granules, and poultry grit.

Several thick quartzite units were examined in recent years both north and east of Prince George and in southern British Columbia as potential raw material for ferrosilicon production.

LIMESTONE AND DOLOMITE

Limestone production in British Columbia for cement, lime, and other industrial uses had reached 5 million tonnes per year by 1980. Most limestone produced from quarries is used and processed in British Columbia, but significant quantities are exported and processed in a variety of places along the Pacific Coast from Alaska to northern California. The main production centre on Texada Island provides chemical, cement, agriculture, and glass grade limestone from four independent operators. In the interior, near Lillooet, Steel Brothers of Canada are quarrying limestone and producing lime at its Pavilion Lake plant. Two small producers in the Prince George area supply chemical grade limestone to local pulp and paper mills, and in Rock Creek local dolomite is used to produce a variety of grades of agriculture soil conditioner and landscaping products. East of Nelson pure white limestone is quarried underground and processed into a micronized product. East of Kamloops, Lafarge Canada is quarrying limestone used in the local cement plant, and in the Fraser lowland marl is processed into soil conditioner. In the past, several small quarries produced limestone for a variety of uses on Vancouver Island, Sechelt Peninsula, near Terrace, in Portland Canal, and in many scattered places throughout the interior of British Columbia.

At present, the Peace River region is a large demand area for agriculture limestone; so far no local limestone sources are known.

DIATOMITE

Diatomite deposits occur in Tertiary basins in the central part of the Province in the area between Quesnel and Kamloops. Diatomite beds have been reported to be up to 35 m thick and are mixed with variable amounts of devitrified volcanic ash, clay, and silt. The Quesnel deposit is mined to be processed into insulating brick, oil absorbant, and animal bedding compound.

PERLITE AND PUMICE

With the exception of a small trial shipment in 1953, no perlite has been produced in British Columbia. There are several known occurrences of volcanic glass throughout the province. Mount Meager, north of Pemberton and Terrace Mountain near Vernon are easily accessible, while Empire Valley and several occurrences to the south and west of Burns Lake are in more remote locations. At present, all perlite used in Canada is imported; the British Columbia market is covered from Oregon.

Pumice in British Columbia is known from several different locations, but because of difficult access only one site seems to have a development potential. The Bridge River ash layer, originating from the Mount Meager area north of Pemberton, occurs as a coarse agglomerate on the eastern slopes of Mount Meager, as a layered deposit a few metres thick in the upper Lillooet River Valley, and as an irregular veneer with pockets up to 1 m thick along Bridge River to the east. Two operations, one north of Pemberton and the other in Bridge River Valley, are presently attempting to produce pumice.

Several cinder cones are known north of Kamloops near Clearwater, but the area is presently proposed for inclusion in a provincial park extension. Other potential sources of volcanic cinder are in northern British Columbia but too remote to be considered for commercial development.

BUILDING STONE

In the past, quarries scattered along the coast and in the southern part of the Province have provided a wide variety of dimension stone applied in many old public buildings.

Pink and white spotted granite from Beaverdell, pink granite from Vernon, light grey granodiorite from Nelson, and grey granodiorite from Nelson Island were at one time popular building materials. Also, black monzonite from Rossland, brown pulaskite with bluish iridescent feldspars from Ymir, bright grey andesite from Haddington Island, streaky grey marble from Kootenay Lake and Tahsis Inlet on Vancouver Island, and red marble from Texada Island can still be seen in several buildings in Nanaimo, Vancouver, and Victoria. The Cretaceous sandstone from many quarries on Vancouver Island as well as on several of the Gulf Islands was used in many old buildings. Also, slate was produced from a quarry at the head of Jervis Inlet north of Vancouver. Neither of the above mentioned stones is presently being produced and most of the quarries were abandoned many years ago despite the unquestionably good quality of the stone. At present, building stone is produced in British Columbia as flagstone and facing stone: quartzite from the Salmo area and a mica-schist from Revelstoke. There are, however, two potential producers ready to start quarrying operations on a commercial scale: Babette Lake quartzite with marble-like massive rock of beige and chocolate brown colours, and dark bluish grey diorite ("black granite") from Knight Inlet.

SUMMARY

This has been a brief summary of the past, present, and future development potential of industrial minerals in British Columbia. There are, of course, other commodities which present opportunities and invite closer examination. Kyanite, for example, has been reported as a common component in schists to the north and northwest of Revelstoke and near Prince Rupert. Similarly, the economic potential of only a few of the known nepheline syenites has been considered. There are also widespread but still subeconomic beds of phosphates in the Fernie and Monkman Pass areas. Distribution of carbonatites, sodalite occurrences, and one kimberlite diatreme in a belt along the Rocky Mountain Trench may be other interesting subjects. Thus, there are other promising exploration targets in the industrial minerals field for many years to come.

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Industrial Minerals as World Travellers

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ABSTRACT

Like some package tour participants, most industrial minerals have a reputation for bulk, crudeness, and cheapness. Papers at many of the previous Forums have concentrated on sand and gravel, crushed stone, and the like, which fail to get across the state or provincial line. However, there is a group of increasingly sophisticated industrial minerals, the nouveau riche, that are becoming world travellers, albeit in steerage.

A variety of factors allow these elite minerals to pay for themselves. Some are rare. For example, the USA, South Africa, and Chile have a virtual monopoly on the production of bastnaesite, baddeleyite, and natural nitrates respectively. Others are oligopolistic having a short list of producers yet consumption is ubiquitous. Examples include potash and phosphate. Quality is another factor that can allow a mineral like feldspar, the most abundant constituent of igneous rocks, to be exported from Finland to Malaysia. Demands by the glass and ceramics industries that the feldspar used as a flux have a maximum alumina and alkali content, a minimum iron content, and a particular grain size have necessitated beneficiation of the natural raw material, and has allowed the price to rise to a level where freight charges can be supported.

The application of sophisticated processing techniques to some industrial minerals has now become commonplace. Quoting from comments by Federal Bentonite, "Gone are the days of the Limestone Cowboys with their motto rip it up, shoot it through, and ship it out". Nowadays, more commonly than not, fluorspar is flotated, monazite magnetically separated, mica micronised, calcium carbonate coated, kyanite calcined, and garnet gravity separated. The price of many industrial minerals can increase multifold when upgraded from the raw material in the ground to a product acceptable to a discerning consumer. Certain minerals can even command a price of several thousand dollars per ton rather than the traditional two or three dollars per ton.

INTRODUCTION

A well-known rule set in stone is that all rules have exceptions. However, the rules governing industrial minerals are truly exceptional, riddled as they are with incongruities, provisos, and asterisks. A major problem is the great diversity of the field, and the variety of approaches available for classification: based on geology, chemistry, specifications, end-use, location, etc.

One of the many classifications proposed to bring order to chaos in the industrial minerals field is the twofold subdivision (Table 1) as proposed by Bates (1969).

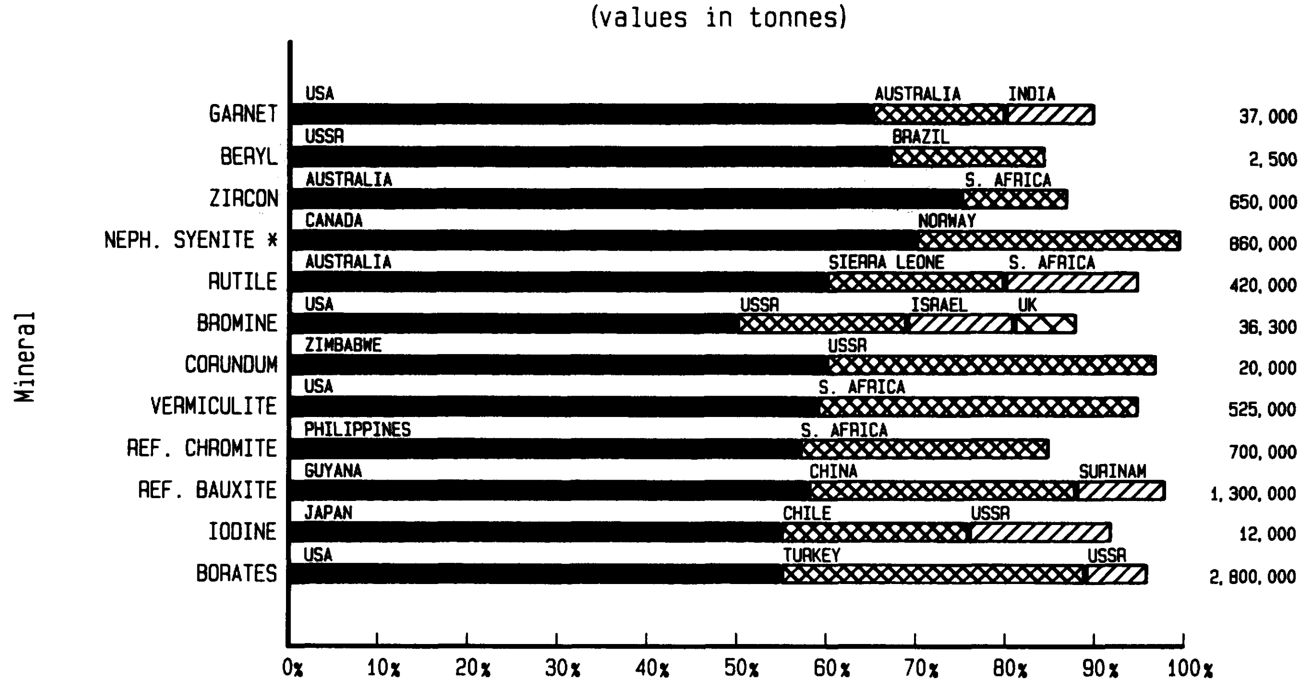
TABLE 1. CRITERIA FOR TWOFOLD SUBDIVISION OF THE NONMETALLICS

Aspect	Group 1	Group 2
Bulk	Large	Small
Unit Value	Low	High
Place Value	Low	High
Imports & Exports	Few	Many
Distribution	Widespread	Restricted
Geology	Simple	Complex
Processing	Simple	Complex

This remains an extremely useful classification for most purposes, but the question of which mineral fits into what category, and why, has changed, and it continues to change. The combination of large bulk and low unit volume makes sand and gravel and crushed stone typical Group 1 materials, and the small bulk and high unit value of industrial diamonds Group 2 minerals. However, a series of technical, political, and other factors is tending to metamorphose some Group 1 minerals into Group 2 (apart, of course, from the geology which remains relatively constant). The following reviews some of the divergent reasons why certain industrial minerals now qualify for Group 2 status and so can enter international trade.

RESTRICTED DISTRIBUTION OR AVAILABILITY

Despite the reputation of abundance, many industrial minerals have a limited number of commercial sources. In an attempt to quantify rarity, and to illustrate the degree graphically, the term rarity is arbitrarily taken to mean 85% or more of world production originating from five countries or less. Thus, of the 50 or so materials regarded as industrial minerals and rocks, 25 are "rare" (Figure 1). This rarity can be caused by a variety of factors, both natural and man-made.



* USSR production unknown

Figure 1. *Suppliers of the rarer industrial minerals.*

Natural Restrictions

Bastnaesite production as a source of rare earths is restricted to one deposit in the USA (Mountain Pass, California) and several (?) in China, and baddeleyite, the zirconium mineral, is mined only from the Palabora Complex in South Africa. Quartz crystal and sheet mica are two minerals now produced in only a handful of countries, mainly due to the rarity of the geological environment required to form the delicate minerals. Nature rarely concentrates bromine up to commercial levels; the element is widely dispersed in seawater, less so in brines, and rarely in a mineral. Nitrates also require special circumstances for formation, and are extremely susceptible to erosion. This of course is somewhat of a pedantic approach since each of these elements or materials have alternative commercial sources: rare earths are also extracted from monazite, mica is now largely scrap material, quartz crystal is manufactured synthetically, bromine is chemically extracted from seawater and brine, and nitrates have largely been replaced as a source of nitrogen by the chemical processing of air.

Producer/Consumer Coincidence

Phosphates and potash, dominant sources of phosphorus and potassium respectively, are not restricted by natural factors. Both suffer from what can be called producer/consumer coincidence, that is where the major producers consume virtually all their own output leaving little to enter world trade. The main phosphate rock producers (Figure 2), the USA and the USSR, require the bulk of their output for domestic or in the case of the USSR, domestic and Comecon needs. Thus it is left to large producers with limited domestic markets, mainly North African countries such as Morocco, to supply world trade (Figure 2). In the case of potash (Figure 3), Canada dominates world trade since production is high compared with domestic consumption, in fact 85% of production is exported, and the mines have been developed specifically for the export market. Other producers, the USSR and several European countries, consume their entire production, and in fact are supplementing declining production through imports. Although more liable to be substituted, borates also come under this category. Borates are produced on a commer-

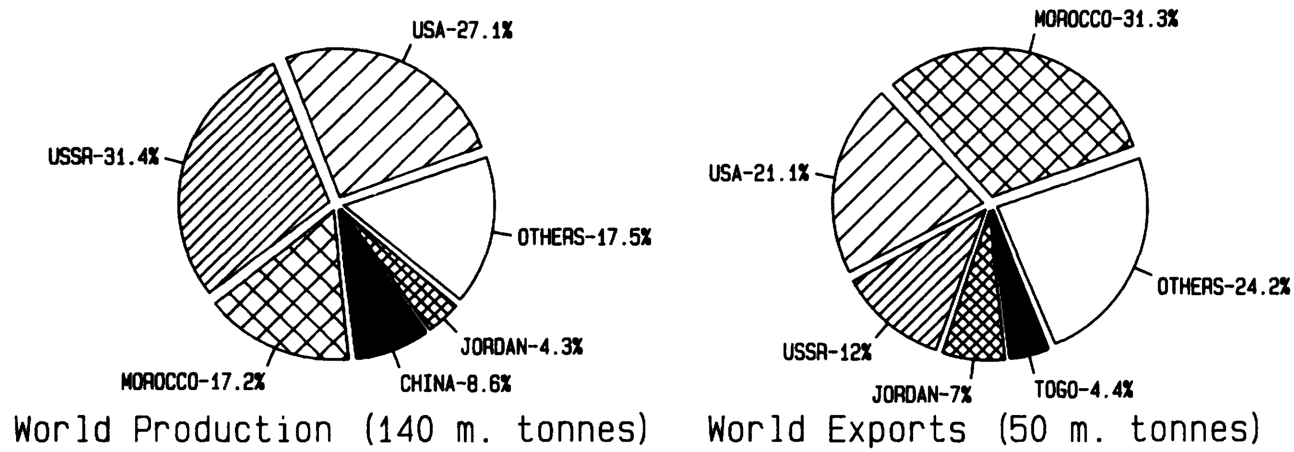


Figure 2. *World production and world exports of phosphate rock.*

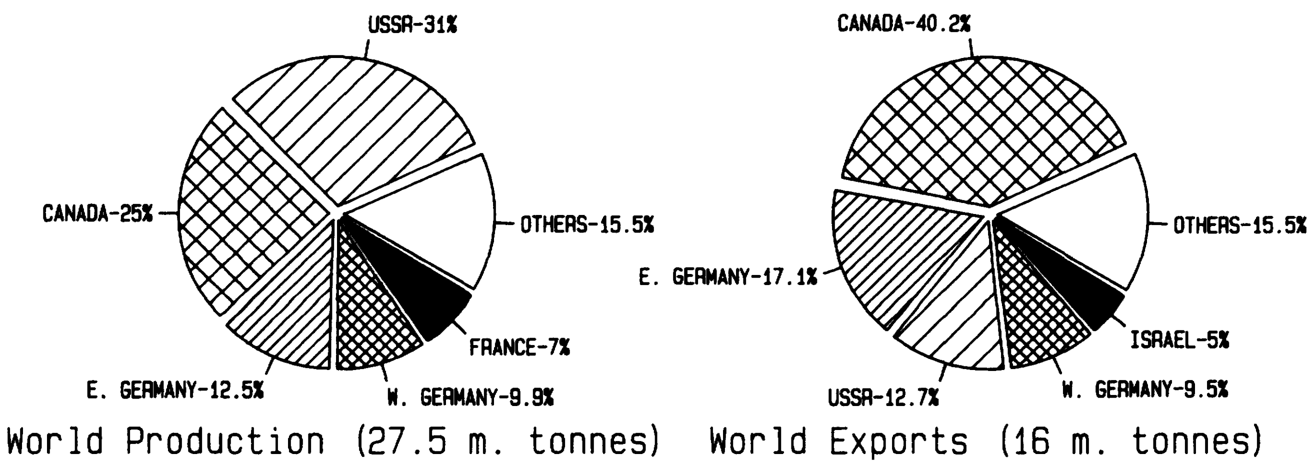


Figure 3. *World production and world exports of potash.*

cial scale at two mines and from one lake bed in California, three districts in Turkey, and on a much smaller scale in South America and the USSR. However, as with phosphates, the USA consumes most of its own output leaving the bulk of the world's trade in the hands of the Turkish borates industry. This in turn is virtually controlled by the government-owned Etibank.

Commercial Restrictions

Supply may be restricted by the structure of the industry. The drilling mud industry for example, is dominated by a handful of US-based companies including Dresser Industries Incorporated, Imco Services, NL Baroid, and Milchem Incorporated. These companies mine barite and bentonite all around the world, and either supply local needs or ship it to the USA. Thus a high proportion of the supply (and consumption) of these two important drilling mud minerals is dominated by just a few companies.

Common minerals may be restricted in their availability because of certain commercial factors. Zircon output, for example is dominated by Australia where deposits are so large and easy to mine that other potential suppliers have difficulty in competing. The same is true for its co-products rutile and ilmenite.

GRADES AND PROCESSING

A mineral's ability to enter trade depends largely on its unit value, and this is often enhanced by matching high specifications required by the consumer. The general trend over the past 5 to 10 years has been to tighten these specifications. In the glass industry, for example, the finer the sand the less energy required to melt the product, the lower the impurities the better the quality of the glass produced. Improved grinding techniques and more sophisticated processing have enabled extremely pure minerals to be produced and sold at a premium price. Take feldspar, one of the most common rock-forming minerals. Processing yields high purity material within very tight size limitations, and can even separate the soda and potash feldspar varieties. How this is reflected in the final price of the product is illustrated by figures (as of April 1983) supplied by a major US producer (Figure 4). The price of feldspar as hard rock in the ground is regarded as nominal, say 25-50 cents per ton, but when it is mined, crushed, and stored it increases to $4-5 per ton. This rises to $27-28 for processed (flotated) feldspar, and then $37-38 for further processed material subjected to rigorous quality control procedures. Still further processing up to 'filler-grade' (-325 mesh) produces a product valued by the producer at $62-63 per ton. In this example, processing increases the value of mined material more than ten-fold.

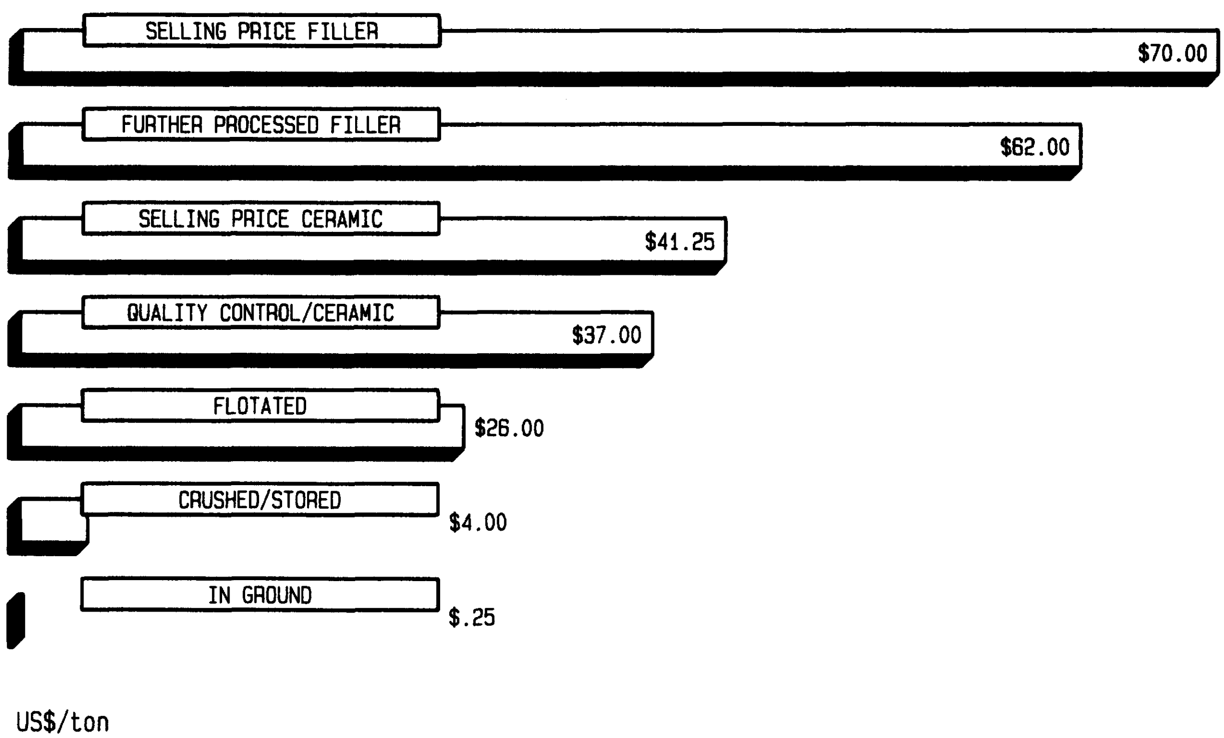


Figure 4. *Components of price for processed feldspar.*

Another fine example of price increments with grade is asbestos. Taking the products produced in Quebec, the refuse or shorts, No. 7 grade, is only C$160 to 300 per ton, whereas the No. 3 or spinning fibre ranges from C$l,500 to 2,450. Another ten-fold increase (Figure 5). Graphite from Sri Lanka ranges from 260 to 850 pounds sterling depending on carbon content, particle size and shape.

Processing also increases the reserve base of the raw materials, thus adding life to the operation and encouraging investment. It can also generate by-products; for example the reserves of feldspar in the Spruce Pine district of North Carolina are virtually limitless since the application of flotation has enabled alaskite to be mined and separated into its main constituents, feldspar, mica, and silica sand. The district is the main source of mica in the USA supplying much of the needs of the drilling mud industry.

GOVERNMENT

Governments may influence or restrict the quantity of minerals entering the market place. Examples include the complete banning of exports (usually of unprocessed material), government ownership, government sales outlets, price manipulation, or local environmental laws that restrict production in certain areas. Governments of course can manipulate the supply side of the equation and regulate prices, the best example being OPEC and oil. Attempts to emulate this (now waning) success in other commodities is extremely limited. Morocco and several of its North African phosphate-producing neighbors attempted a four-fold increase in prices around 1974, however price discounting and consumer resistance undermined the campaign to drive up prices. The major problem was that for many of the producers, revenue from phosphates accounted for a large proportion of the country's foreign exchange, and short-term revenue gains outweighed the potential long-term advantages.

TERRITORIES

Nepheline syenite is an industrial mineral produced on a large scale in only a handful of countries. Some 600,000 tonnes per year are produced near Nephton, about 125 miles northeast of Toronto. Since nepheline syenite competes with feldspar and aplite in serving the fluxing needs of the glass and ceramics industry, territories have developed where one or the other is dominant (Figure 6). There are some technical advantages in using either feldspar, nepheline syenite, or aplite in certain products, but transportation costs tend to dominate. In eastern and central

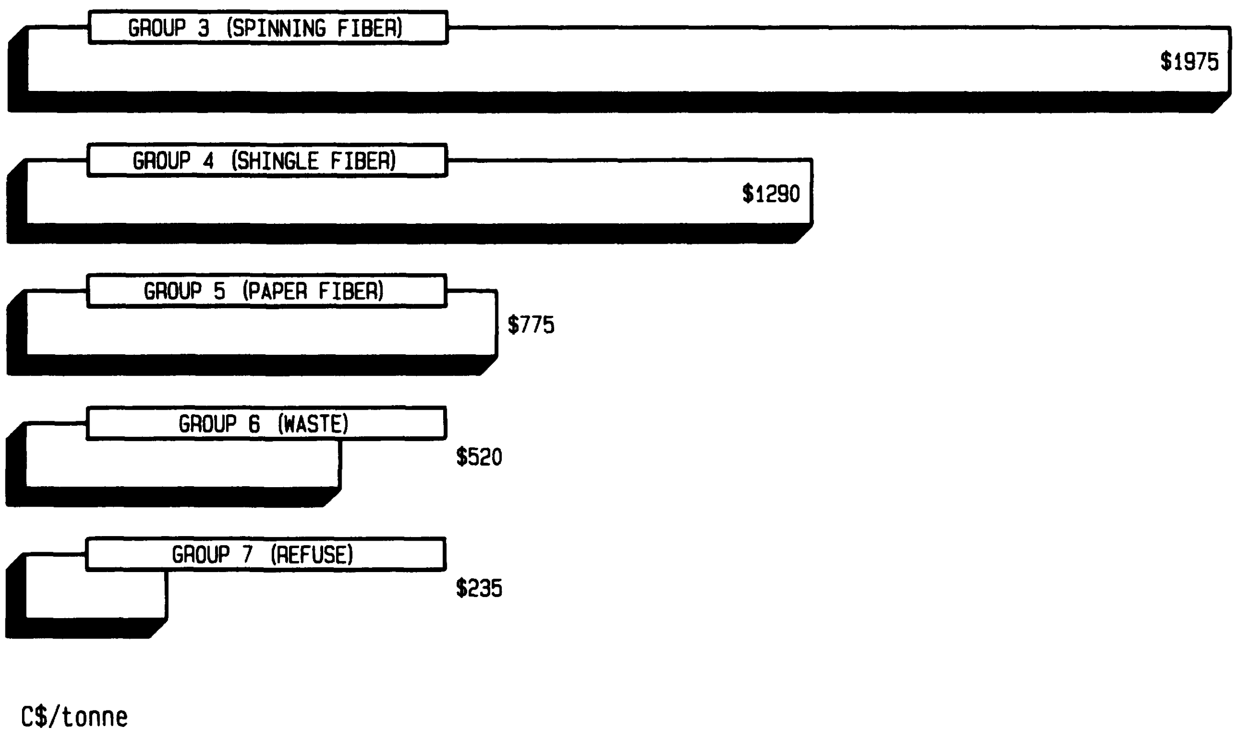


Figure 5. Components of price for grades of asbestos.

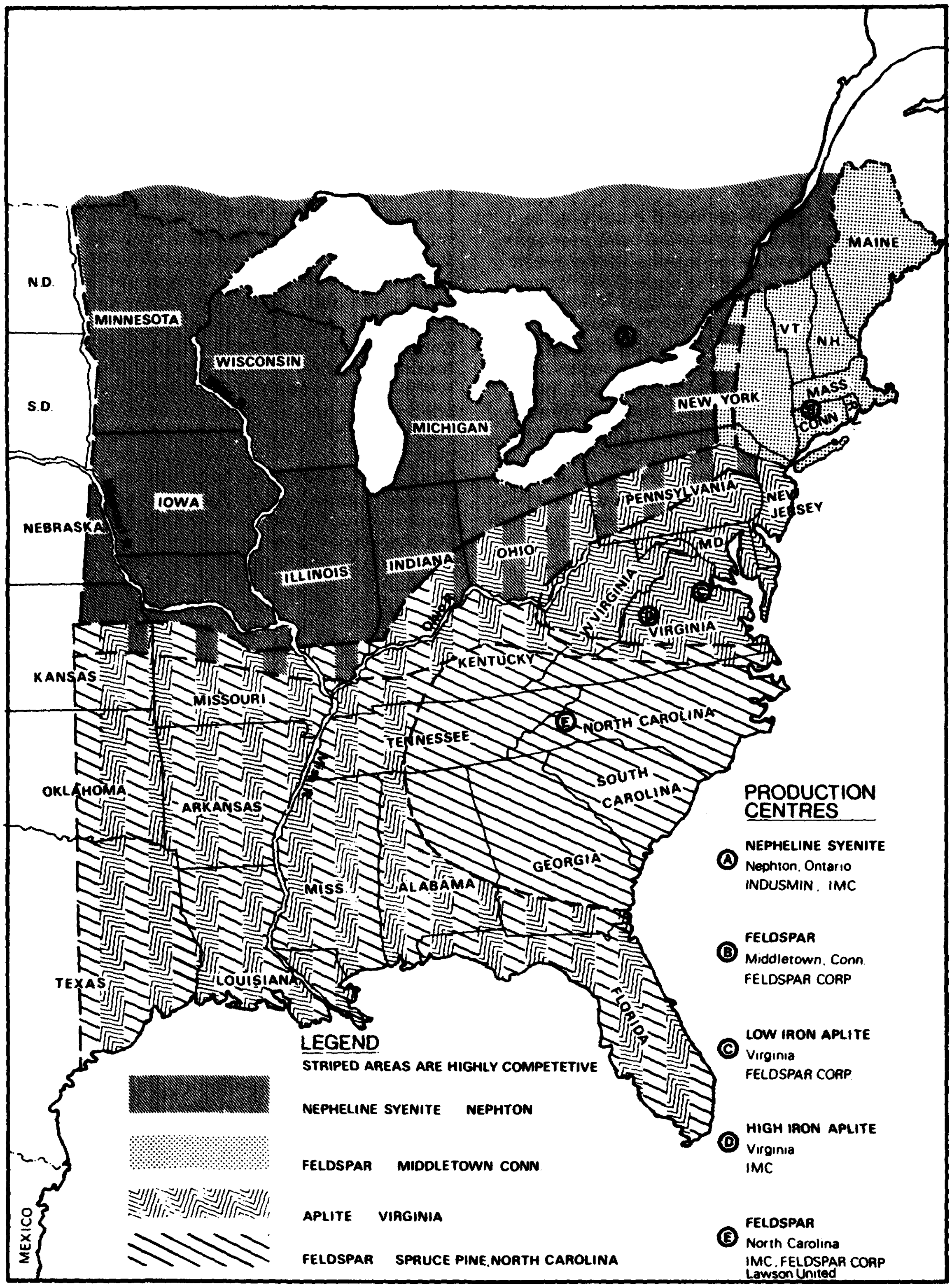


Figure 6. *Market areas for glass grade feldspathics in eastern USA and Canada.*

North America the areas of influence are split: western New York, northern Pennsylvania, and Minnesota are totally dominated by nepheline syenite; the Carolinas, Georgia, eastern Tennessee, and Kentucky rely on the Spruce Pine feldspar; and other smaller feldspathic mineral producers – aplite from Virginia and feldspar from Connecticut – supply local markets. There is an overlap between Canadian nepheline syenite and Spruce Pine feldspar in south-central areas of the USA.

The interaction between technical superiority and local availability is an interesting one. The obvious advantages of using locally available raw material may outweigh any technical drawbacks. In fact, the advantages of using locally produced material may encourage the development of technology to use these local materials. The Finnish pulp and paper industry has developed the use of local talc as a paper filler and coating agent since paper-grade kaolin has to be imported. Also in the paper industry, alkaline sizing has become popular in Europe since calcium carbonate can be utilized in this process, whereas in the acidic method still dominant in North America kaolin has to be used. The alkaline sizing method is gradually being adopted in the US, and although not the prime concern, it allows the more abundant calcium carbonate to compete with paper-grade kaolin, production of which is restricted to Georgia.

GOOD NEIGHBORS

Although some minerals enter 'international trade', the distance involved may be limited. The high production of many industrial minerals in Canada is based on foreign markets, particularly the USA. Canada contributes substantially more than 50% of the US imported lime, asbestos, potash, nepheline syenite, sand and gravel, crushed stone, gypsum, sodium sulphate, sulphur, and ilmenite concentrate (Figure 7). The reasons for this trade are variable. Asbestos is imported because the USA has limited reserves, and recent legislation and public opinion has discouraged domestic development. The incentive to exploit domestic resources is weakened still further because of the major reserves and mines in Quebec (in fact, it was largely US and British capital that developed these deposits to supply home markets). The same can be said for the potash mines of Saskatchewan which were developed largely by US companies eager to feed the home market. The decline in the rate of production and reserve base in the deposits in New Mexico has made imports from Canada still more crucial for the USA. The relatively close political and commercial ties between the USA and Canada are well illustrated by the seemingly casualness of US reliance on Canadian sources for major and important raw materials. Potash is particularly important, providing a

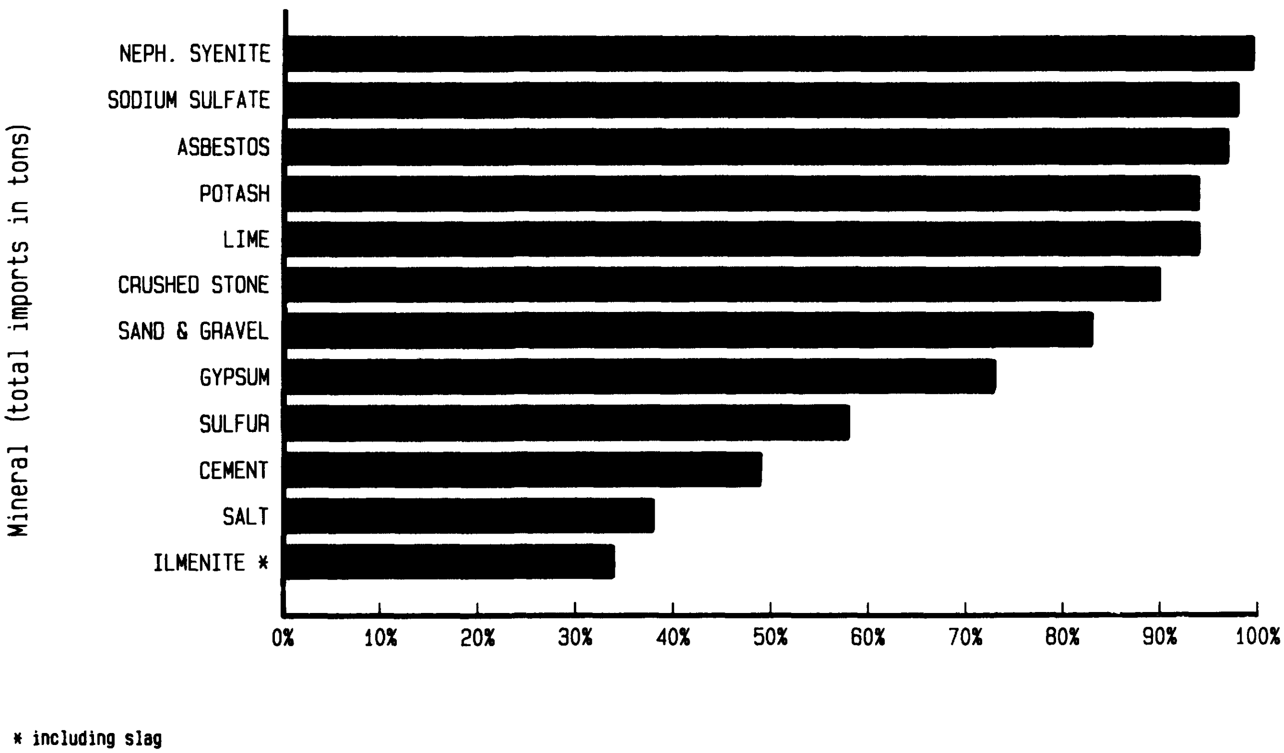


Figure 7. Percentage of US imports of industrial minerals from Canada.

major contribution to agriculture and having no available substitutes. Gypsum in the Maritime Provinces again is dominated by US interest. Major mines are economical because cheap sea freighting can land the raw material into the major East Coast US ports. It seems ironic that gypsum from Canada may be used in the Tampa area of Florida within sight of phosphogypsum dumps generated during the processing of phosphate rock to phosphoric acid. The large fluorspar mines in Mexico have also succeeded in considerably slimming the US domestic fluorspar industry which gave up competing against cheap imports.

REPUTATION AND STANDARDS

Some minerals have gained a reputation for quality or have been used as a standard, so much so they have been able to enter world trade. The best example is Wyoming bentonite which has been used to establish the standard specifications throughout the world, especially for drilling muds. The grades may be matched, with calcium-based montmorillonites treated with soda ash to match the calcium-based variety required. Nevertheless, material from Wyoming commands premium prices and is shipped thousands of miles across land and sea. One factor is that the cost of the raw materials used in drilling muds represent such a small percentage of drilling costs (a rig may cost $2,000 a day to hire), that any cost savings on bentonite could not compensate for any technical or psychological problems.

HIGH-TECH/HIGH PURITY USES

A number of industrial minerals are now being chemically treated in order to alter certain chemical and/or physical properties. Bentonite, for example, may be treated with organic chemicals to form bentones, a clay product that is compatible with oil-based drilling muds. Calcium carbonate is often coated so that it can be used more efficiently as a filler in plastics, and several companies are conducting work on surface-modified mica in polypropylene, since it has been shown that when the mica is treated with certain chemicals flexural and tensile properties are improved so that it acts more like a true reinforcement.

