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LIMESTONE INDUSTRIES OF ONTARIO

Volume I — Geology, Properties and Economics

Volume II — Limestone Industries and Resources of Eastern and Northern Ontario

Volume III — Limestone Industries and Resources of Central and Southwestern Ontario

Limestone Industries of Ontario

Volume I — Geology, Properties and Economics

Prepared for the Aggregate Resources Section,
Land Management Branch, Ontario Ministry of Natural Resources

by
Derry Michener Booth and Wahl
and
Staff of the Engineering and Terrain Geology Section, Ontario Geological Survey,
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The members of the study's steering committee made a valuable contribution to the study by guiding the authors, providing materials and reviewing the report.

A large study such as this is completed only through the efforts of many people. The geological/mining engineering firm, Derry Michener Booth and Wahl, was the lead consultant and was responsible for the plant inventory and descriptions. Staff who prepared the material included David Wahl, Martin Taylor, Wes Roberts and Charles Pitcher, with the assistance of W.G. Wahl, Wahlex Ltd., G. Robert Guillet, Consultant, and Jack Kriens, IMD Laboratories. Don Hains of Hains Technology Associates was responsible for the material on commodities and economics of the limestone industries. Mr. Hains and Mr. W.G. Wahl prepared the plant descriptions for cement, lime and fillers operations.

Staff of the Engineering and Terrain Geology Section, Ontario Geological Survey of the Ministry of Northern Development and Mines prepared the geological description of each site as well as the regional descriptions of the geology of limestone and related carbonate rocks in Volume I. This work was supervised by Dr. Owen White, Chief, Engineering and Terrain Geology Section, and Mike Johnson, Acting Supervisor, Paleozoic/Mesozoic Geology Sub–Section. Staff involved in preparing the site descriptions included Dr. Max Vos, Rainer Wolf, Ruth Bezys, Derek Armstrong, Julie Stevenson–Demeester, Val Mazur, and Chris Fouts. Dr. Peter Telford of the Mineral Development and Lands Branch, Ministry of Northern Development and Mines assisted in the interpretation of geological data and the review of the report.

The project was initiated by the Aggregate Resources Section, Ministry of Natural Resources, under the direction of Dale Scott. Geoff Bell was the project coordinator and report editor.

Preface

Products from the limestone industries find their way into many of the items that are essential to our modern way of life. In one way or another, the output of the various members of the limestone industries is used in constructing or manufacturing items as diverse as office towers, homes, transportation networks, steel, glass, paper, or rubber products.

This report examines Ontario's limestone industries from two perspectives: the geological resource, including limestone, dolostone, marble and carbonatites; and secondly, the various industries which rely on these resources to manufacture products which are vital to Ontario's economy. These products include construction aggregate, cement, lime, fillers and extenders, building stone and pulverized stone.

In order to undertake a study on such a large and important economic sector, a steering committee was struck to formulate the terms of reference for the study and guide the research and field work through to the report stage. Members of the steering committee were:

☐ Dale Scott, Chairman, Ministry of Natural Resources
☐ Norris Walker, Aggregate Producers' Association of Ontario
☐ Vic Perry, Canadian Portland Cement Association
☐ Don Stonehouse, Energy Mines and Resources Canada
☐ Dr. Owen White, Ministry of Northern Development and Mines
☐ Dr. Peter Telford, Ministry of Northern Development and Mines
☐ Dr. Max Vos, Ministry of Northern Development and Mines
☐ Mike Johnson, Ministry of Northern Development and Mines
☐ Zoltan Katona, Ministry of Transportation
☐ Chris Rogers, Ministry of Transportation
☐ Geoff Bell, Executive Secretary, Ministry of Natural Resources

The study brings together the most up to date geological information pertaining to carbonate rocks and describes the current operations of the members of the limestone industry. In addition, information on the economics of the various commodities is presented in order to give a more complete picture of this resource activity. Field work and data compilation were performed in 1986 and 1987. The authors have attempted to incorporate changes in plant design and ownership up until summer 1988.

The geological and plant site descriptions are organized based on the Ministry of Natural Resources administrative districts. This approach was taken to accommodate the multi–commodity nature of the industry, as well as to facilitate review of the material. This format also allows district updates of activity to be produced easily at a future date.

Metric units are used in the geological descriptions throughout the report, and in parts of the plant and operations descriptions. Since plant equipment is normally sized in Imperial units, these measurements have not been converted to metric units for ease of presentation.

Contents

Introduction

Ontario is fortunate in possessing ample resources of limestone and related carbonate rocks, including dolostone, marble and carbonatite. The rocks, which consist primarily of calcium carbonate, have many uses in today's economy. This report examines Ontario's limestone resources as well as the industries which rely on them: crushed stone aggregates; cement; lime, chemical and metallurgical stone; fillers and extenders; building stone; and pulverized stone. These industries supply the materials upon which Ontario's construction and transportation infrastructure rely. In addition, many limestone products are used in industrial processes which manufacture a host of products such as steel, chemicals, paper and composite materials.

This report attempts to capture the many aspects of the resource sector. The geology of Ontario's carbonate rocks has received considerable attention over the last fifteen years. Part 1 of Volume I deals with the geology of Paleozoic limestone formations on a regional scale. Part 1 integrates all the recent interpretation of stratigraphy, lithology and nomenclature. This is particularly important in southeastern Ontario which relies heavily on bedrock aggregates because of a shortage of sand and gravel aggregate. The geology of southeastern Ontario has been analyzed in depth by geologists of the Ontario Geological Survey over the past eight years. The latest interpretation of the bedrock formations is presented. Part 2 describes the geology of marble deposits in southeastern Ontario, and carbonatites in northern Ontario, as well as calcite veins and marl deposits.

Part 3 of Volume I describes the main limestone industries in Ontario. The commodities of the various sectors are examined in light of physical characteristics, processing techniques, end–uses and specifications of products.

Part 4 describes the economics of each of the limestone industries, and deals with factors such as energy and transportation costs, prices, and competing products which determine the viability and competitiveness of the various products. An outlook for the commodities is given.

Volumes II and III of the report describe the geology, plant, processing and products of the active members of the industry. Volume II includes the operations which are located in northern and southeastern Ontario. Volume III examines the sites in south central and southwestern Ontario. The two volumes consist of detailed site–by–site inventories of each operation. The site inventories include a geological interpretation of the exposed rock in the quarry, a description of the operator's quarry operations and stone processing plant, plus a products list and in many instances a plant flowchart. In addition to commercial sites, many sites with important geological features are included in the inventory.

In the almost thirty years since the late Don Hewitt authored the first study of this type (Hewitt, 1960), many changes have taken place in Ontario's economy. The limestone industries have kept pace with this change, achieving higher production rates with lower energy, labour and raw material input. The primary value for the various products manufactured by the limestone industries is currently approaching one billion dollars annually. The limestone industries are positioned to remain a vital segment of Ontario's economy well into the 21st century.

Part 1
Paleozoic Geology of Ontario

Summary

The Paleozoic strata in Ontario occur in a broad arc which stretches from Ottawa and the Quebec border, southwest across the southern peninsula of the province to Windsor (Figure 1.1, Chart, back pocket). Paleozoic rocks also occur to the north along the Bruce Peninsula and across the north end of Lake Huron, and underlie Manitoulin, Cockburn, and St. Joseph islands and the Sault Ste. Marie area. A small Paleozoic outlier also occurs in the Lake Timiskaming area and large areas of the Hudson Bay/James Bay Lowlands are underlain by rocks of Paleozoic and Mesozoic age.

During the Paleozoic era, much of Ontario was covered by a series of inland seas in which sediments were deposited. These sediments are now exposed and include limestones, dolostones, shales and sandstones. Since most of the sedimentary rocks in Ontario are of shallow marine origin, the local conditions at the time of deposition, such as: water depth, salinity, current direction, proximity to shorelines, etc., strongly influenced the type of sediment. Major episodes of subaerial exposure mark the end of each geological time period in Ontario (i.e. Precambrian, Ordovician, Silurian and Devonian).

The distribution of Paleozoic (and Mesozoic) rocks in Ontario can be subdivided into five major regions based on their age and geographic location. These major regions are: eastern Ontario, central Ontario, Niagara Escarpment, southwestern Ontario, and northern Ontario (Figure 1.2). The northern Ontario region includes parts of Manitoulin Island, the Lake Timiskaming area, and the Moose River Basin of the Hudson Bay Lowland.

The Paleozoic strata in southern Ontario possess a shallow southwesterly regional dip and, coupled with erosion, this has resulted in successively younger rocks becoming exposed at the surface to the southwest. From the northeast to the southwest, therefore, the rocks can be described in ascending stratigraphic order, beginning with the Cambro–Ordovician rocks in the northeast and ending with the Upper Devonian rocks in the southwest (Figure 1.3).

Paleozoic sedimentary rocks in the Province were originally deposited as flat–lying units, and most were subsequently subjected to tectonic disruption to varying degrees. Strata west of Kingston dip to the south or southwest at a rate of a few metres per kilometre. Strata east of Kingston, however, have been disrupted by more intensive tectonic processes with displacements across fault zones of up to several hundred metres and beds which display very high–angle dips. The thickness of Paleozoic rocks over the Precambrian basement increases in a southwesterly direction to a maximum of about 1,350 m near Sarnia because of these regional trends (Johnson et al., 1985), and averages about 400 m across the Province. Table 1.1 is a list of average thickness for formations used by the limestone industry.

Major structural elements which affected Paleozoic deposition across southern Ontario are as follows (Figure 1.4):

THE MICHIGAN BASIN

This approximately circular structure is present because of regional subsidence of the Precambrian basement rocks centred near Napeena, central Michigan state. As the basement subsided, Paleozoic sediments tended to collect and deposit more rapidly in the centre of the basin, increasing the thickness of each unit towards the basin centre.

THE APPALACHIAN BASIN

This basin is a foreland regional downwarp which parallels the Appalachian Mountains and is centred south of Ontario. Formations deposited under the influence of this feature thicken to the southeast.

THE ALGONQUIN ARCH

This basement high of Precambrian rocks separates the Michigan and Appalachian basins, forming the spine of the southern peninsula of Ontario. For several intervals during the Paleozoic, this feature was pronounced and therefore some units thin toward the arch or are absent over it. The Findlay Arch is a continuation of this feature south into the United States, and its intersection with the Algonquin Arch in the Chatham area is called the Chatham Sag.

THE FRONTENAC AXIS

This is another Precambrian high which extends from the Canadian Shield to the St. Lawrence River between Gananoque and Brockville. Unlike the Algonquin Arch, this structure presently exposes Precambrian rocks at the surface. This ridge separates the Paleozoic sediments in eastern Ontario from those in the rest of the province. As the rocks on both sides of the axis are very similar, it probably was not a barrier to deposition during much of the early Paleozoic. Its current position is due partly to uplift along major fault zones which border the arch.

The presence of the Michigan and Appalachian basins and the Algonquin Arch had a major impact on the Paleozoic rocks deposited in southern Ontario, both in terms of the thickness and variability of each rock type and in their present day distribution. Also affecting the deposition of Paleozoic rocks in southern Ontario was the supply of clastic sediments which originated from two

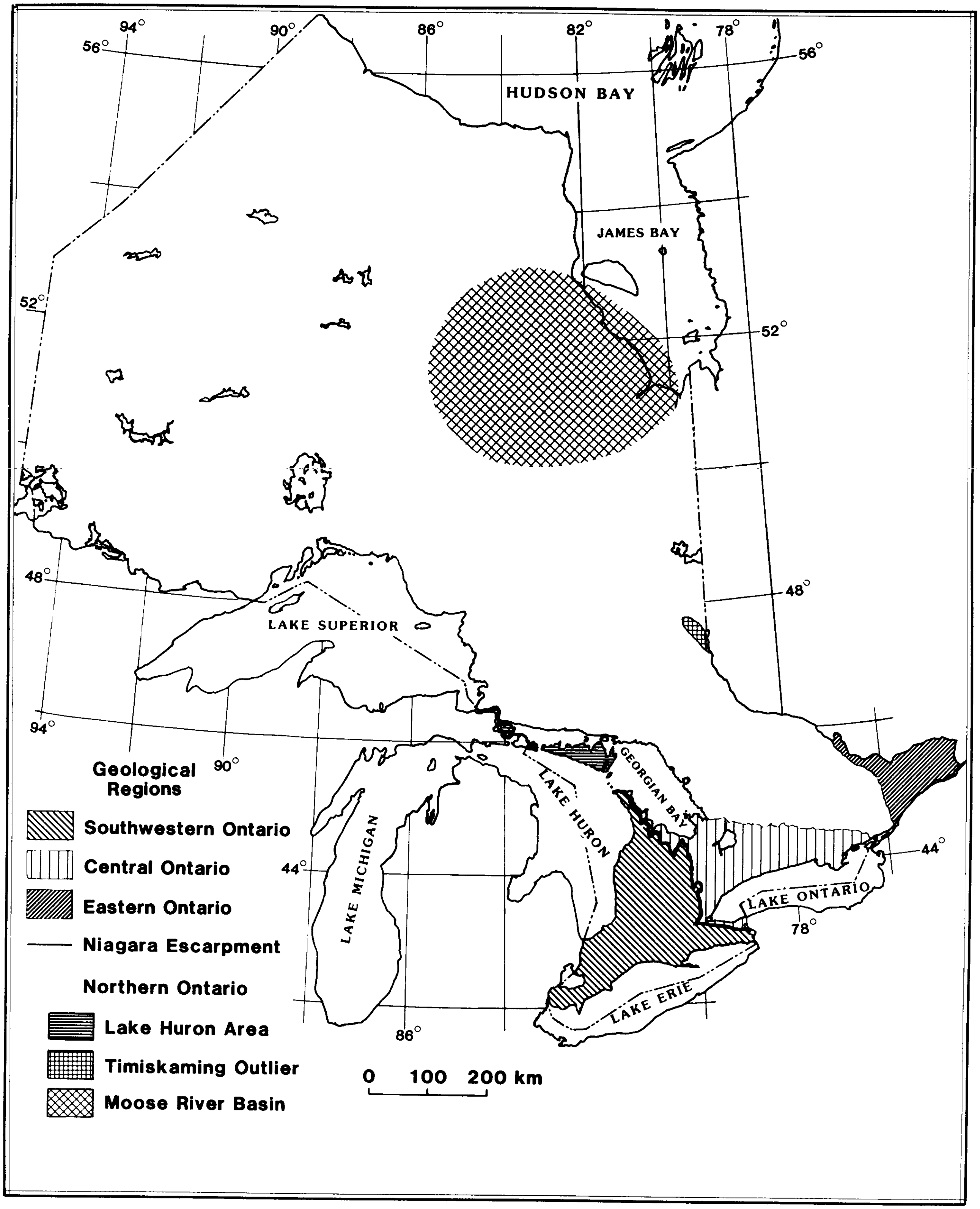
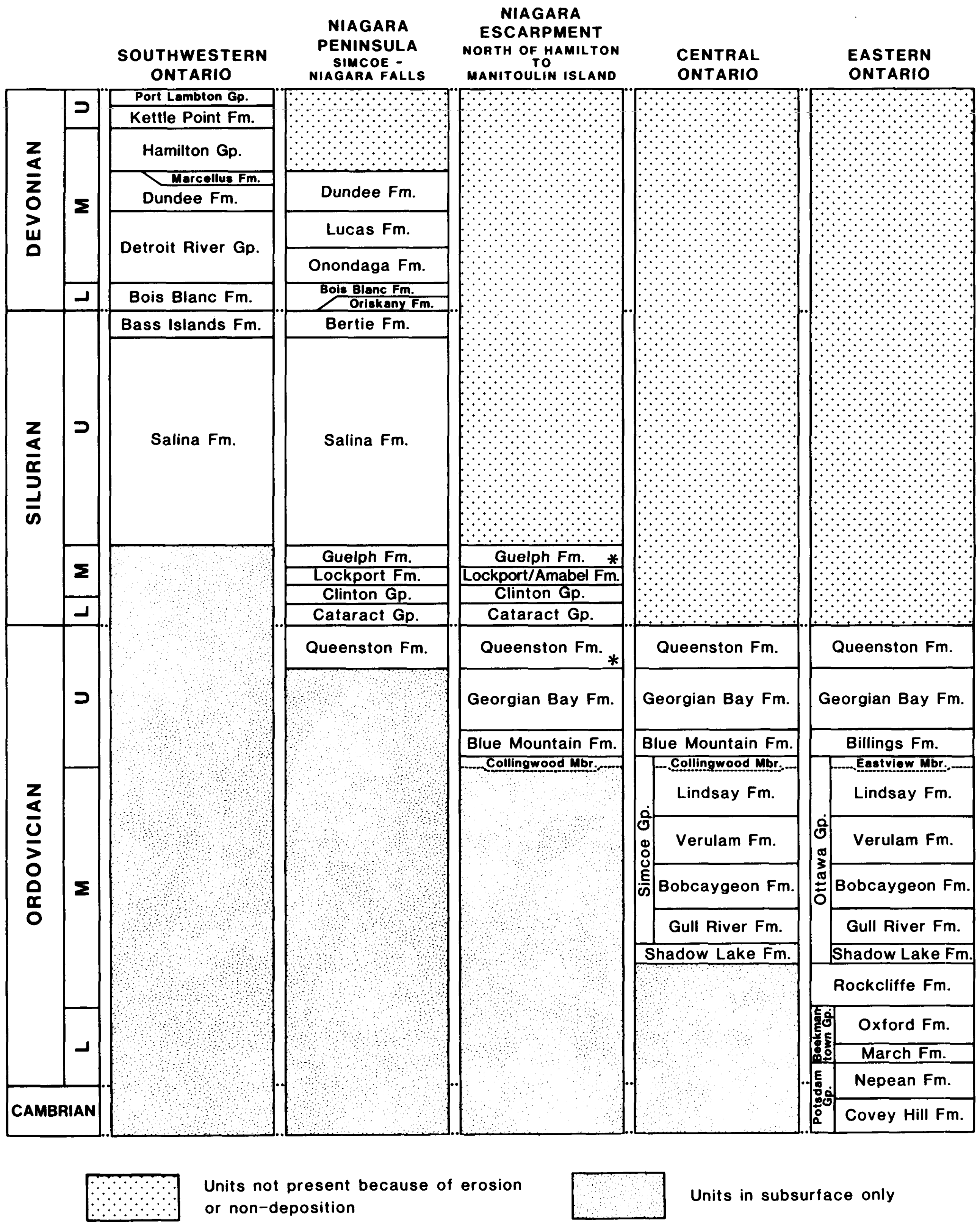


Figure 1.2. DISTRIBUTION OF PALEOZOIC ROCKS IN ONTARIO.