Gypsum of exceptionally high purity and fineness is used in the food, drink, and pharmaceutical industries as a supplemental source of calcium. Cosmetic-grade talc conforming to the Cosmetic Toiletry and Perfumery Association (CTPA) specifications obviously commands a high price which facilitates trade. Italian, Australian, and Chinese cosmetic-grade talc are sold for around $200 per ton, and this price increases as it is sterilized and further ground.

Work is progressing on expanding the applications of glass and ceramics, for example in the fields of communications (optical wave guides, solid state lasers, capacitors, etc.), energy generation and conservation, and pollution control. Although the amount of industrial minerals involved in this industry will be relatively small in tonnage terms, they will have a high value due to the high quality required. This in turn will make availability limited and necessitate trade.

Size and shape can also be important for many uses, and material that can match the requirements commands premium prices. Talc and mica, for example, may be micronized which increases the price of the product by a factor of 2 to 3. Proppant sand is another example of a mineral where size and particle shape is of paramount importance. The major requirements are for a spherical, well rounded quartz sand that is thoroughly washed, dried, and closely screened. It should not have clusters (non-agglomerated), be unfractured and free of materials such as feldspar, calcite, and clays. A minimum of 90% of the sand must be within the stated size range. The most popular size is 20/40 mesh. The main sources are in the Jordan Formation of Minnesota, Hickory Formation of central Texas, St. Peters Formation in northern Illinois, and the Galesville and Ironton Formations in Wisconsin.

SUMMARY

In summary, one major effect of this increased sophistication has been to make the field of industrial minerals more attractive to those companies used to the sometimes generous margins generated in the metals field. It has also allowed some developing countries to increase domestic manufacturing capacity and foreign currency earnings. Crude industrial minerals have long been the basis for the start-up of industry, and now the development of processing allows producers to reap the fullest benefits from their raw material endowment. Developed countries, on the other hand, are losing the business of processing the imported crude raw materials, and many are turning to the specialty, 'high-tech' materials to maximize income. In both cases, industrial mineral trade should continue to grow, and remain important to manufacturers ranging from the village potter to the NASA technocrat.

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Arkansas Novaculite: Indians, Whetstones, Plastics and Beyond*

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ABSTRACT

The Arkansas Novaculite of Devonian and Mississippian age is the most distinctive formation in the central Ouachita Mountains of Arkansas from the standpoint of both topography and lithology. The formation typically forms precipitous, narrow ridges (hogbacks) which reflect the steepness of dip and the resistance and thickness of the rock units. The Arkansas Novaculite varies from less than 200 feet thick in the north to locally over 800 feet thick in the south and outcrops over an east-west distance of 360 km (200 miles) in the Ouachita Mountains of Arkansas and Oklahoma. Most of the rocks of the formation are highly siliceous with novaculite predominating, and lesser quantities of chert, siliceous shale, conglomerate and rarely sandstone. Novaculite is commonly defined as a homogeneous mostly white rock, translucent on thin edges with a dull to waxy luster and composed almost entirely of microcrystalline quartz. The word novaculite comes from the Latin word novacula, meaning razor hone. This term was first used by Richard Kirwan in his mineralogy text of 1784.

The origin of novaculite remains controversial but we believe it was a primary silica derived mostly from the alteration of submarine volcanic-rich materials, with numerous fine biogenic components and some minor clastics (derived mostly from foreland facies via turbidity currents) and deposited as an amorphous siliceous ooze in the deep Ouachita trough. It was subsequently converted to microcrystalline quartz during diagenesis by the compaction of the overlying rocks and the intense Late Paleozoic Ouachita Mountain tectonism.

In the central and southern portions of the region three divisions of the formation have been defined: a Lower Division predominantly of light-colored novaculite; a Middle Division of interbedded dark chert and shale; and an Upper Division of massive often calcareous novaculite. In the northern exposures the formation is thinner and contains more black chert and shale, chert-shale conglomerate, sandstone and less novaculite. The massive novaculite of the Upper and Lower Divisions is a source of high purity silica (99+%).

Indians were the first to use novaculite. They made their various tools and hunting implements from the weathered broken rock until they learned the quarrying techniques. The first white men in the area recognized the use of novaculite for sharpening their tools and knives; previously whetstones were obtained in small quantities from Europe. To this day whetstone is quarried mostly in areas which the Indians and possibly the Spanish previously worked. Some of the current mining practices have changed very little from those of the early quarryman.

In areas where the novaculite of the Upper Division is poorly cemented, this friable tripolitic material has found applications in such uses as an abrasive, as a filler or extender in paints, plastics and other purposes. Some of the dense novaculite is suitable as a filler in fire bricks and also in plastics. Because some of it has the tendency to decrepitate when heated not all novaculite can be used for these applications.

Several quarry operators are crushing novaculite for road, concrete, and other aggregate. This use was formerly rather limited due to the abrasiveness of the novaculite on crushing and screening equipment. Further potential uses of novaculite are speculative but include application of high purity silica in the production of silicon metal for solar cells, seed or "growing", and fusing quartz for electronics.

*Portions of this report including most maps are taken with modifications from *Arkansas Novaculite – A Silica Resource* (Holbrook and Stone 1978).

INTRODUCTION

For many years siliceous rock in the vicinity of Hot Springs, Arkansas, has been used as whetstones. In his book on the geology and physical features of Missouri, Arkansas and surrounding areas, Schoolcraft (1819, p.183) named the rock novaculite, a term that had been in use for sometime to describe a fine quality of whetstone. In 1892, Griswold published a comprehensive report on the very fine-grained siliceous rocks of the Ouachita Mountain region in Arkansas entitled *Whetstones and the Novaculites of Arkansas.* He mapped these rocks and called them the Arkansas Novaculite, but he included what is now known as the Bigfork Chert in the unit. It was Purdue in 1909 that named the group of siliceous rocks lying between the Stanley Shale and the Missouri Mountain Shale as the Arkansas Novaculite. Other workers identified the Arkansas Novaculite in McCurtain County, Black Knob Ridge and Potato Hills in southeast Oklahoma. The Arkansas Novaculite is comprised largely of novaculite, lesser amounts of shale and conglomerate, and a few thin sandstone beds. This report is concerned particularly with those deposits of novaculite that are the source of current tripoli, whetstone and rock aggregate production and that are a potential source of these and other industrial mineral products.

DEFINITION OF NOVACULITE

When the term novaculite was first applied to the rock found in the vicinity of Hot Springs, Arkansas, it referred to a white siliceous rock whose textural characteristics and hardness made it particularly suitable for whetstones. Griswold (1892, p. 89) in fact described the fine-grained whetstone known as Arkansas Stone as a "true novaculite satisfying all the necessary conditions regarding homogeneity, grittiness, finely granular structure and siliceous composition, it is translucent on the edges and has a marked conchoidal fracture". As mapping of these remarkable rocks was extended throughout the Ouachita Mountains, the term novaculite was retained to describe them despite the fact that they showed some variation in both physical and chemical characteristics from place to place. Keller *et al.* (1977, p.843) proposed that the use of the word novaculite be restricted to a petrologic name for a thermally metamorphosed chert which shows polygonal triple-point texture.

To accommodate these variations, novaculite is here defined as a homogeneous, mostly white or light-colored rock, translucent on thin edges, with a waxy to dull luster, and almost entirely composed of microcrystalline quartz.

ORIGIN OF NOVACULITE

The subject of the origin of the novaculite in the Arkansas Novaculite has intrigued geologists ever since the rock was first identified; not only because of its unusual texture, but also because it is essentially pure silica that occurs in massive layers over a very broad area. At the time that Park and Croneis (1969) published their version of the origin, thirteen alternatives had already been proposed. They grouped those theories into three categories: direct precipitation of silica by chemical and/or organic means; replacement of non-siliceous deposits; and recrystallization and silicification of volcanic-rich material. As a result of their studies of both the Arkansas Novaculite and the Caballos Novaculite of Texas, they proposed that novaculite was formed from organically precipitated silica particles in the 1 to 10 micrometre range, and that the ultimate texture was the result of diagenetic processes. Lowe (1975) has agreed that siliceous organisms were the local source of the silica in the novaculite, but proposed further that volcanism away from the immediate sites of accumulation may have provided much of the primary silica. Most investigators, including Sholes and McBride (1975), have considered the Arkansas Novaculite as a deep-water marine deposit, whereas Folk (1973) and a few others give evidence that some, if not all of the formation represents a shallow marine (mostly peritidal) deposit. We are strongly in favor of a deep-water marine origin for the respective Arkansas Novaculite facies that outcrop in Arkansas and Oklahoma.

DESCRIPTION OF ARKANSAS NOVACULITE

The Arkansas Novaculite outcrops along the borders of the Benton-Broken Bow Uplift in Arkansas and southeastern Oklahoma and at Potato Hills and Black Knob Ridge in southeastern Oklahoma, a distance of some 320 km (200 miles) (Figure 1). The formation varies in thickness throughout its outcrop area. It attains its maximum thickness, 950

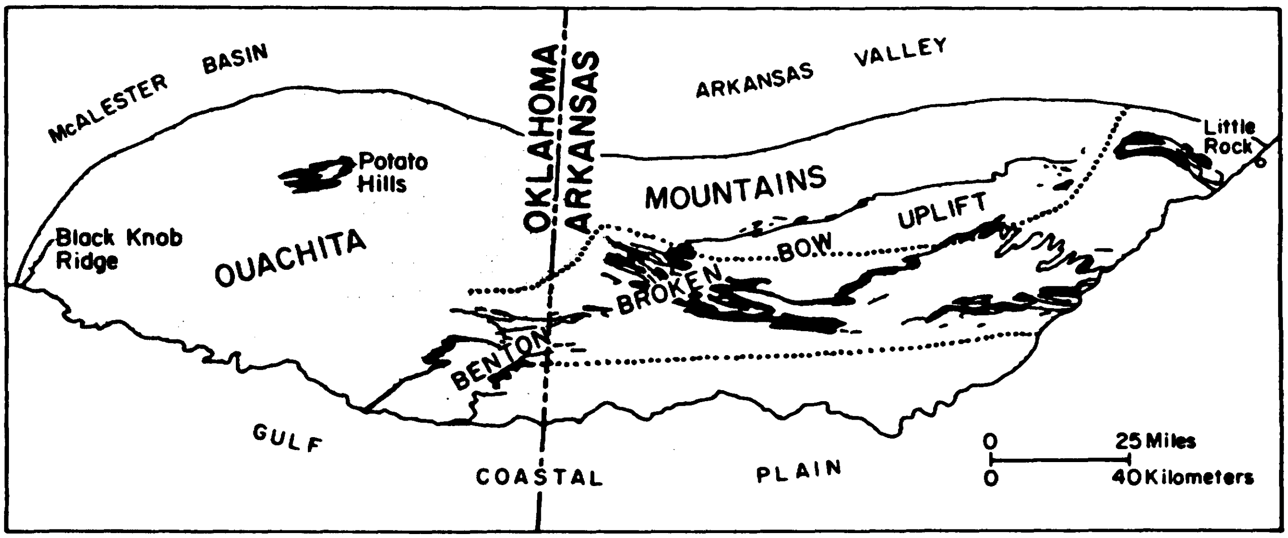

Figure 1. Map of Ouachita Mountains region showing outcrop of the Arkansas Novaculite (black lines) in Arkansas and Oklahoma. Thick, shale-free portions of the novaculite unit are within area outlined by dots.

feet, near West Hanna Mountain in Polk County, Arkansas. It thins rather gradually both eastward and westward from this point, but it thins very rapidly northward. Miser (1917) subdivided the formation into three lithologic divisions based on the exposures at Caddo Gap, Arkansas: a Lower Division of almost entirely massive white novaculite, a Middle Division of interbedded dark chert and shale, and an Upper Division of massive mostly calcareous novaculite (Figure 2).

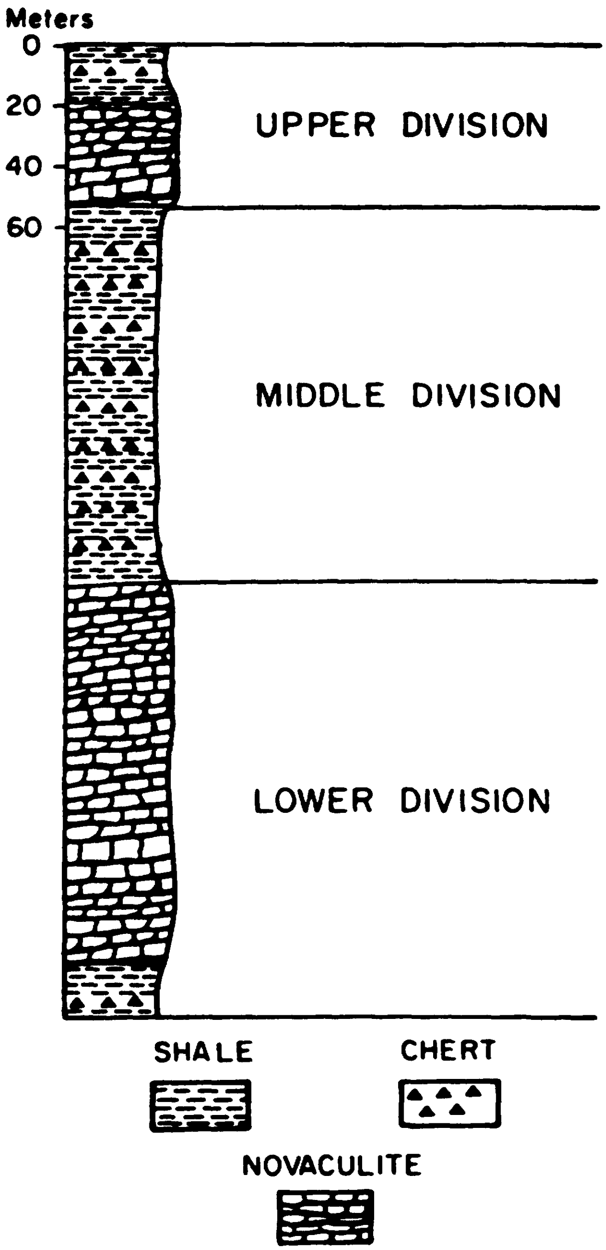

Figure 2. Diagrammatic columnar section of the Arkansas Novaculite (after Sholes and McBride 1975).

Very few fossils have been found in the Arkansas Novaculite. Findings thus far have been limited mostly to conodonts, sponge spicules, radiolarians, and spores. Hass (1951), on the basis of conodont studies at Caddo Gap, placed the Lower Division of the formation, and all except the upper 28 feet of the Middle Division in the Early or Middle Devonian. The remainder of the Middle Division and all of the Upper Division were defined as Early Mississippian in age. The contact between the Arkansas Novaculite and both the underlying Missouri Mountain Shale and the overlying Stanley Shale are conformable.

The Ouachita Mountains are a product of extensive folding and thrust faulting followed by erosion. This intense deformation resulted in the folding and fracturing of the novaculite beds as well as the variation in the attitude of these beds at different places. Along the southern belt of exposures of the formation, particularly, the massive novaculite of the Lower Division forms the steep-sided ridges of the region. The Middle Division cherts and shales underlie very narrow adjacent valleys, and the thinner bedded less resistant novaculites of the Upper Division are commonly expressed as a series of low knobs paralleling the main ridges.

The relative proportions of each constituent (novaculite, chert, and shale) of the Arkansas Novaculite vary throughout the outcrop area. The thicker shale-free sections of novaculite, which are the particular concern of this report, are restricted to the Upper and Lower Divisions along the southern and central outcrop belt, specifically that segment of the outcrop belt within the area outlined by the row of dots on Figure 1.

Lower Division

The Lower Division of the formation contains the thicker sections of novaculite that form the most prominent ridges and outcrops. This division in the southern outcrop belt is composed of massive novaculite in beds 4 to 30 feet thick with the thicker beds being near the top. The novaculite is white, grey, or light brown, with black and reddish-brown beds in a few places. Near the base of the division the massive novaculite is often slightly calcareous, and it is the leaching of the calcite rhombohedra that developed the Washita variety of whetstone texture found in some of the novaculite near Hot Springs. Laminations are present throughout the Lower Division novaculite but they are particularly prominent near the base. Jointing is common, the most prevalent set being normal to the bedding and the joints are frequently filled with quartz. A few very widely spaced thin shale beds are present, and in places thin quartzitic sandstone beds occur near the base of the Lower Division. A submarine slurried conglomeratic interval is often present at the top of the Lower Division.

Upper Division

The Upper Division of the formation is generally thinner than the Lower Division, attaining a maximum thickness of

120 feet at Hot Springs and thinning abruptly to the north and gradually to the south and west. This division is either absent or more likely represented by a more shaly and conglomerate facies in the northern outcrop belt except near Little Rock. Beds are even to irregular and up to 4 feet thick. It consists chiefly of massive novaculite that when fresh is light grey to bluish black and generally resembles the novaculite of the Lower Division. In much of the area, however, the Upper Division novaculite is calcareous, and it has weathered to a light-brown or buff-colored punky rock with a gritty texture giving it the appearance of a porous siltstone. Weathered novaculite varies from a firm, slightly porous rock to tripoli depending on the percentage of carbonate present in the original rock. The carbonate in the fresh novaculite, which can constitute up to 30% of the rock, may be rhodochrosite, calcite, manganiferous calcite, or ankerite. In fact, it is the manganese-bearing carbonates that are a prominent source of the manganese ores and associated minerals found in both the Upper and Lower Divisions of the Arkansas Novaculite in the southern outcrop belt.

NOVACULITE QUARRYING BY THE INDIANS

The first use of novaculite was by the various Indian tribes that quarried it in large quantities for making tools and weapons. The many thousands of tons of novaculite that were mined by the Indians came mostly from the southern Ouachita Mountains, but notably near Hot Springs, Arkansas, an area considered a neutral zone by the tribes because of its renowned healing waters. Much of the denser and harder novaculite was ideal for making tools because it typically broke into very sharp angular flakes. Mining techniques used by the Indians included: (1) the building of a fire adjacent to a suitable ledge or crevice and the ensuing heating of the rock would create flaking when doused with cold water, and (2) the hammering, prying and breaking of the rock with more resilient stones and other materials. This rough rock was then "blanked" at the site and then removed to their various encampments for further processing. Novaculite was a valuable trade item for the Indians who bartered it throughout the Mississippi Valley region.

TRIPOLI

The term tripoli is used in this report in the geologic sense rather than as a trade term, and it refers to a microcrystalline, finely particulate, more or less friable form of silica. In the Ouachita Mountain region of Arkansas and Oklahoma, the tripoli deposits have been formed by the leaching of calcium carbonate from the Upper Division of the Arkansas Novaculite. Tripoli deposits and prospects occur in four general areas of novaculite outcrop (Figure 3). East and northeast of Hot Springs, tripoli float and outcrops occur on the flanks of the novaculite ridges in T.2S., R.18-19W., Garland County, Arkansas, and the only currently active tripoli mines (Malvern Minerals Company) are located in this area. Another Malvern Minerals Company prospect is located to the west in Sec. 24, T.3S., R.23 W., near Sunshine in southeastern Montgomery County. Further west at Blocker Creek are two quarries recently operated by Robert B. McElwaine for buffing compounds in Sec. 1, T.5S., R.27W., Pike County, Arkansas, that mark the eastern end of a tripoli trend that continues practically uninterrupted for 7½ miles to the west. In this same general area just west of the Blocker Creek deposits is a mile-long trend from which a small tonnage of tripoli was produced at a quarry by McElwaine near Shady Lake in the NE¼ SW¼ Sec. 26, T.4S., R.29W., Polk County, Arkansas.

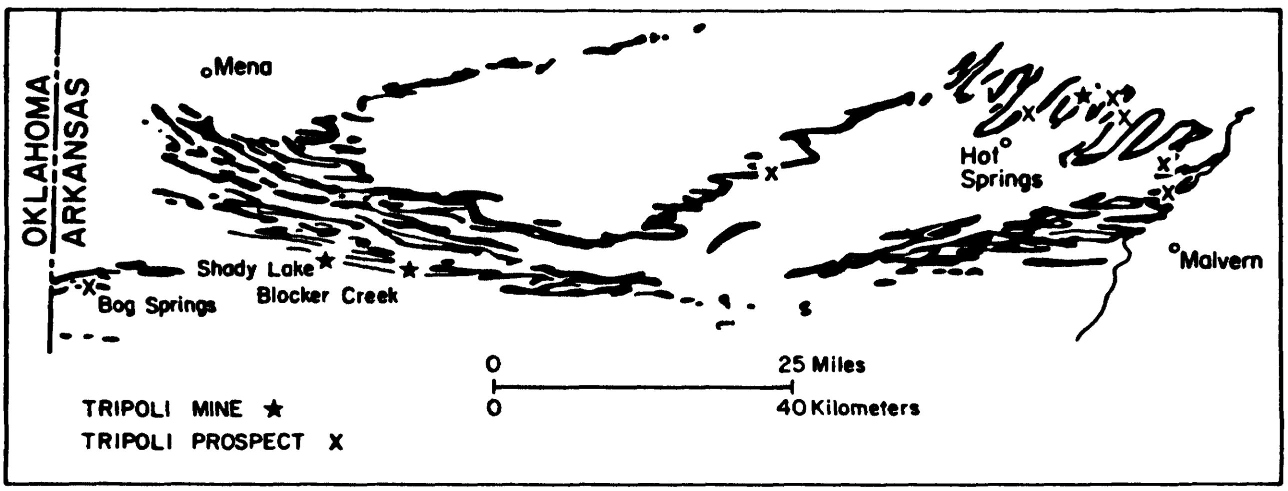

Figure 3. Outcrop map of novaculite (black lines) showing tripoli mines and prospects.

The fourth area is near Bog Springs, Arkansas in the NW¼ NW¼ Sec. 16, T.5S., R.32W., Polk County, near the Arkansas-Oklahoma border. This locality is the beginning of a tripoli occurrence that extends westward a distance of 5 miles into Oklahoma. Also in Oklahoma, tripoli float has been found along the outcrop of the Upper Division of the Arkansas Novaculite in Secs. 19, 20, and 21, T.2S., R.25E., just north of the Broken Bow Reservoir and east of the reservoir in Secs. 4, 5, 6, and 7, T.4S., R.27E.

Exploration and Mining

The tripoli beds are confined to a specific stratigraphic horizon, the Upper Division of the Arkansas Novaculite, that frequently has a characteristic topographic expression, a series of low knobs or ridges that parallel the higher main novaculite ridges. Exposures in stream beds and punky, vuggy, usually tan to red, float blocks are relatively common, and all these factors combine to simplify exploration. The procedure generally used is to bulldoze off the shallow soil and vegetation cover to determine the width and quality of the material, and, if justified, drill to ascertain the depth of the deposit. Open-pit mining methods are used. Both overburden and tripoli must be drilled and blasted, and scrapers and front-end loaders (track hoes) are used to remove the overburden and mine the tripoli.

Character of the Tripoli

The tripoli deposits range from inches to over 100 feet in true thickness. There is a wide range of hardness in the individual beds that constitute the tripolitic zone reflecting the variation in carbonate content of the unweathered novaculite. The beds vary from material that can be crumbled by hand to hard unweathered non-calcareous novaculite layers. The tripoli consists of cryptocrystalline quartz grains or aggregates of grains more or less firmly bonded together.

The range of particle size of individual quartz grains is from 1 to 10 micrometres, and the quartz particles are essentially equidimensional. The color of the tripoli varies considerably even within the same deposit and includes white, cream, tan and brown, with white being the least prevalent and most desired. Discolorations in the tripoli mostly represent minor quantities of iron and manganese oxides formed during surficial weathering.

Malvern Minerals Company Tripoli Deposits

At this time Malvern Minerals Company is the only active producer of tripoli in Arkansas. They have one active mine and two active prospects. The active mine, located in the

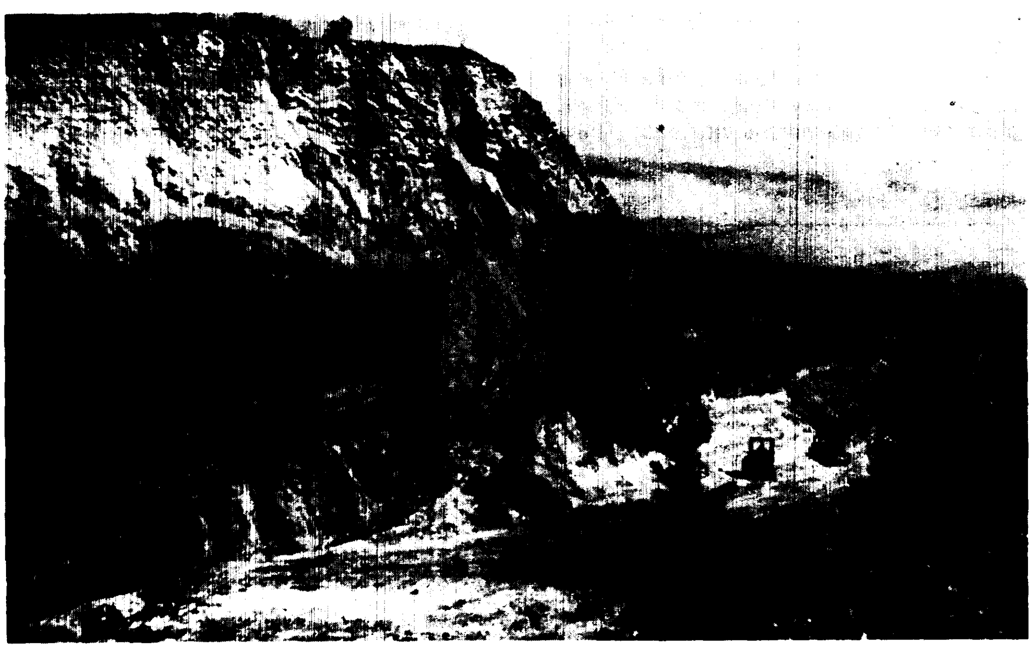

Figure 4. *Malvern Minerals Company novacite (tripoli) mine in Garland County, Arkansas. The Arkansas Novaculite is inverted with the white tripolitic novaculite of the Upper Division at the base, the dense novaculite of the Lower Division at the top, and the black carbonaceous shale of the Middle Division occurring between them. Photograph by John David McFarland, III, Arkansas Geological Commission.*

NE¼ NW¼ Sec. 21, T.2S., R.18W., Garland County, has been in operation since 1947. The deposit is situated on the flanks of an overturned fold so that the tripoli (Upper Division) is overlain by shale of the Middle Division and massive novaculite of the Lower Division of the Arkansas Novaculite (Figure 4). The tripoli bed is 40-50 feet thick, dipping from 32 to 45 degrees to the northwest. The hard novaculite overburden of the Lower Division is drilled, shot and loaded by track hoes onto dump trucks. The shaly Middle Novaculite member is stockpiled for future use. In most cases the tripoli can be dug with track hoes and does not need to be drilled or shot. All of the mining and trucking to the plant is done by contract. At the plant beneficiation consists of drying, grinding, and classification, both by air and screen.

The latest and most active prospect, referred to as "South Mine", is located in the SE¼ NE¼ Sec. 34, T.2S., R.18W., Garland County. The second prospect is referred to as "Sunshine Mine" and is located in the NW¼ SE¼ Sec. 24, T.3S., R.23W., Montgomery County. Interestingly the formations at the operating mine and the two prospects are overturned to the south.

The particle sizes range from about 1 to 7 micrometres according to Keith and Tuttle (1952). Seventy-five percent by volume of the tripoli produced by Malvern Minerals Company is used as a filler or extender. The remaining 25% is used in specialized abrasive applications. Bush and Stroud (1980) indicated there were about 15,500 short tons of tripoli produced in 1979, with an estimated value of over $600,000. Production in 1982 was approximately 14,000 short tons and no estimated value is available.

WHETSTONES

History

The word novaculite comes from the Latin word novacula, meaning razor hone. The anglicized word is attributed to Richard Kirwan who used it in his mineralogy text of 1784 (Griswold 1892, p.2,7).

The first authentic mention of whetstones in America concerns those of Arkansas. Discussion is contained in a letter written by Mr. Bringier of Louisiana in 1818 (Griswold 1892, p.19) about a quarry of honestone which had been worked for several years, a few miles about the "Cove of Wachitta" which is now Magnet Cove.

Another early account was given by Schoolcraft (1819) in which he stated, "a quarry of this mineral (novaculite), three miles above the Hot Springs of Washita, has often been noticed by travelers for its extent and excellency of its quality.... It appears to me, from external character, to contain less alumine and more silex than the common novaculite, and, hence, perhaps, its superiority."

From 1891 to 1918 when Norton-Pike Company bought several hundred acres of land in the Ouachita Mountains near Hot Springs, there were numerous quarries operated for several grades of whetstones. Most of the processing of the novaculite quarried to whetstone was done elsewhere in various out-of-state plants, mainly in Worcester, Massachusetts, and Littleton, New Hampshire.

In 1962 Hiram A. Smith constructed a whetstone processing plant near Hot Springs, and at least one facility has been located in the area since then. The Smith's Whetstone Company is currently the largest producer of novaculite whetstones in the United States. There are some eight additional firms that produce and process whetstones in the Hot Springs area; these include: Pioneer, Arkansas, Wallis, Frontier, Halls, Dan's, Poor Boy, and Rigid. The Norton Company presently transports much of their raw stone to a New Hampshire plant for processing, but they also sell uncut whetstone to local processers. There are significant quantities of whetstone quarried in the area by individuals who process and sell some, but sell most of their product to local processing firms.

Location of Deposits

The main area of active whetstone mining is located just northeast of Hot Springs (Figure 5). Most of the mining and

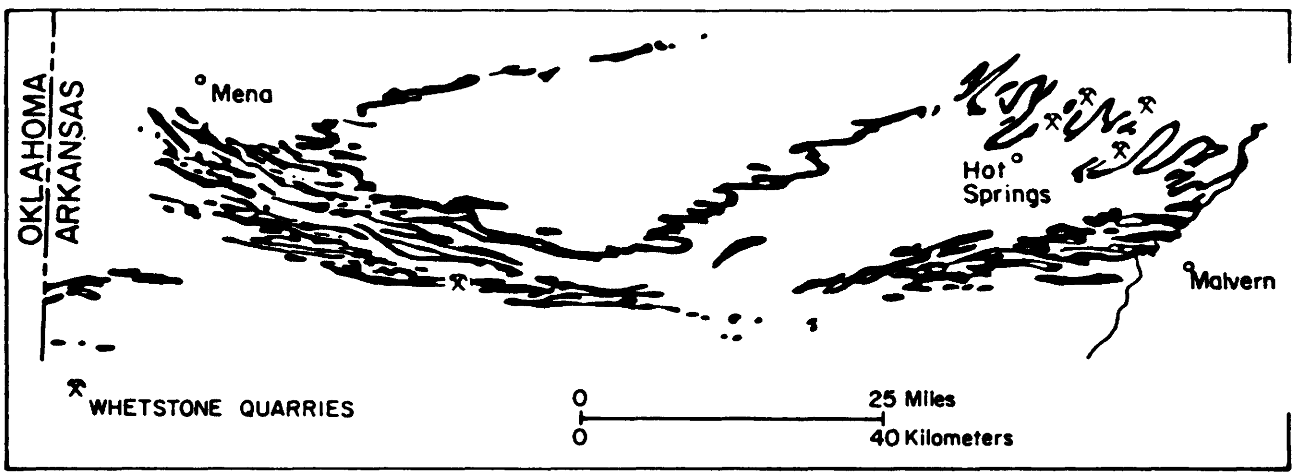

***Figure 5.** Outcrop map of novaculite (black lines) showing whetstone quarries.*

exploration has been confined to two areas: (1) T.2S., R.18W., and (2) T.2S., R.19W., Garland County. Recently a small tonnage has been produced from deposits in Pike and Montgomery Counties. Nearly all of the commercial whetstone rock deposits are confined to massive novaculite in the lower part of the Lower Division of the Arkansas Novaculite.

Exploration and Mining

The area where whetstone rock is mined is one of steep, densely-wooded hills. Good outcrops are scarce, because the hillslopes where the whetstone rock layers occur are usually covered with novaculite debris. Furthermore, these whetstone layers are somewhat less resistant to erosion than the adjacent novaculite. From experience the miners know the approximate elevation on a particular hillside where the whetstone rock layers are likely to occur. They first clear the selected site with a bulldozer, and, if the rock looks promising, the exposure is drilled and shot. Quarrying follows if the quality of the rock persists. Quarrying consists simply of hand drilling and blasting using black powder, because of its low velocity. A follow-the-ore concept is used in quarrying the whetstone rock, following along the strike and dip of the bed until the quality of the rock deteriorates, or quarrying becomes too expensive.

The quality of a particular whetstone rock layer (lead) may vary both along the strike and the dip of that layer. Individual leads are narrow, varying from 6 to 35 feet, but they may persist up to 900 feet along strike. After the rock is partially broken it is then carefully quarried usually by hand tools but track hoes and other equipment may be employed. Blocks are then trimmed to a roughly equidimensional shape weighing 10 to 20 pounds in most varieties. They are then hand sorted for further quality evaluation before shipment to the plant for processing. Quartz veins, cavities, cracks or fractures, laminations, stylolites, and lack of uniform texture are all a basis for rejection.

Characteristics of the Whetstone Rock

Whetstone-grade novaculite or whetstone rock, as it is called here, is found in the lower part of the Lower Division of the Arkansas Novaculite. These particular layers of novaculite are especially suited for whetstones because of their porosity, uniformity of texture, and the sharp edges of the minute quartz grains making up the rock. The porosity is due to rhombic cavities from which carbonate has been leached during weathering. Uniformity of texture implies not only uniformity in the size of the individual grains but more especilly a uniform distribution of the cavities throughout the rock. Individual quartz grains present sharp edges because the grains are not rounded but rather are closely packed in a mosaic texture, the individual grains exhibiting polygonal shapes in cross section (Figure 6).