Gp.=Group, Fm.=Formation, Mbr.=Member

* Does not occur on Manitoulin Island

Figure 1.3. STRATIGRAPHIC COLUMNS OF PALEOZOIC STRATA IN SOUTHERN ONTARIO.

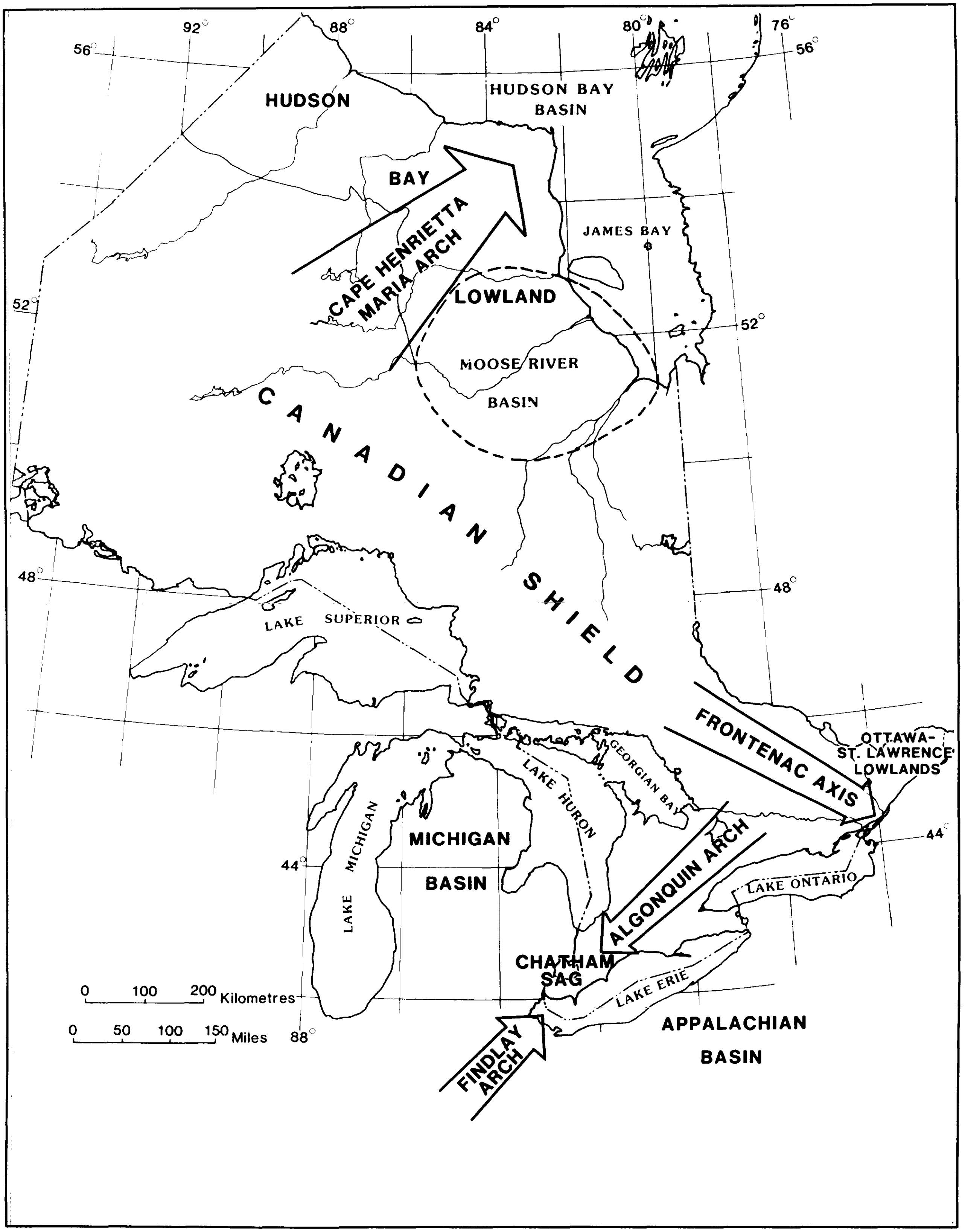


Figure 1.4. MAJOR STRUCTURAL FEATURES OF PALEOZOIC ROCKS IN ONTARIO.

Table 1.1. AVERAGE THICKNESS OF PRINCIPAL FORMATIONS USED BY THE LIMESTONE INDUSTRY.

Age	Formation	Thickness (metres)
Middle Devonian	Dundee	30
	Detroit River Group	180
	Onondaga	20
Lower Devonian	Bois Blanc	40
Upper Silurian	Bertie	14
Middle Silurian	Guelph	30
	Lockport/Amabel	40
Middle Ordovician	Lindsay	100
	Verulam	100
	Bobcaygeon	70
	Gull River	45
Lower Ordovician	Oxford	120

sources — the Canadian Shield to the north, and from periodic uplifting of highlands to the east (i.e. the Taconic [ancestral Appalachian] Mountains). The uplift in the east is quite important to some units as the clays and silts introduced had a deleterious impact on the quality of carbonate being deposited.

The discussion which follows will highlight the five regions of Paleozoic strata in Ontario, concentrating on those units which are of significance for use in the limestone industry. For a more complete discussion of the individual Paleozoic formations, refer to the geological introduction of each district and to the individual quarry descriptions found in Volumes II and III.

Eastern Ontario
(Cornwall, Carleton Place, Brockville, Napanee and Pembroke Districts)

The Paleozoic bedrock in eastern Ontario (Figure 1.2) is bounded by Precambrian rocks of the Gatineau Hills and the Frontenac Axis to the north and west, respectively. The provincial border delineates the southern and eastern boundary of this area, although Paleozoic rocks extend southward into New York State and eastward into the Province of Quebec.

Sandstones, shales and carbonates of latest Cambrian to latest Ordovician age occur within eastern Ontario. Carbonate rocks which are significant to the limestone industry occur in the Lower Ordovician Beekmantown Group and in the Middle Ordovician Rockcliffe Formation and Ottawa Group (Figure 1.5). The distribution of these rocks in eastern Ontario is complicated by the presence of numerous normal faults (Figure 1.6), some of which may have several hundred metres of displacement (Williams, in prep.), and unlike the Paleozoic rocks west of the Frontenac Axis, there are no regional patterns in the distribution of the rocks in eastern Ontario.

The following discussion of the Paleozoic sequence will focus upon the carbonate rocks. Further details on the geology of the entire sequence can be found in Williams (in prep.).

POTSDAM GROUP

The Potsdam Group, which forms the basal Paleozoic unit in most of eastern Ontario, consists of the following two formations: the Covey Hill Formation and the overlying Nepean Formation (Figure 1.5). The age of these units may either be Cambrian or Lower Ordovician. Although the Covey Hill and Nepean have been quarried for building stone and crushed stone in the Ottawa area, they are sandstones and thus will not be discussed further in this report.

BEEKMANTOWN GROUP

Directly overlying the rocks of the Potsdam Group are the dolostones of the Lower Ordovician Beekmantown Group, which is subdivided into the lower March Formation and the overlying Oxford Formation (Figure 1.5). Both units are significantly utilized by the limestone industry, but are found as outcrop only in eastern Ontario although equivalent units are found in the subsurface in southwestern Ontario (Sanford and Quinlan, 1959).

MARCH FORMATION

The March Formation consists of interbedded quartz sandstone, dolomitic sandstone, sandy dolostone and dolostone. As the sandstones in this unit are indistinguishable from those of the underlying Nepean Formation, the lower contact of the March is placed at the base of the lowest appearance of dolostone beds in the section. Its first appearance is quite variable in different surface exposures because of the variety of facies present within the March Formation. The sandstones consist of fine- to coarse-grained quartz sand, whereas the dolostones are fine to medium crystalline. The intermediate lithologies (sandy dolostones/dolomitic sandstones) have characteristics of both the sandstones and dolostones. Generally the formation is thin to thick bedded, and ranges in thickness from 18 to 20 m in the Ottawa area,

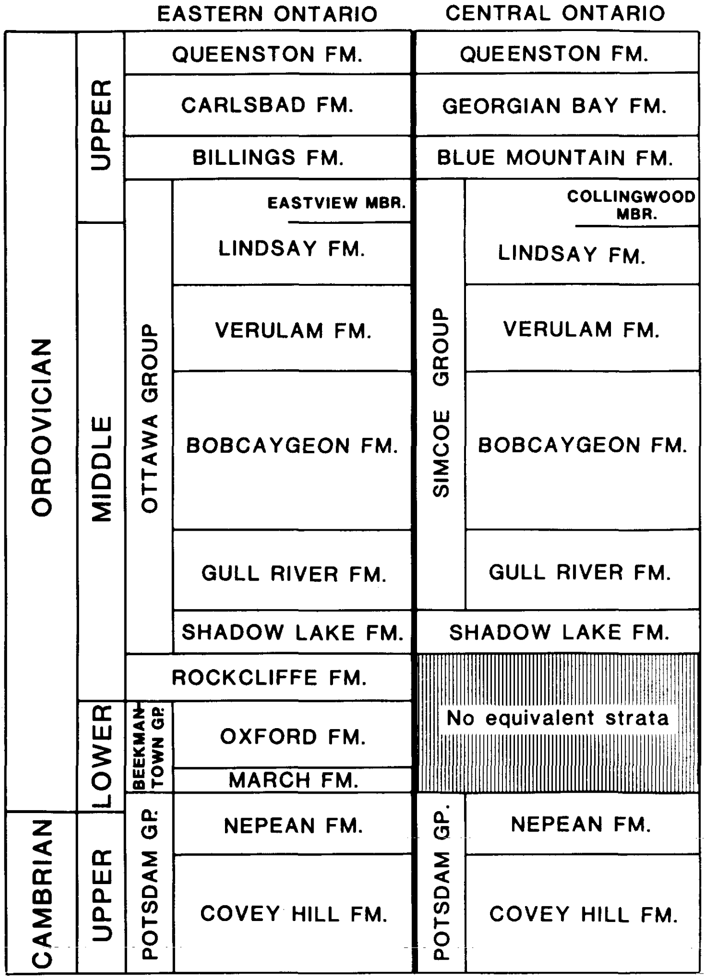


Figure 1.5. STRATIGRAPHIC COLUMNS OF PALEOZOIC ROCKS OF EASTERN AND CENTRAL ONTARIO.

to 25 m in the Brockville area, and to 64 m in the subsurface near the Town of Alexandria (Williams, in prep.). The highly faulted nature of the rocks east of the Frontenac Axis (Figure 1.6) has caused most of the bedrock exposures of this formation to occur in small, lensoid-shaped fault blocks, usually in proximity to the contact with Precambrian rocks.

OXFORD FORMATION

The balance of the Beekmantown Group consists of the Oxford Formation (predominantly dolostones), which has a thickness between 62 and 102 m (Williams, in prep.). The dolostones are thin to thick bedded and range from mirocrystalline to medium crystalline. Scattered sand grains and sand interbeds (up to 30 cm thick) appear in the lower part of the formation, and concentrations of chert nodules occur at some localities. The lower contact of the unit is placed where the sand content becomes relatively insignificant (i.e. less than 5% quartz). Most outcrop exposures occur south of Ottawa (Figure 1.6), although some exposures also follow the Ottawa River eastward. These dolostones are extensively quarried in the Brockville area and in a fault block southeast of Ottawa.

ROCKCLIFFE FORMATION

As originally defined by Wilson (1937) the Rockcliffe Formation, which unconformably overlies the Beekmantown Group (Figure 1.5), consists of interbedded quartz-sandstone and shale. Overlying the Rockcliffe Formation (of Wilson, 1937) is the St. Martin Formation, also defined by Wilson (1937), which is a limestone and silty dolostone. Since these carbonates exhibit shaly and sandy intervals similar to the underlying strata, recent workers (Poole et al., 1970; Williams and Wolf,

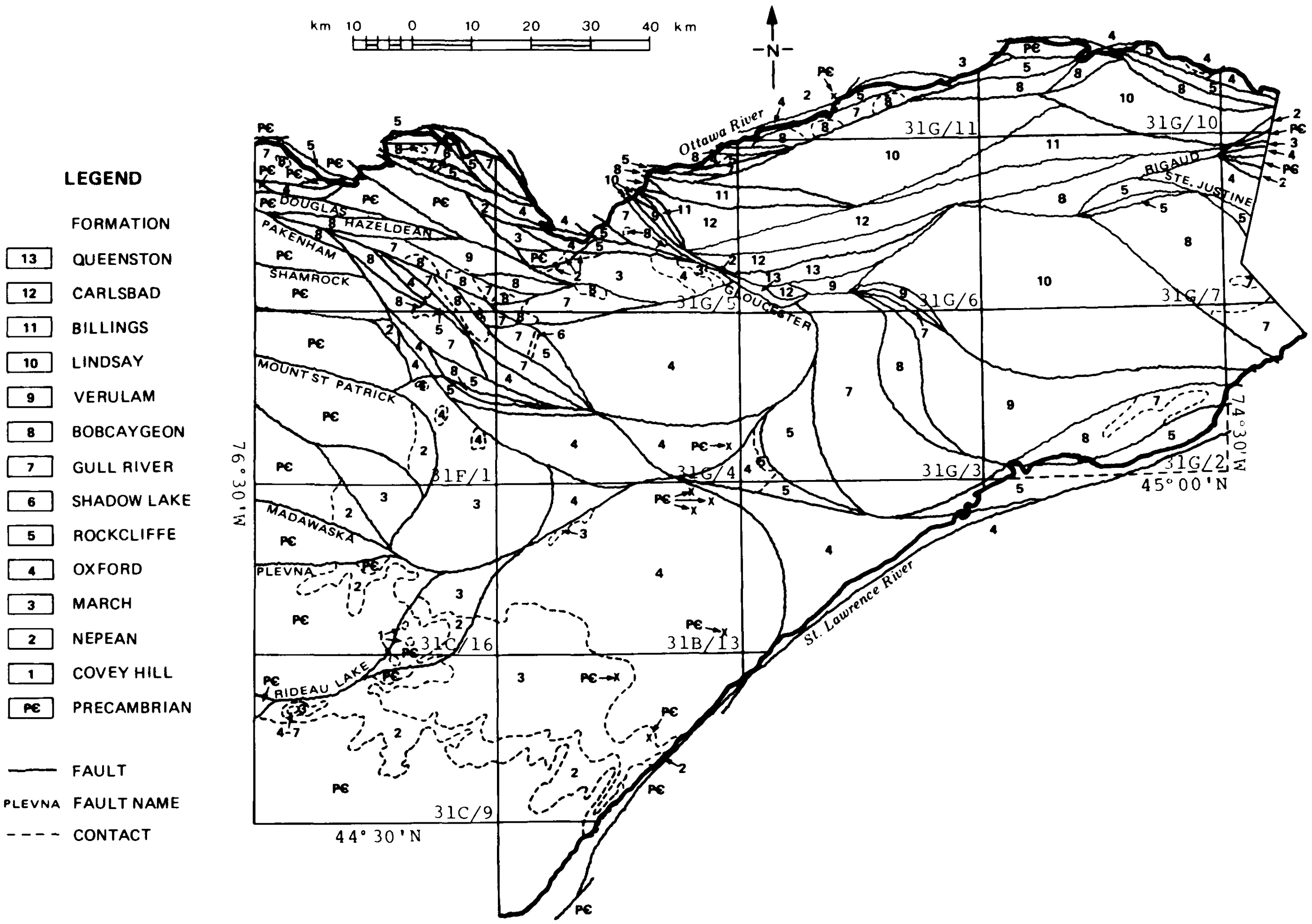


Figure 1.6. MAP OF GENERALIZED PALEOZOIC GEOLOGY OF THE OTTAWA - ST. LAWRENCE LOWLAND.

1982; Williams, in prep.) have combined the two units into the Rockcliffe Formation with the St. Martin Member constituting an upper member of the formation.

The sandstones are light grey to greenish grey, thin to thick bedded and contain abundant sedimentary features such as cross–bedding and burrows. The shales are olive green to dark grey with maroon laminae, whereas the overlying carbonates are light grey to grey–brown and range from microcrystalline to coarse–crystalline. Some of the coarse–crystalline limestones, which are largely restricted to the eastern part of Ontario, are quite high in calcium content. The average thickness for the Rockcliffe Formation is approximately 50 m. Outcrops of the Rockcliffe Formation are restricted and occur mainly along the Ottawa River, or southeast of Ottawa (Figure 1.6). The lower contact of the formation is placed at the lowest occurrence of the sand/shale lithology overlying the dolostones of the Oxford Formation.

Although the lower member of the Rockcliffe Formation (predominantly a sandstone and shale) is not quarried on its own, some quarries have taken material from this unit to be used as general fill. The highly friable nature of this member has limited its use to date, although in recent years several test pits have been excavated to investigate the possible exploitation of the unit. The upper St. Martin Member has been extensively quarried east of the Ottawa area, primarily for aggregate.

OTTAWA GROUP

Significant changes to the nomenclature and subdivisions of the Middle and Upper Ordovician Ottawa Group (see Figure 1.7) have recently been made by the Ontario Geological Survey (OGS). This was the result of considerable new data generated by recent OGS field mapping of these rocks (Williams, in prep.), in an attempt by the Survey to standardize, as much as possible, the nomenclature used in Ontario.

The Ottawa Group was formerly termed the Ottawa Formation (Wilson, 1946), (Figure 1.7), and subdivided into seven "faunal zone" members. Uyeno (1974) subsequently raised the formation to group status and the members to formation status. Initial OGS mapping in the area by Williams and Wolf (1982) led to the adoption of six lithostratigraphic units, A to F (Figure 1.7). Standardization of this stratigraphy with the sections of Central Ontario (specifically the Lake Simcoe area) was made in 1983 with the adoption by Williams and Rae (1983) of five formations to replace the six lithostratigraphic units previously used. The formations adopted by Williams and Rae (1983) are: the Shadow Lake, Gull River, Bobcaygeon, Verulam and Lindsay

Wilson 1946		Williams and Wolf 1982		Williams and Rae 1983 Williams, in prep.		
Formation	"Faunal zone"	Formation	Unit	Gp	Formation	Member
EASTVIEW		EASTVIEW		OTTAWA	LINDSAY	UPPER (EASTVIEW)
OTTAWA	"Cobourg"	OTTAWA	F			LOWER
	"Sherman Fall"		E		VERULAM	
	"Hull"		D		BOBCAYGEON	UPPER
	"Rockland"		C			MIDDLE
	"Leray"					LOWER
	"Lowville"				GULL RIVER	UPPER
	"Pamelia"		B			LOWER
			A		SHADOW LAKE	

Figure 1.7. REVISIONS TO THE LITHOSTRATIGRAPHY OF THE OTTAWA GROUP IN EASTERN ONTARIO.

Formations (in ascending stratigraphic order), (Figure 1.7). In central Ontario these same formations exclude the Shadow Lake Formation and are collectively termed the Simcoe Group. These formations are further discussed in the central Ontario section as there are regional variations between the two.

SHADOW LAKE FORMATION

The basal unit of the Ottawa Group is the Shadow Lake Formation. In eastern Ontario it consists of silty and sandy dolostone with minor interbeds of sandstone. The dolostones are microcrystalline to fine crystalline, very thin to thick bedded and light green–grey in colour. Up to 2.8 m thick in the Ottawa area, outcrops of this unit are very rare and it is not used by the limestone industry in eastern Ontario.

GULL RIVER FORMATION

The Gull River Formation in eastern Ontario, which conformably overlies the Shadow Lake Formation, has been subdivided into two members: a lower member consisting of interbedded limestones and dolostones (which may contain some silt or sand); and an upper member consisting of thin–bedded shaly limestones. The formation is about 50 m thick in the Ottawa area and thins eastward to 40 m in the Hawkesbury area (Williams, in prep.). Features common in the Gull River Formation are small lenses of calcite crystals, termed "birdseye" texture, sulphate nodules and molds, and abundant fossils, especially the coral *Tetradium* in the upper member, and stromatolites.

The Gull River Formation outcrops primarily in the Ottawa area although other exposures occur in eastern Ontario especially in the Westport and Cornwall areas (Figure 1.6). This unit is important to the limestone industry and is extensively quarried in the Ottawa and Cornwall areas for crushed stone and concrete manufacturing.

BOBCAYGEON FORMATION

The Bobcaygeon Formation conformably overlies the Gull River Formation and consists of limestone with planar to undulating shale partings. Three members have been identified within the formation; the middle member is substantially more shaly and resembles closely the overlying Verulam Formation. The lower member is characterized by very thick–bedded, generally microcrystalline limestone beds. The thickness of the Bobcaygeon Formation in eastern Ontario is about 85 m. Within the lower member, black chert nodules up to 20 cm in diameter may be present. This unit occurs throughout eastern Ontario but is most prevalent around Cornwall and Ottawa (Figure 1.6), and is of significant interest to the limestone industry as an aggregate source.

VERULAM FORMATION

Conformably overlying the Bobcaygeon Formation, the Verulam Formation consists of about 35 m of interbedded limestones and shales. The limestones range from microcrystalline to coarse crystalline, thin to medium bedded and range from light to dark grey or grey–brown in colour. Beds of coarse fossil debris often occur within the limestone beds. The blue–grey, often calcareous shale beds can be up to 15 cm thick and constitute a significant portion of the formation. The distribution of the Verulam Formation is restricted to an area directly southwest of Ottawa (Figure 1.6) and to a larger area in the southwestern part of the Cornwall District. The use of these rocks by the limestone industry is largely restricted to cement manufacture because of their lower purity (i.e. high shale content).

LINDSAY FORMATION

The Lindsay Formation in eastern Ontario consists of limestone, with thin calcareous shale interbeds, which conformably overlies the Verulam Formation. Identifying the contact between these two units in an outcrop can be difficult, but it is generally placed where the shale interbeds (which characterize the Verulam Formation) become less than 5 cm thick. The Lindsay Formation is divisible into two members; the upper is called the Eastview Member and the lower is unnamed. Portions of the Eastview Member are equivalent to the well known Collingwood shale, an oil shale which is exposed near Craigleith, Ontario. A distinctive characteristic of the limestones of the lower member is the highly undulating nature of the bedding which produces a nodular texture. The limestones are microcrystalline to coarse crystalline, very thin to thick bedded and tend toward grey–brown colours. Shale interbeds are calcareous and dark grey or dark brown in colour. The Eastview Member consists of calcareous shale and exudes a petroliferous odor from a fresh surface. The lower member is extensively used for general aggregate production by the limestone industry. Distribution of the Lindsay Formation is generally restricted to the Cornwall District (Figure 1.6).

BILLINGS FORMATION

The Upper Ordovician Billings Formation consists mainly of dark grey to black shale, and its lower contact with the Eastview Member of the Lindsay Formation is defined where the shale beds become greater than 2 cm thick. It is considered to be equivalent to the Blue Mountain Formation which occurs in central Ontario. In the Ottawa area (Figure 1.6), the Billings Formation is 62 m thick and consists of non–calcareous to slightly calcareous shale. Minor limestone beds can also be present. This unit is not used by the limestone industry.

CARLSBAD FORMATION

Conformably overlying the Billings Formation is the Carlsbad Formation, which consists of about 180 m of interbedded blue-grey shale, calcareous siltstone and silty limestone. This unit, while not actively used by the limestone industry, has some potential for cement manufacturing and is equivalent to the Georgian Bay Formation of central Ontario. The contact between the Billings and Carlsbad Formations is defined where the shales change colour from black to blue-grey. Subcrop and outcrop exposures of this unit are restricted to fault blocks which parallel the Ottawa River in the Cornwall District (Figure 1.6).

QUEENSTON FORMATION

The Upper Ordovician Queenston Formation consists primarily of maroon and olive-grey shales. The thickness of the formation in eastern Ontario is approximately 50 m whereas in southwestern Ontario it reaches up to 120 m. The only surface exposure occurs within a single fault block in the Russell Township area (Figure 1.6). This unit is not used in the limestone industry, but it is widely used by the ceramic and brick industries.

Central Ontario

(Huronia, Lindsay, Tweed, and Napanee Districts)

For the purpose of this report, central Ontario encompasses that part of Ontario between the Niagara Escarpment and the Frontenac Axis underlain by Ordovician strata (Figure 1.2), and extends southwards from the exposed Precambrian rocks of the Canadian Shield to Lake Ontario. The Ordovician strata exposed in the northern Lake Huron area are discussed in the northern Ontario section.

The Ordovician rocks of central Ontario range in age from Middle to Upper Ordovician (Figure 1.8), and consist of a sedimentary sequence of carbonates and shales. These strata display a very low regional dip to the southwest which results in successively younger rocks becoming exposed to the west. The base of the Niagara Escarpment, the western boundary of the region, also delineates the Ordovician–Silurian contact.

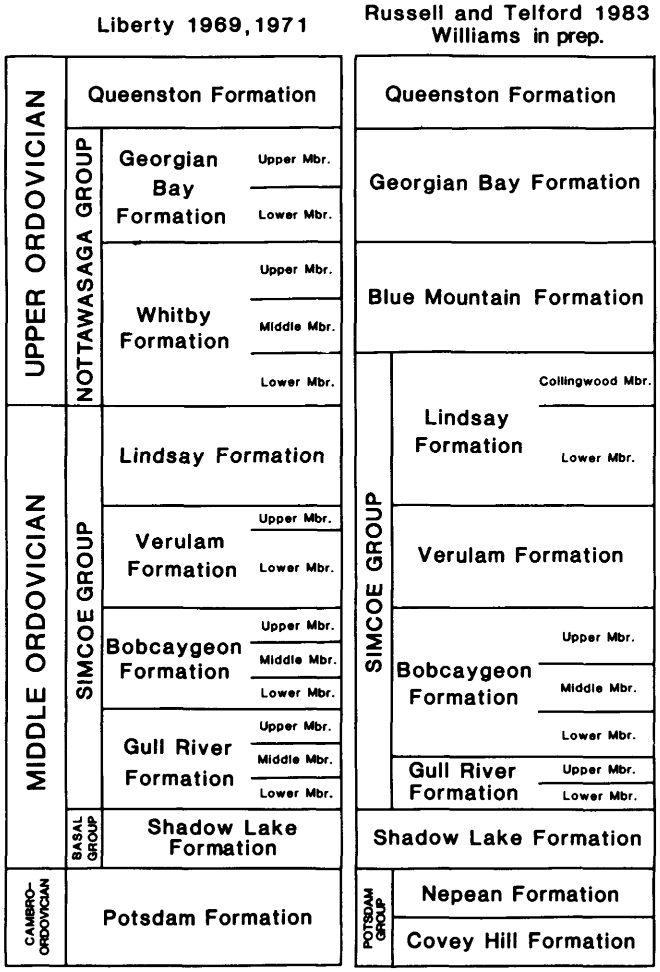


Figure 1.8. REVISIONS TO THE PALEOZOIC STRATIGRAPHY OF CENTRAL ONTARIO.

The stratigraphic nomenclature for the Ordovician strata exposed in central Ontario has undergone considerable revision and alteration since the initial surveys of the Geological Survey of Canada in the mid–nineteenth century. The most recent and comprehensive study by Liberty (1969, 1971) provided the basis for the stratigraphic subdivisions used in this report (Figure 1.8). Only minor revisions to Liberty's (1969) original nomenclature have been made, based on recent work by Russell and Telford (1983) and Williams (in prep.). These revisions resulted from the identification of lithological variations apparently not recognized by Liberty (1969), and from extensive drilling undertaken by the OGS (Johnson et al., 1985) since Liberty's (1969) report.

The following discussion summarizes the description of each Ordovician formation present in central Ontario. Further details on local variations in lithologies are described in the district sections in Volume III. Additional information on Ordovician stratigraphy in this area can be found in Liberty (1969) and Williams (in prep.).

SHADOW LAKE FORMATION

The sediments initially deposited by the Middle Ordovician transgression over the Precambrian basement rocks in central Ontario consist of conglomerates, sandstones and shales, which are up to 12 m thick in some places. These strata are collectively assigned to the Shadow Lake Formation. Older terrigenous rocks may also be present in the subsurface. The Shadow Lake Formation is generally not utilized by the limestone industry of Ontario.

SIMCOE GROUP

The term Simcoe Group was applied by Liberty (1969) to the Middle Ordovician carbonate sequence in central Ontario. The formations of the Simcoe Group are correlative with those of the Ottawa Group in eastern Ontario (which is also now subdivided into the same formations (Williams, in prep.)).

GULL RIVER FORMATION

The Gull River Formation, the lowermost carbonate formation in the Simcoe Group, had been subdivided by Liberty (1969) into three members in the Lake Simcoe area and later (Liberty, 1971a–e) into four members in the Kingston area. Based on the recent geological mapping in eastern Ontario (Williams, in prep.), the Gull

River Formation is now considered to consist of two members only. This subdivision can be used for most of central Ontario, except for the extreme western sector west of Lake Simcoe (i.e. Huronia District) where Liberty's (1969) original three-fold subdivision is maintained. Subtle lateral variations in lithology at the base of the Simcoe Group need to be examined in more detail before further revisions are undertaken in this westernmost sector.

The lower member of the Gull River Formation consists of alternating units of limestone and dolostone. The limestones are dominantly microcrystalline, commonly with a lithographic texture, and are interbedded with rare thin-bedded, fine-crystalline intervals. The fine-crystalline dolostones commonly contain small amounts of terrigenous material that ranges from mud to sand sized. This member thickens from 15 m in the west to over 30 m in the Kingston area and is equivalent to the lower member Gull River Formation of Liberty (1969) (Figure 1.8).

The redefined upper member of the Gull River Formation consists of thin-bedded limestones, commonly containing thin shale partings between the beds, and maintains a uniform thickness of 7 to 8 m across the region. It is equivalent to the lower half of the middle member, Gull River Formation of Liberty (1969), (Figure 1.8).

The Gull River Formation has been quarried for many years, especially around Lake Simcoe and Kingston. Stone has been used for aggregate, lime, cement and building purposes, including bridges, town halls and churches throughout central Ontario. Aggregate producers currently utilize most of the rock which is quarried from the Gull River Formation in central Ontario, especially the lower member. Even though some difficulties with alkali-reactivity have been identified (Rogers, 1985), this unit can still be used for a variety of aggregate purposes. The major areas of production are east and west of Lake Simcoe and around the city of Kingston.

BOBCAYGEON FORMATION

In the Lake Simcoe area the Bobcaygeon Formation had been subdivided into three members by Liberty (1969), whereas in the east only a two-fold subdivision was used (Liberty, 1963; 1971a-e). The Bobcaygeon Formation can now be subdivided into three members across all of central Ontario. The primary distinction between the members is the presence of numerous thin shale partings between the limestone beds in the middle member, while the lower and upper members are virtually shale-free.

The lower member of the Bobcaygeon Formation consists of thick-bedded limestones, with beds usually over 1 m in thickness. The microcrystalline to fine- crystalline limestones are usually intermixed with medium- to coarse-grained calcarenites, and commonly contain nodules of hard, black chert. This redefined lower member of the Bobcaygeon Formation is equivalent to the upper half of the middle member and all of the upper member of the Gull River Formation, as defined by Liberty (1969), (Figure 1.8) and ranges in thickness from about 20 m in the west to about 40 m in the east.

The middle and upper members of the Bobcaygeon Formation are similar to the lower member, except for the higher shale content in the middle member. The thin- to medium-bedded, very fine- to medium-crystalline limestone beds of these members are interbedded with medium- to coarse-grained calcarenites. The upper member may also display a distinctive blue-grey weathered surface. The middle and upper members, as redefined by the OGS, are equivalent to the lower, middle, and upper members of the Bobcaygeon Formation as defined by Liberty (1969), (Figure 1.8).

Outcrops of the Bobcaygeon Formation are rare, relative to the Gull River Formation, although the base of the Bobcaygeon Formation is often exposed as a caprock in some quarries. Where the formation is accessible, the unit is utilized primarily by the aggregate industry. In the past some building stone operations have used material from the lower member.

VERULAM FORMATION

The term Verulam Formation was applied by Liberty (1969) to a sequence of interbedded limestone and shale which overlies the Bobcaygeon Formation. The Verulam Formation thickens from about 65 m in the west to over 100 m in the east; exposures, however, are isolated because of the thick glacial deposits over most of the area where the formation occurs.

The interbedded nature of the limestone and shale lithologies also makes the formation easily erodable and few natural outcrops remain, although the formation can be examined in quarries and roadcut exposures. The carbonate lithologies vary from very fine-crystalline limestones, virtually fossil-free, to coarse-crystalline, bioclastic limestones. The limestone beds rarely exceed 10 cm in thickness and the 1-5 cm thick interbedded shale is commonly calcareous and burrowed extensively.

The Verulam Formation is rarely utilized by the limestone industry because of its high shale content but in an outcrop area between Belleville and Kingston it is used as a source for aggregate and for cement manufacture.