In the sharpening process small microquartz particles bounding the pore spaces break off preventing the pores

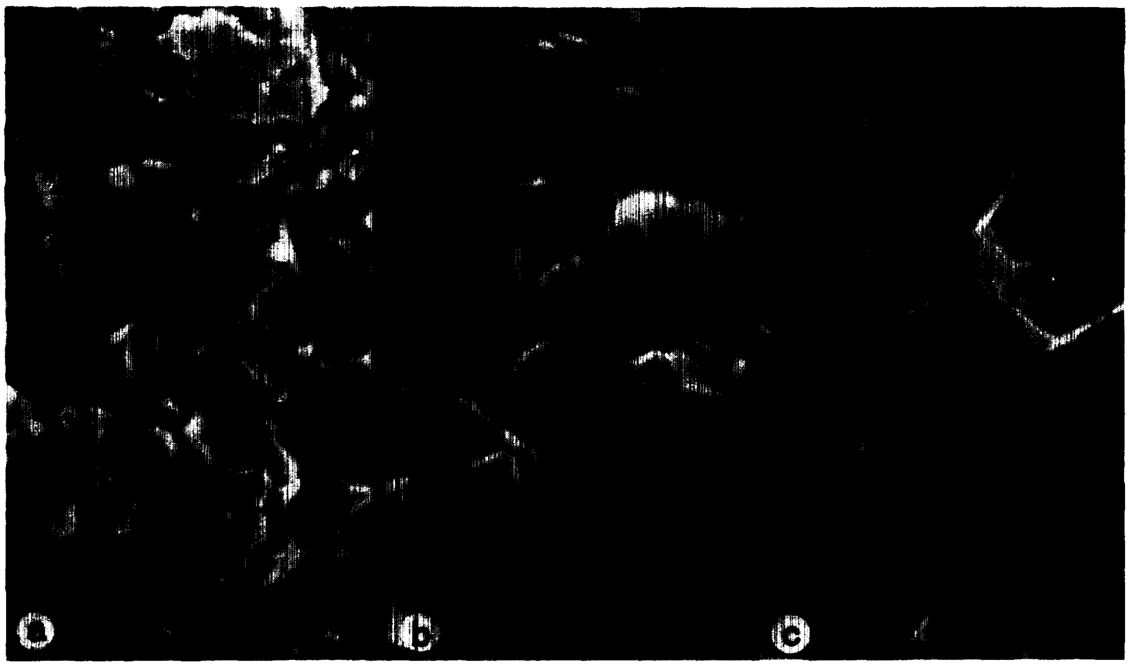

Figure 6. *Variations in the textural types formed by progressive regional metamorphism of the novaculite in the Ouachita Mountains: (a) cryptocrystalline, (b) fine polygonal grains, and (c) medium polygonal grains. The sharp edges of the quartz grains of (b) and (c) afford many of the excellent qualities ascribed to the various Arkansas whetstones. Photomicrograph adapted by John David McFarland, III, Arkansas Geological Commission for Walter D. Keller, University of Missouri-Columbia.*

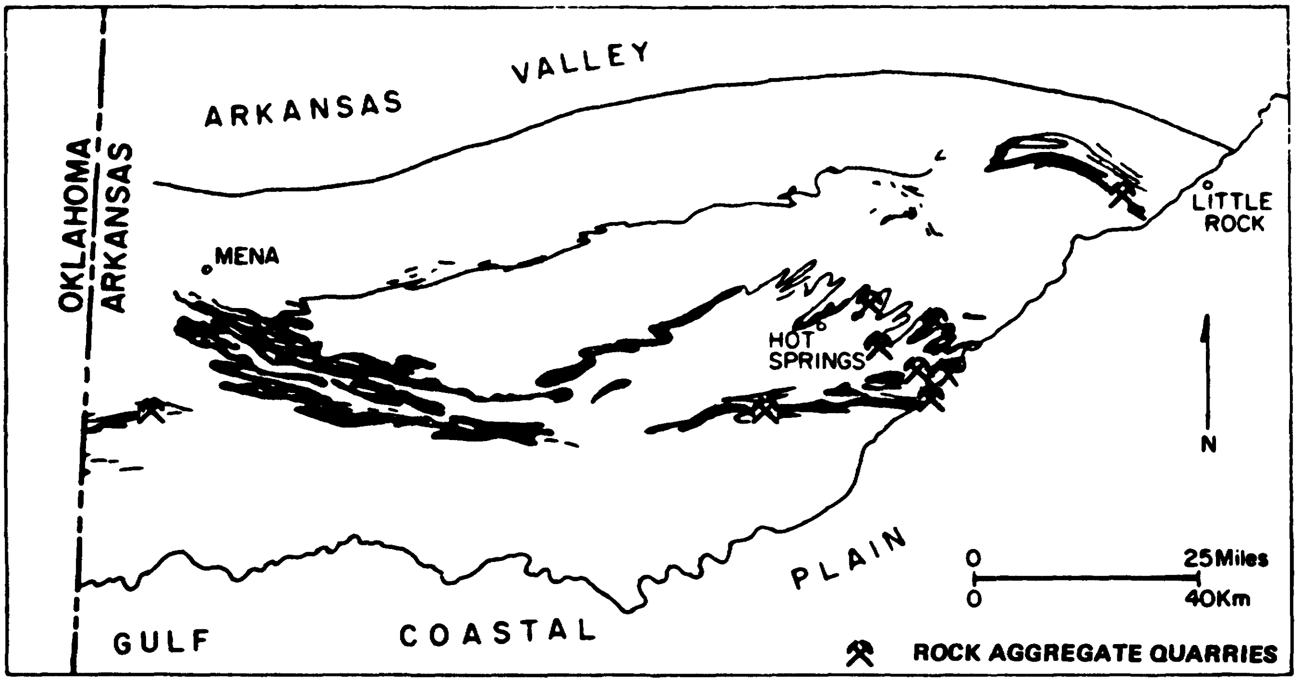

Figure 7. Outcrop map of novaculite (black lines) showing rock aggregate quarries.

from being filled with steel particles which would cause the stone to glaze over. Several varieties of whetstones are manufactured under different trade names, and the essential difference between them is a difference in porosity. Thus, the hard Arkansas Stone has a porosity of 0.07%, while the more rapid-sharpening Washita Stone has a porosity of 16%. The increased porosity in the Washita Stone is due not only to a greater frequency of rhombic cavities but also to an increase in the size of the individual cavities. This variation in porosity is reflected in a difference in luster in the two stones. Thus, the denser hard Arkansas Stone is characterized by a waxy luster while the more porous Washita Stone has the "dead" appearance of unglazed porcelain.

Whetstone Processing

Quarry blocks are sawed into desired shapes with a diamond saw using cutting oil or solvent as a lubricant. These shapes are then finished on a lap with carborundum powder, given a final visual quality-control check, then packaged and shipped. Only about 5% of the blocks quarried end up as finished whetstones.

The five types of stones produced for market are listed in order of decreasing porosity:

Trade Names	Use
Washita Stone	for rapid sharpening
Soft Arkansas	for general all around sharpening
Hard Arkansas	for polishing a blade to a very fine edge
Translucent	for polishing to the finest possible edge
Black Hard	ditto, and miscellaneous

ROCK AGGREGATE

Stone for rock aggregate is widespread in the Ouachita Mountains. Novaculite has generally been bypassed for aggregate uses in past years mostly because of its abrasiveness in various crushing processes. Recently it has been quarried in significant quantities in Arkansas as a result of an increased demand for rock aggregate and the development of more effective crushing techniques (Figure 7).

Novaculite has been mined and crushed for concrete aggregate, road construction, railroad ballast, high-silica refractories and other uses. Production of novaculite used for construction and other miscellaneous purposes has not been segregated from Arkansas' total output of stone except for the period 1941-1949 when 760,000 short tons valued at about $420,000 were produced. In recent years, as much as 1 million short tons have been quarried annually at a value from about $3 to over $5 per ton.

Five quarries are currently operated for commercial rock aggregate mostly in the massive, dense novaculite of the Lower Division of the Arkansas Novaculite. These quarry operations include: The Walker Stone Company in Sec. 6, T.5S., R.31 W., at Hatton in Polk County; the Mid-State Construction and Materials Company in Sec. 21, T.4S., R.20W., north of Bismarck in Hot Spring County; in Sec. 9, T.4S., R.17W., north of Malvern in Hot Spring County; and in Sec. 14, T.3S., R.18W., near Lake Catherine in Garland County; and the West Construction Company in Sec. 9, T.3S., R.16W., near Glen Rose in southwestern Saline County. In recent years novaculite has also been mined for rock aggregate in Sec. 34, T.3S., R.17W., at Butterfield; in Sec. 8, T.3S., R.16W., in Hot Spring County; in Sec. 36, T.2S., R.17W., in Saline County; in Sec. 26, T.2S., R.18W., in Garland County; and in Sec. 19, T.1N., R.13W., near Little Rock in Pulaski County.

Exploration and Mining

Most of the novaculite rock aggregates occur in the massive, dense, cryptocrystalline, highly fractured and often steeply tilted beds of the Lower Division of the Arkansas Novaculite which characteristically forms the tall jagged peaks or hogbacks in the southern and central portions of the region. Massive novaculites are initially examined and tested at the surface in areas adjacent to transportation and/or industrial facilities. Upon the establishment of a quarry site there is close attention directed initially towards drilling and blasting procedures to ensure the desired breakage of the rock. Typically the rock has a primary crush to about a 6-inch size and a secondary crush to various smaller screened sizes that include some by-products. It is then stockpiled in storage bins and transferred to loading facilities. Typically conveyors connect the crushing and screening systems. It is reported that most crushed novaculite meets the various specifications set for highway aggregates, including asphalt, concrete and road sub-base. The high anti-skid characteristics of some novaculite adds considerable potential for partial application to other highway aggregates. Additional uses of novaculite are as railroad ballast, rock aggregate fill in dams, dikes and many other constructional purposes.

Reserves and Outlook

Reserves of massive novaculite represent many billions of tons; however, novaculite located near railroads and other transportation facilities is less abundant. It is likely that exploitation of novaculite for rock aggregates will continue to expand in or near the areas presently established and that except for local needs the cost of transportation will be prohibitive for many other locations.

OTHER USES

The Ouachita Sand and Gravel Company obtains a dense translucent novaculite from their quarry in Sec. 6, T.3S., R.16W., north of Magnet Cove in Hot Spring County for a number of purposes. First a highly selected rock is used for whetstones, next large "rough" blocks are shipped to various dealers for unknown purposes, the remaining material is then crushed to 3/4 – 2¼ inches and sold mostly for use as a filler in fire brick. This rock is further crushed and screened by the brick manufacturers for application in various products. Not all novaculite in the region is ideal for fire brick uses since some of it decrepitates at high temperatures. The Ouachita Sand and Gravel Company also sells some crushed novaculite to the Buffalo Stone Corporation in Hot Springs who further process it in sizes from 1/16 to 2 inches for use as a polishing and grinding media.

The Malvern Minerals Company is currently mining, processing, and marketing quantities of a variety of black siliceous shale as Ebony Novacite® from the Middle Division of the Arkansas Novaculite from their tripoli mine in the NE¼ NW¼ Sec. 21, T.2S., R.18W., in Garland County. This material is used in industry as a black silica pigment in various resinous mediums. Studies are being further conducted on its potential use as a black pigment or an extender since it offers superior rheological features as compared to many other black pigments that often have higher surface areas and sorption properties. The typical chemical composition of Ebony Novacite® shown in Table 1 is published by permission of the Malvern Minerals Company.

An increased demand for novaculite in refractory and in polishing and grinding uses is likely. Since some of this rock is rather unique in occurrence, more selective mining and processing is required. An expanded use of Ebony Novacite® as a pigment and filler in various products is anticipated by the company.

TABLE 1. TYPICAL CHEMICAL COMPOSITION OF EBONY NOVACITE®

	550 Mesh	20 Micron	10 Micron
SiO_2	63.15%	58.00%	60.40%
C	3.24%	3.09%	3.37%
S	0.13%	0.08%	0.07%
Al_2O_3	19.16%	21.06%	22.40%
Fe_2O_3	2.29%	2.29%	2.15%
TiO_2	1.80%	1.40%	1.70%
CaO	0.25%	6.88%	2.00%
MgO	0.15%	0.45%	0.38%
Loss on Ignition	10.25%	8.75%	9.75%

FUTURE CONSIDERATIONS

Crushed dense novaculite has numerous other potential applications: namely, for any purpose requiring an essentially pure silica rock with only minor undesirable chemical impurities, and high physical properties.

In recent years some investigations have taken place concerning the application of crushed novaculite for interlayered sequences with plastics. It reportedly would provide a binding and add other physical qualities to the material upon application with rather intense heat. From our brief tests it has been determined that decrepitation takes place in some of the coarsely crushed novaculite but rarely in the finer mesh sizes. Studies have also revealed that some of the novaculite, especially recrystallized types, does not appreciably decrepitate or spall during the application of heat for processing. In an open report in August, 1980, Robert B. McElwaine stated that testing done on the Blocker Creek tripoli indicates that it meets the qualifications for uses as semi-lightweight aggregate in concrete blocks, as a non-polishing skid-resistant aggregate in asphalt highways, and others.

Chemical analyses of quarry and outcrop samples (Figure 8) reveal that novaculite has a vast potential as a high-silica rock resource (Table 2). The electronics applications are developing and the scope is tremendous.

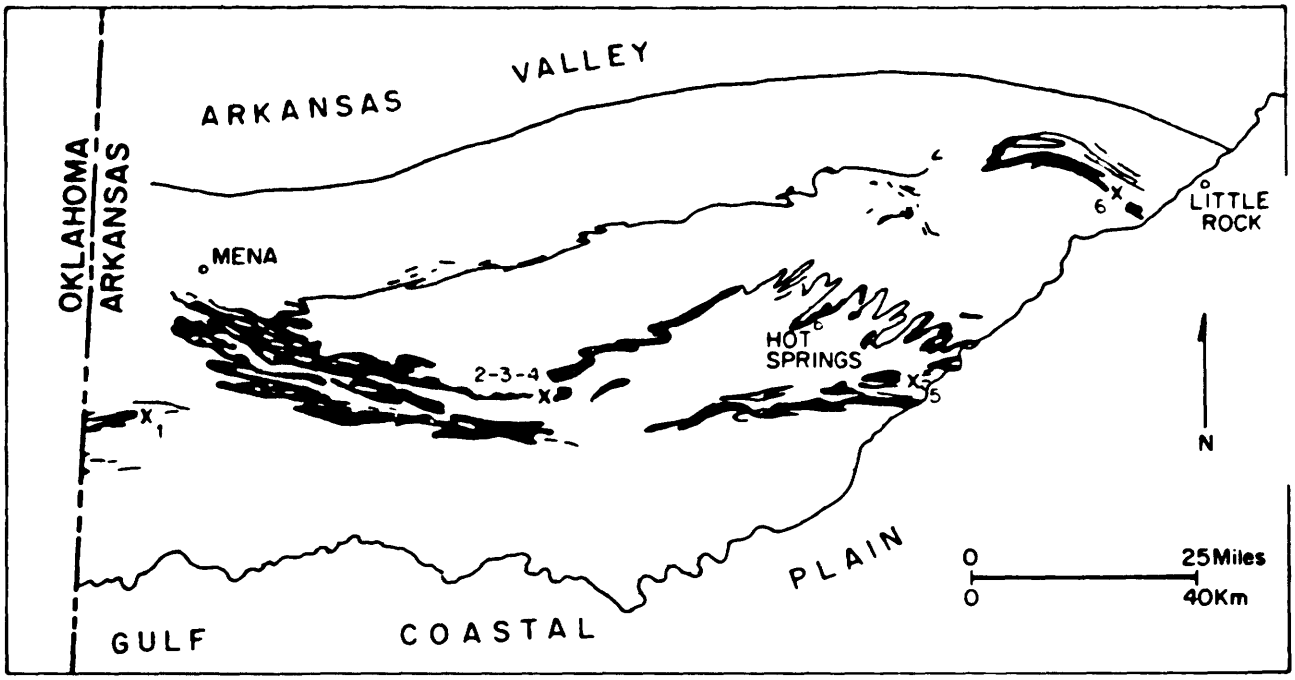

Figure 8. Map of eastern part of Ouachita Mountains showing outcrop of Arkansas Novaculite (black lines) and location of novaculite samples listed in Table 2.

TABLE 2. CHEMICAL ANALYSIS (IN PERCENT) OF ARKANSAS NOVACULITE SAMPLES AND ADDITIONAL DATA ON SAMPLES (SEE FIGURE 8 FOR LOCATION MAP)

Sample Number	SiO_2	Al_2O_3	MnO	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI
1	99.03	0.42	0.01	0.07	0.02	0.03	0.03	0.004	0.10	0.29
2	99.18	0.26	0.07	0.09	0.02	0.03	0.02	0.003	0.03	0.30
3	99.07	0.25	0.01	0.29	0.02	0.03	0.02	0.003	0.05	0.26
4	99.19	0.19	0.03	0.19	0.01	0.03	0.02	0.003	0.05	0.29
5	99.19	0.25	0.01	0.14	0.02	0.02	0.02	0.003	0.05	0.30
6	99.16	0.27	0.04	0.16	0.02	0.03	0.03	0.002	0.01	0.28

Sample Number	True Thickness (Feet)	Division of Arkansas Novaculite	Location
1	130	Lower	Abandoned quarry, NW¼NW¼ Sec. 6, T.5 S., R.3l W., Polk Co.
2	100	Bottom of Lower	Caddo Gap outcrop, SW¼SE¼ Sec.18, T.4 S., R.24 W., Montgomery Co.
3	249	Remainder of Lower	Caddo Gap outcrop, SW¼SE¼ Sec.18, T.4 S., R.24 W., Montgomery Co.
4	105	Upper	Caddo Gap outcrop, NW¼NE¼ Sec.19, T.4 S., R.24 W., Montgomery Co.
5	210	Lower	Butterfield quarry, SW¼NE¼ Sec.34, T.3 S., R.17 W., Hot Spring Co.
6	60	Lower	Lawson Rd. outcrop, NE¼SE¼ Sec.19, T.1N., R.13 W., Pulaski Co.

Surface modification of high-purity silica is now a reality and there are many potential uses. High-purity silica has application for making silicon metal and possibly in the growing of quartz crystals from seed. Billions of tons of dense novaculite have yet to be tapped by the rock aggregate industry. An expanded demand for microcrystalline quartz is anticipated in the next decade and the Arkansas Novaculite of Arkansas and Oklahoma should make important contributions to these expected needs.

ACKNOWLEDGMENTS

We would like to express our deepest gratitude for the kind assistance provided by the personnel of the various companies and other individuals involved in the mining and processing of Arkansas Novaculite. A special thanks is extended to Hewitt Harlow and Jim Moreland of Malvern Minerals Company; Robert B. McElwaine, a consulting geologist; Bryan Willis of Smith's Whetstone Company; Marc Dilatush of Arkansas Whetstone Company; Charles Pate of Pioneer Whetstone Company; Owen Spickard of Norton Company; Clovis Wallis of Wallis Whetstone Company and Ouachita Sand and Gravel Company; Marvin Woodson of Ben M. Hogan Company; Charles Gibbs of Mid-State Construction and Materials Company; David S. Walker of Walker Stone Company; Dick Hedrick of the Hedrick Corporation; Buddy Blood of Arkansas Explosives Company; Ira West of West Construction Company; and Oliver Duty of Little Rock, Arkansas.

APPENDIX — COMMERCIAL USES OF BLACK HARD ARKANSAS STONE

Prepared by Marc H. Dilatush, Arkansas Whetstone Company Inc.

As with other types of Arkansas Whetstones, the primary uses of Black Hard Arkansas are for sharpening knives and honing metal surfaces. However, Black Hard Arkansas is unique because it has a very uniform density and honing quality. The specific gravity of 2.66 makes it the most dense of Arkansas Whetstones and the extremely fine recrystallized structure allows it to hone to an extremely smooth finish on metals. Because of these qualities it is suited for some applications better than any other material.

One of the interesting uses found in recent years is for polishing electronic microcircuit dice pedestals. The microcircuits are manufactured by duplicating a particular circuit thousands of times in one large sheet. The individual circuits are then cut from the large sheet and are called "dice". Although the method varies somewhat, the dice must be connected to other circuits or pin connections before encapsulation. Some methods require that the dice be placed on a small pedestal for manual connection under a microscope with ultrasonic welding devices. In order to minimize damage to the dice, the pedestal must be extremely smooth with no burrs. A small Black Hard Arkansas stone is excellent for removing burrs and polishing the pedestal without leaving grit or mineral deposits.

Another interesting application which has been used for many years is for testing the purity of gold. A particular variety of Hard Black Arkansas which is solid black with no discolorations or other non-uniformities is used to remove a very small amount of gold for testing. The gold is scratched on the stone and then acids are applied to the scratch and the reaction is observed to determine the purity. The stone is sold in a kit, with the proper acids and instructions.

Many stones are cut in special shapes for wood carving tools, gunsmiths, watch and clock repair and manufacture, as well as reciprocating and jet engine repair, and tool and die work. Any application which requires a highly polished lightly honed metal surface can use a Hard Black Arkansas stone.

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Mining the Silica Sands of West Tennessee

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ABSTRACT

Unconsolidated sand deposits of Late Cretaceous age in West Tennessee have been exploited for natural bonded foundry sands since the 1930s. Development of these deposits for glass sands and other washed silica products began later in the early 1950s. Since then, demand has increased and quality has improved to meet the changing needs of the customer. Subsequently, improvements were made in the mining and processing to accommodate these changes.

Excavation takes place in the McNairy Sand which is part of the Gulf Coastal Plain – Upper Mississippi Embayment. The deposit is the result of several different geologic processes, which have caused erratic changes in distribution of grain size, clay lenses, detrital fines, heavy minerals, and iron content. These variations are controlled by selective mining, beneficiation, subsurface geologic investigations, and constant sample testing. This paper discusses these variations and the controlling factors which enable the producer to mine a quality silica product.

INTRODUCTION

In producing silica sands, as in other raw materials mined, certain specifications must be met to achieve a saleable product. The rigid specifications which are imposed on silica sands, namely glass sands, have changed throughout the years, and subsequently mining and processing procedures also have changed.

In the 1930s the Late Cretaceous age McNairy Sand was mined near Camden, Tennessee (Figure 1) for natural bonded foundry sands processed to market specifications. For this product, clay and/or silt is left in the material to help create a bond. Certain percentages of the clay, along with the desired grain size, were obtained by mining from two or three different pits throughout the area. The final product is mixed at the plant and dried to a certain moisture content. The geology of the area plays an important role in mining natural bonded sand.

In the early 1950s, a plant was built to process high purity silica products to compete in the glass sand and other silica sand markets. In doing this, it was necessary to mine different sites as well as to use new processing equipment to produce this type sand.

Today, the complexity of producing a high purity silica sand is controlled by many factors. Although the geology of the deposit is a significant factor, it cannot be changed, while customer specifications, markets, and transportation, among other factors, change all too often.

GENERAL SPECIFICATIONS

In order to understand the mining and processing of silica sands, particularly glass sands, product specifications

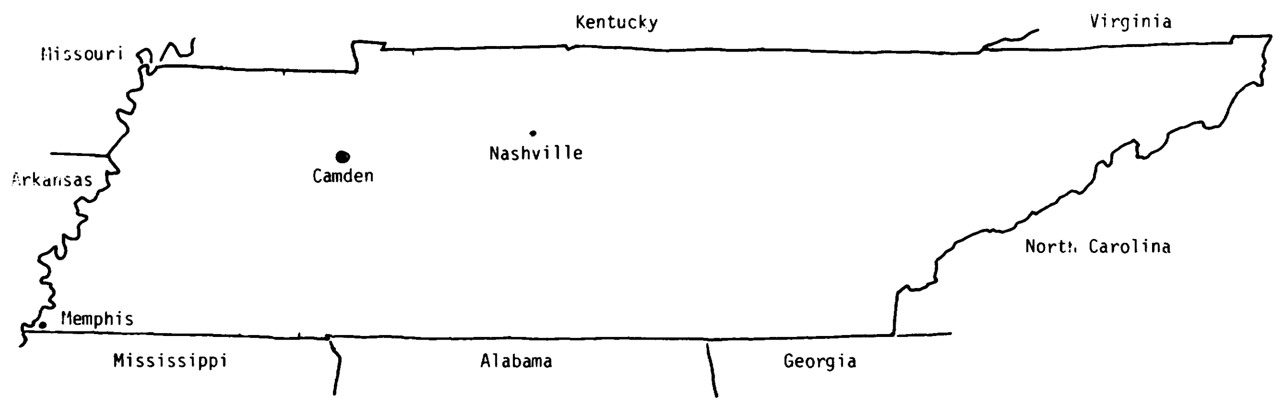

Figure 1. *Location of Camden, Tennessee.*

must be known. The following are physical and chemical restrictions placed on high purity silica sand used in glass manufacturing. These are guidelines and vary from company to company depending upon their products.

Grain Size

Grain size for melting sands start at the 30 mesh sieve where less than 1% should be retained. The 40 mesh sieve is usually held to 8 to 10% retained while the -140 mesh is held to less than 5%. A typical analysis of the McNairy Sand is shown on Table 1.

TABLE 1. TYPICAL SCREEN ANALYSIS (BY TENNESSEE SILICA LABORATORY)

U.S. Standard Sieve	% Retained
30	0.2
40	7.0
50	20.0
70	36.6
100	29.8
140	5.0
−140	1.0

Chemical Composition

The SiO_2 content must exceed 99.5%, the Al_2O_3 should be less than 0.30% and the Fe_2O_3 should not exceed 0.030% by weight. Other limitations are placed on TiO_2, Cr_2O_3, CaO, MgO, ZrO_2, Na_2O and K_2O. A typical chemical analysis of processed McNairy Sand is shown in Table 2.

TABLE 2. TYPICAL CHEMICAL ANALYSIS (BY SHARP-SCHURTZ COMPANY)

SiO_2	99.80 %
Al_2O_3	0.08
Fe_2O_3	0.015
TiO_2	0.011
CaO	0.016
MgO	0.003
Na_2O	0.018
K_2O	0.007
Loss on Ignition	0.09
Total	100.04

Heavy Refractory Minerals

Heavy minerals are generally found in most young unconsolidated quartzose deposits. The McNairy is no exception. These minerals are called refractory because they do not melt with the quartz, causing defects in the glass product.

One manufacturer using this sand limits the +40 mesh "heavies" to 0.0010% by weight and the +60 mesh fraction to 0.005% maximum. This is based on a 100 g sample of finished product separated in the laboratory by using tetrabromoethane (specific gravity 2.96).

GEOLOGY

Regional

The Late Cretaceous McNairy Sand is part of the Gulf Coastal Plain – Upper Mississippi Embayment, and is considered to have formed in a cyclic near-shore geologic environment. Figure 2 shows that the outcrop belt generally parallels the Tennessee River and varies from about 19 km wide in McNairy County to about 13 km wide in Benton County (Russell and Parks l975).

The McNairy Sand consists of (1) a regressive, near-shore, basal sand that is very fine grained, containing heavy minerals; (2) a middle wedge of coarser grained sand that appears to be fluvial, deltaic and partly estuarine in origin; and (3) an upper transgressive marine sand which is present only in southwestern McNairy County (Russell and Parks 1975).

Site Geology

Local deposits mined are generally fine to coarse grained subangular quartzose sand. Colors vary from white to reddish brown, yellow brown, red, and grey. The grey colors seem to be present in the coarser fractions. Cross-bedding and cut-and-fill structures are common; thin kaolinitic clay lenses are discontinuous across the area; heavy minerals are found throughout the deposit especially in the finer fractions; muscovite mica also dominates the finer mesh sand; limonitic concretions are found in the upper weathered McNairy and in some places boulders of friable quartz sandstone are randomly scattered throughout the area.

For mining purposes, it is helpful to divide the McNairy into four units (Figures 3 and 4). These units have been delineated by test drilling.

1. *Brown clayey silty sand:* topsoil and loess approximately 1 m thick.
2. *Coarse-grained red clayey sand:* weathered McNairy approximately 6 m thick.
3. *Fine- to medium-grained, locally coarse-grained, white, reddish brown, yellowish brown sand:* approximately 14 m thick.
4. *Uniform fine-grained white sand:* varying in thickness from about 5 to 12 m. Tables 3 and 4 show the physical and chemical analyses of Unit 4.

Units 1 and 2 are mined near the plant for natural bonded sands. Farther away, these units are stripped to reach the third unit, which supplies sand for the glass industry. Unit 4 is at the surface near the processing plant, but is below the water table toward the southwest away

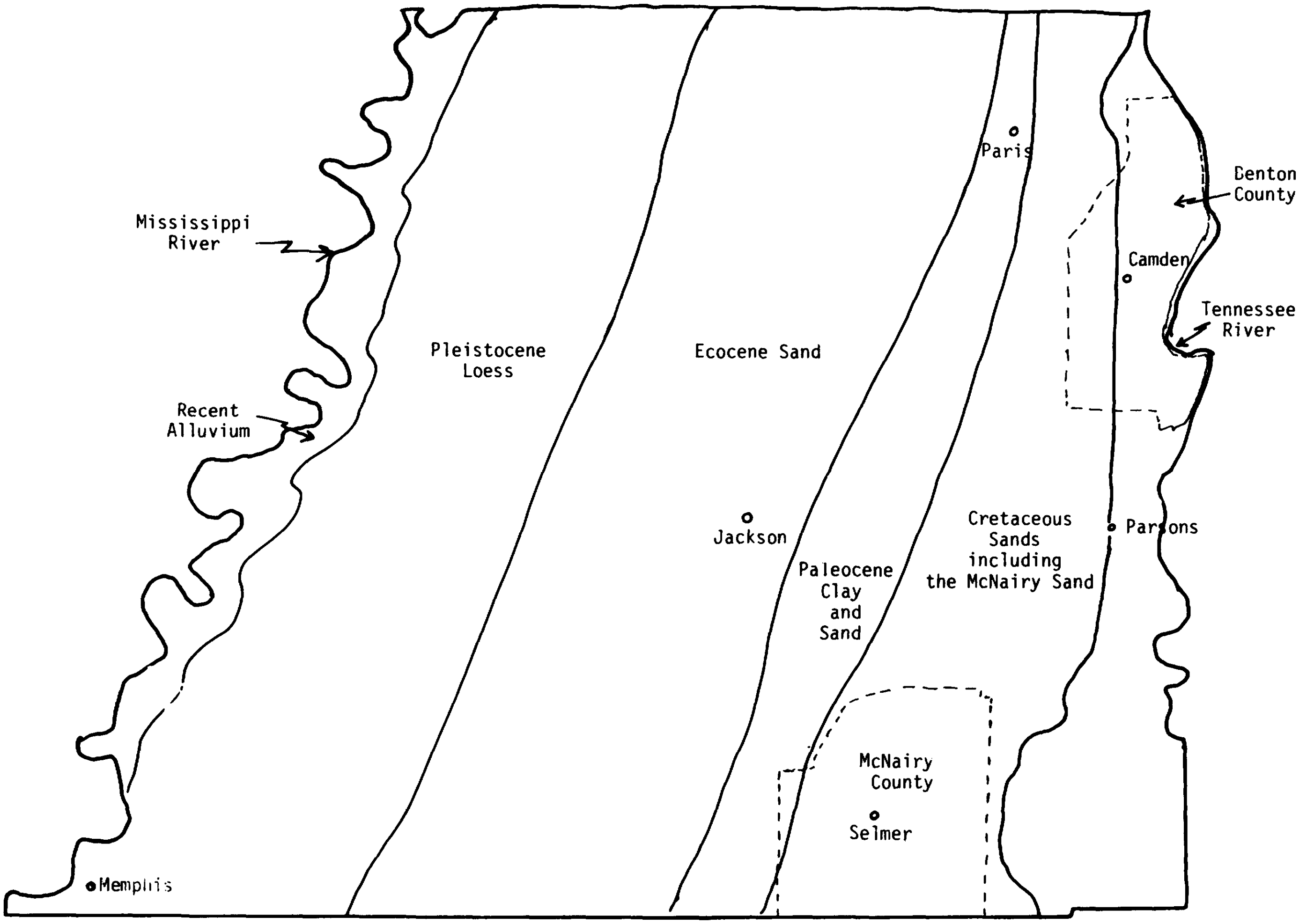

Figure 2. General geologic sketch of west Tennessee. Adapted from Russell and Parks (1975).

Figure 3. *Units 1, 2, and 3 near the active mining site.*

Figure 4. *Active mining site for fine sand near the processing plant, showing Units 3 and 4.*

TABLE 3. TYPICAL SCREEN ANALYSIS (UNIT 4) (BY TENNESSEE SILICA LABORATORY)

U.S. Standard Sieve	% Retained
30	
40	
50	0.2
70	2.6
100	49.4
140	41.8
−140	5.8

TABLE 4. TYPICAL CHEMICAL ANALYSIS (UNIT 4) (BY SHARP-SCHURTZ COMPANY)

SiO_2	99.49 %
Al_2O_3	0.16
Fe_2O_3	0.017
TiO_2	0.023
CaO	0.014
MgO	0.004
Na_2O	0.021
K_2O	0.020
Loss on Ignition	0.15
Total	99.899

from the plant. Figure 5 shows the relationship between processing plant and the four units.

VARIATIONS IN THE MINEABLE UNIT

1. Cross-bedding

Speaking in product terms, Unit 3 is very uniform. Usually, a -30 mesh sand is easily achieved with minimum processing. Sometimes, coarse cross-beds or cut-and-fill structures will cause grains to be retained on the 40 mesh sieve in excess of grain size specifications. This is controlled by working different points of the bank and mixing them at the pit hopper. Dry screening, before loading into the rail car or truck, is also used.

2. Heavy Minerals

According to Wilcox (1971), concentrations of heavy minerals are generally found in the -150 mesh fraction. They are, in order of abundance: ilmenite, leucoxene, staurolite, kyanite, zircon, rutile, monazite and tourmaline. These same minerals are found in Units 3 and 4. Sometimes, aggregates of heavy minerals cemented by iron oxide are retained on the 40 and 60 mesh sieves. The term "dye-balls" was noted by Jones and Hershey (1967) for iron concretions found in this area, which range in size from a fraction of a centimetre to several centimetres. This term has carried over to these fraction-size iron cemented aggregates. "Dye-balls" break apart easily to the lesser mesh sieves.

Unit 3 has an average range of heavy minerals from 0.5 to 1.5% by weight. These heavy minerals are successfully removed by the froth floatation method.

3. Iron Content

The iron content of the mineable units is fairly uniform. Unprocessed pit samples range from about 0.35 to 0.45% iron by weight. The iron has several possible sources, which include iron staining on the grains caused by concretions and red clay, heavy minerals containing iron, and inclusions within the grain.

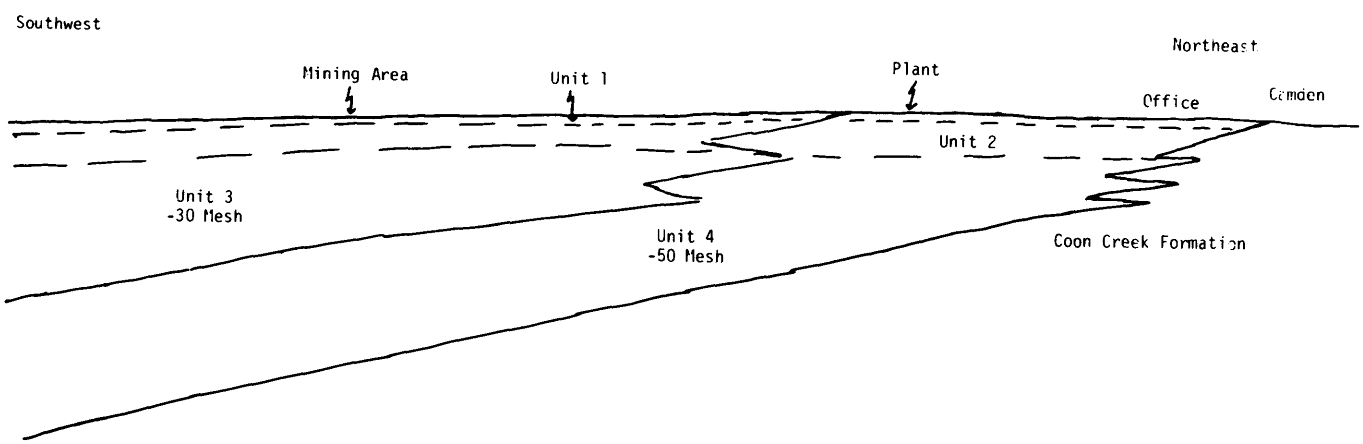

Figure 5. Cross-sectional sketch showing sand units in relationship to location of the plant.

After beneficiation, iron content is relatively low. The final product may contain less than 150 parts per million (0.015%).

4. Clay

The sand grains are covered by detrital silts and clays which adhere loosely to the grains. The clay content ranges from about 1 to 40% according to Jones and Hershey (1967). The higher content is found in Units 1 and 2 and in some of the transitional phases between the McNairy and the Coon Creek Formation. The mineable units contain anywhere from 1 to 8% clay and sometimes slightly more. These fines are washed away as the sand goes through a series of dewatering cones (cyclones) at the wash plant. The clay from the discontinuous lenses in the bank is removed by a rotary screen at the mining site.

MINING AND PROCESSING

Many of the processing techniques serve as controls over the variations within the deposit. Such controls are not out-of-the-ordinary for production of a good quality silica sand. But, somewhat unusual is the method being used now at Tennessee Silica for transporting sand from pit to plants, accomplished with a pipeline approximately 9 km in length. The pipeline was installed in the mid 1970s when higher trucking rates and increased tonnages made it unfeasible to truck the sand to the plant.

Probably, the foundation for this pipeline was set as early as the 1950s, when the plant was built approximately 6.5 km from the source. As the sand in that area became depleted, sources farther away were mined, so extension of the line was necessary.

Along the pipeline is a series of pumps which helps transport the slurry from the pit to the plants. About 45% solids flow through the 20.3 cm diameter pipe. A 25.4 cm diameter pipe is used to transport water from a nearby source to the pit to start the sand slurry.

EXPLORATION TEST DRILLING

In order to determine the continuity of the deposit, test drilling is extremely important. It provides information on all the contaminants and the size of reserves necessary to continue operations.

Above the water table, solid stem augers are the main method of drilling. These are very economical but not recommended for accurate samples. Augers tend to return material from the sides of the test holes at various depths and cave-ins may go undetected. Thick clay lenses will "plug" the augers causing poor sample returns. A rotary drill rig with a split-spoon sampler using fluid-supported holes is a successful method used in unconsolidated sand deposits. This method is very reliable when used below the water table. One disadvantage is that gravels tend to be pushed aside as the spoon is driven into the test hole. Results can be misleading.

LABORATORY

A well-equipped laboratory is essential in the production of silica sands. The laboratory at Tennessee Silica is equipped with a wide variety of testing sieves, pH meters, balances, as well as an X-ray fluorescence machine and the chemicals and equipment for heavy mineral separations. Truck and rail shipments are checked daily, but tests also are performed on samples from the stockpiles, floatation cells, and wash plant as needed.

Recently, two new procedures have helped quality control in the laboratory. They are the introduction of statistical sampling and recording, and the use of a TI-59 computer to interpret data from the X-ray fluorescence machine.

ENVIRONMENTAL CONSTRAINTS

The silica sand industry, like many other mining industries, is required to comply with various state, local and federal regulations.

Permits are necessary for water and air quality, land reclamation, and a variety of other reasons. In addition, health and safety constraints are placed on these mining operations. Some state and local governments have enacted a severance tax on the material mined. All this adds to the complexity of producing these sands as well as to higher costs for the final product.

USES OF SILICA SANDS

Silica sand is used for a wide variety of products, including glass sands, synthetic* foundry sands, filter sand, proppant sand (frac sand), blast sands, golf course bunker sand,and engine traction sand; the list is almost endless. Since the McNairy is a relatively uniform deposit, many different grades of sand are not made, particularly the coarser sized sands. Minor amounts of synthetic foundry sand, blast sand, bunker sand, and other miscellaneous products are sold.

MARKETS

A good quality silica sand may be shipped great distances from its source by rail or truck. High transportation costs

*Term used by the foundrymen for sand free of extraneous material (pure silica).

can eliminate market advantages, but premium-grade silica sand from West Tennessee is shipped to customers in New York State, West Virginia and Ohio, among others. Closer customers such as Ford Motor Company in Nashville and A.F.G. Industries in Kingsport, Tennessee are also provided with a high quality silica sand.

As previously mentioned, grain size is a restriction placed on a quality glass sand. However, grain shape also has its market advantages. For example, round grain silica sand is preferred by oil-well service companies for a proppant in well stimulation. Some foundries use round grained sand because its surface area uses less chemical binders in their molds and casts. Also, some roofing shingle and sandblasting companies prefer round grain sand.

The changing and demanding market is a dominating factor in the silica sand industry. Specifications and transportation costs seem to be always changing, making markets very competitive. Therefore, to continue shipments, the producer must continue to meet specifications, improve on its product, or acquire new operations. Such acquisitions seem to be increasing in the last three years. Ottawa Silica Company purchased a plant in Texas and another in Louisiana. Manley Brothers Sand, of Chesterton, Indiana, was bought by British Industrial Sand Company and the Martin Marietta Industrial Sand Division bought the entire Wedron Silica Sand Company. Unimin Corporation, of New Canaan, Connecticut, has continued to buy, build, and improve its plants, especially in Minnesota and New Jersey. Furthermore, a recent purchase in North Carolina has made them one of the most aggressive silica sand companies in the United States. Just recently, the *Wall Street Journal* reported that Unimin Corporation bought 10 industrial sand plants from Martin Marietta.

Depending on geographic area, quality glass sand prices can vary from $8.00 to $12.00 per ton at the plant. Since the prices are relatively high, some aggregate companies have ventured into silica sands. Vulcan Materials has been developing a site near Brady, Texas, and the J. L. Shiely Company has built a plant near Jordan, Minnesota. Both are for the main purpose of making proppant sand.

SUMMARY

Some of the factors which contribute to the complexity of producing silica sand are:

1. geology of the deposit;
2. changing market specifications;
3. transportation costs;
4. proximity to railways and major highways;
5. water resources;
6. manpower resources;
7. energy costs; and
8. federal, state and local environmental regulations.

Tennessee Silica has had to respond to these factors, in mining the McNairy Sand, but close controls have yielded a quality product. These factors are not much different than those affecting other silica deposits throughout the United States and Canada. A producer must be aware of these factors when expanding its operations or searching for a new deposit. Competition is keen within the silica sand industry, so to stay competitive, a cost efficient operation, a quality product and flexibility are important. If the silica deposit is the purest known, but these factors are not all met, ability to produce from it may become very difficult.

ACKNOWLEDGEMENTS

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The Geology of Industrial Minerals and Rocks in China

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ABSTRACT

Industrial minerals and rocks are abundant resources and widely distributed throughout China. In most provinces, there is a satisfactory variety of non-metal ores as well as construction materials, and some of the mineral deposits display unique geological features.

This article describes the distribution of cement limestone, silica, gypsum, kaolin, talc, graphite, asbestos, zeolite, wollastonite, and bentonite. Together with descriptions of the various occurrences of these minerals or rocks and their geological settings, are discussions of the geological features and genetic classification of the deposits, with some examples of the significant deposits.

INTRODUCTION

Abundant industrial minerals and rocks have been discovered since the establishment of new China. In most provinces, satisfactory non-metal ores as well as construction materials have been found, and some of these deposits have been explored in detail. Although much geological work has been done, more exploration and research are needed for some rocks and minerals in order to meet the demands of economic development. This article can only give an introduction to the geology of some industrial minerals and rocks in China, and we sincerely hope we can learn from the delegates of this forum.

CEMENT LIMESTONE OF CHINA

Limestone deposits suitable for cement manufacture occur in every province of China. These limestones, which have CaO contents exceeding 48%, occur throughout the entire geological column from Precambrian to Tertiary.

Precambrian limestones are not widely used. Most have been metamorphosed and have high contents of SiO_2 and MgO, but some limestone or marble in northeastern China is suitable for cement. Cambrian and Ordovician limestones are widely distributed in northern China and the southern parts of the northeastern provinces, and they are being mined for use by many cement plants. Pelitic limestones and oolitic limestones of Cambrian age are probably of carbonate platform origin. In some of them, the degree of dolomitization increases in the subsurface; thus more drilling has to be done during exploration. Ordovician limestones are better and thicker than Cambrian limestone. This is especially true of the middle Ordovician limestones, which are being used by most of the large scale cement plants in northern China. In southern China, Ordovician limestones are less common. In Jiangxi Province, a very pure Ordovician limestone has CaO content of more than 54%, and is more than 300 m thick.

There are no Silurian sedimentary rocks in northern China. Small Silurian limestone deposits occur locally in northern parts of northeastern and northwestern China. In Qinghai Province, there is a large deposit of Silurian limestone which is suitable for a large scale cement plant.

Devonian limestones are distributed all over Guangxi Province. They have high CaO and low MgO, and are mined by many cement plants.

Carboniferous limestones are important for the Chinese cement industry. They are widely distributed, except in northern China, and many are being mined by cement plants in the maritime provinces. The content of CaO is over 52%.

The Permian limestones in northern China are too thin to be of economic value and some of them are metamorphosed. In southern China, the Permian limestones contain chert in varying amounts. Only those in southwestern China and the middle lower reaches of the Yangtze River have chert content low enough for use in cement production.

There are essentially no Mesozoic rocks in northern China. In southern China, Triassic limestones are widely used and are of very good quality. There are some small deposits of Jurassic, Cretaceous, and Tertiary limestone used by cement plants in Hubei, Henan, and Sichuan Provinces.

GYPSUM AND ANHYDRITE

Gypsum resources are abundant in China. Aside from two provinces which are dominated by volcanic rocks, almost every province has mineable gypsum and anhydrite deposits. The major mineable gypsum deposits occur in two country rock - parent rock associations: (1) carbonate-sulphate type and (2) clastic rock-sulphate type. They would presumably correspond to marine facies and lacustrine facies respectively. The carbonate-sulphate type is found in strata of Triassic, Carboniferous, and Ordovician ages. The Triassic gypsum deposits are mainly located in southern China and the Ordovician gypsum deposits are mainly in northern China. The clastic rock-sulphate type is found in strata of the Tertiary, Cretaceous, and Quaternary Periods.

Triassic Gypsum of Marine Origin

Triassic gypsum deposits of marine origin are located south of a line between Qinling and Dabieshan. The area of occurrence extends east-west, passing through the southern parts of Jiangsu, Anhui, and Hubei Provinces, the northern part of Hunan Province, the southern part of Shanxi Province, the central part of Sichuan Province and the western part of Guizhou Province, to the eastern parts of Yunnan Province and the Xizang Autonomous Region. At the time of gypsum formation, the above area of distribution was a broad epicontinental sea, connecting with the Pacific Ocean on the east and the ancient Mediterranean on the west. There was a peneplaned land to the north of the sea, and island arcs of ancient Huanan, Beiyue and Kangdian to the south. The width of the epicontinental sea corresponded approximately with the present Japan Sea.

Gypsum deposits occur at the upper part of the Olenekian stage and lower part of the Anisian stage, and all the gypsum-bearing rock series can be readily correlated over a wide area. They are characterized by carbonate and sulphate formations of marine facies with intercalated layers of tuff, solution breccia, and primary syngenetic dolomites. The thickness is about 800-1000 m. The sedimentary sequence was probably limestone-dolomite-gypsum, and formed two first-order regional sedimentary cycles. Each first-order cycle includes several second-order cycles. The gypsum beds lie close to the tops of the first-order cycles.

The Triassic gypsum in marine deposits is characterized by thick individual gypsum beds and thick sets of beds, and by uniform thickness over large areas. Individual gypsum beds are several metres thick; the combined thickness of gypsum beds is commonly tens of metres, but locally is as much as 200 m. The top cover and floor of gypsum beds are mainly of marine facies carbonates. The content of calcium sulphate is about 70-90%. The reserves of a gypsum mining area may reach ten million to hundreds of million tons.

Geologic structural compressive forces usually have increased the thickness of gypsum beds at the site of fold axes. Ground water has hydrated the anhydrite beds just below surface to form gypsum, and also has dissolved beds, forming breccia and veins of fibrous gypsum which fill fractures in nearby rock beds. The groundwater in gypsum-bearing beds is a calcium sulphate solution, in which the Ca^{++} and SO_4^{--} are remarkably concentrated compared to the local background values. These secondary changes along with the specific character of gypsum-bearing rock series could be considered to be criteria for looking for new gypsum deposits.

In Triassic times, the climate of the gypsum-forming area was not arid but humid. None of the hypotheses requiring evaporation for the genesis of gypsum deposits, from the sand bar theory to the drained deep basin theory, can be accepted as a good model for prospecting gypsum resources in China.

SILICA

There are 25 silica mines in 21 provinces, solely serving glass plants. The deposits are of Quaternary, Tertiary, Devonian and Precambrian age, and consist of silica sands, sandstone, quartzite and arkose. A few of them are large size quartz veins. In general, the chemical composition of crude ore is SiO_2 83-99%, Al_2O_3 0.14-9.29%, and Fe_2O_3 0.01-0.32%.

KAOLIN

In China, more than 60 kaolin deposits have been explored. Of these, three are classed as exceedingly large deposits, and six as large deposits. The main kaolin deposits are distributed in 22 provinces of China, and may be classified on a preliminary basis into eight genetic types, that is: (1) weathering type of quartz porphyry; (2) weathering type of granite and pegmatite; (3) weathering type of tuff; (4) sedimentary type in the formations of river, lake and bay clastic deposits; (5) sedimentary type in coal formations; (6) karst cavern-filling type on the erosional surface of carbonate rocks; (7) hydrothermal-alteration type of karst cavern-filling on the erosional surface of carbonate rocks; and (8) sericite-quartz rock deposits which aren't kaolin but can be used for pottery manufacture. China was the first country to use kaolinite as a principal feed in ceramic industry. The term kaolin was derived from the name of Gaoling (meaning "high mountain ridge" in Chinese) village which lies 45 km to the east of the town of Jingdezhen in Jiangxi Province. The excavation of kaolin around Gaoling village has ended after exploitation for over one thousand years, but some kaolin samples can still be collected in the abandoned workings. Weathered muscovite granite is widespread and was the source of large quantities of sandy kaolin. The principal minerals in the samples are poorly crystallized platy kaolinite and tubular halloysite. Endellite had been found in weathered pegmatite veins, but the distribution of pegmatite veins is limited.

TALC

There are about 12 large and exceedingly large talc deposits in six provinces of China. All of them were formed during Precambrian time. The three exceedingly large talc deposits are being mined in Liaoning and Guangxi Provinces. Shandong Province has four large deposits, all in production. The famous Haicheng talc mine of Liaoning Province is a carbonate type hydrothermal replacement deposit. Its country rocks are mainly dolomitic marble and magnesite. The chemical composition of the ore is SiO_2 61.18-62.74%, MgO 31.19-32.48%, CaO 0.003-0.14%, Fe_2O_3 0.04-0.102%, Al_2O_3 0-0.042%. The country rocks of most of the main talc deposits are dolomite and magnesite; at one deposit, the country rock is magnesite-bearing chlorite quartzite.

BRIEF INTRODUCTION TO THE GEOLOGY OF ASBESTOS DEPOSITS IN CHINA

There are 37 chrysotile asbestos deposits being mined in China. Twenty-four of them are of ultrabasic rock type, 13 of them are of dolomite type. Most of the ultrabasic-type asbestos deposits are much larger than those of dolomite type; most of the deposits of dolomite type are located in northern China.

A brief account is given of the geology of four asbestos deposits, each of which has a specific significance. Mangai and Shihmian County asbestos mines are the two largest producers. Jian asbestos deposit is of dolomite type but with some unusual geological characteristics. There are also many amphibole asbestos deposits in China. Tremolite asbestos of the Honglong asbestos deposit has unique physical properties. It not only has the merits of ordinary tremolite, but is also as strong and soft as chrysotile.

Mangai Chrysotile Asbestos Deposit

The Mangai asbestos deposit is situated in Qinghai Province, at the northwestern boundary of Chaidamu basin. The deposit lies in the Algin Hong-ahati mountain system which is a southern branch of middle Algin mountain range. The mining area is underlain by gentle undulated rolling hills; its elevation is 3220-3790 m, rising up to 170 m above the surrounding country.

The Mangai asbestos deposit is on the southeastern margin of Chaidamu platform block, marked by a major fault. It is known from available information, that a belt 500 km long, from the eastern Annanba mountain of Gansu Province to the western ingrick of Hsinkiang Autonomous Region, is broadly underlain by ultrabasic intrusions along a geosynclinal margin. Within the ultrabasic intrusions, numerous chrysotile asbestos deposits were formed and Mangai asbestos deposit is the largest of them.

Serpentinite is the principal host rock of the asbestos deposit; its mineral constituents are serpentine, bastite, carbonate, talc, pyroxene, olivine and metallic minerals. The texture, structure, alteration and mineral composition of serpentinite show that the parent rocks of serpentinite were likely peridotite and harzburgite.

Serpentinite can be divided into two facies: (1) serpentine facies (probably derived from peridotite), and (2) pyroxene-bearing facies (probably derived from harzburgite). The fibres in serpentine facies are longer, of better quality, and occur mainly in a stockwork of veins.

Pyroxene-bearing facies rocks form longitudinal rings around the serpentine facies rocks. There is no clear boundary between them. Fibre recovery from pyroxene-bearing facies is lower than that from serpentine facies. The chrysotile asbestos veins appear as multiple gash veins (ribbon veins) and stockworks of thready veins. The fibres are shorter but the quality is good.

The asbestos-bearing rock bodies are strictly confined by faults. The southern and northern boundaries of asbestos-bearing bodies are evenly and clearly bounded by fault planes. Most of the asbestos-bearing bodies are in bedded form. Dip is 50-55° to the north-northwest. Four asbestos bodies occur intermittently along an east-trending belt over a distance of more than 13 km. Only a portion of first body had been explored and evaluated in detail.

Chrysotile asbestos is more enriched where faults, fractures and joints are well developed.

Shihmian County Chrysotile Asbestos Deposits

There are two asbestos deposits in two ultrabasic rock bodies in Shihmian (meaning "rock cotton" in Chinese) County. The ultrabasic bodies were originally a single body, which was later separated into two isolated northeast-trending bodies by the Nanya River fault; displacement was about 8 km in a north-south direction. The Sichuan asbestos mine is in the northern body.

Ultrabasic bodies consist of dunite, peridotite and harzburgite which are serpentinized, and the asbestos deposits occur in the serpentinite masses.

Gabbro dikes trend parallel to the ultrabasic bodies, and form the country rock north-northwest of the asbestos-bearing serpentinite masses. Granite intrusions are well developed at the northeastern end of the two deposits. Petrographically complicated, intermediate to acidic volcanic rocks occur south and southeast of the two deposits, and indicate that volcanic activity took place many times.

Small intrusive veins with various directions and shapes occur within the ultrabasic bodies and have a deleterious effect on the ore. These veins are of diabase, olivine diabase, basaltic diabase and aplitic gabbro, granite-porphyry, felsite and albitite.

The Sichuan asbestos mine consists of five orebodies trending northeastward, with a length of 5 km and a width of 0.5-1.5 km and combining into one at the northeastern end of the deposit. The northeastern parts of the orebodies dip southeast at 70-85°; southwestern parts dip northwest at 65-80°. Fibres are mainly slip fibres.

The Xinkang asbestos mine, the other part of the Shihmian County deposit, also includes five orebodies which are 2350 m long, 250-800 m wide, and trend northeastward. The orebodies are large, layer-like lenses. Fibres are also mainly slip fibres.

Jian Chrysotile Asbestos Deposit

The Jian asbestos deposit, in Jian County of Jilin Province, is situated in the northeastern part of Liaodong anticline which trends northeast. The Anshan group of the Archean metamorphic rock series is widespread over the region, and strongly migmatized granite gneiss prevails in the mining area. Within the migmatized granite gneiss are anorthite-amphibole gneiss, dolomitic marble, serpentinite, serpentinized marble, pegmatite and amphibole andesite veins.

Serpentinite, including dark green or green serpentinite and yellowish green sugary-looking granular serpentinite, is a product of deeply and thoroughly altered dolomitic marble, and consists mainly of serpentine. The accessory minerals are dolomite, talc, calcite, ascharite and more rarely, magnetite, pyrite, pyrophyllite, chlorite, and ludwigite. Serpentinite occurs as lenses and has experienced steatization, chloritization and pyritization.

Serpentinite is not only asbestos-bearing, but also is a borate-bearing rock body. The borate-bearing rock is a lens with a length of 1300 m and width of 30-40 m. The lens dips southeast (105-165°) at 25-65°, and forms a monocline in which some local folds are found.

Chrysotile fibre veins form in fracture zones which are parallel to northeast-trending bedding planes, and are mainly adjacent to the top and bottom beds of the serpentinite rock body. Some of the veins are located at the vicinity of pegmatites. The fibre-bearing zones occur as continuous or intermittent lenses. Fibre veins are continuous, intermittent, or irregular in the belts and have lengths of several to tens of metres to as much as a hundred metres. The fibre-bearing zones are 50-350 m long and 0.5-7.5 m thick. There are about nine zones of which four are major ones. Fibres in veins are cross fibres in echelon and paternoster forms. The lengths of fibres range from 1 to 10 mm. The longest reach 80 mm.

Better, longer fibres and higher recovery are obtained in steatized serpentinite, serpentinized marble, dark green serpentinite (consisting mainly of serpophite) and pyrophillitized serpentinite.

The yellowish green sugary granular serpentinite does not contain asbestos; only borate is enriched in it.

Honglung Tremolite Deposit

The Honglung tremolite deposit is situated in an assemblage of Proterozoic and Paleozoic sedimentary and metamorphic rocks. The tremolite deposit occurs in the lower part of lower Cambrian carbonaceous slate which contains tremolitized dolomitic limestone lenses.

The main structural feature of the mining area is the Honglung syncline which occurs within a regional anticlinorium, and is complicated by subsidiary folds. The lower part of the lower Cambrian strata dips southeast or north-northeast at 10-30°. Faults are well developed.

There are many granite masses of the Indosinian and Yenshanian Orogenies in the region. Gabbrophyre and quartz veins are found along a northeast-trending fracture zone. Some small veins of diorite porphyry and lamprophyre are seen only in the mining area, having a deleterious effect on ore-bearing layers.

Tremolite veins form at the top and bottom rims of tremolitized dolomitic limestone lenses. The mineral composition of carbonaceous slate is andalusite, sillimanite, chiastolite, quartz, sericite, kaolinite and minor chlorite, cordierite, and carbonates. The mineral composition of the tremolitized lenses is tremolite, kaolinite, graphite, anthophyllite, pyrite, marcasite and minor pyroxene, rutile, zircon, garnet, epidote, cordierite, quartz, and carbonates.

The chemical composition of tremolite is SiO_2 57.2%, MgO 17.46%, CaO 8.25%, Al_2O_3 1.14%, H_2O^+ 3.94%. Compared with the ideal composition of tremolite, its MgO and CaO contents are lower, and its H_2O^+ and Al_2O_3 contents are higher.

ZEOLITE

Zeolite deposits were first discovered in China in 1972 by the Zhejiang non-metal geological team of our Company. Since then, more than 100 zeolite occurrences have been documented, and large zeolite deposits have been found or explored in Shandong, Liaoning, Hebei, Xinjiang, Heilungjiang, Zhejiang, Henan Provinces. The principal minerals of most zeolite rocks are clinoptilolite and mordenite.

At present, zeolite rocks are being used in pozzolan cement, some of them are being used for environmental protection.

Tienjing Shan zeolite deposit was the first discovered, and is one of the largest zeolite deposits in China. The mining area is situated in the middle of the Jingyuesuhong terrestrial block-faulted basin of late Jurassic-Cretaceous age. The basin lies along the Lisue-huzhen deep fault zone and is covered by the Tangshang formation of upper Cretaceous series. The upper part of the formation includes three or four strongly zeolitized units of volcanic breccia-agglomerate, forming the most important mineral-bearing rock beds.

The three volcanic breccia-agglomerate beds exposed in the mining area are intercalated with acidic lava or sedimentary tuff-breccia. The volcanic eruptive activities in the area consisted of multiple stages: eruption – overflowing – re-eruption (with sedimentation) – re-overflowing. Each rock bed has a characteristic distribution, shape, and attitude. The morphologic features of the volcano are typical of composite volcanos which are composed of multiple eruptive products.

Volcanic rocks in the area have different degrees of zeolitization. Zeolite minerals are mainly clinoptilolite and mordenite with minor heulandite and clinoptilolite of calcium type.

There are two mineralized rock types: (1) zeolitized pyroclastic rocks (breccia-agglomerate zeolite rocks, zeolitized sedimentary tuff-breccia), and (2) zeolitized acidic lava (zeolitized perlite, zeolitized rhyolitic perlite, zeolitized orbicular bubble-like rhyolite). Strongly mineralized breccia-agglomerate zeolite rock is more continous and more consistent, forming a distinct horizon within the local strata, so it can be classified as a mineable zeolite deposit.

On the basis of the observations mentioned above, regarding the origin of the deposit, it is proposed that zeolitization in the area had an intimate genetic relationship with the volcanic activities of the late stage Cretaceous, and was a product of volcanism. Volcanic activities of multiple stages resulted in mineralization of multiple rock layers.

The zeolitization, resulting from devitrification of the glassy materials of the host rocks during the process of diagenesis, was by way of secondary hydration, which is the basic form of zeolitization in the area. The zeolitization is a manifestation of hydro-pneumatolitic alteration accompanying volcanic eruptions which were repeated and overlapped many times. The composition, texture, and structure of mineralized host rocks, and the fissures, cavities, and degree of fracturing of the rocks, are important contolling factors of zeolitization. The strongly mineralized volcanic breccia-agglomerates, which are composed of randomly stacked glassy material and cavity fillings, make up the three layers of the zeolite deposit in the mining area. At the top and bottom of the dense massive perlite and in places where fractures have been well developed, zeolitization is comparatively well developed. Locally, zeolitization has been intense. Zeolitization of other kinds of rocks is less developed and more variable.

GRAPHITE

The discovered mineable graphite deposits are distributed in 13 provinces and two autonomous regions. They are being developed by both small and large scale mining methods. The large producers are in Shandong, Helungjiang, Inner Mongolia Autonomous Region, Jiling and Hunan.

Most of the graphite is flake graphite, which was formed by regional metamorphism during the Archean. A few of the graphite deposits are amorphous graphite, which was formed by contact metamorphism of coal beds. For instance, the Jiling graphite deposit was derived from coal beds of Jurassic Period, and the Hunan graphite deposit was derived from coal beds of Permian Period. Graphite deposits in vein form are rare in China, and graphite deposits of the skarn type are unknown in China.

Some large graphite deposits have been explored in detail, and are awaiting mining by advanced techniques.

WOLLASTONITE

A wollastonite deposit was first discovered in 1975 in Hubei Province. After that, one deposit after another was found, totalling 17 deposits in 11 provinces. Most deposits are of Permian age. The modes of occurrence can be divided into two types: (1) skarn type (contact metamorphism), and (2) chert-bearing marble or siliceous limestone (regional metamorphism). Both types of wollastonite deposits may be found in the same mining area.

The first discovered deposit is of the skarn type. It consists of lower Permian siliceous limestone, which forms a wholly enclosed body lying on a granodiorite intrusion. Most of the wollastonite minerals are fibrous and acicular, comparatively pure, and easy to open; the major associated minerals are andradite, diopside and quartz.

BENTONITE

In China, more than 200 bentonite occurrences have been discovered. More than 100 bentonite deposits are mined by people's communes, and 18 major bentonite deposits distributed in 15 provinces are mined by local government. Most of the bentonite deposits were formed in the Tertiary, Cretaceous and Jurassic, with parent rocks of trachyandesite tuff, andesite tuff, rhyolite tuff, rhyolite, dacite, trachyandesite, trachyte, andesite porphyry, and andesite-dacite porphyry. The bentonite deposits were formed by alteration of volcanic ash or tuff in lacustrine environment or marine environment. The thickness of bentonite beds in the 18 major deposits range from 2 to 35 m. In recent years mineable sodium-type bentonite beds have been found in five major deposits in which only calcium-type deposits had previously been recognized.

A major bentonite mine is the Heishan (meaning "black hill" in Chinese) mine in Liaoning Province. The bentonite bed occurs within volcanic rocks of upper Jurassic age; the overlying rock is rhyolite, and the underlying rock is andesite. Lenses of glassy rocks (perlite, obsidian, pitchstone) and layered crystal tuff are intercalated within the bentonite bed; the bentonite was formed by montmorillonitization of these rocks. The perlite was also zeolitized to form a mineable zeolite deposit which is mainly composed of clinoptilolite.

The bentonite bed is zoned, and outcrops as two parallel belts which have been classified as soft and hard bentonite by the miners. The hard bentonite is the lower zone and is usually of the sodium type.

Practical Procedures for Siting Crushed Stone Quarries

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ABSTRACT

The purpose of this paper is to describe the rock mechanics and structural geologic methods that have been recently applied to the location and development of crushed stone quarries. The methods involve the normal cost-effective requirements of the construction aggregate industry and the need to produce crushed stone products at minimum volume-unit costs. The application of these various methods took place during studies in connection with four crushed stone quarries developed in Vermont during the last five years. These quarries are used as examples of the application of the methods.

The relationship between the modulus of elasticity and the uniaxial compressive strength of various rock types is expressed in this paper as the Modulus Ratio, since it is believed that this relationship best describes the intact strength properties desirable for sources of crushed stone. Plots of Modulus Ratio are included, and their use in quarry site reconnaissance is described. The Talobre (1967) method of stereographic analysis is described in relation to its usefulness in the design of quarry layouts. The paper demonstrates the procedure by which the optimum working design for a quarry can be calculated so as to insure maximum fragmentation efficiency.

INTRODUCTION

The purpose of this paper is to review the structural geologic and rock mechanics considerations that have been recently applied to the location and development of four crushed stone quarries located in the State of Vermont. The paper describes techniques that are a combination of the published theoretical work of a number of individuals. It is believed that these combined techniques help to provide for the production of high-quality crushed stone aggregates at minimum volume-unit costs. (Fowler 1982).

Figure 1 shows the locations of the four crushed stone quarries where these techniques have been effectively applied. These quarries will be referred to later in this paper. Quarry No. 1 is located in Barnet, Vermont, in the quartzite of the Siluro-Devonian Gile Mountain Formation (Hall 1959). Quarry No. 2 is located in Shaftsbury, Vermont, in the siliceous dolomitic limestone of the Cambrian Monkton and Winooski Formations (MacFayden 1956). Both of these quarries have been closed and fully reclaimed. Quarry No. 3 is a permanent development located in Middlebury, Vermont, in the siliceous dolomitic limestone of the Ordovician Chipman Formation, and Quarry No. 4, which is also a permanent development, is located in Waterford, Vermont, in the metaquartzite and metadiabase of the Ordovician Albee Formation (Eric and Denis 1958).

ROCK MECHANICS CONSIDERATIONS

Various mechanical and physical properties are used to describe the strength of rocks, and thereby their suitability as sources of crushed stone. However, for the purposes of

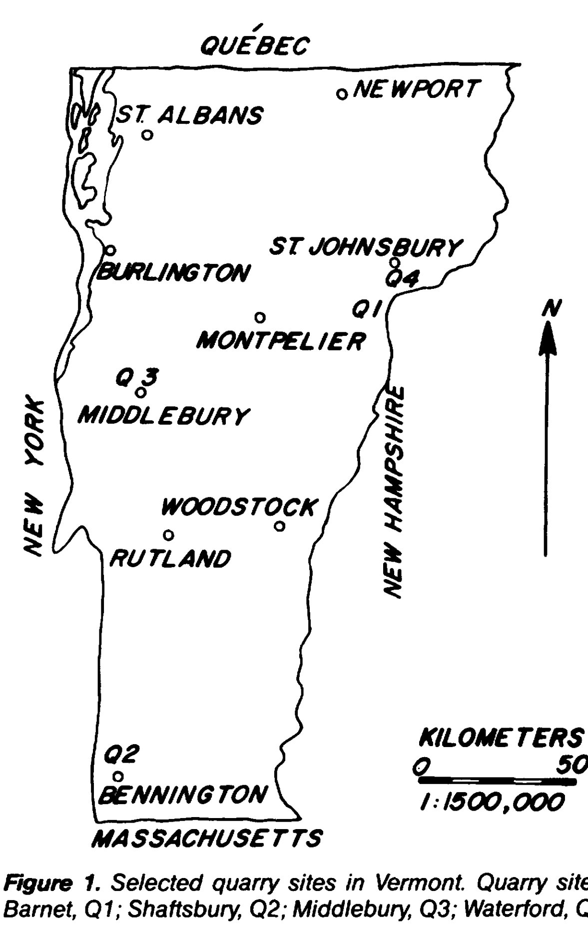

Figure 1. Selected quarry sites in Vermont. Quarry sites: Barnet, Q1; Shaftsbury, Q2; Middlebury, Q3; Waterford, Q4.

this paper, only those groups of properties which have been shown to be most directly related to the mechanical breakage characteristics of rock will be discussed.

The first group consists of those specific *quantitative* mechanical properties which represent a rock's *intact* strength. Obert has defined "intact" rock as "pieces or possibly bodies of relatively uniform rock of a single petrological type that do not contain gross mechanical defects of a geologic origin, such as faults, joints or micro-fractures" (Obert 1973; see also Jaeger 1972 and Hendron 1972). The strength of a piece of "intact" rock is described on the basis of an intact specimen's response to specific, controlled laboratory tests, such as those measuring unconfined compressive strength and elastic moduli.

The second of these properties is that group of *qualitative* physical properties which represent the *in situ* strength of a rock mass. Once again, Obert has provided a simple definition. *In situ* rock is a "mass of rock of sufficient size to contain a representative sample of the gross mechanical defects" typical of the rock mass in question regardless of the rock type present or the individual intact strength properties (Obert 1973; see also Hendron 1972). The *in situ* strength of a rock mass is based upon the distribution and character of these gross mechanical defects, which are referred to as "discontinuities" (see Deere 1972; Jaeger 1972; Goodman 1976). Discontinuities include such geologic features as joints, bedding surfaces, banding and mineral segregations, contacts, cleavage, schistosity, foliation, sheared zones and faults. The properties of discontinuities that are important are orientation, distribution, extent and planarity (Goodman 1976; Jaeger 1972).

Obviously, the suitability of a mapped rock unit for use as a crushed stone quarry site involves a combination of favorable intact and *in situ* properties. The specific intact properties of elasticity and uniaxial compressive strength will determine the rock's crushing and drilling characteristics, along with its level of compliance with the prevailing durability or abrasion specifications. The specific *in situ* properties of the discontinuities, on the other hand, will determine the blasting and fragmentation characteristics of the rock mass, along with the orientation of the quarry workings.

During the preliminary phases of a quarry siting study, it is helpful to be able to eliminate from consideration those sites where the existing rock exhibits inferior intact properties. This can be done by referring to one of the numerous schemes for classifying rock types according to their intact strength properties (e.g. Jaeger 1972; Goodman 1976; Deere 1972) and by careful field study.

Experimentally derived data obtained from unconfined axial loading tests have been summarized in a series of seven plots published by Deere (1972). Figures 2, 3, and 4 are composite diagrams taken from these plots, which further summarize the information for the purpose of this paper. These plots are believed to represent one of the more useful classification schemes for rock types, because they are based upon the more important mechanical properties of intact rock. Referring to the figures, it will be noted that the strength of each rock type is expressed as its "modulus ratio". This ratio is calculated by determining the ratio between the test results for the rock's uniaxial compressive strength and the test results for its modulus of elasticity (Young's Modulus). In both the original plots and

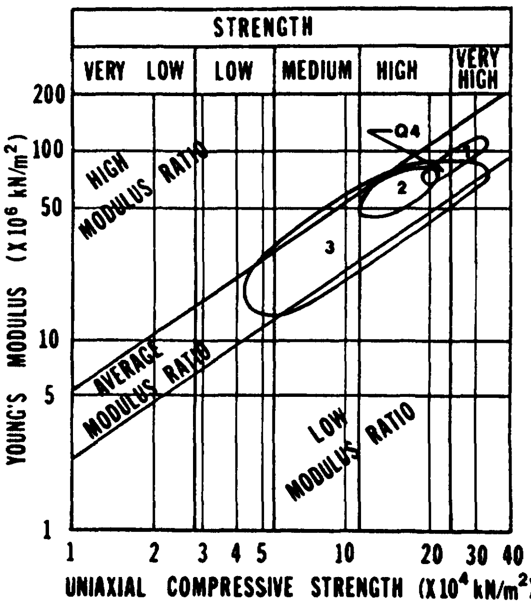

Figure 2. *Summary plot of modulus ratio for igneous rocks. Unless otherwise indicated, all data from Deere (1972). Envelope designations: 1 – diabase; 2 – granitic rocks; 3 – basalt and miscellaneous flow rocks.*

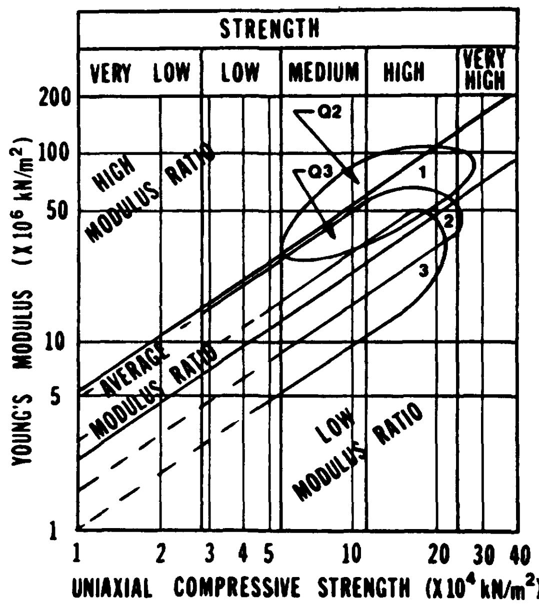

Figure 3. *Summary plot of modulus ratio for sedimentary and low-grade metasedimentary rocks. Unless otherwise indicated, all data from Deere (1972). Envelope designations: 1 – dolomite and limestone; 2 – sandstone; 3 – shale.*

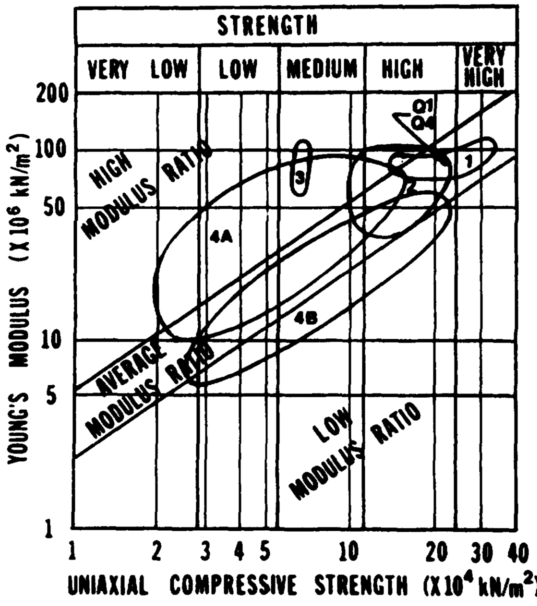

Figure 4. Summary plot of modulus ratio for metamorphic rocks. Unless otherwise indicated, all data from Deere (1972). Envelope designations: 1 – quartzite; 2 – gneiss; 3 – marble; 4A – schist, foliation-parallel; 4B – schist, foliation-normal.

those presented here, the modulus of elasticity is calculated at 50% of the limiting stress for each rock, and the envelopes contain 75% of the data points obtained from the calculations (see Deere 1972).

The estimated locations of the modulus ratios for the rock types in each of the four Vermont quarries are also shown on the plots. These are qualitative estimates based upon the actual mechanical requirements of the crushing operations undertaken at each site, and not upon controlled laboratory tests. Similar estimates can also be made utilizing a Rebound Hammer procedure which is described later in this paper.