LINDSAY FORMATION

The uppermost formation in the Simcoe Group is the Lindsay Formation. Originally defined by Liberty (1969) from exposures around Lake Simcoe, it has subsequently been revised by Russell and Telford (1983), (Figure 1.8). A detailed and widespread drilling program of the upper part of the formation across Ontario by the OGS (Johnson et al., 1983) revealed that the black shale, originally called the Collingwood Shale (Parks, 1928), and assigned by Liberty (1969) to the lower member of the Whitby Formation, can be included with the Lindsay Formation. Its stratigraphic relationship to the under– and overlying strata and its lithology, as determined by geochemical analysis, suggested to Russell and Telford (1983) that this unit was more similar to the Lindsay Formation than Liberty's (1969) Whitby Formation. The balance of the Whitby Formation was renamed the Blue Mountain Formation, reverting to Parks' (1928) original subdivision of these strata.

The Lindsay Formation, as used in this report, can be subdivided into two members: the lower member, a nodular limestone (Liberty's Lindsay Formation), and the upper Collingwood Member, a black calcareous shale (Liberty's lower member, Whitby Formation). The lower member ranges from very fine– to coarse–crystalline nodular limestones with most beds medium crystalline and fossiliferous. On weathered surfaces these thin–bedded limestones commonly exhibit a nodular texture because of very thin, undulating shale partings. The black shales of the overlying Collingwood Member may either overlie the limestones with a minor disconformity, or may be interbedded with the limestones over a thickness of several metres. This member is characterized by black, petroliferous, very calcareous shale which contains a rich fossil assemblage. The Middle–Upper Ordovician boundary occurs near the contact between the lower and upper members of the Lindsay Formation.

The limestones of the lower member range in thickness from 60 m in the west to over 100 m in Prince Edward County, south of the City of Belleville. The black shales of the Collingwood Member maintain a uniform thickness of about 10 m across central Ontario.

The limestones of the Lindsay Formation are used primarily as raw material for the manufacture of cement.

BLUE MOUNTAIN FORMATION

The Upper Ordovician Blue Mountain Formation (Russell and Telford, 1983) includes the middle and upper members of the Whitby Formation of Liberty (1969). The blue–grey shales of the Blue Mountain Formation outcrop only rarely in the western part of central Ontario and are not used by the limestone industry.

GEORGIAN BAY FORMATION

The Georgian Bay Formation (Liberty, 1969) is rarely exposed in central Ontario, and where it is exposed the formation consists of interbedded limestone (rarely dolostone) and shale. The formation averages 100 m in thickness and has been subdivided several times into members by various workers (see Liberty, 1969, for a summary). The formation extends across central Ontario southward from Collingwood to underlie a significant portion of Metropolitan Toronto. Thick glacial overburden, limited exposures, and a high shale content limit the usefulness of the formation to the limestone industry, although St. Lawrence Cement Inc. have quarried the rock at their Mississauga plant for use in cement manufacture. Rock from the formation is used in the Toronto area as a raw material for brick manufacturing.

QUEENSTON FORMATION

The youngest Ordovician strata in central Ontario are the red shales of the Upper Ordovician Queenston Formation. These shales occur below the Niagara Escarpment and extend from the Niagara River west and northward to Georgian Bay in Lake Huron. West of Toronto these shales are used to produce brick and ceramic products.

Niagara Escarpment

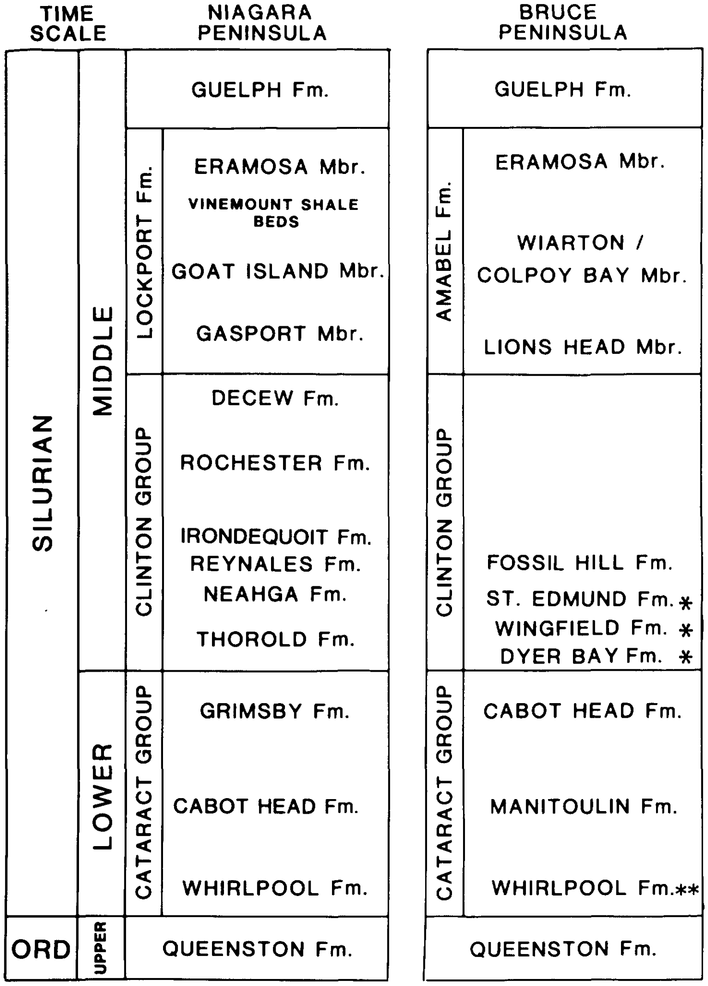
(Niagara, Cambridge, Huronia, Owen Sound Districts)

The Niagara Escarpment in Ontario extends from the Niagara River Gorge, westward along the Niagara Peninsula to Hamilton, northward to Georgian Bay, northwestward along the Bruce Peninsula, and westward across to Manitoulin and Cockburn islands (Figure 1.2). This erosional feature exposes a Silurian dolostone caprock overlying shales and softer carbonates of Silurian and Ordovician age. The escarpment consists of a series of steep north or northeast–facing cliffs, with the exposed strata dipping gently to the southwest. Except for local lithological variations within the units, the following descriptions are applicable throughout the Ontario portion of the escarpment.

Upper Ordovician strata underlie and form the base of the escarpment throughout most of this region and represent the northerly extent of a wedge of clastic sediments shed from the ancestral Taconic and Appalachian mountains. Silurian age units of the escarpment were deposited under the influence of both the Michigan and Appalachian basins (Figure 1.4). The Silurian strata deposited under the influence of the Appalachian Basin tend to have a higher clastic content, due to their proximity to highland source areas in the east. In northwestern areas adjacent to the Michigan Basin, however, carbonates of higher purity were deposited in predominantly shallow marine shelf and related environments away from clastic sources. Therefore rocks which make up the southern portion of the Niagara Escarpment (Niagara Falls to Milton), tend to contain more terrigenous material than those deposited in the northern portion. These differences have resulted in the application of two sets of nomenclature for the Silurian strata exposed on the escarpment (see Figure 1.9), one each for the northern and the Niagara Peninsula (southern) portions of the escarpment.

Deposition of the rocks exposed on the Niagara Escarpment commenced with the Upper Ordovician Queenston Formation. This was followed by deposition of the Lower Silurian Cataract Group, the Middle Silurian Clinton Group, and culminated with the Middle Silurian Lockport, Amabel and Guelph formations.

The Queenston Formation, which consists mainly of red shales, has been described in the previous section. The Cataract and Clinton groups consist predominantly of sandstones and shales, and are therefore not generally utilized by the limestone industry. The dolostones of the Lockport, Amabel and Guelph formations are of great significance to the limestone industry. Other units, such as the Reynales, Irondequoit and Decew formations, are used only to augment the above formations. More detailed geological discussions are presented in Bolton (1957), Liberty and Bolton (1971), and Sanford (1969) and more recent descriptions by Liberty, Bond and Telford (1976a,b,c), Bond, Liberty and Telford (1976), Bond and Telford (1976), Telford (1976a,b; 1979a,b) and Liberty, Feenstra and Telford (1976a,b).



***Not present south of Owen Sound **Not present north of Collingwood**
Modified after Bolton, Table 1, 1957

Figure 1.9. STRATIGRAPHIC COLUMNS SHOWNING NOMENCLATURE OF LOWER AND MIDDLE SILURIAN UNITS OF THE NIAGARA AND BRUCE PENINSULAS.

CATARACT GROUP

The Lower Silurian Cataract Group is subdivided into four formations (Figure 1.9) of which only one, the Whirlpool Formation, occurs in both the northern and the Niagara Peninsula (southern) portions of the escarpment. The Manitoulin and Cabot Head formations occur only in the north and the Grimsby Formation is restricted to the southern portion of the escarpment. Because of the generally clastic nature of most of the Cataract Group formations, only the Manitoulin Formation is used by the limestone industry.

WHIRLPOOL, POWER GLEN, AND GRIMSBY FORMATIONS

The oldest unit of the Cataract Group, the Whirlpool Formation consists of about 8.0 m of quartzose sandstone which becomes thinner to the north. The erosional edge of this unit is reported to be just north of the Duntroon area (south of Collingwood), (Liberty and Bolton, 1971; Telford, 1976a). Overlying the Whirlpool Formation in the Niagara Peninsula are the interbedded shales, limestones, and impure sandstones of the Cabot Head Formation (up to 15 m thick) (Telford and Tarrant, 1975). The Cabot Head Formation is in turn overlain by the Grimsby Formation which is of comparable thickness and consists of interbedded sandstones and shales. The Grimsby Formation is restricted to the Niagara Falls–Milton portion of the escarpment.

MANITOULIN AND CABOT HEAD FORMATIONS

North of Stoney Creek, the Manitoulin Formation directly overlies the Whirlpool Formation and is equivalent, in part, to the more clastic Cabot Head Formation located on the Niagara Peninsula. The Manitoulin Formation consists of up to 22 m of predominantly thin-bedded, blue–grey to brown dolomitic limestones and dolostones. Although it is locally chert–rich, the Manitoulin Formation where exposed (on Manitoulin Island and on the lower Bruce Peninsula), has good potential as a source of building stone, and presently it is under- exploited. Overlying the Manitoulin Formation are the green, grey, and red shales of the Cabot Head Formation. These shales weather recessively and generally occur at the base of the steep cliffs formed by the overlying resistant dolostones (Lockport and Amabel formations). They are not utilized by the limestone industry.

CLINTON GROUP

The Middle Silurian Clinton Group has been subdivided into ten formations; some are restricted in their occurrence to either the northern or Niagara Peninsula (southern) portions of the escarpment (Figure 1.9). The oldest units of the Clinton Group are clastic or shaly dolostones and include (in ascending stratigraphic order) the Dyer Bay and Wingfield formations in the north, and the Thorold and Neahga formations on the Niagara Peninsula. The upper units are predominantly dolostones and include (in ascending stratigraphic order) the St. Edmund and Fossil Hill formations in the north, and the Reynales, Irondequoit (a limestone), Rochester (a shale), and Decew formations on the Niagara Peninsula.

THOROLD AND NEAHGA FORMATIONS

On the Niagara Peninsula or southern portion of the escarpment, the Thorold Formation is a 2 to 3 m thick-bedded quartz sandstone overlain by the Neagha Formation, a black–grey to green shale with minor interbedded limestones.

DYER BAY, WINGFIELD, AND ST. EDMUND FORMATIONS

At about the same time as the Thorold and Neahga formations were deposited on the Niagara Peninsula, three formations were deposited in the area exposed by the northern part of the escarpment. These northern units consist of (in ascending stratigraphic order) the Dyer Bay, Wingfield, and St. Edmund formations (Figure 1.9), and are restricted to Manitoulin Island and the northernmost portion of the Bruce Peninsula.

The lowest unit, the Dyer Bay Formation, is a highly fossiliferous impure dolostone. Its thickness (only 2 to 4 m) and lack of outcrop exposure have combined to inhibit its development as a building stone. Overlying the Dyer Bay Formation is the Wingfield Formation, a 10 m thick, olive–green to grey shale with dolostone interbeds.

Although not significantly quarried by the limestone industry, the overlying St. Edmund Formation (previously termed the Mindemoya Formation, Liberty, 1968) has potential as an aggregate source. This formation consists of pale grey to brown, micro- to medium–crystalline, thin- to medium–bedded dolostone. Little or no chert is present, although shaly partings are present on some bedding planes. The St. Edmund Formation tends to fracture naturally into brick–sized blocks, a useful attribute when crushing it for aggregate. Currently this unit is only excavated from wayside pits, and is used for general fill and crushed stone for paving. The formation reaches a thickness of about 25 m at the western end of Manitoulin Island, where it is extensively exposed.

FOSSIL HILL AND REYNALES FORMATIONS

The Fossil Hill Formation overlies the St. Edmund Formation and is seen in the northern portion of the escarpment. This unit is stratigraphically equivalent in part to the Reynales Formation exposed on the Niagara Peninsula portion to the south (Figure 1.9). Both the Reynales and the Fossil Hill formations are dolostones of relatively low purity. The Fossil Hill Formation is a fine- to coarse–crystalline dolostone, and has a high silica content (chert and silicified fossil debris). It is up to 25 m thick on Manitoulin Island and thins southward to 6 m on the Bruce Peninsula.

The Reynales Formation, which overlies the Neahga Formation, is a thin- to thick–bedded shaly dolostone and dolomitic limestone, and is generally less than 3 m thick. The Reynales Formation does not have the high silica content of the Fossil Hill Formation.

Neither the Reynales nor the Fossil Hill formations are excavated individually. Both units, however, are quarried where the overlying Amabel and Lockport formations make extraction economical. The Fossil Hill Formation has good potential for skid-resistant aggregate due to its high silica content.

IRONDEQUOIT, ROCHESTER, AND DECEW FORMATIONS

South of the town of Waterdown, the Reynales Formation may be overlain by one or all of the following formations: the Irondequoit, Rochester or Decew formations (Figure 1.9). Exposures of the Irondequoit and Rochester formations are extensive, and occur on the escarpment at least as far north as Clappison's Corners (near Hamilton). The Decew Formation, however, is exposed only in the area between the Niagara River Gorge and Ancaster (near Hamilton).

The Irondequoit Formation is a massive, coarse-crystalline, crinoidal limestone with a typical thickness of approximately 2 m. The overlying Rochester Formation is a black to dark grey calcareous shale with numerous limestone lenses, and is called informally the Rochester Shale. Thinning westward from 17.5 m at the Niagara River Gorge, this formation is only 4.2 m thick at Hamilton and pinches out around Clappison's Corners. The Decew Formation consists of sandy to shaly, dolomitic limestones and dolostones and thins westward from a maximum thickness of 4 m at the Niagara River. Although shaly partings are present, the Decew Formation generally occurs as a single bed.

AMABEL AND LOCKPORT FORMATIONS

Overlying the Clinton Group are rocks of the Middle Silurian Lockport Formation and equivalent Amabel formations (Figure 1.9). Both units are predominantly dolostones with the Lockport Formation clearly recognizable south of Waterdown (near Burlington). North of Waterdown, these dolostones have been assigned to the Amabel Formation which can be traced northwards and westwards into the state of Michigan where it is called the Engadine Dolomite.

The Lockport Formation consists of three formal members and one informal member (in ascending stratigraphic order): the Gasport Member, the Goat Island Member, the informal Vinemount shale beds, and the Eramosa Member. The Eramosa Member forms the upper part of both the Lockport and Amabel formations. The Gasport and Goat Island members are only clearly identifiable as far north as Waterdown. The Gasport Member is typically a thin- to massive-bedded, blue-grey to grey, fine- to medium-crystalline, crinoidal dolomitic limestone of variable thickness but averaging about 6 m. The overlying Goat Island Member consists of massive, irregularly bedded, dark to light grey, fine-crystalline dolostone. Locally it is shaly (Hamilton area), or contains vug-filling mineralization (Niagara Falls area). Chert is strongly characteristic of the Goat Island Member and varies from occasional nodules and lenses (as at Niagara Falls), to such abundance at Hamilton that this zone is informally referred to as the "Ancaster chert beds". The Goat Island Member reaches a maximum thickness of 15.8 m, although the average is closer to 10 m.

The upper portion of the Lockport and Amabel formations is the Eramosa Member which is, in the area between Niagara Falls and the village of Rockwood, a dark brown, fine-crystalline, bituminous dolostone. Dark grey shaly partings are seen in some exposures. North of Rockwood, in the Owen Sound-Bruce Peninsula area, the Eramosa Member exhibits several lithologies. It ranges from very fine-crystalline to sugary, pale buff to almost black, laminated to massive-bedded dolostone, with variable bitumen content and local biostromal development. The Eramosa Member typically emits a strong petroliferous odor when freshly broken. The thickness ranges from 15 m on the Bruce Peninsula to almost 20 m at the Town of Dundas, these variations partly reflecting the discontinuous nature of the unit and partly the difficulty in identifying contacts.

On the Bruce Peninsula, the Amabel Formation has an average thickness of 45 m (at the Town of Wiarton), and is subdivided into the following three members (in ascending stratigraphic order): Lions Head, Wiarton/Colpoy Bay and Eramosa members. The Lions Head Member consists of blocky, dark brown to white, very fine- to fine-crystalline dolostone, with a maximum thickness of 13.7 m (average 4.5 m). The Wiarton/Colpoy Bay Member is a thick-bedded to massive, fine- to coarse-crystalline, blue-grey to white dolostone with abundant crinoidal debris. Bioherms (reefs) and thinner bedded inter-reefal rocks commonly occur within this 23 m thick member, overlain by the Eramosa Member.