As can be seen in the figures, the modulus ratios for the various rock types fall into representative envelopes across the strength designations. Using the plots for estimating the suitability of rock types for crushed stone quarrying, however, requires caution and careful field study of the rock type in question, unless, of course, facilities are available for the appropriate types of controlled mechanical property tests. This caution is necessary, because the rocks with large envelopes, and, therefore, with widely ranging intact strength characteristics, need to be carefully located to determine in what portion of the appropriate envelope their designation lies. This is especially important if foliated rocks are under consideration, because intact strength properties can vary widely from the foliation-normal to the foliation-parallel loading direction (see Figure 4). In such cases, field methods such as that described below, may not be sufficiently precise, and controlled laboratory tests may be required.

The following field method has been successfully applied in estimating the location of points on the plots of Modulus Ratio when access to equipment or project costs make mechanical testing impractical. The equipment required includes a Schmidt Rebound Hammer or a Shore Scleroscope and a scale for weights.

First, a standard Hammer or Scleroscope test is performed on either a piece of core or a sample from an outcrop of unweathered rock. Three separate impacts are averaged to obtain a representative result. The dry unit weight of the rock is then calculated as per standard procedure, and reference is made to Figure 5, where the uniaxial compressive strength correlation to the rebound results can be read directly, using the unit weight (see Deere 1972). Next, reference is made to Table 1 where the elastic equivalents for the rebound readings have been calculated (Protodyakonov 1963). The final step is to refer to Figures 2, 3, or 4, as appropriate, where one can find the uniaxial compressive strength and the elastic equivalent, and then estimate a "modulus ratio" for the rock sample being tested. This method produced sufficiently accurate estimates in the four cases discussed in this paper so that the operators could select quarry sites and rock types which provided optimum production at minimum volume-unit costs.

STRUCTURAL GEOLOGICAL CONSIDERATIONS

The foregoing information is used to locate geologic units that may provide rock with adequate intact strength

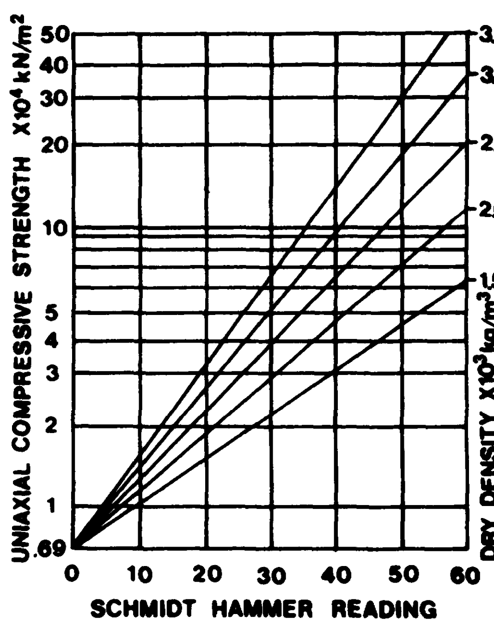

Figure 5. Conversion chart: rebound hammer readings to uniaxial compressive strength, based upon dry density.

TABLE 1. ELASTIC EQUIVALENTS FOR REBOUND HAMMER READINGS

Hammer Reading	Young's Modulus of Elasticity (X 10^6 kN/m^2)
5	3.5
10	6.9
15	11.0
20	15.8
25	20.0
30	25.5
35	31.0
40	37.9
45	43.5
50	50.4
55	58.0
60	66.9

Note: The elastic equivalent relationship upon which this table is based is considered to be statistically invalid for hammer readings over 60. After Protodyakonov (1963).

Conversion: kN/m^2 = 6.9 p.s.i.

properties to meet prevailing specifications and requirements for economical fragmentation and processing. However, structural geologic or *in situ* information is required in order to properly locate the proposed quarry within the bedrock unit in order to insure an efficient quarrying operation.

Once a potential quarry site has been identified and an estimate of the rock's intact properties made, a detailed structural geologic map must be prepared for the site. During the preparation of this map, special attention must be paid to the determination of the orientation of all discontinuities in the rock mass. The structural geologic survey should extend to outcrops lying as far as 500 feet from the proposed quarry site to ensure the establishment of a fully representative data base. Once the field work is complete, all observations should be plotted on a map base at a fairly detailed scale, for example, 1 inch to 50 feet (1:600), and all strike and dip data should be analyzed stereographically.

A diamond core drilling program is always advisable in addition to detailed structural mapping. Data to be collected from the core samples include petrography, drilling rates, density variations, thickness and attitude of structural discontinuities, and the presence of any stratigraphic or structural marker horizons that may be useful in plotting the position of the workings within the rock mass as excavations proceed. In addition to the bedrock verification that can be obtained from the cores, the resulting core holes also provide an opportunity to obtain information about the sub-surface ground water conditions in the area of the proposed working, thus assisting in the design of adequate drainage expedients and reclamation plans.

Following completion of the field work and the preparation of the structure map, stereograms must be prepared and analyzed. Many methods of stereographic analysis have been evaluated for their utility in this specific type of quarry application, and none has emerged as more useful than a technique developed by Talobre (1967; see also Goodman 1976). This technique allows for the determination of the direction within the rock mass in which the maximum *in situ* compressive strength (or resistance) will be developed upon the application of stress. The method is based upon the *in situ* orientations of the observed structural discontinuities in the rock mass.

Referring to Figure 6, the method can be described as follows. First, the poles to the planes of all observed discontinuity surfaces are plotted on a polar equal-area stereonet. If there is a large number of poles plotted, the resulting stereogram should be contoured and an average pole should be selected to represent the poles from each discrete set of poles. This was done in the preparation of Figure 6, where a large number of observations was available for plotting.

The next step is to construct small circles around the average pole of each discrete set of structural discontinuities, as shown on Figure 6. The radii of these small circles, as measured on the stereonet, is equal to the estimated value of the intact angle of internal friction (ϕ) for the rock type under study. A ϕ value of 35° was used in the construction shown in Figure 6 as estimated for the dolomitic limestone in Shaftsbury, Vermont (Fowler 1982). At this point, "one can try to find a position which makes an angle with each pole of less than the angle of friction. Such a direction will be in the area common to the small circles of radius ϕ about each pole..." (Goodman 1976). The center of the hachured area common to the circles in Figure 6 represents the pole to the plane in which the maximum compressive strength or resistance can be mobilized within the rock mass. In the case of the distribution shown in Figure 6, the plane is oriented N70°E, 20°NW. The direction in the horizontal plane would simply be N70°E.

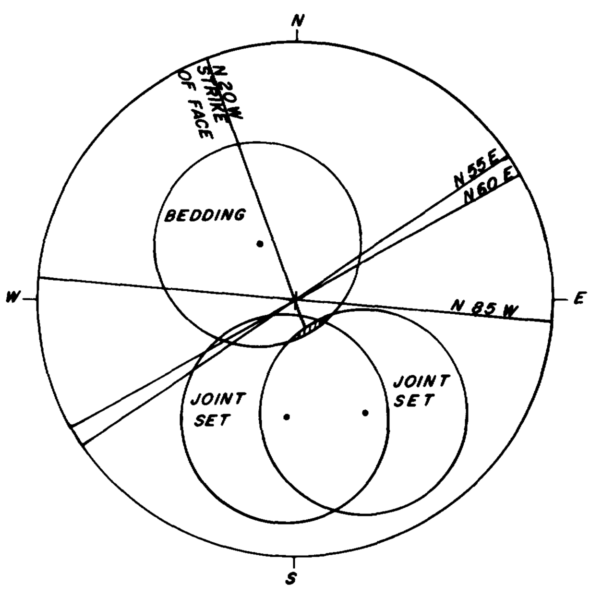

Figure 6. *Polar equal-area stereonet (pole diagram) with constructions to determine quarry orientation: Quarry No. 2, Shaftsbury, Vermont. Lower hemisphere projection. Total points plotted prior to average pole selection equals 412.*

This orientation or direction represents the attitude within the rock mass in which maximum compressive strength will be available, if a strong rock-based foundation is desired. It also represents the direction in which the rock mass will offer the greatest resistance to breakage or *in situ* disaggregation of its mass. Consequently, a blasting face (working face) in a quarry oriented parallel to this plane or vertically parallel to this direction will not exhibit optimum efficiency in producing broken rock. This is due to the fact that blasting impact forces will be dissipated along the adjacent and nearly parallel *in situ* discontinuities before they can be coupled in sufficient strength directly to the intact rock to overcome its maximum compressive and elastic limits. On the other hand, a blasting face oriented vertically perpendicular to this plane or direction will exhibit optimum efficiency, because the blasting forces will not be dissipated as rapidly along the now nearly perpendicular *in situ* discontinuities. This allows for the coupling of the blasting impact forces directly to the intact portions of the rock mass at maximum magnitude immediately upon detonation and prior to any significant dissipation. When dissipation does finally occur, it further assists in the breakage process by providing for secondary and tertiary impacts as the rock fragments begin to displace along the discontinuities and collide with one another within the mass of broken rock.

An analysis such as this establishes the centerline orientation for the quarry workings. Working faces are then oriented perpendicular to this centerline. If one is working on a site where folding or faulting rapidly changes the attitude of the discontinuities in the rock mass, this type of stereographic analysis may have to be undertaken a number of times during the quarry excavations to ensure proper orientation of the workings from time to time.

CONCLUSION

The various concepts and techniques described in this paper have been used to provide a quarry operator in Vermont with specification-quality crushed stone products at lower volume-unit cost. Prior to the application of these techniques, more experiential and intuitive methods had been applied with considerable historic success. Consequently, one might question the additional time and expense of these studies for quarry development. The need for this type of approach lies in the nature of today's competitive economy, with its variable and often high interest rates and deteriorating markets for larger volumes of crushed stone products (e.g. the completion of the Interstate Highway System). The application of techniques such as these can help to refine the methods already being intuitively applied, and can provide an operator or his mining geologists with methods to anticipate and compensate for the natural variations that occur in quarry rock masses while holding costs to a minimum.

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Search for Skid Resistant Aggregates in Ontario

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ABSTRACT

Aggregates make up about 95% of the surface of asphaltic concrete pavements. As a result, the physical properties of the aggregates have a great influence on the skid resistance or frictional properties of the pavement. Aggregates with excellent frictional properties are required on highways with high volumes of traffic.

The frictional properties of wet pavements depend on a correct asphaltic concrete mix design and the use of satisfactory aggregates. A stable, high stone content mix design is required to give initial macrotexture. Macrotexture is the projection of coarse aggregate particles above the matrix, and is important at high vehicle speeds. The particles break the water film, and provide bulk drainage, reducing the chance of hydroplaning. The property that determines the ability of the pavement to retain this macrotexture is the aggregates' resistance to abrasion. A laboratory test to measure resistance to abrasion is the Aggregate Abrasion Value test. A good microtexture or a rough sandpaper-like feel to the aggregate particle surface is needed at all vehicle speeds to penetrate the thin water film and come in contact with the tire. A laboratory test to measure the ability of an aggregate to retain or develop microtexture is the Polished Stone Value test. Good resistance to freezing and thawing is also required. This property is measured by routine durability tests such as the Magnesium Sulphate Soundness test and Absorption test. Petrographic examination, often including the use of thin sections, is also performed.

Recent work in Ontario has involved the search for new sources of skid resistant aggregate. The techniques and procedures have included field exploration and diamond drilling of likely prospects. This is followed by laboratory testing. If results are encouraging, test sections of the aggregate are placed on the highway. Long term durability is evaluated, and actual frictional values are then measured using a skid trailer prior to approval of new sources.

The following types of rock are currently used or being evaluated for use as skid resistant aggregate: hard, angular rocks such as trap (metavolcanic), quartzite, granite and igneous gravel; hard, vesicular materials such as steel and blast furnace slags; hard, gritty rocks such as sandy carbonates and sandstones.

INTRODUCTION

Until the early 1970s, major highways in southern Ontario were normally paved with asphalt, using trap rock aggregate, or with Portland cement concrete, using locally available carbonate aggregates. With increased traffic, there has been a greater awareness of the influence of the frictional properties of pavement on safety. Since the late 1960s, major efforts have been made in Ontario to measure and improve the frictional properties of these pavements. This has included the selection and use of new types of asphalt mix, and the search for, and the selection of, new aggregate sources with improved frictional characteristics.

It has been demonstrated, in a number of studies, that an improvement in frictional properties or skid-resistance will reduce accidents caused by skidding in emergency braking, sliding in curves, or during emergency manoeuvres (in Ontario, Kamel and Gartshore 1982; in the USA, Harwood *et al.* 1976; Burchett and Rizenbergs 1982; and, in the United Kingdom, Giles *et al.* 1964), It should be noted that accident rate is also related to such factors as the geometry of the highway, the amount of traffic, sight distance, and visibility (water spray, lighting).

Direct methods of measuring frictional properties of pavement surfaces include: distance skidded by an automobile with locked wheels (ASTM E 445-76), side force friction using a mu-meter (ASTM E 670-79), or the brake force skid trailer (ASTM E 274-79). The actual friction measured varies, depending upon the technique used (Hegmon 1982), the time of year (Giles *et al.* 1964; Dahir and Henry 1979), and the weather conditions (Hill and Henry 1981). In Ontario, the brake force trailer (ASTM E 274-79) technique has been chosen.

There are also indirect measures of frictional properties. These involve measurements of the kind and amount of surface texture. Developments up until 1972 were summarized by Rose *et al.* (1972). Volumetric methods can be used for measuring the projection of coarse aggregate above the surface, or the macrotexture. The sand patch, silicone putty, or grease specimen techniques have been reviewed by Yager and Buhlmann (l982). Direct contact measurements, using stylus techniques (Orchard *et al.* 1970) have also been investigated. A remote sensing technique using stereophotography was employed in the

United Kingdom by Sabey and Lupton (1967). In general, satisfactory correlations with skid-resistance have not been obtained with these indirect techniques. Using these techniques, only one or two textural components are measured, whereas frictional properties are determined by all the textural features of the surface.

In Ontario, a remote sensing technique has been developed, using stereo-photography, which has an excellent correlation with skid-resistance at high speeds (r = 0.93, n = 195) by Schonfeld (1970). This technique has been adopted by ASTM (ASTM E 770-80). A number of surface properties, such as angularity and amount of coarse aggregate, projection of coarse aggregate above the surface, microtexture of the coarse aggregate, and matrix are recognized and measured (Schonfeld 1974; Holt and Musgrove 1977). Subsequent work on this technique has been directed toward automation of the collection of data (Howerter and Rudd 1976; Holt and Musgrove 1982).

The use of indirect measurement techniques allows the recognition of those properties that improve friction, and, subsequently, enable design modifications of the asphaltic concrete, or a change in aggregate type, to improve friction. As a result of work using indirect measurements, it has been recognized that there are two basic properties, macrotexture and microtexture, required to give a pavement satisfactory friction. Macrotexture, or projection of coarse aggregate above the surface, provides bulk water drainage and reduces the tendency of tires to hydroplane on wet surfaces at high speeds. Good microtexture, or the "sandpaper-like feel" of the surface, is important at all speeds in penetrating the remaining thin water film and coming in contact with the tire. Aggregates make up about 95% of asphaltic concrete, thus the nature and properties of the aggregate determine the subsequent frictional performance of asphalt pavements.

TABLE 1. PRINCIPAL TYPES OF SURFACE COURSE ASPHALT MIX USED IN ONTARIO

MIX TYPE	MAXIMUM STONE SIZE	NORMAL STONE CONTENT PERCENT	FINE AGGREGATE TYPE	AADT*
HL4	16.0 mm	40 – 50	natural sand	<2500
HL3	13.2 mm	40 – 50	natural sand	<2500
HL1	13.2 mm	40 – 55	natural sand	>2500 <5000
D.F.C.	13.2 mm	45 – 55	angular screenings	>5000
O.F.C.	9.5 mm	65 – 70	angular screenings	>5000 Urban

* Annual Average Daily Traffic

TABLE 2.
PHYSICAL REQUIREMENTS FOR COARSE AGGREGATE FOR PRINCIPAL ASPHALT SURFACE COURSE MIXES

PHYSICAL TEST	ASPHALT MIX TYPE		
	HL1	HL3	HL4
Los Angeles Abrasion & Impact Test, % Max. Loss	15	35	35
Magnesium Sulphate Soundness Test, % Max. Loss	5	12	12
Absorption by Weight, % Max.	1.0	1.75	2.0
Petrographic Number, Max.	100	135	160
Loss by Washing Pass 75 μm Sieve, % Max.	1	1.3*	1.3*
Flat and Elongated Particles, % Max.	20	20	20
Crushed Particles, % Min.	100	60	60

* When Quarried Rock is Used, a Maximum of 2% is permitted

ONTARIO ASPHALT PAVEMENT TYPES

On secondary highways, with generally less than 2,500 AADT/lane (Annual Average Daily Traffic), the types of asphaltic concrete used for the surface course are designated as HL3 (hot-laid) or HL4 (Table 1). The coarse aggregate physical test requirements are shown in Table 2. HL3 aggregates have a maximum size of 13.2 mm, allowing a minimum mat thickness of about 25 mm, but normally 38 mm. HL4 aggregates have a maximum size of 16.0 mm, allowing a minimum mat thickness of about 30 mm, but normally 44 mm. There is, except in parts of northern Ontario, no requirement as to the frictional properties of the aggregates.

In northern Ontario, most locally available aggregates are of igneous or metamorphic origin, with hard wear-resistant minerals. These aggregates generally give good frictional properties in contrast to pavements made with carbonates of low wear-resistance. Drivers become used to the good friction supplied by the local aggregates. When carbonate aggregates of relatively poor frictional properties are used for paving, the frictional properties, compared to granitic pavements, have been poorer, yet driver behaviour, used to the better friction, has not been modified. The result has been an increase in complaints about the friction of the road surface in these locations. The level of friction required in any area depends, to a large extent, on driver behaviour and expectations, as much as on road geometry and traffic volumes. As a result, in many parts of northern Ontario, where granitic aggregates are commonly used, the use of aggregate containing carbonate rocks is prohibited.

On highways carrying more than 2,500 AADT/lane, the types of asphalt used are designated as HL1, DFC (dense friction course), or OFC (open friction course) (see Table 1). HL1 asphalt has the same gradation as HL3, only the nature of the stone is different. DFC has angular fine aggregates to increase stability, and to prevent the embedment of the stone into the mat. OFC is an open graded mix, allowing internal drainage through the matrix rather than over the pavement surface. This prevents a buildup of water on the pavement surface, which reduces the likelihood of hydroplaning at high speeds, reduces water spray, and also reduces tire noise. It is used on very high volume, urban highways.

The selection of the coarse aggregate for HL1, DFC, and OFC pavements is based on actual performance of the aggregate in test sections. At present, the following aggregate types are used: trap rock (metavolcanic), steel slag, blast furnace slag, dolomitic sandstone, and some igneous gravels from the north shore of Lake Huron.

SEARCH FOR NEW AGGREGATE SOURCES

In the years 1979, 1980, and 1981, an annual average of 250,000 tonnes of HL1, DFC, and OFC aggregates were used in Ontario. The Ministry of Transportation and Communications (MTC) uses about 15 million tonnes of aggregates every year for highway construction. Thus, the supply of skid resistant aggregates is a small specialized market. Producers have not found it worthwhile to open a deposit devoted exclusively to the supply of these specialized aggregates. These aggregates are usually the waste by-products of mining and smelting operations; Trap rock from iron mining or roofing granule operations, and slags from iron or steel production. As a result, supply is controlled by economic considerations unrelated to the needs of highway construction. Thus, cutbacks in the steel industry or closing of an iron mine have had an adverse effect on the supply of these aggregates. In recognition of these problems of supply, alternative sources were investigated.

Three criteria were established for selecting new sources: (1) the source should be an open deposit, preferably with production facilities; (2) the sources should be closer to the area of use than those currently available to reduce haulage, an ever-increasing component of the cost of aggregate, and (3) the sources should have frictional properties as good as, or better than, those currently available.

A literature review was conducted (Truax-Harrison 1979). The purpose was to recognize the properties and nature of potential aggregate sources, and to find those test methods most suitable for measuring frictional properties of aggregates.

WEAR-RESISTANCE (MACROTEXTURE)

Macrotexture is determined by the wear-resistance of the aggregate, and also by the mix design of the asphaltic concrete. On heavily used pavements, a high stone content, in a mix of high stability, is required to resist the embedment of the coarse aggregate into the mat by the repeated impact of tires (Ryell *et al.* 1979; Clark 1980). The high stability is achieved by using an angular fine aggregate, such as crusher screenings or manufactured sand. Rounded sand from gravel deposits does not normally give high stability, due to its lack of angularity and its rather smooth or polished surfaces.

The ability of rock to resist abrasion is determined by the hardness of the constituent mineral grains and the strength of the bond between them. A quartz sandstone of Moh hardness 7 has excellent resistance to natural abrasives found on the pavement, but only if the individual grains are well-bonded together (usually with calcite or dolomite cement). Poorly cemented, friable sandstones have low resistance to abrasion, and are unsuitable, despite the hardness of the individual grains.

Figure 1 shows the typical Moh hardness of various minerals, rock types, and abrasive agents found in Ontario. MTC uses about 1 million tonnes of ice control sand annually. This sand usually contains significant amounts of quartz and other hard materials. These minerals are a potent abrasive, especially on the carbonate rocks commonly used for HL3 and HL4 paving in Southern Ontario. Tire studs with a Moh hardness of 9 also have considerable abrasive power, even on igneous rocks. It was this factor which led to their prohibition in Ontario (Smith and Schonfeld 1972).

The test selected as the most suitable for measuring wear-resistance was the Aggregate Abrasion Value (AAV) test (BS 812, 1975). This is a modern development of the old Dorry abrasion test (Knight and Knight 1948). Two test specimens are made. Each specimen consists of at least 24 cubical particles, passing the 13.2 mm, and retained on the 9.5 mm sieve, held in an epoxy binder. These specimens are laid aggregate face down on a 600 mm diameter steel lap (Figures 2, 3). Each specimen is held down with a 2 kg weight. The lap is rotated for 500 revolutions at a speed of 30 revolutions/min. A coarse sand is fed onto the lap at a rate of 800 g/min in front of each specimen. The abrasive used in Ontario is Ottawa silica sand (ASTM C 109). The mass loss of each specimen in the test is recorded. The result reported is expressed as the percentage loss (in mass) of an assumed 33 ml volume of the aggregate. The lower the value obtained in the test, the more resistant the aggregate is to abrasion.

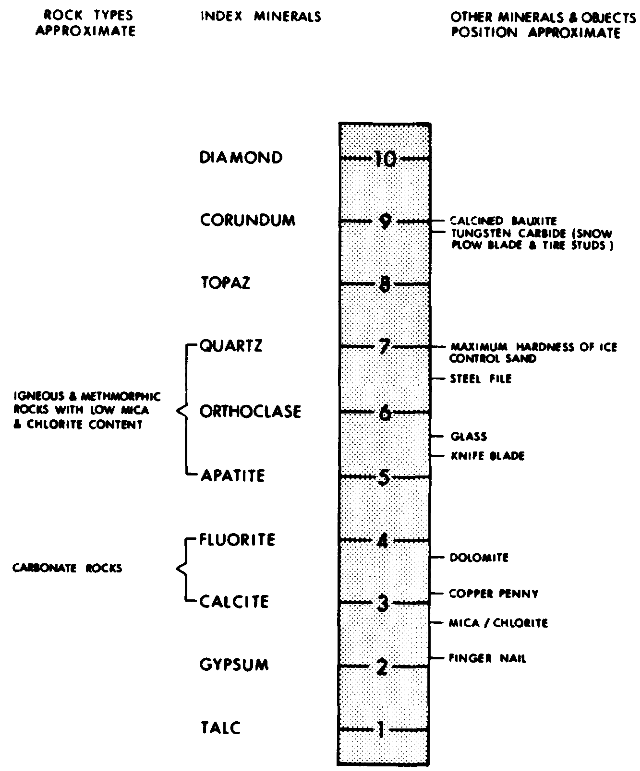

Figure 1. *Mohs scale of hardness.*

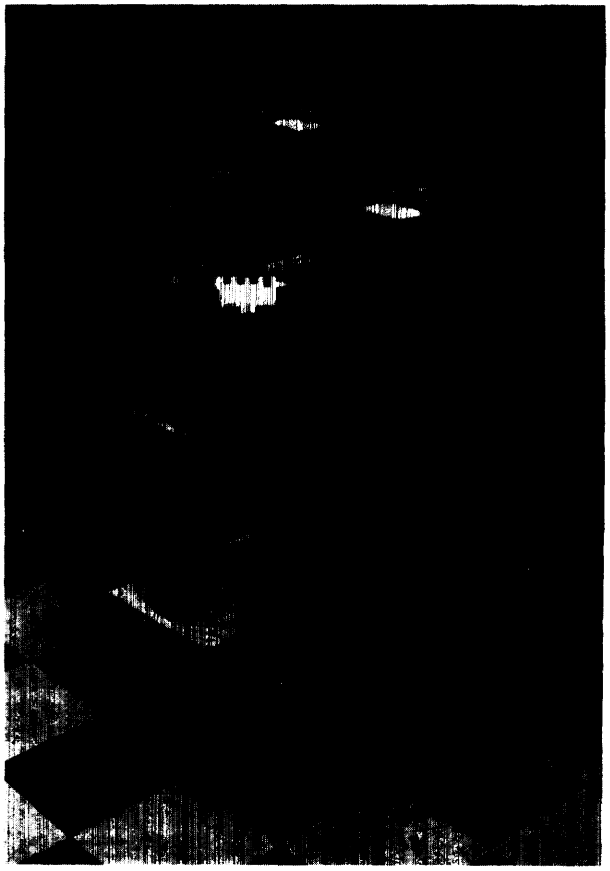

Figure 2. Aggregate abrasion value machine.

In the United Kingdom, the standard abrasive used in this test is Leighton Buzzard sand. A short study was done on the correlation between results obtained using the Leighton Buzzard sand and Ottawa sand. Twenty different aggregates were selected and tested using both sands. The rate of flow of the sand was regulated to 800 $\pm$ 10 g/min. The results are shown in Table 3 and Figure 4. It can be seen that there is an excellent correlation between the results obtained using the two different abrasives.

The Aggregate Abrasion Value (AAV) test is a more realistic measure of the resistance of aggregate to surface abrasion than other so-called abrasion tests, such as the Los Angeles Abrasion and Impact Test. The mechanism employed in the test and the abrasive used reflect, to some degree, the actual conditions found on pavement surfaces: abrasion caused by tires, ice control sand and other debris. In the United Kingdom, Hosking (1973) found that one unit of AAV was equivalent to a difference of 0.05 mm in texture depth after nine years of heavy traffic.

POLISH RESISTANCE (MICROTEXTURE)

Polish resistance is much harder to measure and predict than wear-resistance. Microtexture is the fine scale (less than 0.5 mm) texture possessed or developed by the individual aggregate particles. It may be thought of as the "sandpaper-like feel" of the particle. Most materials, when freshly crushed, have a good microtexture. Desirable aggregates are those that either resist loss of this texture or behave in such a manner as to regenerate this texture. These are generally termed "polish-resistant aggregates".

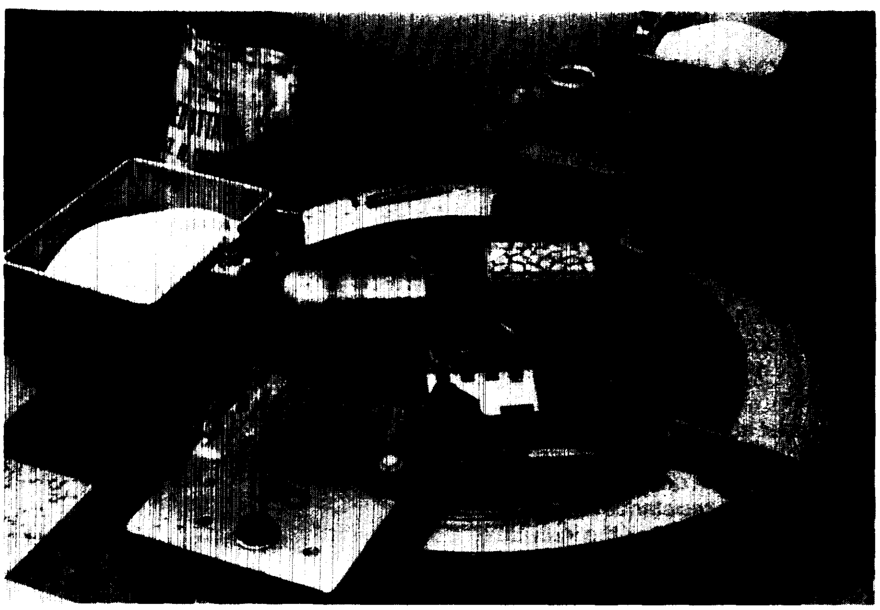

Figure 3. Aggregate abrasion value machine showing the steel lap, abrasive sand feeders and aggregate test sample.

TABLE 3. AGGREGATE ABRASION VALUES USING LEIGHTON BUZZARD AND OTTAWA SILICA SAND ABRASIVES

AGGREGATE TYPE	LABORATORY TEST			
	AGGREGATE ABRASION VALUE		POLISHED STONE VALUE	RELATIVE DENSITY
	LEIGHTON BUZZARD	OTTAWA C 109		
Blast furnace slag	19.1	18.0	54	2.24
Trap rock	2.2	2.5	44	3.03
Trap Rock	2.5	2.7	45	2.95
Dolomitic sandstone	4.2	4.0	62	2.64
Sandstone	9.3	9.8	68	2.50
Blast furnace slag	16.1	15.2	52	2.19
Sandy limestone	47.6	38.5	72	2.43
Quartzite	2.0	2.1	40	2.64
Dolostone	10.1	10.4	36	2.81
Gabbro	3.0	2.7	46	2.88
Gravel, granite	2.1	2.0	45	2.73
Granite	4.5	4.4	52	2.62
Granite gneiss	7.3	6.1	58	2.81
Sandstone	14.4	15.0	67	2.38
Gabbro	3.0	3.3	45	3.01
Steel slag (B.O.F.)	2.9	3.2	58	3.33
Blast furnace slag	16.2	14.5	51	2.09
Steel Slag (B.O.F.)	3.6	5.1	59	2.97
Limestone	24.7	22.9	51	2.50
Synopal	3.1	3.9	48	2.02

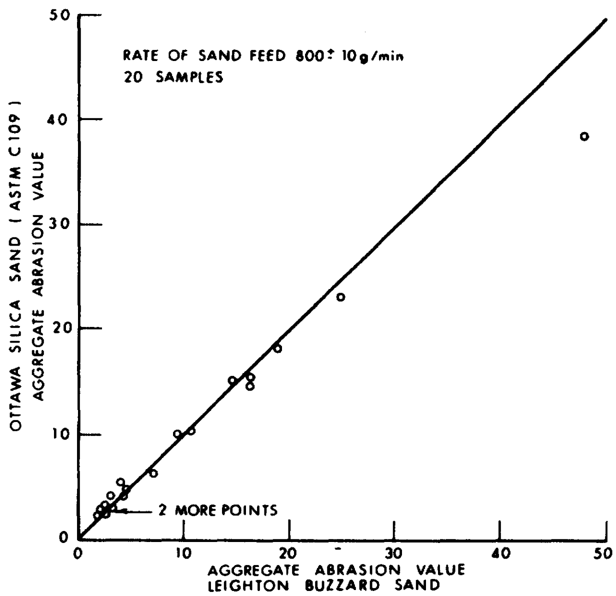

Figure 4. *Aggregate abrasion value with Ottawa silica sand plotted against Leighton Buzzard sand.*

Figure 5. *Polished stone value machine.*

The microtexture developed by an aggregate is not only a function of the physical nature of the material, but is also a function of the environment in which it is used. The amount of traffic, the nature and availability of abrasives and climatic conditions all determine the degree to which an aggregate will polish, and the microtexture that will be developed. Response of the aggregate to these environmental conditions is determined by such attributes as mineralogy, grain size and grain size distribution, and the porosity and pore size distribution of the individual particles.

The test selected as being the most suitable for evaluating microtexture was the Polished Stone Value (PSV) test (BS 812, 1975). This accelerated polishing technique was developed in the United Kingdom (Maclean and Shergold 1959), using a sliding pendulum to measure the frictional properties of the aggregate after three hours of abrasion with coarse emery, and three hours of polishing with a fine emery powder (Figures 5, 6, 7). This test has been extensively investigated, both in the United Kingdom (Hosking 1968), and in the USA (Underwood *et al.* 1971). The higher the PSV obtained in the test, the better the frictional properties of the aggregate.

A major drawback of the PSV test is that the final polish with the fine abrasive does not always create the polish experienced in the field. The emery powder used for the final three hours of the test may continue to abrade softer aggregate particles, rather than polishing them to the same degree as is experienced under field conditions. This sometimes results in a PSV higher than warranted by the field performance. The softer, porous carbonate rocks are susceptible to this problem. Quartzites and blast furnace slag may also give misleading results. Hosking (1973) showed that frictional properties of pavements made with these two aggregate types were equivalent to those made with aggregates which were 3 PSV units higher. In other words, the PSV test underestimates the frictional properties of quartzites and blast furnace slag by 3 units. The field performance and AAV of aggregates must be considered together with PSV before selection for use in asphaltic concrete.

Despite these anomalies, it has been shown by Maclean and Shergold (1959), and Szatkowski and Hosking (1972) that the PSV is the most important aggregate characteristic affecting skidding resistance of asphalt pavements. Studies in Ontario have confirmed the significance of PSV of aggregates in determining frictional properties of pavements (Heaton *et al.* 1978; Kamel *et al.* 1982).

Figure 6. *Polished stone value machine showing road wheel with aggregate samples.*

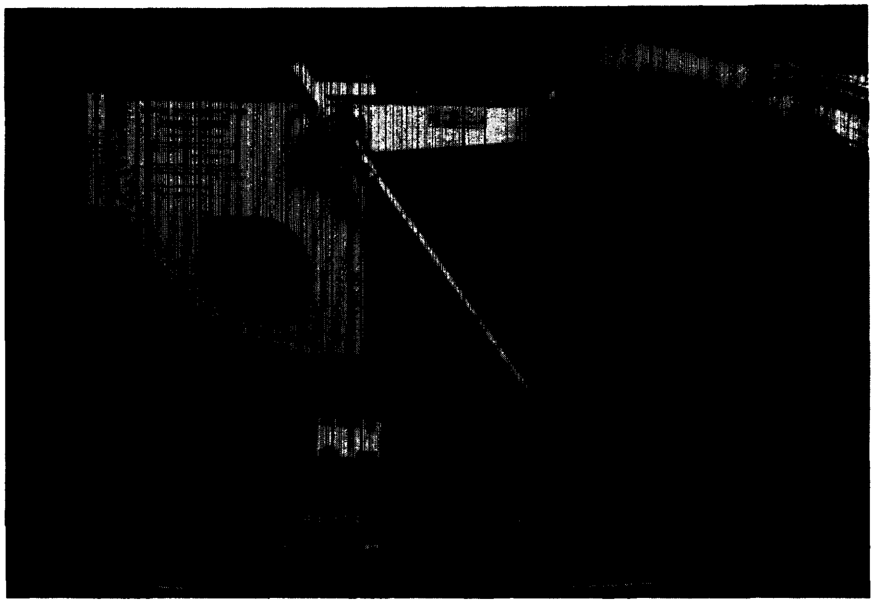

Figure 7. Portable skid resistance tester used for evaluating frictional properties of aggregate following the polishing test. Rubber pad on base of swinging arm strikes aggregate sample. The frictional value is recorded by pointer on the scale.

FIELD WORK

Following the literature review, and a review of the performance of some existing pavements, a number of rock types were identified as targets for exploration and evaluation. These were: basaltic rocks such as diabase and gabbro, granites, calcareous sandstones and slags. Study of existing geological maps and reports led to the identification of likely deposits. These deposits were visited, and samples taken. In unexposed or undeveloped deposits, diamond drilling was conducted (Rogers 1980). Generally, only those deposits were studied where subsequent commercial production was viable. In addition, a general survey of the frictional properties of Ontario aggregates was also conducted. The location of the deposits tested are shown in Figure 8.

LABORATORY TESTING

Samples were subjected to normal aggregate durability tests such as: Magnesium Sulphate Soundness (MTC-LS-606), Los Angeles Abrasion and Impact (MTC-LS-603), Absorption and Bulk Relative Density (MTC-LS-604), Petrographic Examination (MTC-LS-609), and Polished Stone and Aggregate Abrasion Value tests (BS-812, 1975). In the case of calcareous sandstones, sandy carbonates, and carbonate gravels, an insoluble residue test (MTC-LS-613) was conducted. Detailed petrographic examination involving the study of thin sections was also carried out. The results of testing are shown in Table 4.