South of the Bruce Peninsula these members are not recognizable except for thin-bedded strata in the upper portion of the Amabel Formation (assigned to the Eramosa Member). Southward the Amabel Formation becomes a buff to blue-grey, often mottled, fine- to coarse-crystalline dolostone which is commonly massive bedded, although thin-bedded intervals are occasionally seen. This lithology continues into the Lockport Formation.

The Amabel and Lockport formations are the principal sources of aggregate for the province, particularly in the Milton-Hamilton area. The dolostone is also used for building stone, armour stone, metallurgical flux, and a variety of other purposes.

GUELPH FORMATION

The Guelph Formation overlies the Lockport and Amabel formations and occurs just west of the Niagara Escarpment in a band trending north from Niagara Falls up to the northern tip of the Bruce Peninsula

(Figure 1.1). The Guelph Formation is not exposed northwest of this area. Lithologically the Guelph Formation is a brown, thick–bedded to massive, porous, sugary dolostone. Massive reefal intervals occur in the formation and are often associated with thinner bedded inter–reefal strata. The thickness of this formation varies from 4 to 50 m. The Guelph Formation is principally used by the limestone industry in Cambridge District (especially around Guelph and Hamilton) as dolomitic lime for metallurgical and flux stone and only rarely as an aggregate source.

Southwestern Ontario
(Niagara, Simcoe, Aylmer, Chatham, and Wingham Districts)

The southwestern Ontario region is bounded on three sides by the Great Lakes: Huron, Erie, Ontario, and Lake St. Clair and its eastern side is bounded by the Niagara Escarpment. Paleozoic sediments deposited in this area were influenced by both the Appalachian and Michigan basins with the Algonquin Arch acting as a topographic high between these two basins. The Chatham Sag is present in the extreme southwestern portion of the region where the Algonquin and Findlay arches meet (Figure 1.4). Paleozoic stratigraphic terminology for most of the units are Michigan Basin terms and are applicable throughout most of the region. In the extreme easterly portion of the region (southern Niagara Peninsula), Appalachian Basin terminology is more appropriate (Figure 1.10) (Uyeno et al., 1982; Telford and Johnson, 1984).

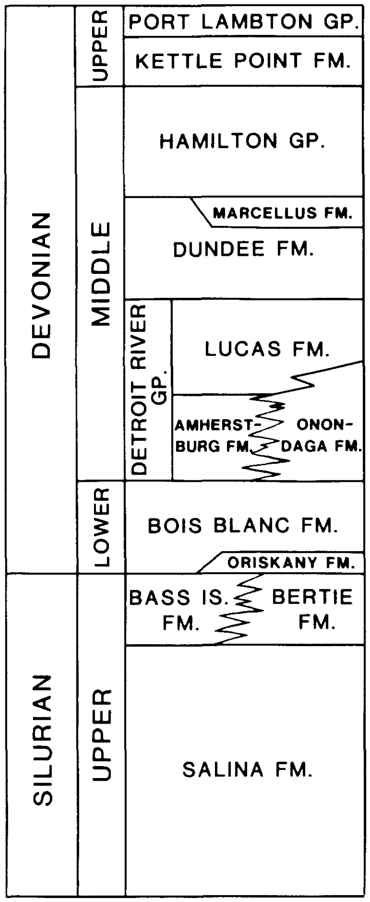


Figure 1.10. STRATIGRAPHIC COLUMN OF PALEOZOIC ROCKS IN SOUTHWESTERN ONTARIO.

The Paleozoic stratigraphy of southwestern Ontario consists predominantly of shallow-water platform deposits that range in age from Upper Cambrian to Upper Devonian. The carbonates, clastics and evaporitic units dip gently and show little evidence of structural disturbance (Telford and Johnson, 1984).

Evidence of Cambrian or Lower Ordovician strata is from drill hole information only. These strata represent the initial marine transgression in the southwestern Ontario region and are truncated against the flanks of the Algonquin Arch. Subsequent Middle Ordovician units onlap and overlap the Arch which was a positive topographic feature in early Paleozoic times. Since no Upper Cambrian to Middle Silurian units subcrop in the area, they will not be discussed further.

SALINA FORMATION

The oldest exposed unit in southwestern Ontario is the Upper Silurian Salina Formation which overlies the Middle Silurian Guelph Formation. The Salina Formation consists of easily weathered argillaceous dolostone, shale and evaporites. A 6 m thick section occurs in a railway and road cutting adjacent to the new Welland Canal, along Townline Road south of Welland. In the subsurface the Salina Formation attains a thickness of approximately 115 to 120 m, and although well known for its evaporite minerals, particularly the extensively mined gypsum and halite (salt) deposits, it is not used presently by the limestone industry.

BERTIE AND BASS ISLANDS FORMATIONS

The Bertie Formation (in southern Niagara Peninsula) is composed predominantly of resistant dolostones which are exposed in the Onondaga Escarpment (up to 7.6 m in relief), on the Niagara Peninsula. The lower contact of the Bertie Formation with the Salina Formation is gradational, and its upper contact with Devonian age rocks (either the Oriskany or Bois Blanc Formations) is a distinct erosional surface representing a major disconformity. In Ontario the Bertie Formation is represented by five members (in ascending stratigraphic order): the Oatka, Falkirk, Scajaquanda, Williamsville, and Akron members. The lithologies range from shaly dolostones to calcareous dolostones with interbeds of calcisiltites and calcilutites. (See southern Niagara District section, Volume III, for more details on these members.)

Individual members of the Bertie Formation are best seen in the eastern portion of the Niagara Peninsula, since westward, the units pinch out because of the influence of the Algonquin Arch during their deposition. The top of the Bertie Formation is marked by features representing a period of shallowing and subaerial exposure. The Michigan Basin equivalent of the Bertie Formation in the extreme southwestern portion of the region is the Bass Islands Formation. The Bertie Formation reaches a maximum of 14 m in thickness in southwestern Ontario.

The Bertie Formation is an important crushed stone source for the limestone industry, and major operations are located near the towns of Fort Erie, Cayuga, Hagersville, and Dunnville. The Bass Islands Formation is not utilized by the limestone industry.

ORISKANY FORMATION

The Lower Devonian Oriskany Formation is the oldest Devonian unit in the region. It can be identified with certainty in outcrop at only one locality in Ontario, where it forms the bedrock of an approximately 600 ha area, 10 km east of the town of Hagersville. It is a thick–bedded to massive, coarse–grained, grey–yellow sandstone that disconformably overlies the Silurian dolostones of the Bertie Formation and attains a thickness of approximately 4.5 m. The Oriskany Formation has previously been quarried for siliça sand.

BOIS BLANC FORMATION

The Springvale Sandstone Member forms the basal portion of the Lower Devonian Bois Blanc Formation and consists of medium– to coarse–grained, green, glauconitic sandstone with interbeds of limestone, dolostone, and brown chert. It is discontinuous and is sometimes difficult to distinguish from the Oriskany Formation sandstones.

The Bois Blanc Formation, typically a Michigan Basin unit, is an eastward thinning carbonate wedge which spilled over the Algonquin Arch and interfingered with clastic and carbonate strata of the Appalachian Basin. It is a cherty limestone (excluding the Springvale Sandstone Member) with shaly partings and minor interbedded dolostones, and is very diverse in texture and composition. Fossils are common and the chert can be light grey or brown in colour, and occurs as thin beds or nodules. Toward the centre of the Michigan Basin, the limestones of the Bois Blanc Formation are gradually replaced by grey–brown microsucrosic dolostones, and chert decreases. In the Niagara Peninsula area, the Bois Blanc Formation's thickness may reach 15 m, whereas in southwestern Ontario its thickness reaches approximately 50 m.

The Bois Blanc Formation's upper contact with the overlying Onondaga Formation, on the Niagara Peninsula, is sharp and probably disconformable but, westward towards the Michigan Basin, the contact loses its definition. Outcrops of the Bois Blanc Formation in the southwestern portion of the region are sparse and it is best seen in subsurface drill hole records. On the Niagara Peninsula, the Bois Blanc Formation forms the bedrock in a narrow belt extending west from Fort Erie to Hagersville, and then northwest through Innerkip, Listowel, and Mildmay to Port Elgin on the shore of Lake Huron. Outcrops through these areas are numerous and the unit is often exposed as the caprock of the discontinuous Onondaga Escarpment. Quarry operations have utilized the Bois Blanc Formation near Hagersville, Cayuga and Port Colborne for crushed stone.

ONONDAGA FORMATION

In the Niagara Peninsula area, the Middle Devonian Onondaga Formation is well exposed. It is an Appalachian Basin unit which has been subdivided into four members (in ascending stratigraphic order): the Edgecliff, Clarence, Moorehouse, and Seneca members. The Edgecliff, Clarence, and the lower part of the Moorehouse Member extend into the Niagara Peninsula of Ontario from New York and can be traced towards the town of Selkirk. Further west, these three members become less distinct and beyond the Port Dover area they grade laterally into limestones and dolostones of the Detroit River Group (a Michigan Basin unit). The members represent a diversity of lithologies which include: bioclastic limestones; biohermal and biostromal limestones; cherty limestones; and argillaceous, fossiliferous limestones. The maximum thickness of this formation is 27 m with reefal mounds sometimes reaching 300 m in diameter.

Member contacts within the Onondaga Formation are gradational, whereas the formation's upper contact with the Dundee Formation is sharp. The Onondaga is quarried around the cities of Welland and Port Colborne for crushed stone.

DETROIT RIVER GROUP

The Onondaga Formation correlates, in part, with the Middle Devonian Detroit River Group from the Michigan Basin. The two formations in this group are the Amherstburg and Lucas formations (in ascending stratigraphic order) (Figure 1.10). Outcrops of these formations are rare, although they can be seen in quarries located in the Chatham and Aylmer districts. The lower contact of the Amherstburg Formation with the Bois Blanc Formation is difficult to identify and appears to be gradational. The upper contact of the Amherstburg Formation with the Lucas Formation is distinct only in the Woodstock–Ingersoll area.

AMHERSTBURG FORMATION

The Sylvania Sandstone Member is the basal portion of the Amherstburg Formation. It does not outcrop and only occurs in the extreme southwestern corner of the region (near Amherstburg and Windsor), as reported in drill hole records. It is a strandline deposit consisting of an orthoquartzitic sandstone and overlies the Bass Islands Formation around the western, southern, and southeastern margins of the Michigan Basin. In Essex County, its maximum thickness is 25 m. The Amherstburg Formation (excluding the basal Sylvania Sandstone Member) is a coral/stromatoporoid–rich, bioclastic limestone that is very bituminous and contains grey chert nodules. Its upper contact with the Lucas Formation appears to be conformable with a change from dark coloured, bituminous, coarsely bioclastic limestone (Amherstburg Formation), to a generally light brown micritic limestone (Lucas Formation).

The Formosa Reef Limestone (part of the Amherstburg Formation) is a localized reef development which is approximately 15 m thick and covers about 39,000 ha in Bruce and Huron counties (Owen Sound and Wingham districts). The reefs and bioherms which make up the Formosa Reef Limestones are the remnant surface exposures of large platform reefs that characterized the southeast rim of the Michigan Basin during the deposition of the Amherstburg Formation. The type section for the Formosa Reef Limestone can be seen in a roadcut 4 km north of the village of Formosa. This limestone is of high purity; stromatoporoids were the dominant reef–builders. The maximum thickness of the Amherstburg Formation in the region is approximately 50 m.

LUCAS FORMATION

The Lucas Formation is well exposed in southwestern Ontario and forms the bedrock of a broad area extending northward from the Ingersoll area to Lake Huron. Excellent exposures of the formation occur in quarries near Amherstburg, Ingersoll, and St. Marys. The Lucas Formation is complex but tends to be an evaporite–rich (halite and anhydrite) dolostone and limestone. Along the rim of the Michigan Basin the formation becomes a platform carbonate deposit of high purity limestone and dolostone.

The Anderdon Member forms the upper portion of the formation but is found only around the rim of the Michigan Basin. The Anderdon Member is usually defined as a high purity limestone (Uyeno et al., 1982). In the quarries around the Woodstock–Beachville area (Aylmer District), the Anderdon Member represents the majority of the Lucas Formation that is exposed (interbedded limestones and calcarenites). In the upper portion of the Stelco Steel quarry (A–4, Aylmer District, Volume III), the Anderdon Member is a sandy limestone which acts as a very distinctive caprock for the quarry face. In subsurface the Lucas Formation can reach thicknesses of approximately 80 m, and is disconformably overlain by the Dundee Formation.

In southwestern Ontario, the Amherstburg and Lucas formations are important to the limestone industry. The high purity limestones of the Lucas Formation are used to produce high–calcium lime for metallurgical processes, and for the manufacture of chemicals. Rock from the Lucas and Amherstburg formations is also used for cement manufacture, agricultural lime, fillers and aggregate.

DUNDEE FORMATION

The Middle Devonian Dundee Formation is assigned to strata lying between the Detroit River Group and the Marcellus Formation, or the Hamilton Group. Outcrops are not abundant, although extensive exposures occur in the Selkirk–Port Dover area on the Niagara Peninsula; on Pelee Island; in quarries near Amherstburg; and along the Thames and Maitland rivers near the towns of St. Marys and Goderich. Thickness varies from 20 m to 40 m with the best known section occurring in the St. Marys Cement Co. Ltd. quarry (W–1, Wingham District, Volume III).

The Dundee Formation has a relatively uniform lithology: a medium– to thick–bedded, fossiliferous, micritic limestone with occasional brown chert nodules. On Pelee Island, the lower part of the formation is exposed and consists of a massive–bedded, bioclastic limestone. Bituminous laminations are abundant and pockets of bituminous material are generally concentrated in the porous structure of colonial corals. While the upper contact of the Dundee Formation is not exposed, subsurface records indicate lithologies change abruptly from the micritic limestone to the shales of the Marcellus or Bell Formations. The Dundee Formation is used by the limestone industry for cement manufacture, crushed stone, rock dust, chips, and riprap.

MARCELLUS FORMATION, HAMILTON GROUP, KETTLE POINT FORMATION, AND THE PORT LAMBTON GROUP

The overlying Marcellus Formation, Hamilton Group, Kettle Point Formation, and Port Lambton Group (in ascending stratigraphic order), (Figure 1.10) consist predominantly of grey shales, blue–grey shales, black shales and shaly limestones, respectively, and are rarely utilized by the limestone industry. Uyeno et al., (1982) provide more information on these units.

Northern Ontario

For the purposes of this report, the northern Ontario region includes all of the Canadian Shield north of the French River that is overlain by Paleozoic rocks (Figure 1.2). This region includes Paleozoic rocks in the northern Lake Huron area (Manitoulin, Cockburn, and St. Joseph islands, and the Sault Ste. Marie area); the northern end of Lake Timiskaming; and the Moose River Basin in the Hudson Bay/James Bay Lowlands. The geology of each of these widely scattered areas is unique and will be discussed separately.

NORTHERN LAKE HURON

In the northern Lake Huron area, the Silurian strata of Manitoulin and Cockburn islands (Figure 1.11) represent the northernmost extension of the Niagara Escarpment, and trend north– and westward from the Bruce Peninsula in the south. St. Joseph Island is underlain by Ordovician strata, overlain mostly by thick glacial deposits.

SAULT STE. MARIE AREA

The oldest Paleozoic rocks in this region are the quartz sandstones of either Late Precambrian, Cambrian, or Ordovician age which occur in the Sault Ste. Marie area. Small exposures are present along the shoreline of Lake Superior and along the St. Mary River, and on islands throughout the area. These rocks have been a source of building stone in the past.

ST. JOSEPH ISLAND

St. Joseph Island is underlain by Ordovician limestones and shales. Immediately overlying the Precambrian surface are conglomerates and sandstones of Cambrian or Ordovician age, some of which are similar to the sandstones which outcrop near Sault Ste. Marie. The Middle Ordovician limestones are superficially similar to the sequence of carbonate rocks which occur in southern Ontario but have not, however, been differentiated into specific formations. The Upper Ordovician is represented by the Collingwood Member (Lindsay Formation), which consists of black, organic–rich, argillaceous limestone; the Blue Mountain Formation, composed of blue–grey shales; and the Georgian Bay Formation, composed of interbedded dolostones, dolomitic limestones and shales (see Russell, 1985, for more detailed information). Much of the island is covered with thick glacial deposits limiting exposure of these formations, and even though this island is the only limestone source in the area, much of what is exposed is rich in terrigenous material that make it unsuitable for a number of applications.

MANITOULIN AND COCKBURN ISLANDS

Manitoulin and Cockburn islands are northern extensions of the Niagara Escarpment and expose primarily Silurian strata (Figure 1.11), which consist of (in ascending order) the Manitoulin, Cabot Head, Dyer Bay, Wingfield, St. Edmund, Fossil Hill and Amabel formations. The lithologies of these Lower and Middle Silurian units are similar to their descriptions given in the Niagara Escarpment region.