CRITERIA FOR SELECTION

For further investigation, the criteria in Table 5 had to be met or exceeded. The owner or operator of the deposit also had to be interested in subsequent commercial production. Note that the values given in this table are limiting values, and not necessarily the most desirable values. For instance, in the case of PSV, the higher the value, the better. Note that the Los Angeles Abrasion and Impact Test was not used. Many excellent materials, such as blast furnace slag, granites, and granite gneiss, gave values that exceeded the 35% maximum loss normally allowed in Ontario.

IMPLEMENTATION

Following the identification of likely sources, the economics were considered. If the use of a new source would lead to immediate savings in cost compared to currently available sources, a decision was made to authorize immediate use, with test sections being placed on the first contract. Alternatively, a decision was made to construct a trial test section to evaluate long-term durability and frictional performance before further use was considered. Not all test sections have been constructed to evaluate the aggregates alone; they are also used to evaluate the effectiveness of various types of asphalt mix design (Ryell *et al.* 1979; Kamel *et al.* 1982).

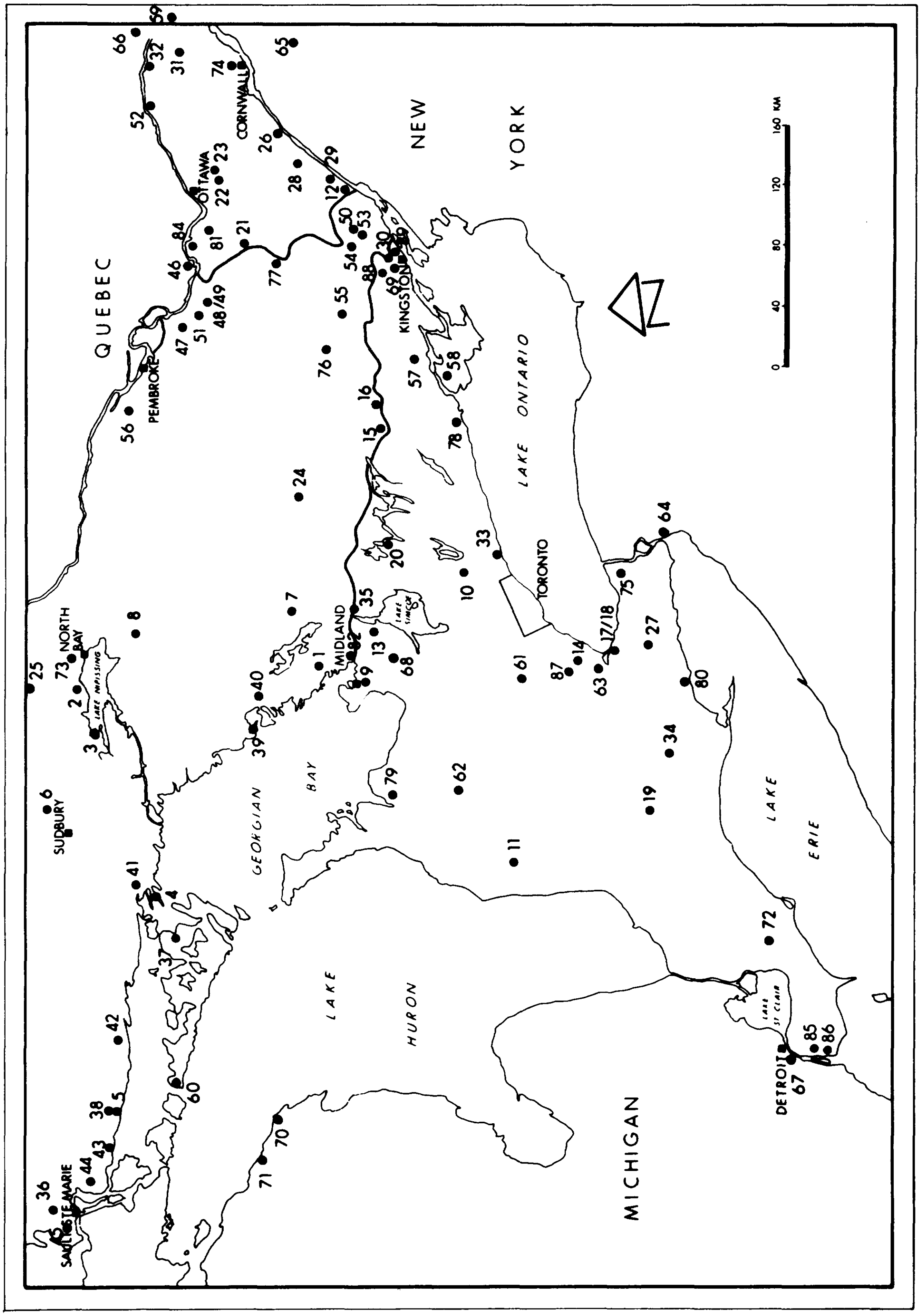

***Figure 8.** Aggregate sample locations. Results of laboratory tests are given in Table 4.*

TABLE 4. LABORATORY TEST DATA FOR AGGREGATE SAMPLES FROM ONTARIO. SAMPLE LOCATIONS ARE GIVEN IN FIGURE 8.

SOURCE DATA							LABORATORY TEST DATA							
LOC NO.	SOURCE NAME	Q	G	NTS MAP NAME	GRID REF.	AGGREGATE TYPE	PSV	AAV	$MgSO_4$ % loss	L.A. ABR % loss	ABS^n %	RELATIVE DENSITY	PETRO. NO.	INSOL RES %
1	M.T.C.	X		Penetanguishene	962790	Granite gneiss	47	–	0	30	0.35	2.77	104	–
2	Bourassa	X		Sturgeon Falls	953385	Granite gneiss	47	–	1	33	0.53	2.64	119	–
3	Perrault	X		Verner	635296	Granite gneiss	47	–	0	39	0.50	2.65	104	–
4	Indusmin	X		Little Current	545900	Quartzite	42	2.1	0	22	0.30	2.64	100	–
4	Indusmin	X		Little Current	545900	Diabase	46	4.0	2	14	0.62	2.97	118	–
5	M.T.C.		X	Iron Bridge	127274	Granite, volcanic, greywacke	46	1.5	1	13	0.40	2.75	100	–
6	Pioneer		X	Capreol	150615	Greywacke & granite	45	–	0	14	0.47	2.71	102	–
7	Fowler		X	Bracebridge	345935	Granite gneiss	45	–	4	43	0.60	2.68	141	–
8	Ciglen		X	South River	276924	Gneiss & granite	49	5.4	4	47	0.73	2.67	115	–
9	Cedarhurst		X	Elmvale	888527	Carbonate & gneiss	45	–	4	27	0.92	2.67	120	37
10	Miller		X	Newmarket	523808	Carbonate	41	–	3	23	0.70	2.66	121	<20
11	Whitechurch		X	Wingham	648619	Carbonate	41	–	6	23	2.16	2.58	131	13
12	Henderson	X		Brockville	370295	Sandy dolostone (March)	59	4.2	5	15	0.85	2.65	110	53
13	Uhthoff	X		Orillia	195495	Limestone (Gull River)	42	–	7	20	0.91	2.68	101	1
14	Nelson	X		Hamilton	905060	Dolostone (Amabel)	45	–	2	28	1.54	2.69	102	0.1
15	3M	X		Campbellford	755245	Trap (Metavolcanic)	46	3.5	0	14	0.37	2.90	112	–
16	Armbro	X		Campbellford	890270	Trap (Metavolcanic)	45	2.0	2	13	0.40	3.02	105	–
17	National Slag	–	–	Hamilton	993903	Blast Furnace slag (Air cooled)	52	15	2	44	4.32	2.09	–	–
18	Dofasco Red-D-Mix	–	–	Grimsby	021876	Steel slag (BOF)	58	3.2	1	17	2.05	3.33	–	–
19	Warren		X	Lucan	873689	Carbonate	43	–	2	24	1.27	2.64	128	<20
20	Royel		X	Lindsay	751278	Carbonate	43	–	3	27	0.97	2.65	117	<20
21	Duffy	X		Carleton Place	105015	Dolostone (Oxford)	47	6.7	1	–	0.75	2.74	117	12
21	Duffy	X		Carleton Place	105015	Dolomitic sandstone (March)	57	5.0	1	18	0.58	2.61	111	79
22	Armbro	X		Ottawa	545165	Dolomitic sandstone (March)	58	5.1	5	27	0.67	2.64	127	60
22	Armbro	X		Ottawa	545165	Dolostone (Oxford)	47	8.2	2	19	0.70	2.75	108	
23	Drummond	X		Ottawa	566160	Dolomitic sandstone (March)	60	5.1	6	45	0.57	2.63	136	67
24	Friar		X	Wilberforce	030907	Granite & gneiss	50	6.4	3	43	0.57	2.67	158	–
25	M.T.C.		X	Ingall Lake	917818	Granite & greywacke	45	3.0	1	14	0.60	2.74	104	–
26	Fetterly	X		Morrisburg	733635	Weathered dolostone (Oxford)	58	20.4	41	24	3.55	2.57	198	–
27	Oneida	X		Dunnville	860560	Calcitic sandstone (Oriskany)	64	6.1	2	29	1.26	2.55	107	53
28	M.N.R.	X		Merrickville	573590	Quartzite	47	3.2	1	33	0.40	2.63	100	–
29	Permanent	X		Brockville	475395	Dolomitic sandstone (March)	60	6.0	17	38	0.90	2.62	149	59
30	Hughes	X		Gananoque	900116	Sandstone (Potsdam)	68	9.8	32	81	1.58	2.50	337	96
31	Kennedy	–	–	Alexandria	233303	Sandstone (Rockcliffe)	63	–	12	–	1.92	2.55	122	85
32	I.M.S.	–	–	Hawkesbury	295510	Steel slag (Electric arc)	53	3.6	2	21	2.07	3.18	–	–
33	I.M.S.	–	–	Oshawa	679575	Steel slag (Electric arc)	53	3.1	0	23	2.25	3.15	–	–
34	Stelco	X		Woodstock	124690	Sandy limestone (Columbus)	72	39	24	59	3.72	2.42	224	24
35	Rama	X		Orillia	317532	Granite/Meta-arkose	53	4.4	7	42	0.50	2.64	115	–
36	Rankin	X		Sault Ste. Marie	054609	Sandstone (Root River, Jacobsville)	65	–	5	29	2.20	2.44	113	–

TABLE 4. CONTINUED

SOURCE DATA LOC NO.	SOURCE NAME	Q	G	NTS MAP NAME	GRID REF.	AGGREGATE TYPE	LABORATORY TEST DATA PSV	AAV	$MgSO_4$ % loss	L.A. ABR % loss	ABS^n %	RELATIVE DENSITY	PETRO. NO.	INSOL RES %
37	Rolston	X		Little Current	295835	Quartzite	42	–	1	26	0.30	2.63	100	–
38	Maple Ridge		X	Iron Bridge	129283	Granite, volcanic, greywacke	45	2.0	1	12	0.50	2.73	102	–
39	M.N.R.	X		Parry Sound	599238	Granite/meta-arkose	50	–	3	60	0.43	2.60	117	–
40	Macklaim	X		Sequin Falls	800225	Gneiss & diorite	48	4.0	3	35	0.50	2.85	135	–
41	Lawson	X		Whitefish Falls	435075	Quartzite	41	2.4	1	–	0.38	2.64	100	–
42	Beamish		X	Algoma	505189	Arkosic sst. & granite	50	2.2	1	–	0.43	2.69	110	–
43	J. Heidgen	X		Bruce Mines	868305	Diabase/gabbro	46	2.7	1	13	0.43	2.73	100	–
44	Bar River	X		Lake George	302472	Quartzite	41	1.9	1	–	0.23	2.63	100	–
45	McLean		X	Sault Ste. Marie	978606	Granite, gneiss & volcanic	47	2.0	2	13	0.53	2.77	100	–
46	Hilton Mines	X		Arnprior	955387	Granite & gneiss	47	3.3	4	22	0.73	2.66	135	–
47	Rock Cut	–	–	Cobden	600430	Gabbro	47	3.4	2	15	0.40	3.05	100	–
48	Rock Cut	–	–	Renfrew	810330	Gneiss	58	6.1	5	40	0.64	2.81	105	–
49	Rock Cut	–	–	Arnprior	8332	Calcareous gneiss	49	3.3	2	24	0.50	2.66	113	92
50	Wiesener	X		Gananoque	080265	Sandstone (Potsdam)	67	15.0	16	55	2.57	2.38	171	96
51	Jamieson		X	Renfrew	720360	Granite, marble, gneiss	46	3.1	3	22	0.74	2.70	108	–
52	Rock Cut	–	–	Hawkesbury	052535	Gneiss	63	8.2	3	22	0.97	2.73	170	–
53	Rock Cut	–	–	Gananoque	047227	Granite	48	4.1	1	30	0.53	2.62	104	–
54	Brown	X		Westport	295045	Coarse grained granite	44	2.9	1	29	0.47	2.66	100	–
55	Mountain Grove	X		Tichborne	5455	Gabbro	45	3.3	1	–	0.33	3.01	100	–
56	Hoffman		X	Pembroke	203837	Gneiss & granite	51	5.0	5	29	0.80	2.63	111	–
57	McGrogan	–	–	Belleville	193968	Limestone (Bobcaygeon)	51	23	–	32	2.37	2.50	100	0.3
58	Rock Cut	X		Belleville	075844	Granite	47	1.9	–	23	0.50	2.64	100	–
59	Mont Rigaud		X	Vaudreuil	5430	Granite	49	2.9	2	26	0.84	2.60	113	–
60	Manitoulin Dol	X		Meldrum Bay	277863	Dolostone (Amabel)	36	10.4	3	25	0.40	2.81	100	0
61	Caledon		X	Bolton	816556	Carbonate, sandy, granite	46	8.2	10	26	1.37	2.62	135	<40
62	Durham		X	Durham	157907	Carbonate	44	–	3	26	1.44	2.68	116	<10
63	Steetley (Stelco)	–	–	Hamilton	935820	Steel slag (BOF)	59	5.1	4	22	1.84	2.97	–	–
64	Bethlehem	–	–	Lackawana, N.Y.		Steel slag (BOF)	60	3.5	2	22	2.24	3.19	–	–
65	Hannawa	X		Potsdam, N.Y.		Sandstone (Potsdam)	67	9.9	59	61	2.90	2.44	172	–
66	Whissell	X		La Chute	545625	Gneiss	47	2.8	3	21	0.47	2.72	100	–
67	E.C. Levy	–	–	Detroit	–	Steel slag (BOF)	57	3.3	2	20	1.47	3.44	–	–
67	E.C. Levy	–	–	Detroit	–	Blast furnace slag (air cooled)	54	13.1	4	42	3.91	2.34	–	–
68	Beamish		X	Elmvale	010360	Limestone & granite	50	5.5	5	26	0.66	2.67	124	39
69	Glen Lawrence	X		Gananoque	804045	Limestone (Gull River)	42	9.5	7	24	0.44	2.70	135	<5
70	Presquile	X		Michigan	–	Carbonate (Devonian)	48	11.4	1	26	1.38	2.57	108	1
71	Calcite (U.S. Steel)	X		Michigan	–	Carbonate (Devonian)	49	18.7	3	–	1.84	2.49	127	0.5
72	Huron		X	Chatham	150973	Carbonate & granite	42	5.2	2	21	0.84	2.68	134	30
73	Standard		X	North Bay	160433	Gneiss & granite	51	3.8	1	28	0.43	2.68	109	–
74	MacLeod	X		Cornwall	200915	Limestone (Gull River)	44	9.3	5	21	0.37	2.70	109	5
75	Walker Bros	X		Niagara	485770	Dolostone (Lockport & Decew)	52	11.2	17	24	1.54	2.67	113	–
76	W.L. Wise		X	Mazinaw Lake	277624	Gneiss & granite	51	5.2	4	37	0.80	2.61	144	–
77	Lanark S & G		X	Carleton Place	945887	Marble, gneiss & granite	49	6.9	8	37	0.97	2.69	123	
78	Trent Valley		X	Trenton	745785	Limestone	40	6.7	2	21	0.60	2.68	115	
79	Sydenham	X		Owen Sound	110350	Dolostone (Amabel)	48	13.5	2	31	1.47	2.64	101	

TABLE 4. CONTINUED

SOURCE DATA LOC NO.	SOURCE NAME	Q	G	NTS MAP NAME	GRID REF.	AGGREGATE TYPE	LABORATORY TEST DATA PSV	AAV	$MgSO_4$ % loss	L.A. ABR % loss	ABS^n %	RELATIVE DENSITY	PETRO. NO.	INSOL RES %
80	Stelco	–	–	Simcoe	760400 (APPROX)	Steel slag (BOF)	58	3.9	1	15	2.21	3.19	–	–
81	Smith	–	–	Ottawa	258245	Sandstone (Nepean)	54	4.5	9	44	1.63	2.50	131	>80
82	Cook	X		Penetanguishene	065584	Limestone (Gull River)	50	8.4	7	17	1.49	2.65	113	<10
83	Fowler		X	Bracebridge	345920	Gneiss & granite	48	5.6	4	41	0.53	2.66	114	–
84	Kennedy	X		Arnprior	217320	Calcite Siltstone	58	10.7	32	25	1.81	2.62	158	84
85	Allied Chem	X		Amherstburg	340694	Carbonate	46	15.4	2	28	1.07	2.63	103	<10
86	Smith	X		Amherstburg	276626	Carbonate	57	18.6	16	34	4.72	2.41	125	<10
87	Longstar		X	Hamilton	813143	Carbonate & Sandstone	53	10.2	17	21	1.61	2.61	156	–
88	Elginburgh	X		Sydenham	756078	Limestone (Gull River)	41	11.8	6	25	0.33	2.70	114	<10
89	Pittsburgh	X		Gananoque	835020	Limestone (Gull River)	44	8.1	12	18	0.84	2.70	111	<10
						NORTHERN ONTARIO & SPECIAL MATERIALS								
	Zysko	X		Thunder Bay	401730	Diabase	49	3.6	–	16	0.93	2.95	100	–
	Hamilton	X		Jarvis River	169316	Diabase	51	4.2	–	–	–	2.92	100	–
	M.T.C.		X	Temagami	863256	Greywacke & granite	46	2.4	–	–	0.57	2.74	106	–
	Pearl Lake	X		Loon	788923	Granite	45	–	0	27	0.40	2.61	100	–
	-----	–	–	-----	---	Synopal	48	3.9	1	19	1.77	2.02	–	–
	-----	–	–	-----	---	Expanded shale	65	29	–	–	7.66	1.51	–	–
	M.T.C.		X	Nassau Lake	940125	Carbonate & greywacke	45	3.8	4	20	2.11	2.55	185	–
	Marblehead	X		Ohio	–	Limestone	52	16.7	12	31	2.64	2.56	109	–
	M.T.C.		X	Pickerel Lake	158004	Granite & volcanic	47	2.7	1	14	0.53	2.71	113	–
	Grann		X	Loon	760901	Granite & sandstone	53	3.8	12	25	1.04	2.61	115	–

Q = Quarry Source, G = Gravel source, PSV = Polished Stone Value, AAV = Aggregate Abrasion Value, $MgSO_4$ = Magnesium Sulphate Soundness Test, L.A. ABR = Los Angeles Abrasion and Impact Test, ABS^n = Absorption, PETRO NO. = Petrographic Number, INSOL RES = Insoluble residue +75μm

TABLE 5. LIMITING TEST VALUES USED TO SELECT SOURCES FOR SUBSEQUENT INVESTIGATION

TEST METHOD	LIMITING VALUE
Magnesium Sulphate Soundness, Max. %	12
Absorption (natural aggregates), Max. %	2
Polished Stone Value (PSV) Min.	50
Aggregate Abrasion Value (AAV), Max.	6
Petrographic Number, Max.	145
Insoluble Residue Retained on 75 μm sieve (sandy carbonates only), Min. %	45

The frictional properties of these test sections are normally measured using a brake force skid trailer (ASTM E 274-79). Remote sensing (Holt and Musgrove 1977) and the mu-meter (ASTM E 670-79) techniques have also been used.

Long term durability has been evaluated by field inspection and remote sensing, to observe ravelling and aggregate surface loss due to freezing and thawing or asphalt stripping, and by Benkleman Beam to evaluate wear leading to wheel track rutting. Samples of the pavement were also taken to check for compaction, voids, correct mix proportions, and Marshall stability.

RESULTS

Available Sources

In 1970, two sources of trap rock (metavolcanic) were authorized for use on HL1 pavements. In 1983, one blast furnace slag, three steel slags, three dolomitic sandstones, and one igneous gravel source, in addition to the original two trap rock sources, were being or had been used for HL1 paving. In addition, other sources of aggregates, such as granite, diabase, quartzite, and other sources of steel slag, and blast furnace slag, were being evaluated in test sections.

Cost

Figure 9 shows the per-tonne cost for HL1, DFC, and OFC mixes placed in the years 1979, 1980, and 1981. Cost includes cost of aggregates, haulage, placing and compaction, but excludes the cost of liquid asphalt cement. It can be seen that dolomitic sandstone, a locally available and recently developed source for use in the Ottawa area, gave the lowest cost per tonne. It is also worth noting that, as the quantity of asphaltic concrete required on a contract increases, the unit cost is generally reduced.

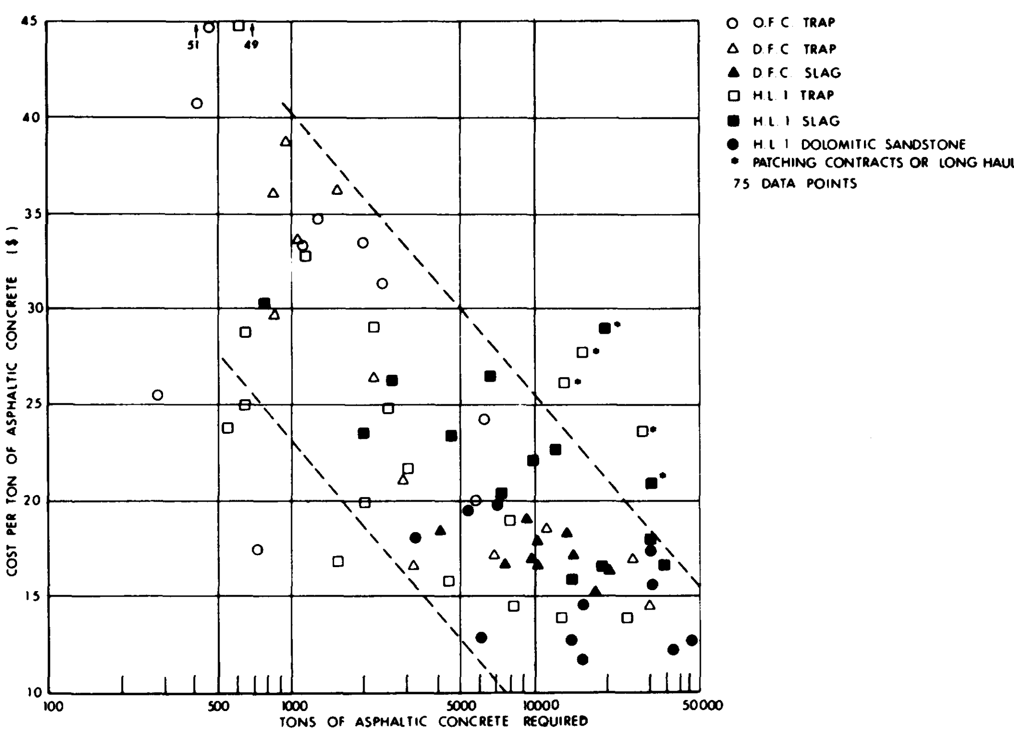

Figure 9. Cost per ton of mix plotted against quantity for 1979-1981 contracts.

Frictional Performance

The frictional properties of pavement are notoriously difficult to measure and compare. Properties of the aggregate are but one factor in determining the friction. Age, amount and type of traffic, mix design and time of year all play an important part in determining the friction obtained.

In the following examples, all variations in environment and pavement properties, other than the coarse aggregate properties, have been eliminated. This has been achieved by using two different coarse aggregates on the same highway, paved at the same time, using similar or identical fine aggregates in similar asphalt mix designs. Figures 10, 11, 12, 13, 14, and 15 all show that, with increasing PSV, the SN (skid number) also increases. This does not necessarily mean that the use of an aggregate with high PSV will ensure a high SN. Choice of the correct asphalt mix design will also play an essential role as can be seen in Figure 15.

DISCUSSION

Studies to predict skid resistance of asphalt surfaces have often been hampered by the failure to use an adequate measure of resistance of aggregate to abrasion. In North America and Australia, the Los Angeles Abrasion and Impact Test has been used without much success. Figure 16 shows a plot of Aggregate Abrasion Value against Los Angeles Abrasion and Impact Test Value. It can be seen that an aggregate with a low (less than 15% loss) Los Angeles Abrasion and Impact loss will always have good resistance to abrasion as measured by AAV. The converse

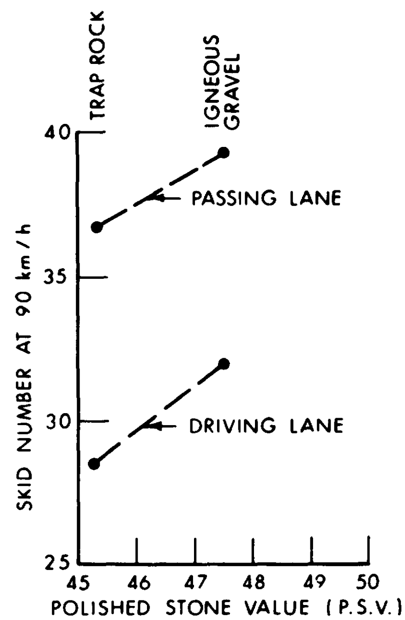

Figure 11. Skid number plotted against polished stone value (PSV) for HL1 after 4 years, Highway 11 near Orillia, 3125 AADT/lane.

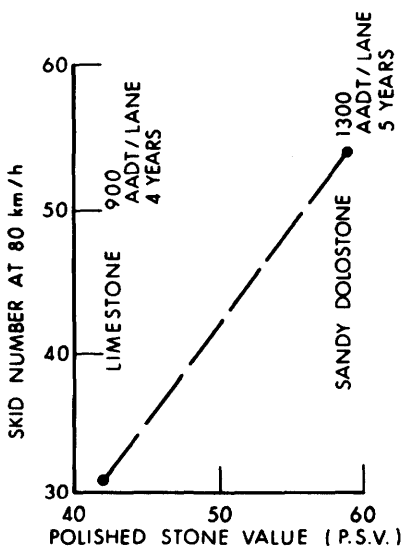

Figure 10. Skid number plotted against polished stone value (PSV) for HL4 after 4 and 5 years, 1000 Island Parkway.

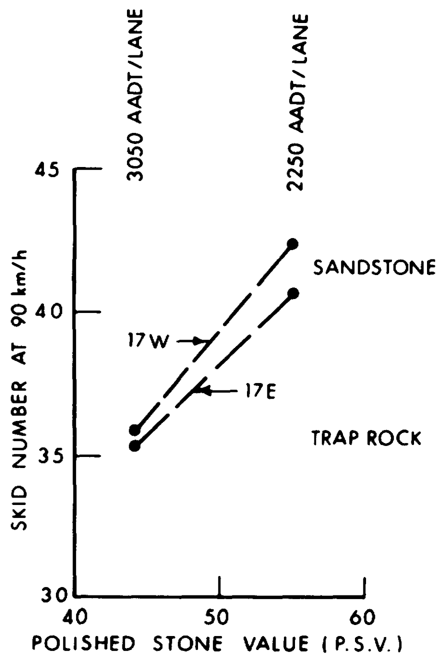

Figure 12. Skid number plotted against polished stone value (PSV) for HL1 after 2 years, Highway 17 near Arnprior.

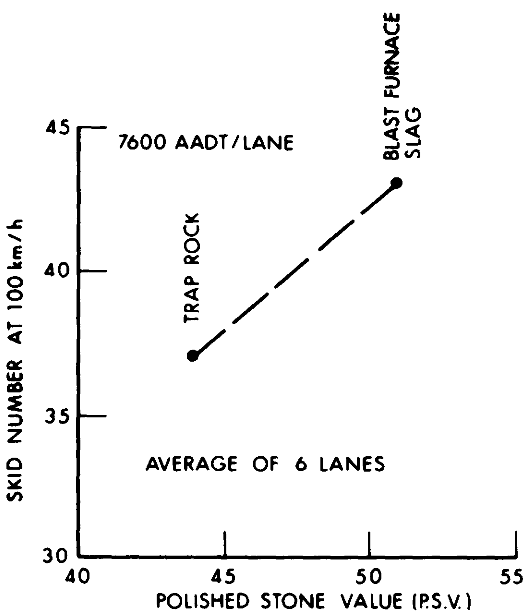

Figure 13. Skid number plotted against polished stone value (PSV) for open friction course on Highway 400 north of Highway 401 after 1 year.

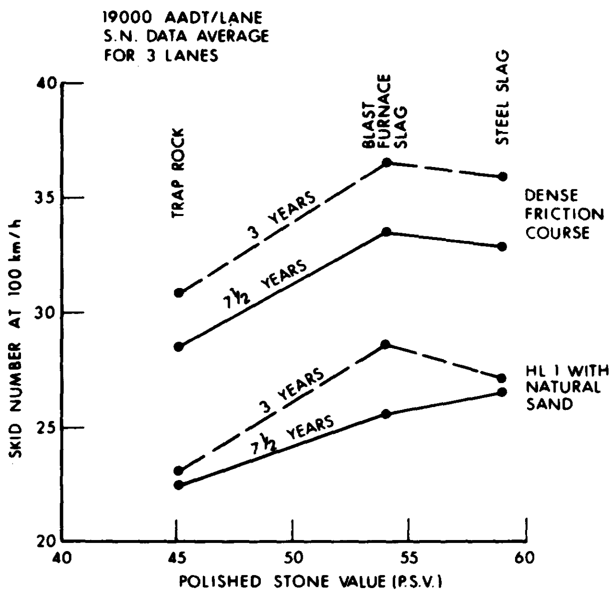

Figure 15. Skid number plotted against polished stone value (PSV) Highway 401. Skid number data at 3 years from Ryell et al. (1979). PSV data from Heaton et al. (1978).

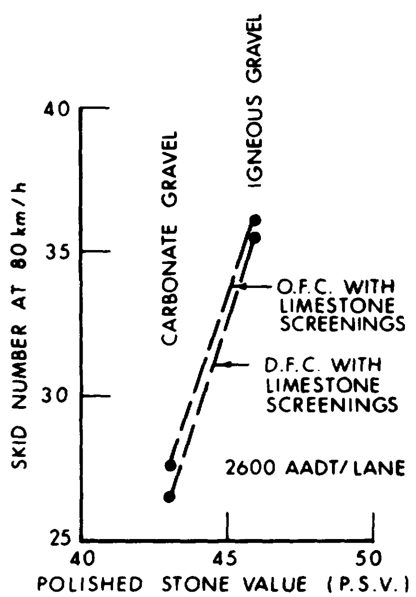

Figure 14. Skid number plotted against polished stone value (PSV) after 4 years for open friction and dense friction courses on Highway 7 near Lindsay, see Kamel et al. (1982).

is not always true; aggregates with high Los Angeles Abrasion and Impact losses may also have good resistance to abrasion. The carbonate rocks show some linear correlation between AAV and Los Angeles Abrasion and Impact loss. The other rock types do not. The Los Angeles Abrasion and Impact Test is not a reliable predictor of the resistance of aggregates to abrasion measured by the Aggregate Abrasion Value Test.

Aggregates commonly found in Ontario can be divided into a number of broad types based on their microtexture development.

1. Moderately hard rocks consisting of approximately equal amounts of relatively hard and soft minerals. The difference in hardness between the minerals should ideally be 2 Moh divisions or greater. A typical example is dolomitic sandstone (Figures 17, 18). The relatively soft dolomite wears away, leaving rounded quartz sand grains protruding above the dolomitic matrix. This gives a natural sandpaper-like texture. Dolomitic sandstones found in eastern Ontario typically give PSV's between 55 and 60, low AAV's and have excellent durability. They are the best, naturally occurring skid-resistant aggregates used in Ontario as determined by the PSV test.

The occurrence of this type of texture was first recognized by Maclean and Shergold (1959) and Knill (1961). Subsequent work has been summarized by Dahir (1979), who found that optimum microtexture is developed when 50 to 70% hard particles are embedded in a soft matrix. Hosking (1976) reported that the optimum size for the hard mineral was about 0.2 mm. It was in recognition of this phenomenon that the insoluble residue test was

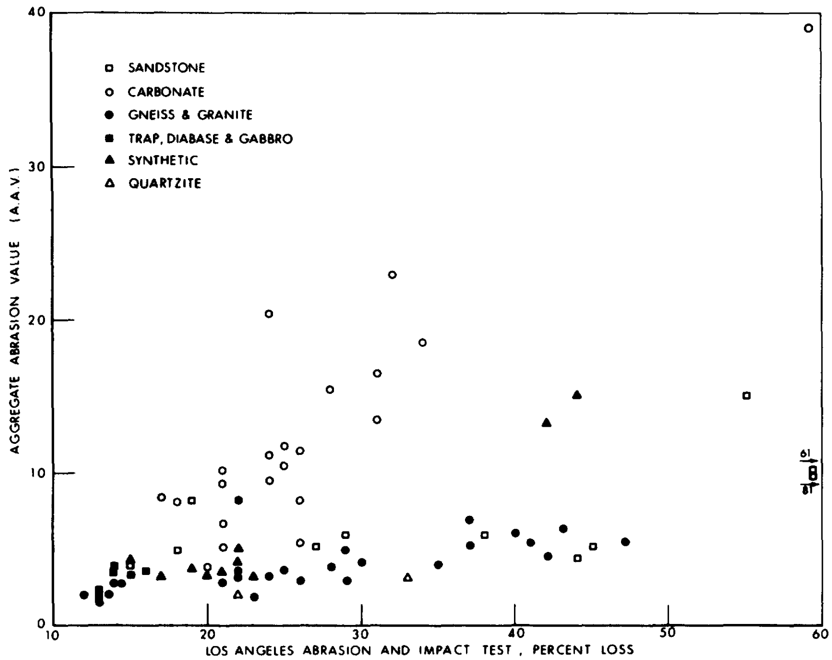

Figure 16. *Aggregate abrasion value plotted against Los Angeles abrasion and impact loss.*

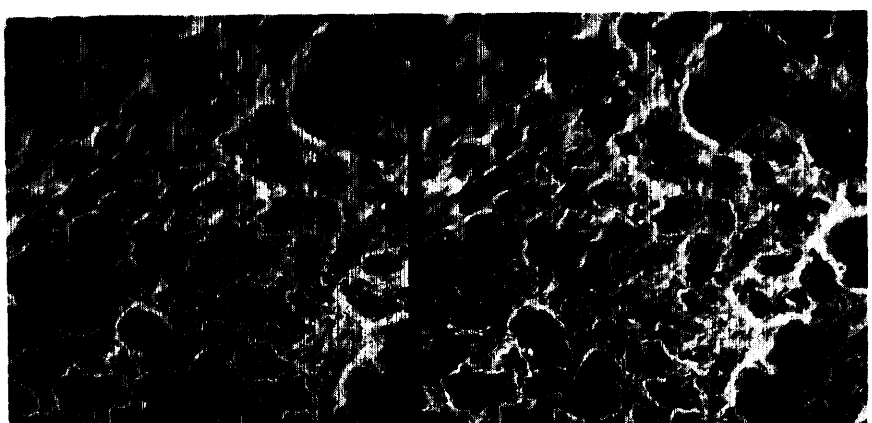

Figure 17. *Scanning electron microscope stereopair of the surface of a dolomitic sandstone after exposure to abrasion and polishing. The softer dolostone has worn away leaving the quartz sand grains protruding above the matrix, giving a rough microtexture. Length of scale bar = 0.5 mm.*

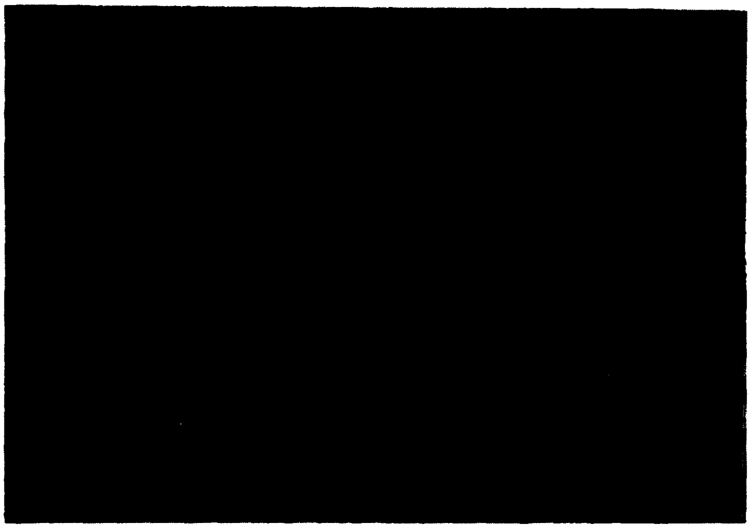

Figure 18. Photomicrograph under plane light of the dolomitic sandstone shown in Figure 17. Rounded quartz grains surrounded by a dolomite cement. Length of scale bar = 0.2 mm.

developed (ASTM D 3042). A carbonate rock is dissolved in acid, and the proportion of insoluble material retained on the 0.075 mm sieve is determined. Insoluble minerals in carbonate rocks are principally quartz, which has a Moh hardness of 7 compared to the Moh hardness of carbonate rocks of between 3 and 3½. This is, however, a special case of the general principal of hard particles in a soft matrix. The same phenomenon can be observed in biotite-rich gneisses (20% biotite) which gave PSV's of 58 and 63. The biotite preferentially wears away, leaving quartz grains protruding above the matrix. Quartzite and granite (see Table 4, No. 28 and 53) containing even small amounts of mica (5%) have an improved texture, due to wearing away of the biotite, leaving holes in the surface. Orthoquartzitic sandstone with a micaceous matrix also develops this texture (Figures 19, 20).

2. Angular, extremely hard rocks or minerals that resist abrasion, preserving their sharp angular edges. Quartzite is a typical example. Unlike sandstones, quartzites fracture through, rather than around, the grains, giving a relatively smooth flat surface. This results in low PSV's (Figure 21). Hosking (1973) found that the PSV's of quartzites underestimated their true frictional performance by 3 PSV units. Despite their low PSV, these rocks retain their sharp angular edges. Unfortunately, the action of compacting asphaltic concrete tends to embed the sharp aggregate edges downward with the flat surfaces exposed to the traffic.

3. Vesicular, porous, synthetic materials, such as air-cooled blast furnace slag and steel slag. The constituent minerals are relatively hard (Moh 6-7), and resist wear. The large pores with relatively thin walls provide excellent microtexture. Hosking (1976) found that the optimum pore size for blast furnace slags was about 0.15 to 0.3 mm. As porosity increased, so did PSV with optimum results being obtained with materials with a porosity of between 25 and 35%.

The steel and blast furnace slags tested in this study gave PSV's between 53 and 60, the highest values being given by BOF (Basic Oxygen Furnace) steel slags. Blast furnace slag is more porous and generally has thinner pore walls compared to steel slag, which promotes the slow attrition by breakage of the friable pore walls. This has the advantage of continual exposure of fresh, angular mineral grains throughout the life of the pavement. This may account for the better frictional performance of blast furnace slag pavements than predicted by their PSV alone, as reported by Hosking (1973). Evidence to support this was also found in this investigation. Figure 15 shows PSV against skid number for three aggregates used on Highway 401 (Ryell *et al.* 1979). It can be seen that the blast furnace slag generally gave the highest skid number, despite its intermediate PSV. Observation of cores of the blast furnace slag pavement under the microscope showed significant amounts of freshly broken, unpolished crystals after 6 years of exposure to very heavy traffic.

Unfortunately, the slow attrition of the blast furnace slag results in a loss of macrotexture and a reduction in the ability to prevent hydroplaning. Generally, as porosity or

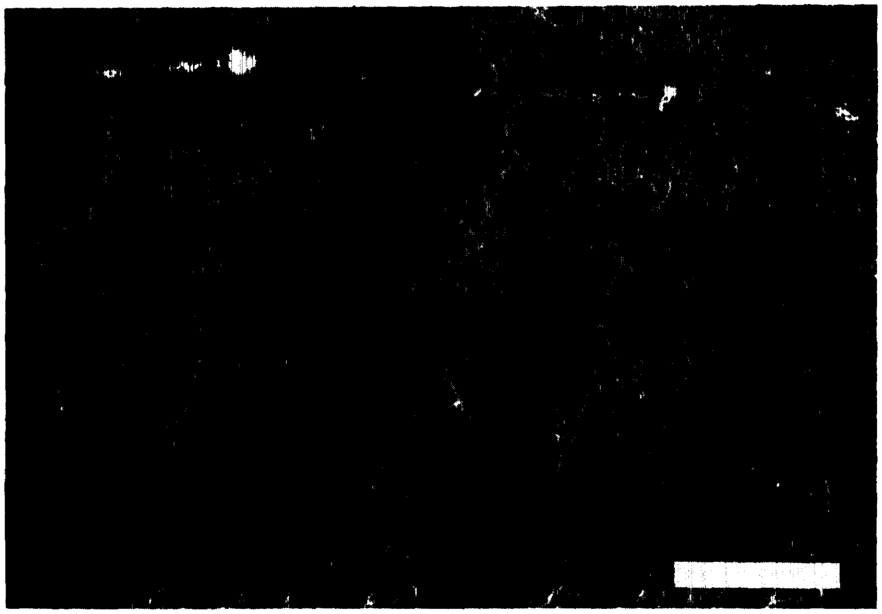

Figure 19. *Scanning electron microscope stereopair of the surface of a micaceous sandstone after exposure to abrasion and polishing. Quartz sand grains protrude above the micaceous matrix, giving rough microtecture. Length of scale bar = 0.5 mm.*

Figure 20. *Photomicrograph under plane light of the micaceous sandstone shown in Figure 19. Angular quartz grains surrounded by muscovite mica. Length of scale bar = 0.2 mm.*

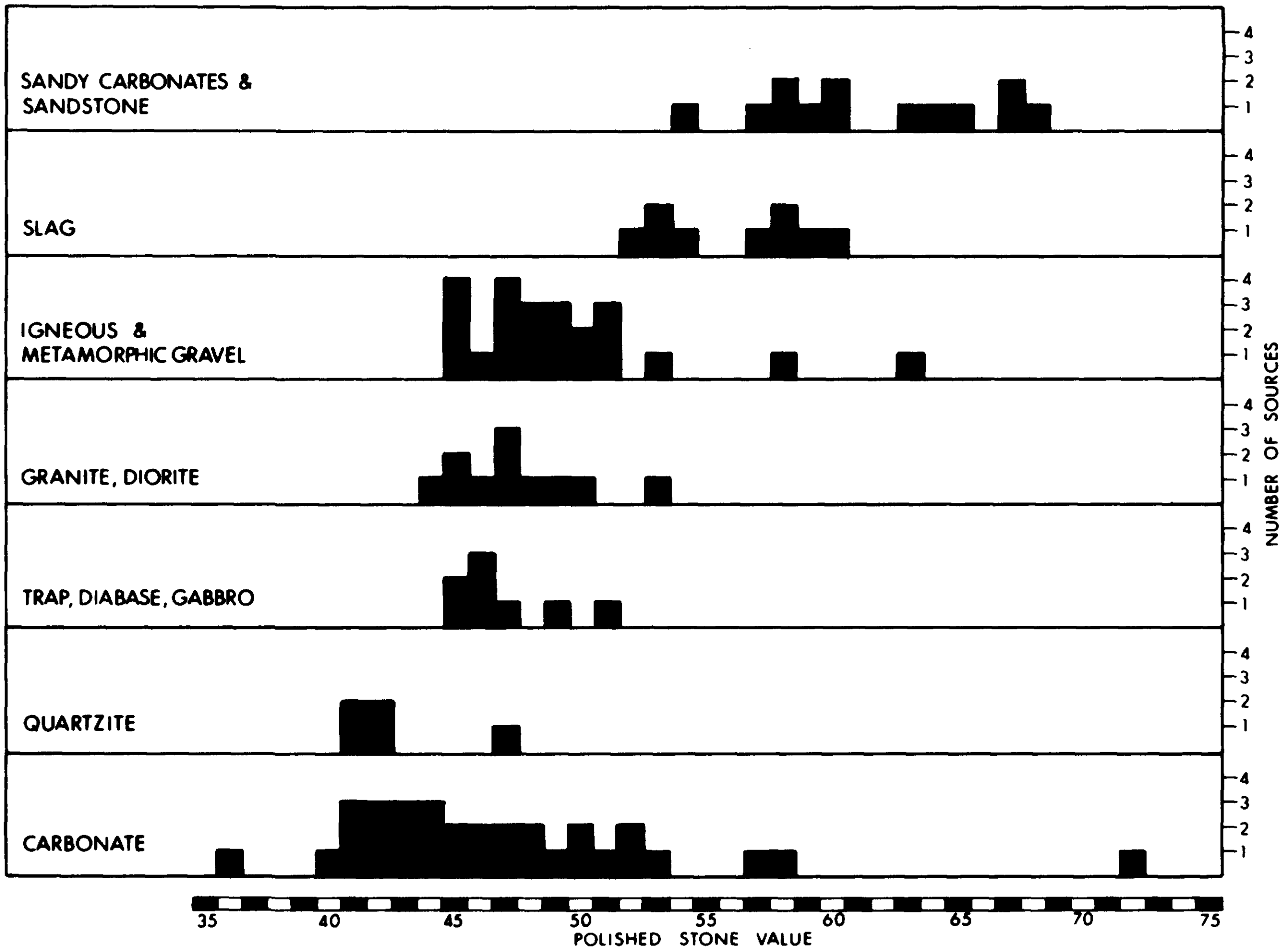

***Figure 21.** Frequency plot of polished stone values for different aggregate types.*

absorption of synthetic materials increases, resistance to abrasion is reduced (Figure 22), which, in turn, reduces macrotexture. A similar relationship was found by Heaton *et al.* (1976), who showed that, as porosity increased, resistance to abrasion and impact measured by the Los Angeles test was reduced. Hosking (1976) also reported that increased porosity resulted in decreased abrasion resistance as measured by AAV.

4. Hard igneous or metamorphic rocks, such as basalt, gabbro, gneiss and granite. Initial microtexture is determined by the fracture characteristics of the rock when crushed. Equigranular, medium-grained (0.5 to 1 mm) rocks appear to perform best, giving a rough initial microtexture. The fine-grained basalts and coarse-grained pegmatitic granites give relatively smooth initial microtexture. Subsequent microtexture development and retention is determined by the relative hardness of the individual minerals; quartz-rich rocks retain their initial texture the longest. With sufficient time, however, nearly all rocks in this group give relatively smooth, polished surfaces, the only exceptions being rocks with significant amounts of relatively soft biotite mica that develop the texture described in Type 1.

5. Soft rocks with low resistance to abrasion which polish rapidly. The sedimentary carbonate rocks are typical of this group. The initial microtexture is determined by the porosity and grain size of the rock. Lithographic limestone gives a smooth, flat surface, while equigranular, medium crystalline dolostone gives a rough initial microtexture. In the pavement surface, the angular edges and microtexture are quickly lost, giving a smooth, polished surface with little macrotexture. Medium crystalline dolostones polish less quickly than their finer grained equivalents or limestones. This is probably due to their better initial microtexture taking longer to wear away, macroporous, reefal dolostones giving the best microtexture. Porosity, hard

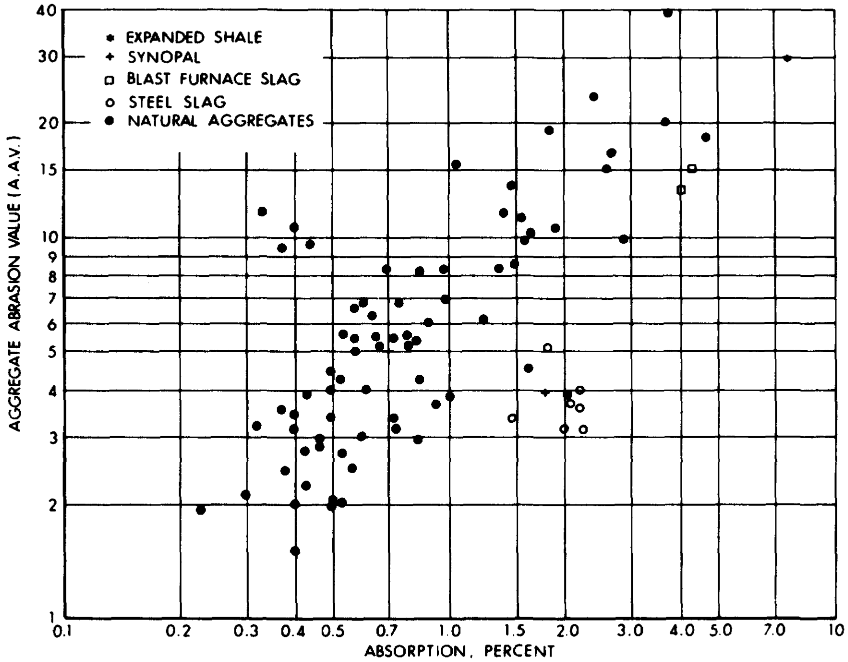

Figure 22. Aggregate abrasion value (AAV) plotted against percent absorption.

mineral content (insoluble residue), grain size and mineralogy are important factors controlling the final microtexture and rate at which it is developed.

Some carbonates give high PSV's (see Figure 21). These are the rocks with low resistance to abrasion. Figure 23 shows that, for the carbonate rocks, as resistance to abrasion decreased (higher AAV), PSV increased. Dahir (1978) reported a similar relationship between friction and percent wear in a jar-mill, for a group of eight aggregates of various rock types. In the polishing test, there is a continual loss of material by abrasion, due to the extreme hardness of the emery abrasive used (Moh 9). As a result, the polish attained under field conditions, where the maximum hardness of the abrasive is Moh 7, is never reached.

6. Porous, weakly cemented rocks composed of hard minerals. Porous, weakly cemented sandstone is a typical example. These rocks, when crushed, break around, rather than through, the individual sand grains, giving excellent initial microtexture. The hardness of the individual grains makes them resistant to wear. Microtexture is renewed over the life of the pavement by plucking of individual grains, exposing fresh, unpolished surfaces. Samples of these sandstones gave PSV's between 62 and 68.

These rocks are, unfortunately, extremely susceptible to frost action. Freezing and thawing in the presence of water results in deterioration and loss of macrotexture. This action, combined with attrition of the individual grains results in depressions rather than projections in the pavement surface.

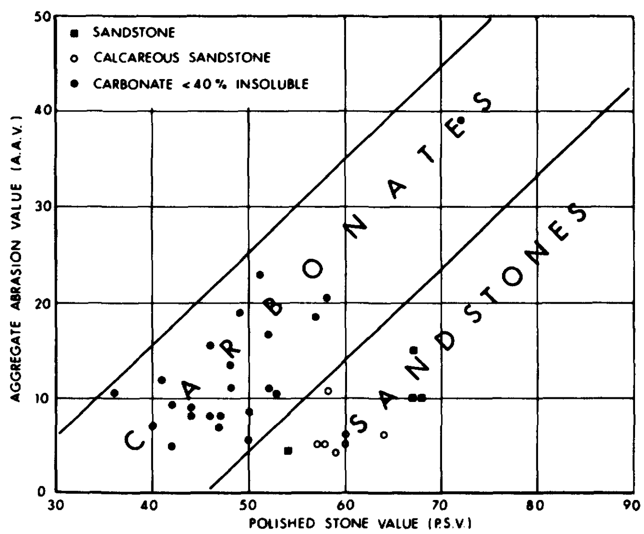

Figure 23. Aggregate abrasion value (AAV) plotted against polished stone value (PSV) for sedimentary rocks.

CONCLUSIONS

1. The frictional performance of aggregate is determined by its mineralogy, grain size, and porosity. This can be predicted by laboratory tests, such as polished stone value, and aggregate abrasion value tempered by experience derived from field performance.

2. Locally available aggregate sources of previously unsuspected quality and utility may sometimes be found, using geological and petrographic criteria, confirmed by laboratory testing. The use of these aggregates may lead to cost savings and improvements in the frictional properties of the pavements in which they are used.

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Computer-Aided Mine Planning

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ABSTRACT

The Atlantic Cement Company mines limestone from three quarries on its property in Ravena, New York. The cement-producing limestone units include the Manlius, Coeymans, and Becraft formations. Between the Coeymans and Becraft are the Kalkberg cherty limestone and the New Scotland shaly limestone. These two units combine to make 49 m of rock that must be removed in order to fully expose the Manlius and Coeymans. To most efficiently and economically mine the deposit, a 20-year mining plan was developed for the entire property. To integrate all of the geologic information necessary, computer technology was applied to the problem. All drillhole information, as well as surface and subsurface geology for about 3.5 square miles of reserves were digitized for use in the Surface II Spatial Analysis Program. Contour maps of formation contact surfaces, isopach maps, and stripping-ratio maps were generated to provide the basis for the mine planning. The superposition of units as a result of thrust faulting was resolved by assuming a vertical fault at each formation horizon. The resulting contours were a steeply dipping slope that would closely approximate the actual mine configuration. The computer generated contour map of the base of the Manlius is a map of the ultimate floor of the quarry, and led to decisions on direction of face advancement and sump locations to control water. Isopach maps of the cement-producing units were generated along with tonnage calculations for blocks 500 feet square. Maps showing the ratios of the cement-producing units and stripped units were also generated. This information helped in the selection of rock from various parts of the quarries to minimize haulage distance to the primary crusher. The information was also used to select locations for placement of the stripped rock, both to avoid interference with mining over the next 20 years and to minimize haulage distance. The result of this study will lead to significant savings in mining costs over the life of the plan and extend the life of the economically available reserves. Additional computer-aided phases of work have been initiated to integrate rock chemistry with the stratigraphy in order to control more precisely the chemistry of the quarry production and to use the computer to more directly control day-to-day mining.

INTRODUCTION

Atlantic Cement Company, Incorporated, produces portland cement from its quarry in Ravena, New York. The Manlius and Coeymans limestones are mined together in one face and the Becraft limestone is mined from a separate quarry. Separating the two are 49 m of siliceous and cherty limestone of the Kalkberg and New Scotland formations.

The quarry is just west of the Helderberg Escarpment. The beds dip to the west and are offset by a series of northeast-trending low angle thrust faults dipping to the east and folded along axes that parallel the faults. The Manlius and Coeymans limestones outcrop along the top of the escarpment where the Kalkberg and New Scotland are thinnest.

The outcrop pattern has controlled the development of the quarry. Because an aggregate market has not been found, the Kalkberg and New Scotland are stockpiled for possible future use. Their removal is a direct mining cost and mining practice has tended to minimize their removal. The result is a long narrow quarry following the outcrop pattern, advancing away from the centrally located primary crusher, increasing haul distance and leaving behind limestone covered by many metres of rock that must be stripped.

Atlantic Cement management realized that continued economic mining required long-term planning. Dunn Geoscience Corporation was asked to develop mine plan alternatives with accompanying economic analyses in order to select a specific mining approach that could be planned in detail. Definition of geology, manipulation of the data including the computer analyses, and the development of the mine plan were done by Dunn Geoscience. Peter Nalle of Behre Dolbear & Company, Inc., performed the economic and equipment analyses associated with the various alternatives.

AIMS OF THE STUDY

The study developed a 20 year mining plan which considered the following:

Availability of economically mineable reserves in the future

Reduction in mining costs

Reduction in haul distance for both production rock and stripped rock

Location of waste piles where they would have minimum impact on future mining

Equipment requirements to achieve the plan for capital budgeting.

METHOD OF DATA COMPILATION

A computer database using the Surface II Spatial Analysis Program was constructed using existing topography, drill hole logs, currently exposed faces, cross-sections and surface geologic maps. Geologic data were assembled for six geologic units and the topographic surface. The initial data sets for each geologic contact surface were computer-contoured to compare their accuracy with known controls such as the topographic surface and the quarry floor (top of Rondout dolomite).

Initial contour plots indicated a strong directional bias to the data distribution along the east-west cross-sections. Various gridding algorithms were tried to reduce the biasing effect. Rather than remove data to reduce the sample density in the biased direction, data were added to low density areas by using linear interpolation along north-trending fold axes between the section lines. Contour plots of the augmented data sets created maps that produced a high degree of correspondence with known elevations and structural trends. The faults were handled by entering a large number of paired points on each side of the fault. This produced a steeply dipping surface along the fault trace which is an averaging along the trace of the fault. Since the fault throw is generally minor, quarrying would generally ramp up or down between fault blocks. The computer-generated maps in the vicinity of the faults do not represent geologic reality, but rather quarrying technique.

A series of top-of-formation elevation maps was produced for each of the six formations plus the topographic surface. These surfaces were subtracted to produce isopach maps of the stripped and mined formations. A thickness-ratio map of stripped to mined rock was produced by dividing the thicknesses of the two sets. Use of a tonnage calculation program utilizing the computer-generated isopach data grids produced averaged tonnages for different sized blocks over the entire property. The ratio map provided a graphic representation of least and most favorable areas for stripping to produce mineable material.

ANALYSIS OF DATA

Using the stripping ratio map and tonnage calculations, various quarry limits were defined that would provide the required annual production, but with varied stripping requirements. Annual and overall stripping ratios were calculated for several quarry configurations and tonnages were determined.

For each quarry configuration, a preliminary analysis of trucking distances and grades was made and transportation costs were calculated as well as mining costs.

RESULTS

The data analysis led to two mining alternatives for detailed consideration. One, designated the "Minimum Stripping Approach", was to continue to mine much as had occurred in the past – following the strike – minimizing stripping costs and allowing transportation costs gradually to increase. The quarry limits for this plan were set at a stripping ratio of 0.5 to 1, i.e. 0.5 m of Kalkberg-New Scotland stripped to each metre of Coeymans-Manlius mined. The second method, designated the "Centralized Approach", was to reverse the direction of mining, concentrating Coeymans-Manlius production around the primary crusher at the expense of minimum stripping. The quarry limits for the plan were set at 0.75 to 1, but occasionally went over 1.0 to 1. For each plan, drilling costs were considered to be the same, but haulage and stripping costs varied. Based on haul distances and tons of Kalkberg and New Scotland to be removed, comparisons of total quarry costs were made. It was determined that the mining cost of the Minimum Stripping Approach was about 8.5% per ton higher than that of the Centralized Approach over the 20 year period of planning.

The contrast of the quarry condition after 20 years is also important. Following the Minimum Stripping Approach, quarry faces will have advanced to the north property line and north of the crusher, production rock with a stripping ratio less than 0.5 will have been removed. However, with the Centralized Approach, a large volume of low-stripping-ratio production rock will remain, allowing more flexibility in future approaches to mining.

Based on this analysis, the Centralized Approach was selected for detailed planning and implementation. Mine planning was done in the following stages: first and second six months, years 2 through 5, and years 10, 15 and 20. The development of the mining plan was based on such factors as rate of stripping of Kalkberg and New Scotland, drainage control and sump location. Based on the locations of the quarry faces after 20 years, sites could be selected for stripping piles and a new quarry office-garage complex.

Implementation of the new mining plan has been rapid. Once the Centralized Approach was selected and general mining areas were identified, overburden removal was initiated and new faces were developed prior to plan finalization. Of most importance is the establishment of new Kalkberg-New Scotland faces, abandoning those which perpetuated the extension of mining along the escarpment.

The future will see continued refinement of the computer model. The application of the computer to Atlantic

Cement's chemistry needs is being explored. It is now possible to combine face geology and production tonnages to calculate the average chemical composition of quarry production. The computerized control of mining to meet specific chemistry needs is also being considered.

Further into the future, it is possible that the computer will control quarry equipment. By being able to determine the location of a piece of equipment, the computer may be able to tell the driller how deep to drill, or the operator of the front-end loader if he is excavating to the right depth.

Economic Potential of Various Sandstone Units within the Nubian Sequence: Examples from Israel

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ABSTRACT

The Nubian Sequence of the Middle East which is largely composed of variegated sandstones, is well known for its excellent exposures and the wild landscape that has been carved from them. Most of the Nubian Sequence is remote from industrial centres and has thus been kept far from economic utilization. In Israel, however, three white-sand types within the section, probably of fluviatile origin, have been studied from an economic point of view and one is now being exploited.

Almost pure silica sand lenses occur within the Lower Cretaceous section of the Negev, southern Israel. Lenses of 500 m^3 to 100,000 m^3 of unconsolidated sandstones are known and they differ in their chemical and physical properties. The average Fe_2O_3 content is 0.05 to 0.06% but lenses of 0.02% Fe_2O_3 content were also found. They are medium to fine grained. The small plant in the Makhtesh Gadol produces annually almost 100,000 tons of raw material which meets most of the domestic demands for glass sand. Certain amounts are shipped to the foundry and building industries and small quantities are exported.

The white Amir Formation exposed in southern Israel exhibits a sequence characterized by disseminated white kaolinitic clays in a relatively pure quartz sand. The authigenic kaolinite constitutes an average of about 15% of the total rock. It is of well ordered type with a high crystallinity index. An almost complete disaggregation of the sediments was achieved in the laboratory. Typical properties of these kaolinites are the comparatively coarse particles of high crystallinity, low contaminants content, high brightness, low plasticity, and a reasonable viscosity concentration.

Although the reserves are vast and some of the silica sand by-product may be marketable, the scarcity of fresh water is a clear limitation for economic development.

The White Member of the Cambrian Shehoret Formation is composed of fine-grained, moderately sorted subarkose. Quartz is the main detrital component (60 to 70% of the rock) and feldspar (microcline) content ranges from 15 to 25%. Minor constituents are lithoclasts, mica, and clays (illite and montmorillonite). In laboratory tests, it was possible to obtain a concentrate containing 90% feldspar, but this is not economic because of the high ratio between ore and the feldspar product. However, an intermediate product may change economic evaluation.

Certain of the rock units discussed are widely spread in neighbouring countries and some results may be applicable there.

INTRODUCTION

Israel is relatively poor in regard to known metallic minerals and hydrocarbon resources. On the other hand, the potential of industrial minerals is promising. Impressive technological and prospecting progress, especially in the last 25 years, has led to the utilization of minerals such as phosphate, potash and bromine, whose production play a role in the international mineral market. The well-established building industry is based mainly on domestic sources for sand, rock aggregate, building and dimension stone, cement, etc. The country is self-sufficient in gypsum, salt and silica-sand while certain industrial minerals such as clays and industrial carbonates are partially supplied by domestic sources. Many other industrial minerals are imported.

Most of the domestic minerals are mined from strata of the Upper Cretaceous and younger rocks. A thick sequence with economic potential, presently with limited mining activity, is the Nubian Sequence in southern Israel.

GEOLOGY

The Palaeo-Mesozoic Nubian Sandstone sequence of Israel is part of the wide, sandstone-dominated belt which flanks the northern margins of the Arabian Shield. Large exposures occur in the neighbouring countries of Jordan (Bender 1968), Saudi Arabia and Egypt (Weissbrod 1970). Most of the outcrops in Israel (Figure 1) appear in the southernmost part of the country along a narrow, non-continuous strip some 40 km long. The exposures are located in the lower part of the cliffs marking the western border of the Arava Rift Valley, along faults and tilted blocks in the crystalline basement, and in relict hills overlying the basement. There are also some isolated, rather small, outcrops to the west of this strip. The upper part of the sandy sequence is also exposed in some erosional cirques in the central and northern Negev. An excellent

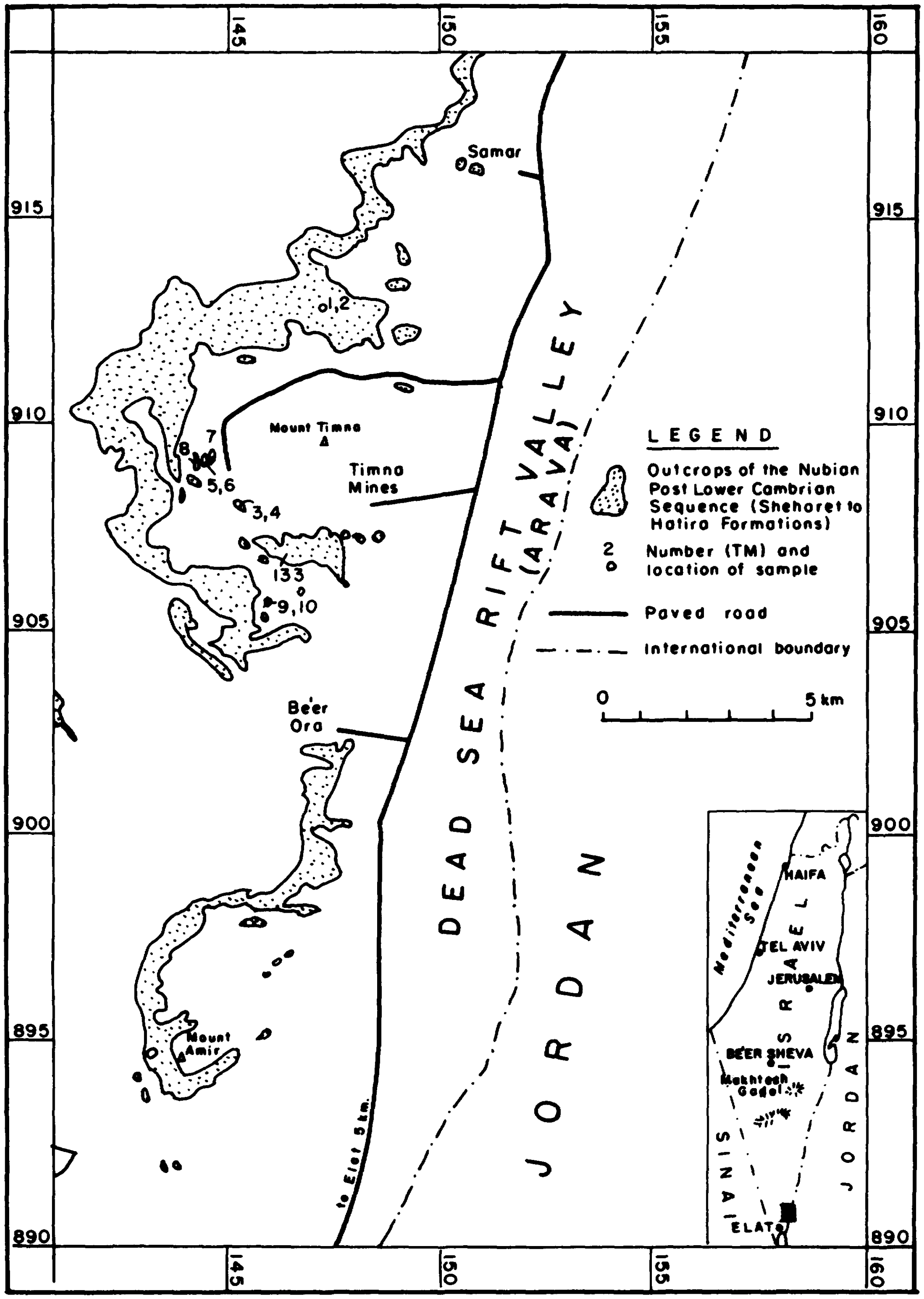

Figure 1. Distribution of outcrops of Nubian Sequence in Israel, and locations of samples.

example of the entire sequence may be observed in Timna Cirque (about 8 by 9 km).

The thickness of the Nubian Sequence in southern Israel is approximately 250-500 m (Weissbrod 1970). It is composed mainly of variegated sandstones, which are subarkose in the lower part of the section and quartz arenite in the upper part. Minor siltstone and clay layers occur in several parts of the section and marine beds of Cambrian age, consisting of dolomite, dolomitic limestone and shale occur in the lower part. In the upper part of the section exposed in the northern Negev, several marine intercalations can be distinguished.

Although most of the clastic sequence is composed of red, brown and purple sandstones, some rock units are relatively white in color. The older subdivision of the section was based on the general colour. Thus, since the lower and upper parts of the section are variegated and the middle one is white, the unit names were given as "Lower Variegated", "Middle White" and "Upper Variegated" Nubian Sandstone (Bentor and Vroman 1955). A new subdivision was suggested in 1970 and has been used ever since (Weissbrod 1970). The six formations are (from bottom to top): Amudei Shelomo Sandstone, Timna Formation (includes the marine beds and copper ore), Shehoret Formation, Netafim Formation, Amir Formation and Hatira Formation (Figure 2). Three of these units are white in places. The lower of these consists of subarkose (Shehoret Formation). The Amir Formation and the lower (Avrona) Member of the Hatira Formation comprise quartz arenites as do certain horizons and lenses in the upper (unnamed) member of the Hatira Formation.

SUBARKOSIC SANDS

The middle White Member of the Shehoret Formation outcrops in a few localities of southern Israel, the best exposure being the Nahal Shehoret area where it was studied in detail (Weissbrod and Minster 1980).

The sequence consists of some 65 m of medium to hard subarkose with local siltstone interbeds. It forms two vertical, hard cliffs with softer horizons in between and above (Figure 3). The general color is white to grey. Some purple to reddish, small shale layers occur and the weathering crust is brown.

Petrography and Chemistry

The grains are fine (mean diameter = 0.125 mm), moderately sorted (s.d. = 0.54 mm) and positively skewed (ski = 0.6 to 1.1). They are subangular to subrounded, and somewhat elongated. The main detrital component is quartz forming 60-70% of the rock. Feldspar grains, mostly microcline, constitute about 15-25%. In places, microcrystalline quartz replaces margins of feldspar grains. Minor detrital constituents are rock clasts (mainly quartz porphyry) and micas, with a very small amount of heavy minerals (about 0.15%). Clay minerals (montmorillonite and illite) and microquartz form the cement of the subarkose. Chemical analyses show additional components. Iron oxides (0.4-0.7%) are probably concentrated in the coloured layers as coatings of detrital grains, and in association with the clays, micas and heavy minerals. Pyrolusite impregnations are common and analyses give values of 0.002-0.07% MnO. In places, black manganese layers occur. Copper minerals such as chalcocite, malachite and parathacamite are disseminated in the subarkose, locally as spherical concretions. These contribute to the composition to the extent of up to several hundred ppm Cu. The exposures in the desert region are characterised by secondary salts such as halite and gypsum yielding anomalous values of Na_2O and CaO.

Industrial Assessment

Litani (1978) found that naturally occurring raw material could be used for vitreous ceramic bodies with some admixtures of Na-feldspar. Beneficiation research by Gorin and Wiegner (1980) showed that it is technically feasible to obtain a concentrate containing 90% feldspar. However, an economic evaluation of the Israeli raw material may indicate that production only of feldspar is not feasible since 1 ton of product is processed from about 10 tons of ore. The economics of the product may be changed by finding a market for intermediate products and particularly for the very fine clay concentrate.

KAOLINITIC SANDS

The thicker white part of the Nubian section in southern Israel is formed of quartz arenitic units: the Mesozoic(?) Amir Formation and the Avrona Member of the Lower Cretaceous Hatira Formation. The former is characterized by a higher clay fraction content. The Amir Formation (Weissbrod 1970) is composed of white, predominantly very fine-grained sandstones with subrounded to subangular grains. Scattered coarse grains of quartz occur in places. The cement consists mainly of clay, with some amorphous silica and rare calcite. The sandstones are finely laminated, and in places are cross-stratificated. Locally variegated siltstone occurs mainly in the middle part. They are harder than the adjacent sandstones which can even be unconsolidated. The formation exhibits a characteristic yellow-brownish weathering crust, which is very convenient for field identification. Its thickness is up to 55 m and the largest exposed area is in the Timna Cirque (see Figure 1) (Weissbrod 1970).