The Ordovician units present on Manitoulin Island and the smaller islands directly to the north include (in ascending order) the Georgian Bay and Blue Mountain

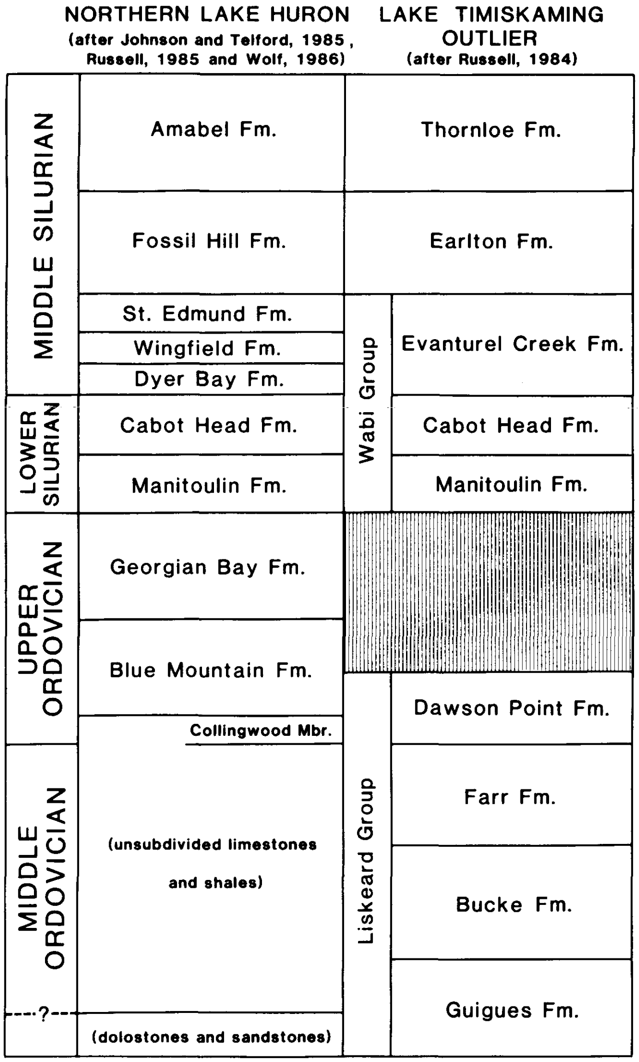


Figure 1.11. STRATIGRAPHIC COLUMNS OF PALEOZOIC ROCKS IN THE NORTHERN LAKE HURON REGION AND THE LAKE TIMISKAMING OUTLIER.

formations, and the Collingwood Member of the Lindsay Formation (Figure 1.11). Ordovician strata underlying these units in the subsurface cannot be adequately differentiated using any of the stratigraphic systems presently available. This is similar to the situation on St. Joseph Island.

Bedrock resources on both islands (especially from the Amabel and Fossil Hill formations) are significantly under–utilized by the limestone industry, largely as a result of the distance from suitable markets. Recent quarry developments on Manitoulin Island using ship transportation (see Quarry ES–1, Northern Ontario Region, Volume II), suggest aggregate/flux production will continue and expand. In addition, the St. Edmund Formation is used locally for crushed stone and fill, and the Manitoulin Formation is used for building stone.

LAKE TIMISKAMING AREA

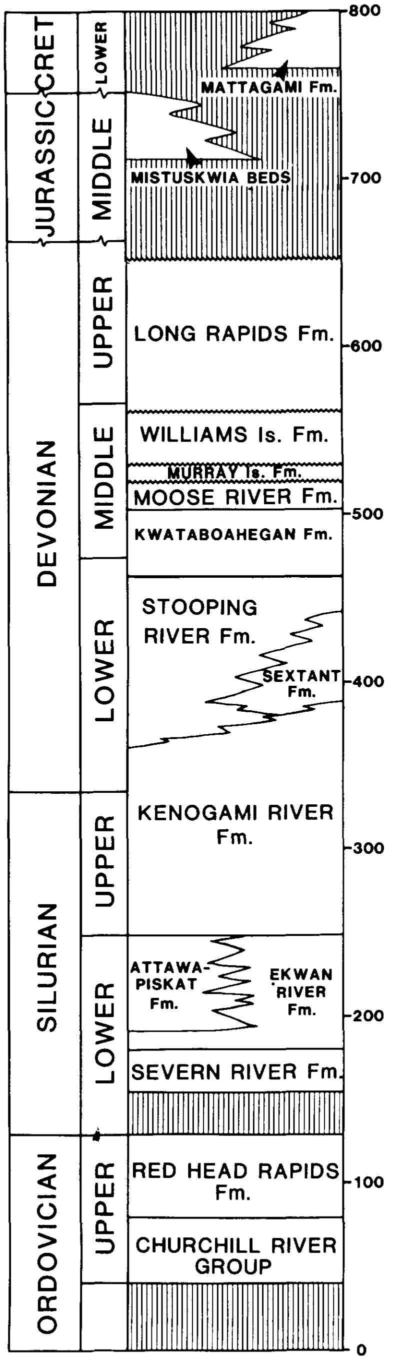
In the Lake Timiskaming area (Figure 1.2), a section of Paleozoic strata has been preserved in a large graben structure. Movements of smaller–scale faults within the graben result in major changes in the geology between adjacent outcrops (a situation which is similar to the Paleozoic geology in eastern Ontario).

The Paleozoic succession in the Lake Timiskaming area includes Orodovician and Silurian strata (Figure 1.11). The Ordovician sequence consists of (in ascending stratigraphic order) the Guigues, Bucke, Farr and Dawson Point formations, and differs significantly from the Ordovician sequence of southern Ontario. The Farr Formation is currently being developed as a source of flux for use in smelting.

The following Silurian units are present in this area (in ascending stratigraphic order) the Manitoulin, Cabot Head, Evanturel, Earlton and Thornloe formations (Russell, 1984). In general the Silurian sequence in the Lake Timiskaming outlier correlates with strata exposed in southern Ontario (compare Figure 1.11 with Figure 1.9); the Thornloe Formation is very similar to parts of the Amabel Formation on Manitoulin Island, and the Earlton Formation is similar to the St. Edmund Formation.

HUDSON BAY/JAMES BAY LOWLANDS AND THE MOOSE RIVER BASIN

Paleozoic and Mesozoic age strata underlie a broad area (approximately 920,000 sq. km) of northern Ontario called the Hudson Bay Platform. Two–thirds of the platform is under water (Hudson and James Bays) and the remaining third underlies three physiographic regions: the Southampton Plain (Southampton, Coats and Mansel islands) in the north, and the Hudson Bay and James Bay Lowlands in the south. The strata in the Hudson Bay Platform occur in two sedimentary basins, the Hudson Bay Basin in the northwest and the Moose River Basin in the southeast, separated by a northeast–trending feature called the Cape Henrietta Maria Arch (Figure 1.4). While the Hudson Bay Basin is mainly submerged, the Moose River Basin underlies the James Bay Lowland and



Modified after Norris(1986) p.23

Figure 1.12. STRATIGRAPHIC COLUMN OF PALEOZOIC ROCKS OF THE MOOSE RIVER BASIN.

contains some strata of interest to the limestone industry. Unfortunately large areas of the James Bay Lowland are covered by poorly drained muskeg which is dotted by numerous lakes, and therefore information on underlying rock units is confined to scarce river bank outcrops and geological drill holes.

The Moose River Basin is infilled with a Paleozoic and Mesozoic succession which includes Ordovician, Silurian, Devonian, Middle Jurassic and Lower Cretaceous rocks with a total thickness of approximately 760 m. The stratigraphic succession and corresponding lithologies for the Moose River Basin are shown in Figure 1.12. Middle Devonian carbonate units appear to be the most desirable strata for quarrying purposes in the basin and the more attractive units are the Kwataboahegan Formation (see Labelle Quarry, MO–1, Northern Ontario Region, Volume II), the Murray Island Formation, and the upper member of the Williams Island Formation.

The Kwataboahegan Formation predominantly consists of resistant, thick– to massive–bedded, medium–crystalline, biostromal limestone with abundant stromatoporoids and corals. Its Southern Ontario equivalent is the Edgecliff Member of the Onondaga Formation and it is the only unit quarried for stone in the Moose River Basin. The Murray Island Formation is a succession of banded, bituminous, highly calcareous dolostone, fine– to very coarse– crystalline clastic limestone and thin– to medium–bedded argillaceous limestone. It is stratigraphically equivalent to the Dundee Formation in southern Ontario. The Murray Island Formation is disconformably overlain by the Williams Island Formation, which consists of a lower, recessive shale member, and an upper, resistant carbonate member. The upper member consists of thin– to medium–bedded, argillaceous limestones and calcareous shales; medium– to coarse– crystalline saccharoidal and oolitic limestones; and partly brecciated, vuggy, oolitic limestones.

These carbonate units (the Kwataboahegan Formation, the Murray Island Formation and the upper member of the Williams Island Formation) occur in areas of the Moose River Basin which are accessible by the Ontario Northland Railway line and may be potential sources for quarried products.

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Part 2

Precambrian Carbonate Resources

Additional carbonate resources for the limestone industries are Precambrian marbles, carbonatites and calcite vein deposits. Minor postglacial marl deposits are also a potential resource.

Marble

Marble, as used in this report, is defined as a metamorphic rock consisting predominantly of recrystallized calcite and/or dolomite, usually with a granular or saccharoidal (sucrosic) texture. In Ontario, marbles are confined to the Precambrian rocks of the Canadian Shield.

To most of the commercial limestone industries, especially the building stone operators, the term marble is applied to almost any type of crystallized carbonate rock (including true marble, limestone, and dolostone) which is capable of taking a polish and can be used as architectural or ornamental stone. In Ontario, this use includes the "marbles" of the Amabel Formation on the Bruce Peninsula (see Owen Sound District) and the "marbles" of the Gull River and Bobcaygeon Formations of Eastern Ontario (see Cornwall District).

For the purposes of this part of the report, the term marble is only used for metamorphic, recrystallized carbonate rocks. The unmetamorphosed carbonate rocks are referred to by their common geological name, eg. limestone, dolostone, etc.

Marble deposits are identified both in the following text and on Figure 2.1 and Figure 2.2 (Chart, back pocket) according to their geographic distribution, starting in the west and progressing eastward. Deposits are centered in the Kenora, Sudbury, Thunder Bay areas and in southeastern Ontario. Terrazzo (marble chip) quarries in the Madoc area of southeastern Ontario presently account for most of Ontario's marble production. Descriptions of the Madoc operations are included in the quarry descriptions for Tweed District in Volume II, thus they are not discussed in detail in this section.

KENORA

Marble deposits in the Kenora region include those at Hahn Lake, west of Red Lake and at Woman Lake Narrows, approximately 80 km east of Red Lake.

HAHN LAKE, RED LAKE AREA

Production of lime in a kiln on the north shore of Hall Bay, Red Lake, was based on marble exposed to the north in a 2.5 km long, 550 m wide belt running north–northeast across Hahn Lake (Figure 2.1 deposit NO–1). This operation was undertaken in the late 1930s. This calcitic marble is intercalated with felsic metavolcanics. White to light grey carbonate forms approximately 25% of the rock in outcrop (Storey, 1986).

WOMAN LAKE NARROWS, CONFEDERATION LAKE AREA

At Woman Lake Narrows (Figure 2.1, deposit NO–2) a 2.79 billion years old calcitic, stromatolitic marble is exposed. The 100 m thick marble contains minor cherty lenses. The deposit has a strike length of 1.6 km (Storey, 1986). Elsewhere in the area an equally thick older marble is reported with scattered lenses of massive pyrite and pyrrhotite.

THUNDER BAY

The Rossport Formation in the Thunder Bay area may be divided into three members: (a) lower dolomite, (b) central chert–carbonate (stromatolitic to the north), and (c) upper dolomite. Only when metamorphosed by Keweenawan diabase dikes or sills does the carbonate recrystallize to white dolomitic marble (Speed et al., 1985). Four locations are known where sections of 3 to 6 m of this dolomitic marble constitute a potential resource. The following are the most significant deposits in the Thunder Bay area.

COOKE POINT, SOUTH SHORE OF LAKE NIPIGON

A quarry was opened at Cooke Point (Figure 2.1, deposit NO–7) for the purpose of producing building and ornamental stone. At the base of a diabase sheet, thin–bedded, gently folded dolomitic limestones, either white or pale green in colour, rise to a height of 6 m above lake level, for about 1.5 km along the lakeshore. A silica content in excess of 20 percent within the limestone is quoted by Pye (see Hewitt, 1964, p.85).

EAGLE HEAD LAKE, 71 KM NNE OF THUNDER BAY

A quarry for the production of decorative stone from white, brucitic marble and grey, wavy banded dolomitic marble is operated at Eagle Head Lake (Figure 2.1, deposit NO–8) by H. Lundmark and W. McAteer. The 4.5 to 5.5 m thick marble unit is associated with greenish or red carbonate mudstone and overlain by diabase along an irregular contact.

ITREN LAKE, 69 KM NNE OF THUNDER BAY

A good building and decorative stone material is obtained by H. Lundmark from an exposure of white brucitic marble and grey to multicoloured dolomitic marble on the southwestern shore of Itren Lake (Figure 2.1, deposit NO–9). Associated with purple spotted mudstone and overlain by diabase, the marble attains a maximum thickness of 3 m and is exposed for a strike length of approximately 72 m (Speed et al., 1985, p.84–87).

WABIKON LAKE, 110 KM NORTH OF THUNDER BAY

White, grey and red calcareous mudstone, intercalated with black shale, is exposed on the west shore of

Wabikon Lake (Figure 2.1, deposit NO–6). A maximum thickness of 3 m of red tinted impure carbonate, grading to white in the vicinity of diabase is exposed. This showing is staked for potential production of decorative building stone (Speed et al., 1985, p.155–158).

SUDBURY

The Espanola Formation is part of the Huronian Supergroup of metasediments and is the only limestone–bearing formation in the Huronian. Although localized areas are contact metamorphosed to marble, the majority of this unit has remained a limestone in spite of its 2 or more billion year age. The presence of limestone has been reported in several widely spaced locations, suggesting a deposit of large areal extent, eg. Endikai Lake Area (Siemiatkowska, 1978), Benny Area (Card and Innes, 1981), Shining Tree Area (Carter, 1981), Hutton, Parkin, Afton and Clement Townships (Meyn, 1968, 1977). The Espanola Formation is characterized by a lower member rich in carbonate, followed by one or two members with increased sand or silt content. Even in the lower member, siltstone interbeds or sandy limestone or dolostone are common.

The thickness of the Espanola Formation is variable. In the Benny Area the formation ranges in thickness from less than 15 m to over 90 m and averages about 45 m (Card and Innes, 1981, p.59). Elsewhere the formation consists of two more or less equal parts, neither estimated to exceed 60 m in thickness (Meyn, 1968). Development of the Espanola limestone resources north of Lake Huron would be in competition with efficient production from large scale operations in the south that benefit from easy access via Great Lakes shipping (on Manitoulin and Drummond Islands).

SOUTHEASTERN ONTARIO

Late Precambrian rocks of southeastern Ontario fall within the Grenville geological province. These rocks can be grouped into two major rock types and geographic areas: rocks northwest of a line running northeast between Bobcaygeon and Pembroke are part of the Central Gneiss Belt and consist predominantly of gneissic rocks. Rocks southeast of this line are part of the Central Metasedimentary Belt and consist of mostly clastic rocks. Marble deposits of southeastern Ontario mostly occur in the Central Metasedimentary Belt.

CENTRAL GNEISS BELT, GRENVILLE PROVINCE

Several marble deposits in the Central Gneiss Belt have been investigated, at one time or another, for production of refractory magnesite (Rutherglen deposits, west of Mattawa (Figure 2.2, NO–23)), calcite filler (Burcal deposits, Huntsville (Figure 2.2, NO–22)) or building stone and lime (Parry Sound area (Figure 2.2, NO– 20, 21)). Satterly (1943) provides a general characterization of the deposits: "Very little pure crystalline limestone occurs, and most of it is speckled with grains of silicate minerals."

CENTRAL METASEDIMENTARY BELT

Ontario's most extensive marble resources are contained in the Central Metasedimentary Belt of the Grenville Province. In Ontario, a tentative subdivision, based on differences in rock groupings, structural style and metamorphic facies, separates the area of so–called "Grenville Super Group" formations into the Bancroft, Elzevir, Sharbot Lake and Frontenac terrains (Bartlett et al., 1984, p.4). Marble is common in all these terrains but correlation across terrain boundaries is difficult due to the tectonic character of the boundaries. At least two ages of deposition have been established in the Elzevirian terrain where the Flinton Group sediments in the Flinton–Kaladar area represent deposition subsequent to the Elzevirian orogeny (Bartlett et al., 1984, p.5). Locally, as many as four cycles of volcanic activity and carbonate sedimentation have been distinguished in the Belmont–Marmora area (Bartlett et al., 1984, p.9–28).

A statistical analysis of the chemical composition of over 1900 marble samples covering a large part of the Central Metasedimentary Belt is provided by Grant and Kingston (1984).

The respective major marble deposits of the Central Metasedimentary Belt will be discussed according to areas of distribution in the following geographic order: Kinmount, Haliburton, Maynooth, Renfrew, Coe Hill, Plevna, Carleton Place, Kaladar and Westport.