Petrography and Mineralogy

Sedimentological separations indicate very fine sands (mean diameter 0.107 mm) which are poorly sorted

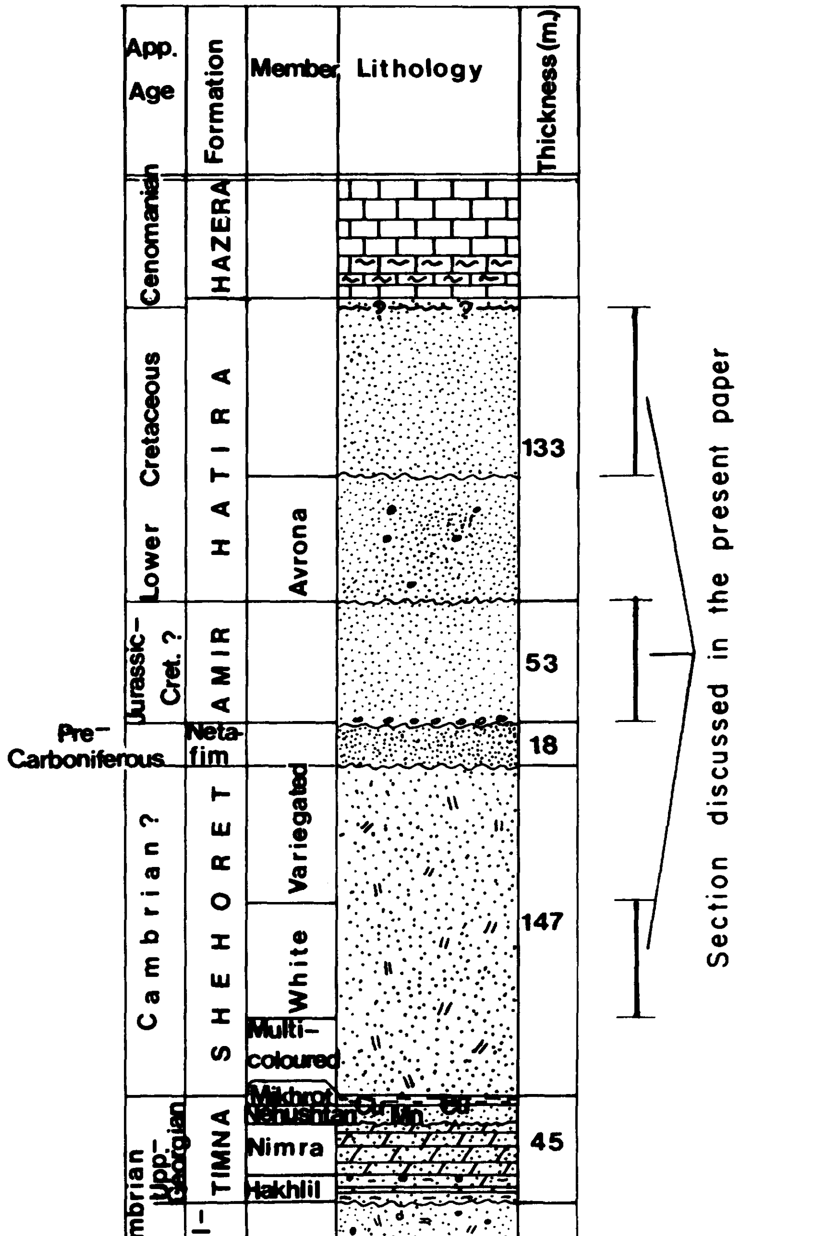

Figure 2. *Composite columnar section of the Nubian Sequence, southern Israel.*

Figure 3. *The lower cliff of the White Member, Shehoret Formation at Nahal Shehoret. The cliff, about 30 m high, forms about half of the entire section. Part of the section was sampled using a ladder.*

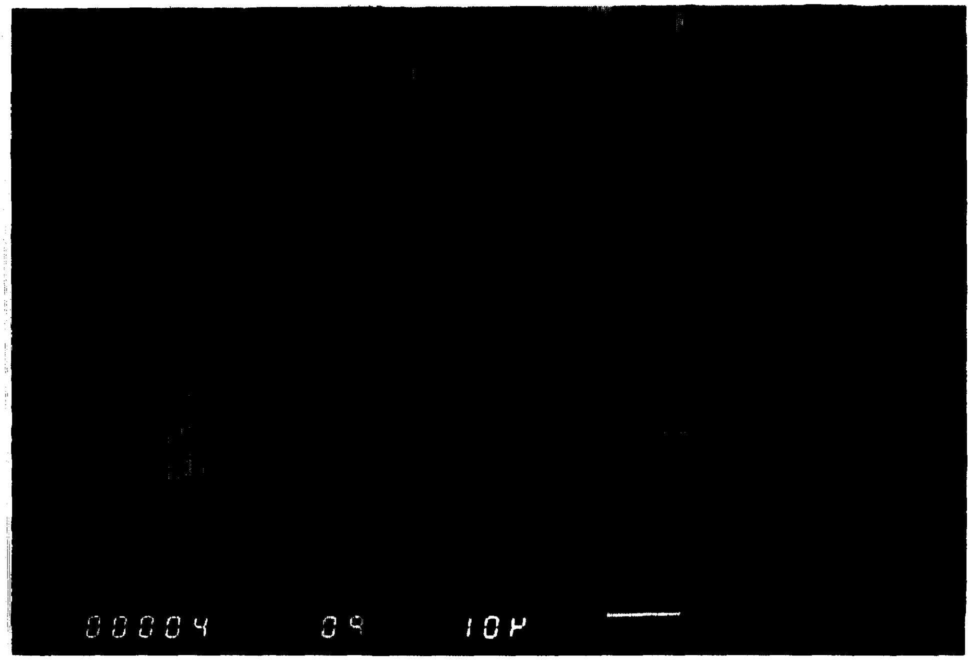

Figure 4. *Amir Formation. Relation between quartz grains and kaolinite. The kaolinitic plates sometimes coat the grains and in places form bridges between grains. Pseudohexagonal "books" and vermicular plates are frequent. Common size of particles 2-5 micrometres.*

(average s.d. = 0.34 mm) and strongly (positively) fine-skewed. It should be noted that if only the population of the detrital grains is considered, the material will have somewhat a coarser grain-size and will gain a significantly better sorting. The quartz grains are generally unweathered, subrounded to subangular, sometimes elongated. The cement consists mainly of authigenic kaolinite with the following variations (Minster and Fraser 1982):
(1) as a thin coating on quartz grains; (2) in aggregates probably representing pore filling; (3) in aggregates of "accordion-shaped" flakes. The kaolinite usually forms stacked plates and in places forms bridges between grains (Figure 4).

Analyses point out that the two main phases are quartz (62-88%) and kaolinite (10-38%). The amount of impurities is small, apart from soluble salts (mainly halite and gypsum) which are enriched near the surface of the rock. The amount of heavy minerals is low, excluding anatase which is clearly identified in most X-ray diffraction patterns. The copper content was found to be 20 to 200 ppm. The kaolinite is very well-ordered as indicated in part by the narrow profiles and sharp peaks and by some well-developed zones of reflections. It has a high degree of crystallinity in comparison to various kaolinitic clays (Minster and Fraser 1982).

Industrial Applications

Some technological and beneficiation aspects have been examined in Israeli institutes (Azmon *et al.* 1979; Gorin 1979). Both wet and dry enrichment methods were tested, but since the scarcity of water is an important factor in the area, the dry beneficiation was more thoroughly studied. At present, the process developed is not economically feasible. However, it is believed that some features of the pure kaolinite (which is easily separated in laboratory) such as the coarse particle-size, the high crystallinity, very low contaminants content, and the high brightness, as well as the high-grade silica sand by-product may contribute to reconsideration of the economic evaluation.

SILICA SANDS

The Lower Cretaceous Hatira Formation forms the roof of the Nubian Sequence. In the southern Negev, it is entirely clastic and its lower member is white. In the northern Negev, it contains some marine intercalations; the sandy section is variegated and no complete units of white sands are known. The type section of Makhtesh Gadol (large erosional cirque) is some 400 m thick (Greenberg 1968). The clastic sections consist mainly of sandstones but some clays, quartzite and ferruginous sandstones occur. In places, lenses of white sandstone are present with an average Fe_2O_3 content of 0.05-0.08%. Their grain-size is variable, usually medium but in places consist of very fine to coarse sands. The sandstone is usually soft and in many cases unconsolidated. It is interbedded with clays and variegated sands and gypsum veins are locally present (Figure 5). The large lenses are up to 20 m thick with a volume of approximately 100,000 m^3. These lenses have been utilized for the domestic glass industry for the past 30 years. However, in recent years, with the development of industrial installations, a wider range of products and uses was obtained. The following fractions are produced:

1. Very coarse sand 1.5-3.2 mm (main uses: abrasive floors).
2. Coarse to very coarse sand 0.8-1.5 mm (abrasives, wall decoration).
3. Coarse sand 0.6-0.8 mm (wall decoration, sand blasting, bedding for greenhouses).
4. Medium to fine sands ≤ 0.6 mm (flat glass and containers, ceramic industry, foundries).
5. Fine sands AFS 70, AFS 100 (foundries – partially in coated form).

Figure 5. Hatira Formation, Makhtesh Gadol. Cross stratification and graded bedding are common features in old quarry wall. Gypsum veins form "dike-like" morphology.

6. Silica flour 98% < 0.07 mm (filler in some industries – ceramics, detergents, etc.).

The flow sheet of the present plant is presented in Figure 6. Cleaner material with an Fe_2O_3 content of 0.02 to 0.04% has recently been discovered.

REGIONAL VIEWPOINT

The data provided above have some value aside from the domestic point of view. The Nubian Sequence has enormous exposures in the neighbouring countries, especially Saudi Arabia, Jordan and Egypt. Many of those areas are remote from presently existing infrastructures. However, in places, some roads, railway lines and harbours are not far away from potential sections. It has also been shown that the Nubian Sequence is a very large aquifer (Issar *et al.* 1972), so that ancient water resources, although not renewed, may be a source of supply for the processing of sedimentary deposits. The above mentioned sequences may hint at utilization trends in the future.

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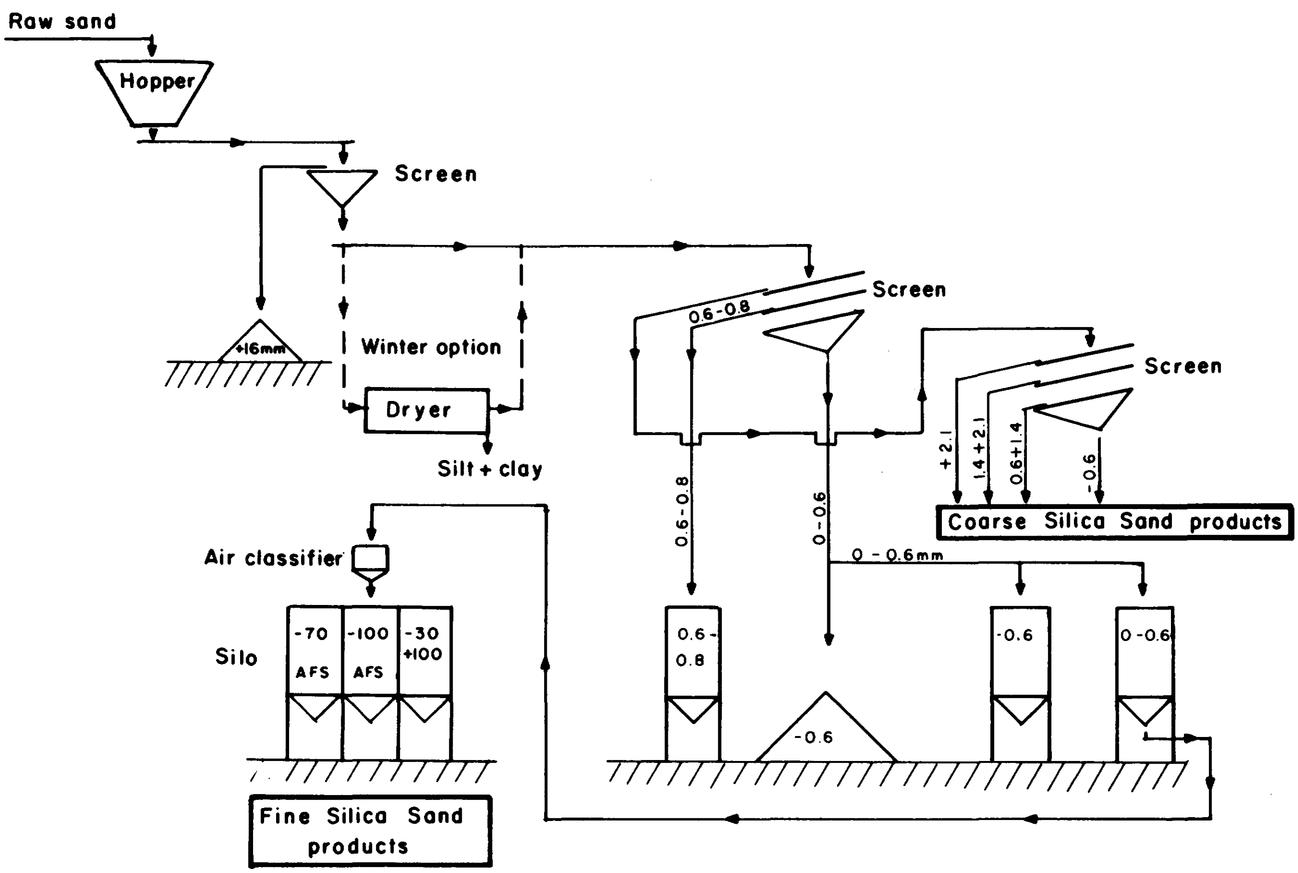

Figure 6. Flow sheet of the Makhtesh Gadol silica sand beneficiation plant operated by Negev Ceramic Materials Limited (with the courtesy of A. Shenberg, Director).

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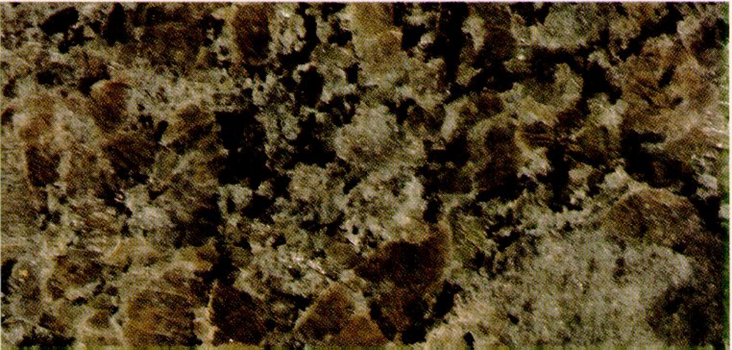

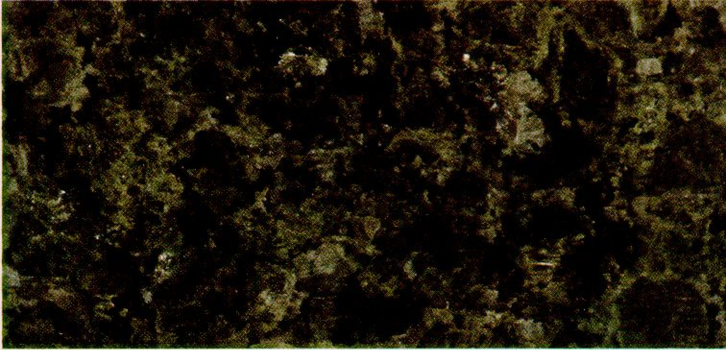

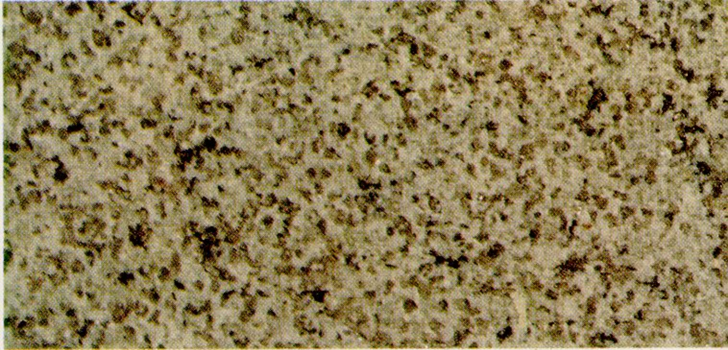

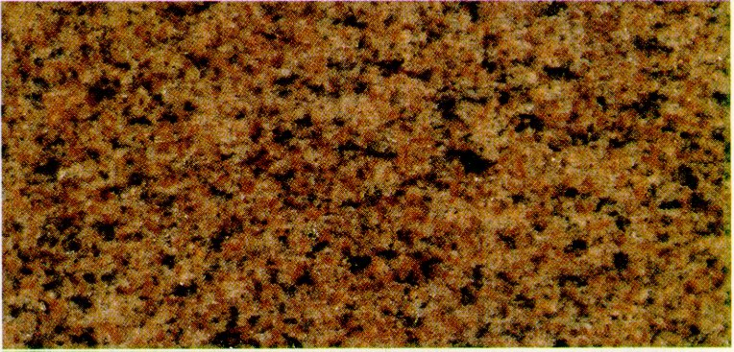

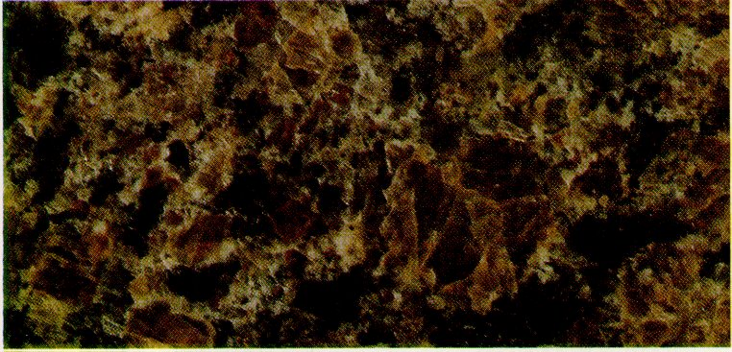

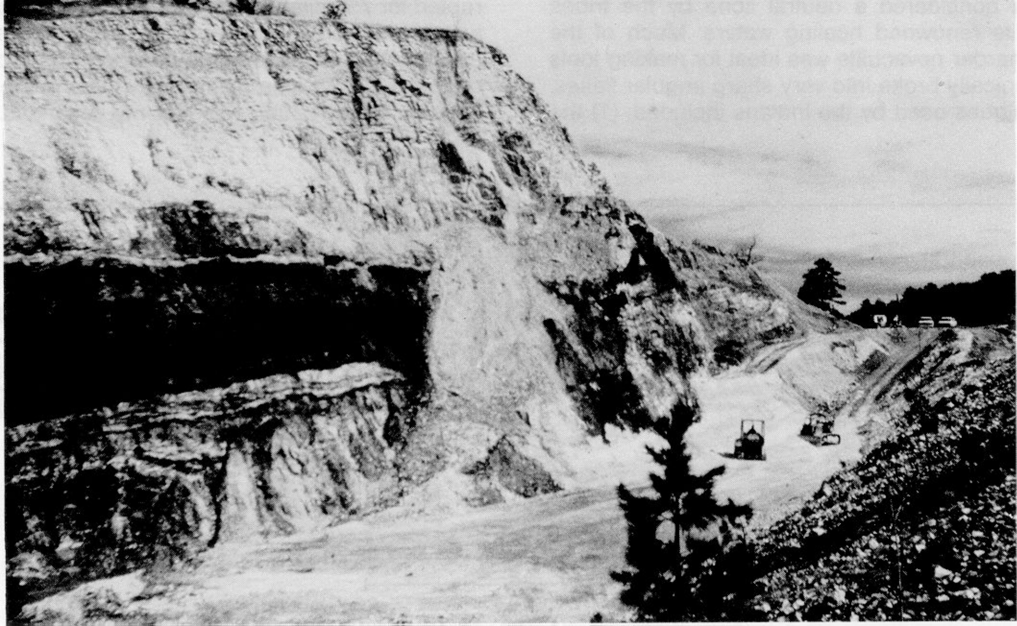

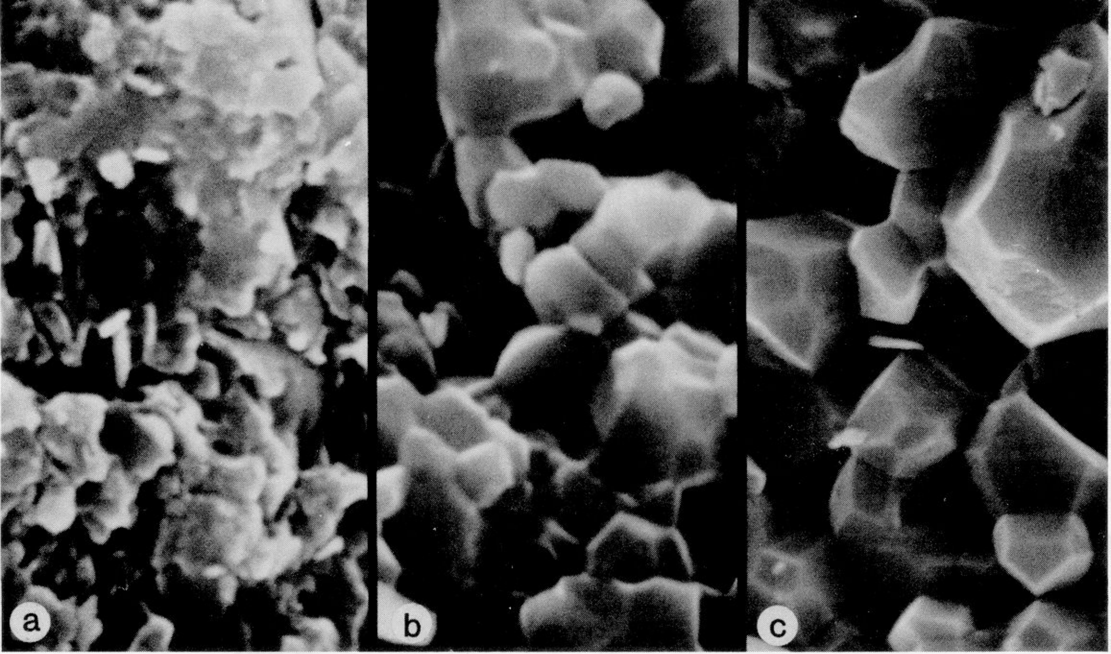
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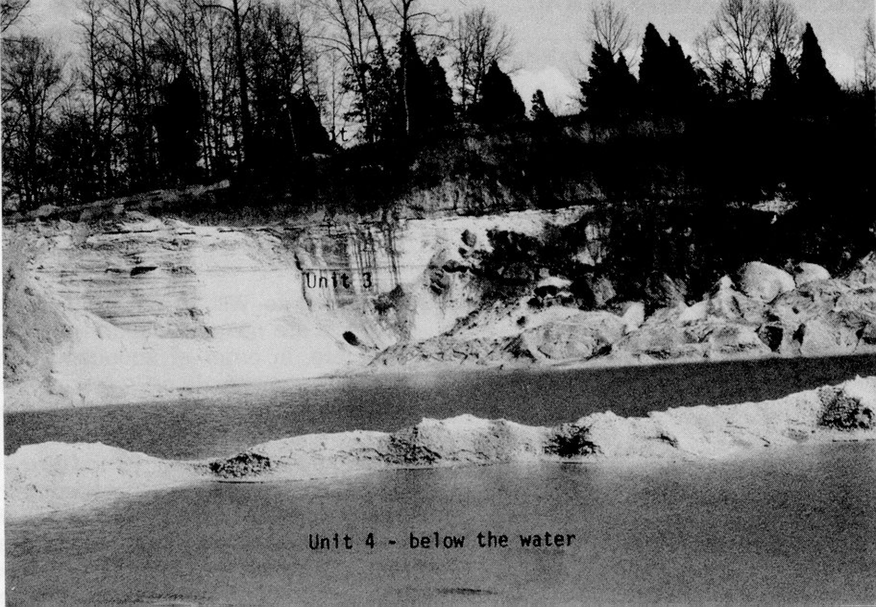
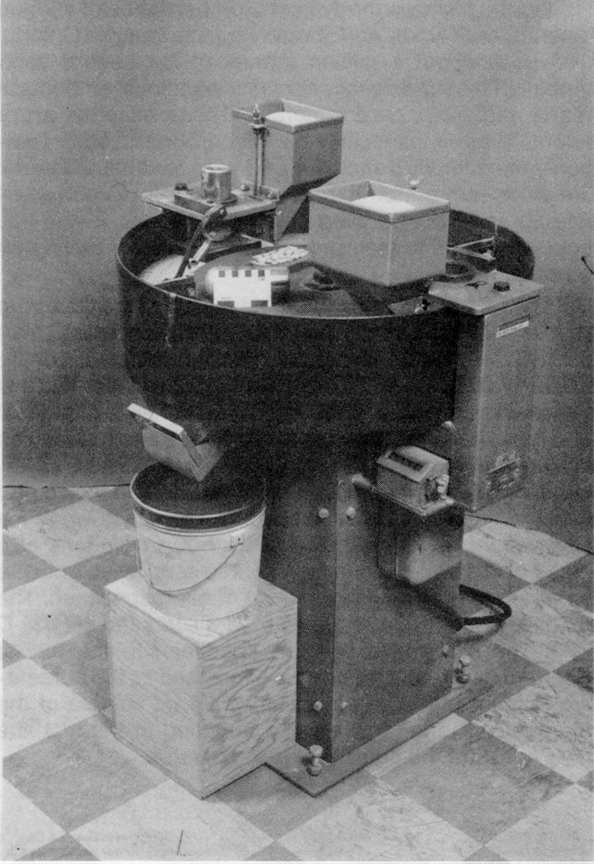
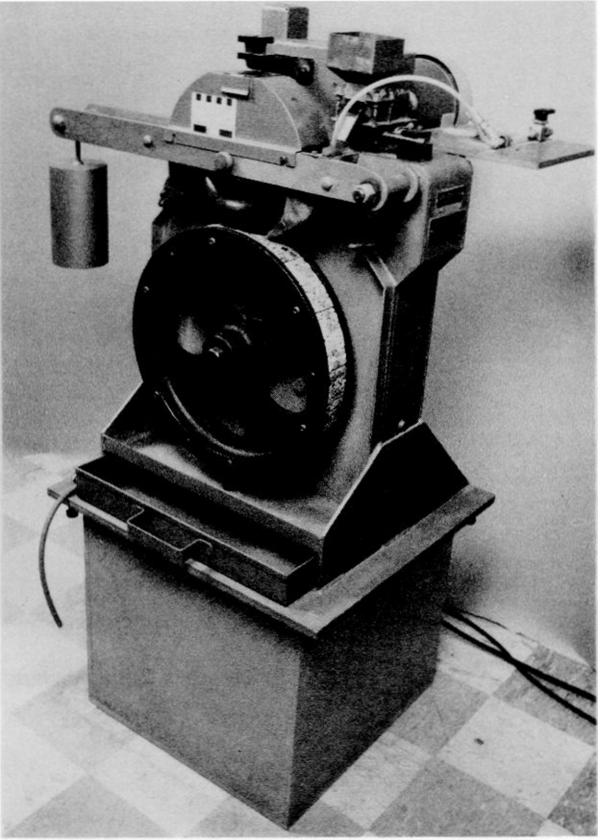
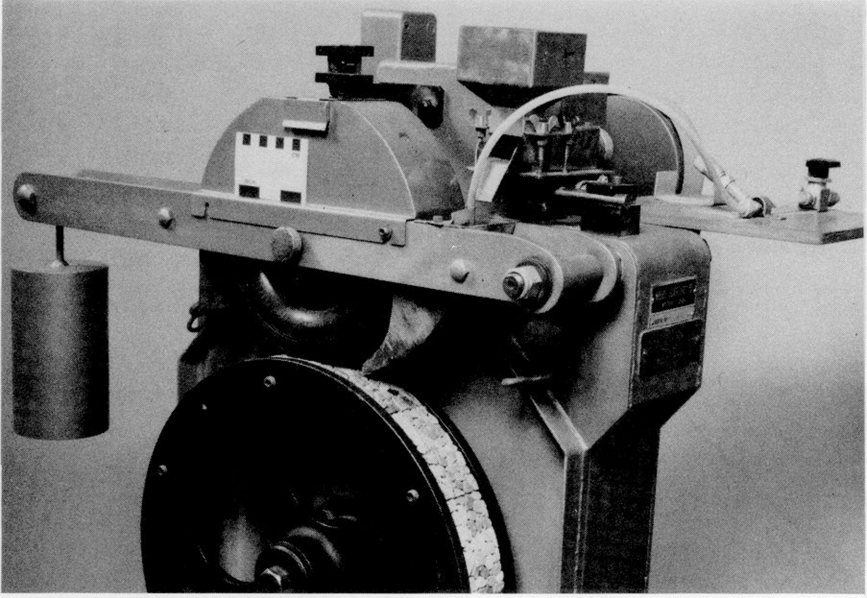

Unit 3
Unit 4 - below the water

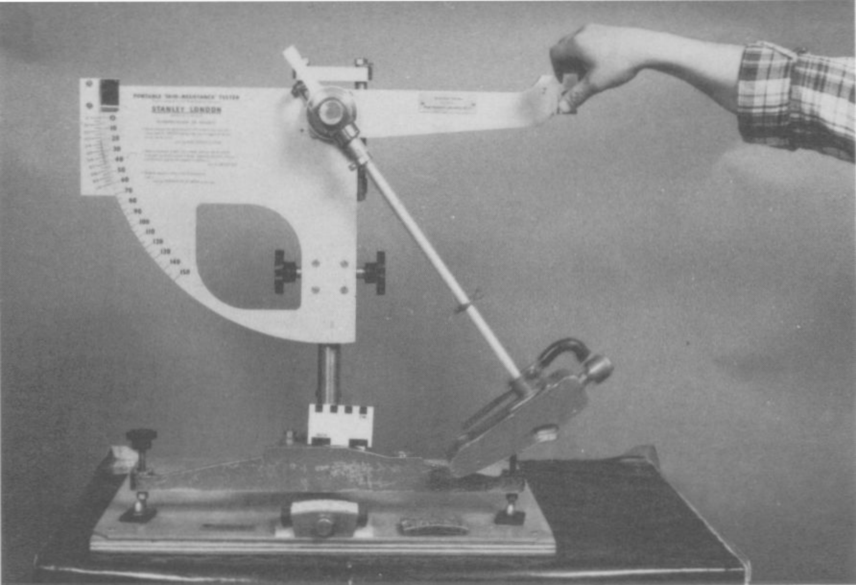

Unit 1 - stripped
Unit 4

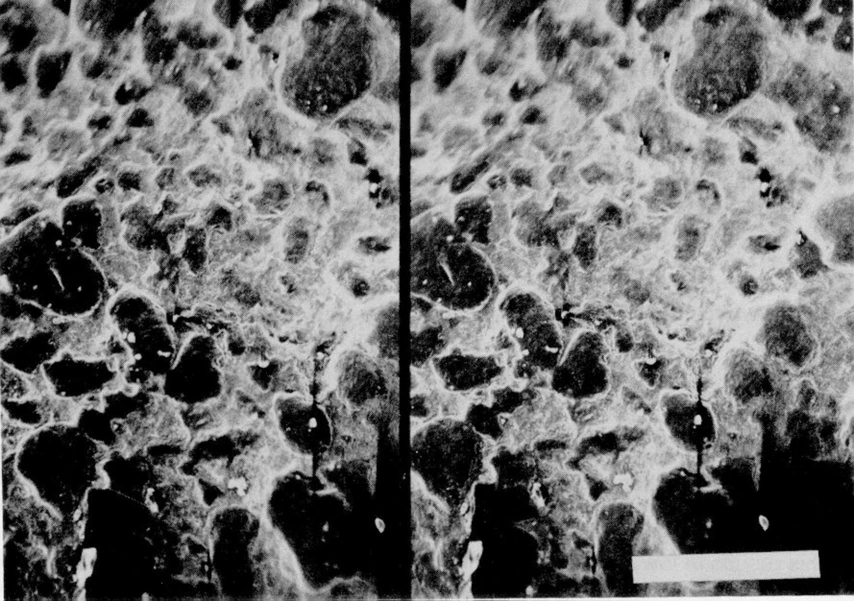


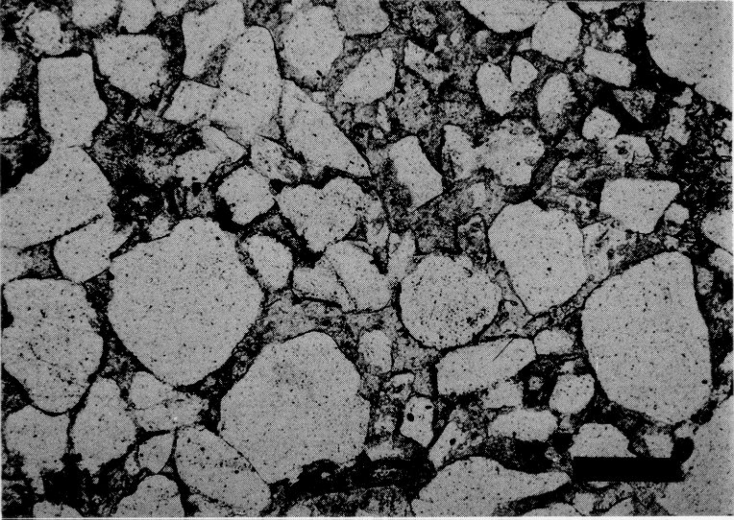

OTTAWA SAND

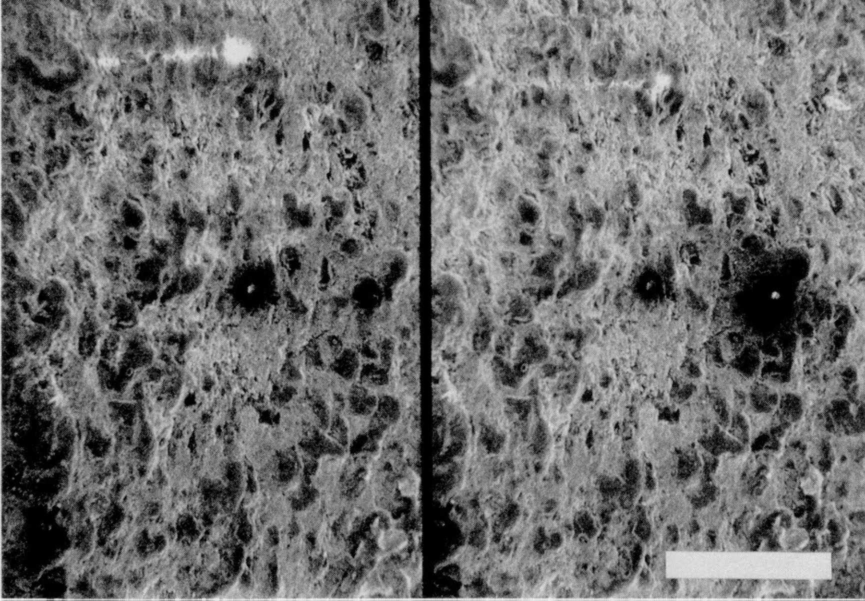


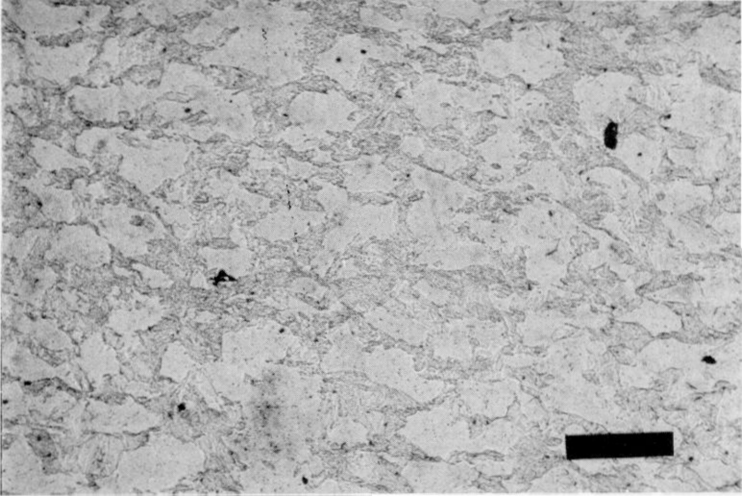


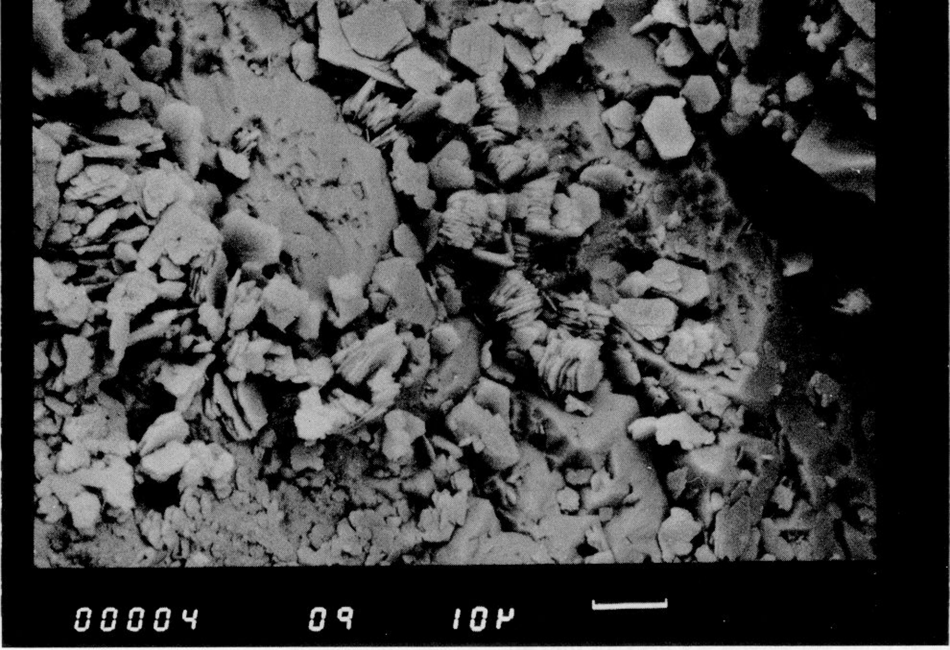

STANLEY LONDON







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