KINMOUNT, HALIBURTON, MAYNOOTH

Many small deposits are known in this area with a number of small abandoned marble quarries. Geological mapping of the area by Bright (1977) suggests there are several marble units in the area of considerable thickness. The following formation descriptions pertain to the Eels Lake area east of Kinmount:

(1) Monmouth: Thickness less than 30 m up to 900 m; limestone and dolostone; minor greywacke siltstone (calcitic to dolomitic marble; minor biotite–rich gneiss).

(2) Tory Hill: Thickness less than 30 m up to 1350 m; thinly interbedded limestone, calcareous greywacke, arkosic sandstone, and chert; subordinate tuff (calcitic silicated marble, calc–silicate gneiss, clean quartzofeldspathic gneiss, impure quartzite; minor amphibolite).

(3) Dungannon: Thickness 300 m to 1350 m; dolostone and limestone; subordinate calcareous sandstone and siltstone; minor arkosic sandstone, chert and mafic tuff (dolomitic and calcitic marble, calc–sili-

cate gneiss, amphibolite, biotitic quartzofeldspathic gneiss and quartzite).

A graphic display of the geological environment that brings about the alternating sequence of marble, volcaniclastic units and siliceous sediment is given by Easton (1986, p.141–151).

Due to the localized nature of volcanic activity associated with the carbonates, the marbles cannot be regionally correlated.

RENFREW

Marbles in the Renfrew area (Figure 2.2, NO–27) are derived from impure limestone and dolostone (Lumbers, 1982, p.19). Calcitic and dolomitic marbles are distinguished by Lumbers into relatively pure varieties and those with substantial siliceous impurities, though these units are frequently intercalated.

Marbles in the Renfrew area are predominantly coarse crystalline and occasionally, in highly strained structural zones, very coarse crystalline. Minor dolomitic layers are found intercalated with the predominantly calcitic marble in this area, while major units of dolomitic marble show a spatial association with metavolcanic rocks (Lumbers, 1982, p.19). Some of these units are quarried for building stone and the production of magnesium (Figure 2.2, NO–27).

Chemical analyses of marble in the Renfrew area are reproduced in: Industrial Minerals of the Pembroke–Renfrew Area, Part 1: Marble (Storey and Vos, 1981).

COE HILL

Coe Hill designates an area from Bancroft to Madoc, and Apsley to Weslemkoon. Marbles in this area are generally medium to fine crystalline, corresponding to an intermediate to low grade metamorphism (Lumbers, 1964, p.7).

Part of this area was mapped in detail by Bartlett and Moore (1985) who make, where possible, the following distinctions in carbonate metasediments: dolomitic marble, calcitic marble, interlayered calcitic/dolomitic marble, dolomitic marble with abundant lenses and layers of chert, tremolite marble and skarn. As a group these map units are distinguished from interlayered carbonate and siliceous metasediments.

MADOC TOWNSHIP

In his report on the geology of Madoc Township, Hastings County, Hewitt (1968, p.11, 12) characterizes marble of the northern part, occurring in the Queensborough syncline, as blue grey and well bedded. Elsewhere, white, buff, green, black and pink marble are common. Several quarries are operated for the production of terrazzo chips in the area (Figure 2.2, NO–25) which are detailed in the Tweed District descriptions.

MARMORA TOWNSHIP

Resources in Marmora Township, Hastings County, are largely part of the Marmora Formation (Bartlett *et al.*, 1984, p.15), a predominantly carbonaceous metasediment in Cycle III of the Belmont Lake volcanic complex. Up to 2,000 m thick, this formation can be distinguished into a lower, predominantly dolomitic part (algal mats), and an upper non–stromatolitic calcitic part.

BARRIE, CLARENDON AND PALMERSTON TOWNSHIPS

Fine crystalline pink and white dolomitic marble extends across Lots 27, 28 and 29, Concessions 9 and 10, Barrie Township, Frontenac County (Hewitt, 1964, p.56). The presence of tremolite in the marble detracts somewhat from its potential as a building stone, although it may still have potential for terrazzo.

Marbles of the Clarendon Lake area, Clarendon Township, are distinguished into dolomitic and calcitic dominated varieties (Moore and Morton, 1980, p.26). They consist of massive or layered white, grey, bluish grey, greyish buff and buff, fine to coarse crystalline carbonates with occasional intercalation of metavolcanic or metasedimentary beds.

Verschuren et al. (1985, p.52) mention two areas in Lot 37– 39, Con. 2, Clarendon Township, Frontenac County, which have potential for marble development. Verschuren et al. (1985, p.85) also mention an area in Lot 10, Con. 11, Palmerston Township, Frontenac County, with a similar potential for development.

In the literature, Clarendon and Palmerston Townships are mentioned in connection with a wide band of dolomitic marble (Hewitt, 1964, p.58) between Ompah and Plevna. This marble was tested for building stone purposes as early as 1935 (Goudge, 1938, p.74).

CARLETON PLACE

The area surrounding the Town of Carleton Place is characterized by medium to high grade metamorphism of the underlying rocks. In a study of the Lavant area Pauk (1984, p.7, 8) correlates older metasediments and metavolcanics with the Herman and Mayo Groups in the Bancroft area, and some younger formations, caught up in structural zones in the northwest part, with the Flinton Group. Carbonate metasediments are generally medium to coarse crystalline, occasionally fine crystalline, calcitic and dolomitic marbles that occur as thick beds or as thinner beds intercalated with clastic metasediments or metavolcanics (Pauk, 1984, p.35).

In the Lavant area massive units of white, medium to coarse crystalline, calcitic marble, with occasional colour variations to grey–blue or salmon pink, are the most widely distributed variety of a total of 8 subunits. These subunits are distinguished primarily on the basis of mineral content (Pauk, 1984, p.35).

DARLING TOWNSHIP

A major operation for the production of calcite chips, filler and whiting is conducted by Steep Rock Calcite in Darling Township, Lanark County. The property includes two building stone quarries in the Tatlock area previously held by Angelstone Limited (Guthrie Farm) and Omega Marble Tile and Terrazzo Limited (Lot 6, Con. 5, S.W. half), respectively (Hewitt, 1964, p.61, 64). A white medium–crystalline calcitic marble is reported by Hewitt (1964, p.62).

A wide belt of low silica content (<3% silica) marble is bounded by dolomitic marble to the west and by zones with higher silica content (3% to 11%) to the east. The latter zones underlie the initial quarry, which produced crushed marble of high brightness but of limited use as a calcite filler.

The low silica zone marble reaches true thicknesses of 85 m. Here the marble is white, medium to coarse crystalline, with negligible phlogopite and essentially free of graphite.

The footwall boundary is determined by impure dolomitic marble with increased silica content and inclusions of boudinaged amphibolite. Rare boudinaged quartz veins cross cut the marble belt.

Along strike, the ore body is also limited by higher silica content. Quartz and tremolite are the major silicate minerals. The presence of phlogopite and diopside (Hewitt, 1964, p.66) has been recorded.

LANARK AND RAMSAY TOWNSHIPS

Banded, white and grey, calcitic marble trends northeasterly through Lanark Village, in Lot 1, Con. 1, Lanark Township, Lanark County (Hewitt, 1964, p.60). Building stone, lime and road metal were produced locally (Storey and Vos, 1981, p.62).

Northeasterly trending calcite marble, layered with graphite, silicate minerals and dolomite crystals, and interlayered with paragneiss units, is reported in Lots 26 and 27, Con. 5–9 of the same township (Storey and Vos, 1981, p.95). Additional analyses are given by Grant and Kingston (1984, p.201- 204).

White calcitic marble is reported in Lot 8, Con. 6, Ramsay Township, Lanark County, by Hewitt (1964, p.17). Grant and Kingston (1984, p.211–212) record coarse to medium crystalline marble with minor graphite, phlogopite and muscovite in this area.

SOUTH SHERBROOKE TOWNSHIP

White, calcitic marble, occasionally white and grey laminated with phlogopite and graphite, occurs in Lot 13, Con. 2, South Sherbrooke Township, Lanark County (Grant and Kingston, 1984, p.192).

Predominantly fine crystalline dolomitic calcite marble, grey or light and dark grey laminated, with occasional pods or blocks of white, plagioclase–rich silicate rocks, occurs in Lots 16, 18, 19, Con. 10 and 11, South Sherbrooke Township (Grant and Kingston, 1984, p.214–216).

KALADAR

In the Kaladar area, marble quarries are located in Lot 7, Con. 1 and Lots 2 and 3, Con. 6, Elzevir Township, Hastings County (Hewitt, 1964, p.52), as well as in Lot 11, Con. 14, Hungerford Township, Hastings County (Figure 2.2, NO–26).

WESTPORT

Favourable mention is made by Grant and Kingston (1984) of marble outcrops in the following townships in the Westport area.

OLDEN TOWNSHIP

White, massive, medium to coarse crystalline calcite marble occurs within the Mountain Grove Intrusion in Lot 2, Con. 5, Olden Township, Frontenac County, in an area 150 to 200 m wide and 650 m long on the site of the former Long Lake Zinc Mine. This is potentially of interest as industrial filler material (Grant and Kingston, 1984, p.133–135), although a larger body would be more desirable for economic operation.

White to light grey, fine to medium crystalline calcitic marble with only minor graphite and phlogopite occurs in Lot 6, Con. 3 (Grant and Kingston, 1984, p.127–130).

UNITED COUNTIES OF LEEDS AND GRENVILLE

White calcitic, coarse–grained marble in Lot 14, Con. 7, Rear of Leeds and Lansdowne Township, United Counties of Leeds and Grenville, is of potential interest as filler material (Grant and Kingston, 1984, p.159–161). Predominantly white calcite marble, with grey bands and minor graphite and pyrite, outcrops in Lot 21, Con. 9, South Crosby Township, United Counties of Leeds and Grenville (Grant and Kingston, 1984, p.170).

STORRINGTON TOWNSHIP

White calcitic marble with minor phlogopite and graphite and some pyrite and muscovite occurs in Lot 10, Con. 13, Storrington Township, Hastings County (Grant and Kingston, 1984, p.170–172).

Calcite Veins

Substantial amounts of calcium carbonate have been encountered in calcite veins. In the Thunder Bay area they are associated almost exclusively with shales and wackes of the Rove Formation and ironstone of the Gunflint Formation. Here they occur as simple and composite veins in faults and fissures structurally related to diabase dykes and sills (Speed et al., 1985, p.10). The veins were described as follows by Speed et al. (1985, p.11):

> "The veins commonly consist of a gangue of calcite and/or barite with minor quartz and fluorite. Metallic minerals found in these vein systems are argentite, native silver, galena, sphalerite, chalcopyrite and pyrite. The majority of these veins were mined for their silver, lead, zinc or copper content in the late 1800s and early 1900s."

Vein deposits of potential economic importance as a source of calcium carbonate include the Gaherty Island and Kawashegamuk Lake deposits in the Kenora area, the Gravel River, Neepatyre Mine, South McKellar Island and Spar Island deposits in the Thunder Bay district and the Parkin Township deposit, northeast of Sudbury.

Elsewhere in Ontario, calcite veins of a purity and size to be of interest as sources of filler–grade calcium carbonate are scarce. A particular example occurs in Frontenac County in southeastern Ontario, as described below.

In 1946, a large vein of massive, cream–coloured to slightly pink calcite was worked by Marlhill Mines Limited in Palmerston Township. The vein cuts a granite and varies in width from 18 m to 30 m, with an east–west strike and a near vertical dip. It has been traced by drilling over a length of more than 200 m and to a depth of 45 m and, except for rare wallrock fragments, consists totally of calcite.

GAHERTY ISLAND DEPOSIT

The Gaherty Island deposit (Figure 2.1, NO–3), 16 km south of and accessible by boat from Kenora, consists of a dolomitic carbonate vein with minor amounts of quartz and sulphide minerals in a pyroclastic host rock (Storey, 1986, p.79). The vertical vein is at least 6 m wide. The dolomite content weathers rusty brown and appears to be predominantly ankerite (Storey, 1986).

KAWASHEGAMUK LAKE DEPOSIT

Carbonate veins occur in the area of Kawashegamuk Lake, 27 km southeast of Dinorwic (Figure 2.1, NO–4) (Storey, 1986, p.83–85). The area can be reached by forest access road exiting south from Highway 17 at 10.7 km southeast of Dinorwic. Chemical analyses indicate that the carbonate is an iron–rich dolomite.

GRAVEL RIVER CALCITE OCCURRENCE

Calcite veins in Archean hornblende–biotite granite are found in a high cliff on the western shore of the Gravel River, north of Rossport (Figure 2.3, NO–14) (Speed et al., 1985, p.72–75). A timber access road leads north from Highway 17 at a point 52 km east of Nipigon. After 15 km this road passes close by the occurrence after having crossed the Gravel River itself. Samples taken from the veins, the largest of which is 4 to 5 m wide, show the carbonate to be very pure calcium carbonate with only minor amounts of silica.

NEEPATYRE MINE

The Neepatyre Mine is located on the widest part of an east–trending vein cutting across Paipoonge and Neebing Townships, 10 km west of Thunder Bay (Figure 2.1, NO–10). The near vertical vein cuts flat–lying cherty taconite iron formation of the Gunflint Formation (Speed et al., 1985, p.97).

The Neepatyre Mine consists of 2 open cuts, respectively 9 m and 6 m wide, in Neebing Township. Coarse crystalline calcite from these cuts was crushed and screened for production of stucco dash, chicken grit and landplaster. Up to July 1927 one hundred and fifty tons of material had been marketed (Speed et al., 1985, p.99). The mineralization in this vein is described by Speed et al. (1985) as follows:

> "The main constituent of the Neepatyre vein is massive white calcite. A transparent variety of calcite (Iceland Spar) is also said to occur. This form of calcite was not observed during the visit to the property. Quartz occurs as either the white or amethystine variety. Barite and fluorite also occur sporadically throughout the vein. Metallic minerals are rare and sparsely disseminated in the vein material and include galena, sphalerite, chalcopyrite and pyrite."

SOUTH MCKELLAR ISLAND DEPOSIT

The South McKellar Island deposit, 22 km southeast of Thunder Bay on South McKellar Island (Figure 2.1, NO–13), is only accessible by boat. The island is the most northeasterly of a chain of islands including Jarvis, Spar and Thompson Islands, all of which are underlain by a diabase dike striking in this direction and extending from the mainland at McKellar Point. A vertical, composite barite–calcite vein with minor fluorite, sphalerite, galena, pyrite and silver, strikes due northwest across the island (Speed et al., 1985, p.142). The 150 m exposed length of the vein is from 13 to 20 m wide and is the largest known composite vein in the region (Speed et al., 1985, p.142). Sections of this vein are either predominantly barite or calcite and as such the vein is a major source of good quality barite and calcite in the region (Speed et al., 1985). Mining of this vein has taken place since discovery by the McKellar brothers in 1869; shipments of barite were made in 1894 and further drilling took place in 1967.

SPAR ISLAND OCCURRENCE

Spar Island is one of the islands underlain by a northeast striking diabase dike leaving the mainland at McKellar Point. It is approximately 35 km due south of Thunder Bay (Figure 2.1, NO–12). Calcite occurs in a near–vertical composite vein striking 160 degrees across the southern part of the island. Vein walls and a central rib of barite alternate with massive calcite bands in which some quartz and barite occur. A large horse of diabase in parallel attitude is enclosed in the 5 m wide south shore outcrop (Guillet, 1963, p.12). The proportion of major minerals is approximately: calcite – 65 percent; barite – 25 percent; and quartz – 10 percent (Guillet, 1963, p.12).

The history of the mining operations of this deposit since 1846 is described by Speed et al. (1985, p.148, 149). Production figures are not available.

PARKIN TOWNSHIP DEPOSIT

A body of massive calcite, here classified as a vein deposit, is found in Parkin Township, 40 km north–northeast of Sudbury (Figure 2.3, NO–19). Drilling has shown that this body has limited depth extension.

The calcite deposit is located in Lot 8, Con. 3, Parkin Township, in an area of brecciated quartzites and diabase, which includes some fragments of the carbonate–rich Espanola Formation. The area is characterized by faults and fractures which Karvinen (1982) relates to a local rift structure which had been active from early Proterozoic to post–Nipissing time. The hydrothermal alteration and brecciation is apparently related in time to the intrusion of Nipissing diabase. It is conceivable that carbonates originating in the Espanola Formation were remobilized and concentrated in the present lens–like body as suggested by W. Meyer (Resident Geologist, Ministry of Northern Development and Mines, Sudbury – see Vos, 1986).

The calcite deposit can be subdivided into three grades according to drill results by Raretech Minerals Inc. (Constable, 1986). These grades are provisionally classified as good, fair and poor calcite (Table 2.1).

Whereas good–grade calcite has assayed 99.2 percent $CaCO_3$ in surface showings, the contents of MgO, SiO_2 and Fe_2O_3 increase towards the contact with the fair grade calcite.

On the basis of a total of 8 drill holes combining 1458.5 feet (444.5 m) of BQ drill core, a possible tonnage of 23,370 tonnes good grade calcite, 58,015 tonnes fair grade calcite and 52,390 tonnes fair to poor grade calcite was established by Constable (1986). Sulphide stringers and disseminated pyrite in siliceous units with low values in nickel, copper, zinc and gold also occur within the deposit (Constable, 1986).

Table 2.1. CHEMICAL ANALYSES OF PARKIN TOWNSHIP CALCITE

Grade:	Good	Good to Fair	Fair
SiO_2	0.93	2.47	9.94
Al_2O_3	0.02	<0.01	0.06
CaO	55.6	54.5	27.1
MgO	0.26	0.55	17.6
Na_2O	0.03	0.02	<0.01
K_2O	0.01	0.01	0.01
Fe_2O_3	0.11	0.14	3.62
MnO	0.07	0.08	0.22
TiO_2	<0.01	0.01	0.01
P_2O_5	0.01	0.01	0.01
LOI	43.2	42.5	41.8
TOTAL	100.2	100.3	100.4

Analyses by X-Ray Assay Laboratories Limited, Don Mills, Ontario (Constable, 1986)

Carbonatites

The term carbonatite applies to carbonaceous material in igneous rock complexes. In surface outcrop the complexes are characterized by concentric distribution of a great variety of rock types.

In carbonatite complexes there is frequently a gradational transition between rock types, and not all of the types are necessarily represented in each complex. A typical distribution sequence is an outer ring of altered or fenitized country rock followed by syenitic rock low in quartz, calcium and ferromagnesian minerals (Heinrich, 1966, p.323). Towards the centre, ferromagnesian–rich ultramafic rocks in rings, dykes or bodies may be encountered, accompanied by concentrations of magnetite, ilmenite and/or other metallic minerals. Either pure carbonate or calc–silicate rock occupies the core of the complex.

In many instances the elements lacking from the outer rings of a carbonatite complex are compensated for at the centre, the chemical balance indicating a transport of elements from the outskirts toward the centre of the complex. Whether this chemical distribution was obtained magmatically or by metasomatic transfer of elements, possibly with the help of groundwater circulation as suggested previously (Vos, 1980), remains to be established for each deposit individually. Such knowledge is essential for a comprehensive evaluation of mineral potential. For purposes of resource evaluation it is necessary only to establish the quantity and chemical composition of carbonaceous material available in the complex. In areas of granitic terrain in the Canadian Shield the carbonatite complexes are frequently the only geological environment in which economic concentrations of calcium carbonate are found. As such they are an important complement to the limestone resources of Ontario.

ONTARIO DEPOSITS

The distribution of carbonatite–alkalic complexes in Ontario is shown by Satterly (1968; Map P.452). Some of these complexes have been examined much more closely than others and whether or not calcium carbonate is present is not known with certainty in some instances.

Four of the better known complexes with a carbonate content of potential economic interest are discussed below. They are the Firesand River and Prairie Lake complexes in the Wawa and Marathon areas, northeast and north of Lake Superior, the Cargill Complex southwest of Kapuskasing, and the Spanish River Carbonatite Complex west of Sudbury.

FIRESAND RIVER COMPLEX

The Firesand River Complex, approximately 7 km east of Wawa (Figure 2.3, NO–17), covers approximately 4.5 km^2 (Sage, 1983a; OFR 5403, p.2) that is underlain by a core of ferruginous dolomite and a calcitic rim which consists of "a complex mixture of carbonate, silicocarbonatite, ijolite and wall rock fragments ..." (Sage, 1983a, p.8).

Fenitization has affected the Early Precambrian supracrustal host rocks adjacent to the complex (Sage, 1983a, p.13–16). In a quartz–feldspar porphyry Sage notes a loss of silica and sodic metasomatism of the feldspars. The calcite carbonatite of the calcitic rim occurs in a ring, or a succession of rings, up to a total width of 600 m (Parsons, 1961, p.26). The potential of these rocks as a source of lime was tested by the Algoma Steel Corporation Ltd. in 1970 with surface work and drilling totalling 717 m in eight holes. The contents of phosphorous, silica and magnesium apparently proved too high for use of this material as a source of lime in the sinter plant at Wawa.

PRAIRIE LAKE COMPLEX

The Prairie Lake Complex is a circular carbonatite approximately 3 km^2 in an area located northwest of Marathon, about 25 km north of Lake Superior (Figure 2.3, NO–15).

The complex consists of an intricately interfingered sequence of arcuate to curvolinear bands of carbonate rock and ijolite, the ijolitic rocks being more abundant towards the core. While calcite is the dominant carbonate phase in the complex, dolomite commonly occurs as accessory grains in carbonate units or ijolitic rocks (Sage, 1983b, p.26–31).

The possibility of using Prairie Lake calcium carbonatite for production of cement has been considered by Nuinsco Resources Limited, the company presently holding options on the deposits. Consistent with production of cement and lime from carbonatites in Sweden (Alno Complex), Uganda (Tororo Complex) and Brazil (Jacuparanga Complex) both the Firesand River and Prairie Lake Complex provide an exploration target for cement stone north of Lake Superior.

CARGILL COMPLEX

A readily accessible carbonatite intrusion is located 32 km southwest of Kapuskasing in Cargill Township (Figure 2.3, NO–16). The intrusion took place approximately 1.74 billion years ago (Gittins et al., 1967) in an environment of hybrid quartz diorite gneiss and amphibolite of Archean age (Bennett et al., 1967). Major rock types of the complex are carbonatite and pyroxenite (Sandvik and Erdosh, 1977). The surface magnetic expression of the intrusion indicates three centres, identified respectively with the South and North Subcomplexes and a poorly defined West Subcomplex, 4 km west of the main intrusive.

In the South Subcomplex a total area of approximately 1 km^2 consists of an outer ring of calcite carbonatite and a core of dolomite carbonatite. Siderite carbonatite is indicated as well, but very little of this material has actually shown up in subsequent drilling (Ford, 1986, p.326). The calcite carbonatite is near the surface or exposed in contact with the pyroxenite envelope in some areas.

In his report on the Cargill Complex, Sage (1983c, p.23–26) reports 45 major element analyses of sovite of which 18 have a CaO content of 45% or more. The balance in these analyses is made up of SiO_2 (average: 2.66%), Al_2O_3 (average: 0.57%), Fe_2O_3 (average: 0.95%), FeO (average: 2.37%), MgO (average: 3.39%), Na_2O (average: 0.47%), K_2O (average: 0.22%), TiO_2 (average: 0.14%), P_2O_5 (average: 3.93%), S (average: 0.34%), MnO (average: 0.11%), CO_2 (average: 3.36%) and water (average: 0.38%). Some beneficiation or selective mining would be necessary to obtain a suitable cement source rock from this deposit, though calcium carbonate could be produced as a by-product if the phosphates present were to be mined.

SPANISH RIVER COMPLEX

The Spanish River Carbonatite Complex is approximately 55 km northwest of Sudbury, on the boundary of Venturi and Tofflemire Townships (Figure 2.3, NO–18). The complex has a total surface area of approximately 2 km^2, but bedrock is exposed in only two areas where extensive bulldozing has been completed (Sage, 1983d, p.4). The rock types of the complex, occurring within a halo of fenitized granitic rock, include silicocarbonatite, ijolite and pyroxenite in the periphery, and purer carbonatites towards the core. The latter 5 samples have more than 45% CaO (Sage, 1983d, appendix). Not enough information is available to evaluate the potential of this complex as a source of calcium carbonate due to poor exposure and limited drilling. It is identified here primarily because of its geographic location near an area of industrial and agricultural markets.

Marl

Marl is essentially a soft limestone mud that accumulates in the beds of certain spring–fed landlocked lakes and marshes. It results from biochemical precipitation induced by photosynthesis of algae. Where the lake waters are nearly saturated with calcium carbonate, as a result of the abundance of nearby limy tills or bedrocks, these algae are so prolific as to give a most distinctive and attractive blue–green colour to the water.

Marl lakes are particularly abundant in southern Ontario, but a few deposits are also known in the Timmins area and the Nipigon and Thunder Bay areas. More than a hundred occurrences have been described (Guillet, 1969).

From 1889 to 1919 marl was extensively used in Ontario for making portland cement. For much of this period it was used exclusively, with clay, in fourteen plants throughout southern Ontario, but by 1919 all had either closed or converted to limestone. For cement, as for most limestone markets, marl proved inferior because of its high water content and greater variability, the latter due in part to the dredging method of excavation.

In recent years, marl has received more interest in northern Ontario, in spite of the fact that deposits are scarcer than in the south and their quality is generally only fair. This interest stems largely from the scarcity of limestone in the predominantly Precambrian terrains. Deposits near Timmins, Thunder Bay (Figure 2.1, NO–10) and Sioux Lookout (Figure 2.1, NO–5) have each been considered for portland cement manufacture and agricultural soil conditioner, neither of which require particularly high purity.

Finely–divided organic matter and clay are the principal impurities in marl, and Ontario deposits vary considerably in these regards. The purer deposits are moderately white in colour, and several attempts have been made to develop them for filler applications. However, their high natural moisture content (50 to 75 percent) and their extreme fineness (70 to 90 percent finer than 325 mesh) has made their handling and processing both difficult and costly. The best products have had whiteness ratings of only about 80 (on a standard scale of 1 to 100), while whiteness ratings from the best marble deposits are 95–96.

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Part 3 — Properties, Specifications and Uses of Limestone Commodities

Limestone Aggregates

Limestone aggregates (crushed limestone) represent the single largest category of limestone production. Most of the production is associated with the requirements of the construction industry as either road building material or as concrete aggregate. Other major uses include rubble and riprap, railroad ballast and stone for a wide variety of other uses.

Ontario is blessed with an abundance of limestone resources. However, regional differences in the supply and economic accessibility of the resource do result in significant differences in the supply and demand patterns for stone. As a consequence, the industry shows a degree of dynamism unusual for a low priced commodity.

SOURCES

As documented in other parts of this report the limestone resources of Ontario are extensive and deposits are found in most regions of the province. The industry, however, is concentrated in southern Ontario, especially along the Niagara Escarpment, and in eastern Ontario. The major producing centres include Halton, Ottawa–Carleton, Simcoe, Niagara, Hamilton–Wentworth, Northumberland, Essex and Oxford. Together, all these areas accounted for 71% of all stone production for all uses.

Centres of major urban growth such as Metropolitan Toronto, Peel Region, York Region and Durham Region lack accessible deposits of limestone for use as aggregate material. However, crushed gravel is readily available in these regions and is usually an acceptable substitute for crushed limestone. Transportation costs play a significant role in determining the relative use of crushed limestone and gravel in construction applications in these regions. As a rule of thumb, the area west of Highway 11 (Yonge St.) relies on crushed limestone from quarries on the Niagara Escarpment to meet its aggregate requirements. Conversely, the area east of Highway 11 relies on crushed gravel for much of its aggregate requirements. Similarly, the southwestern Ontario counties of Lambton, Huron, Middlesex, Kent, Essex and Elgin rely on imports of crushed stone from other regions of Ontario or from the United States to meet their aggregate requirements. These aspects of regional supply/demand and transportation costs will be more fully explored in a later section of this report.

PRODUCTION TECHNOLOGY

The production methods for crushed limestone have not changed significantly in their basic principles in many years. Technological change has been mainly associated with increases in the size of equipment for drilling, blasting, hauling and crushing rather than the actual methods of quarrying.

In Ontario, production of crushed limestone is exclusively by open quarry; there is no underground mining of limestone. Quarries vary considerably in size; number, depth and width of benches; and type of processing equipment. The principal factors affecting quarry size and scope of operations are the quality of the deposit (depth, width, bedding integrity, and physico–chemical uniformity of the deposit), available markets (number of product sizes and market volumes for each size), and the financial capability of the operator.

There is no standard design for aggregate plants. Each deposit and each range of desired products requires careful analysis and a specific design engineered for the location. By selecting various available standard components and assembling them in combinations that provide the required crushing, sizing, washing, benefication, stockpiling and loading, a wide variety of needs and problems can be efficiently handled. Some of the components can be purchased as portable units, thus permitting ready relocation after the depletion of a source or the satisfaction of a short–term need such as a highway project.

The optimum size of a plant depends on the demand for the desired quantities of product. Currently in Ontario crushed stone operations can be found with annual production volumes ranging from about 50,000 tonnes to 9 million tonnes. Due to the heavy investment required for a large fixed plant it is necessary to carefully evaluate production capacity in relation to the size of the deposit available for processing and the market. A minimum of a 20–year supply of extractable material is generally required before a large fixed plant can be justified.

As mentioned previously, the major technological factors affecting the crushed stone industry have to do with the increasing size of both mobile and fixed production equipment. Plants with through–puts in excess of 1,500 tonnes per hour are now common, whereas 30 years ago a large plant would have an effective capacity of approximately 400 tonnes per hour.

Equipment has increased dramatically in size. Haulage trucks have changed from 12 to 15 tonne capacity to 50 to 75 tonnes. The shift to larger haulage trucks has been parallelled by a shift to larger extraction equipment, as equipment manufacturers and users seek to optimize overall production efficiencies and thereby reduce the unit costs of production. Smaller crawler shovels of 0.75 to 3 cu. m capacity have been replaced by units of up to 6 cu. m, or by rubber–tired front–end loaders of 7.5 to 9 cu. m or even up to 18 cu. m capacity.

A similar tranformation has occurred in terms of the size of the operators. Large equipment is very expensive and can only be purchased by large organizations. There has been a significant trend to consolidation in the industry in terms of the integration of smaller producers into a larger organization and the development of major vertically integrated operations such as those of the cement producers. The cement producers, in particular, have significantly extended their interests in aggregate production in recent years. This expansion has been brought about to satisfy the internal demand of the cement producers for concrete aggregate, as well as a strategic decision on their part to diversify operations. While there will always be a role for the smaller operator serving local markets, the trend is certainly to larger plants financed by large corporations.

Because the demand for aggregates in Ontario is highly seasonal, and because of the difficulties and expense of operating in the winter months, most quarries operate less than 12 months. Larger operators are able to satisfy winter demand from stockpiles. All operators take advantage of the winter slowdown to conduct necessary maintenance on key items of plant and equipment and in many cases perform progressive rehabilitation of extracted areas.

Figure 3.1 depicts a flow diagram for a typical large, modern crushed limestone processing plant. The basic production processes and features of some of the equipment associated with such plants are detailed below.

DRILLING AND BLASTING

Drilling and blasting operations represent the first major phase of crushed stone production after the removal of the overburden. Drilling is generally conducted using rotary percussion drills, although churn drills and down–the–hole drills may also be used. Typically, holes are 7 to 15 cm in diameter. Hole spacing is dependent on the fracturing properties of the rock and the desired bench width, but is typically conducted on patterns of 1.8 m x 1.8 m, 1.8 m x 3.0 m, 2.4 m x 3.0 m or 3.7 m x 3.7 m. Holes are generally drilled to bench height.

Modern blasting techniques rely almost exclusively on AN/FO (ammonium nitrate–fuel oil) as the explosive. Dynamite and other such explosives are rarely used. The AN/FO may be mixed in the hole but is typically mixed in a batching plant on site and transported to the drill site in special trucks. There is a wide variation in the make–up of the mixture due to variations in the integrity of the rock and the desired shattering pattern. It is normal for full bench faces to be blasted in a single shot, and this generally implies one or two shots per week. Many operators rely on contract drillers and blasters, having found such arrangements to be less expensive than employing their own staff in what may be only a part–time operation.

Secondary breaking of rock, if required, is generally conducted by either impact hammer or drop ball. The choice depends on the amount of secondary breaking required and the difficulty of breaking. On occasion secondary blasting may be used for particularly large and/or highly competent blocks. Very large pieces of stone may be reserved for sale as armour stone for shoreline protection or sold to dimension stone producers if the material is of suitable quality.

PRIMARY CRUSHING

Proper sizing of the primary crusher to match the capacity of the bucket or loader is essential for high productivity. The crusher should be able to accommodate the largest–sized stone that the bucket can efficiently handle. This minimizes the chance of oversized rock jamming the crusher and obstructing the flow of material.

The selection of the primary crusher is influenced by the required capacity, the range of stone sizes to be produced and the compressive strength of the rock. Jaw crushers are the oldest type of primary crusher. They may be of the double toggle or dual jaw type, the single toggle or overhead eccentric type, or have two movable jaws. Jaw crushers are generally more compact than gyratory crushers and can be set with wider discharge ends than gyratory crushers. However, for the same size unit the gyratory has over twice the capacity of the jaw crusher. Gyratory crushers are also available in much larger sizes than jaw crushers. Jaw crushers range in capacity up to approximately 600 tonne/hr. and in size from 61 cm x 91 cm to 168 cm x 213 cm and can crush stone down to 7.5 cm to 13 cm. The jaw crusher is typically less expensive to operate than the gyratory for lower capacities.

Gyratory crushers consist of a conical head inside an outer concave bowl, a slow gyratory or eccentric movement of the head compressing the stone against the fixed crushing surface. Gyratory crushers are available with capacities in excess of 300 tonnes per hour and sizes up to 183 cm or larger. The smallest discharge openings range between 9 cm and 23 cm. For equal capacity, the gyratory weighs less and costs less than the jaw crusher, but requires more space, has more restricted discharge openings and generally high maintenance costs. However, it is the unit of choice when high through–put is required.

Impact crushers may also be used. The impact crusher consists of one or two impeller breakers that rotate at speeds of 250 – 1000 rpm. Rock size reduction is caused by the stone hitting the sides of the breaker, other pieces of stone and steel breaker bars inside the crusher chamber. The breaker bars can be adjusted to allow for the production of stone down to 4 cm to 5 cm, thus perhaps eliminating the need for secondary crushing. The crusher tends to produce a cubic–shaped product. Capacities range from 200 to 2,000 tonnes per hour.

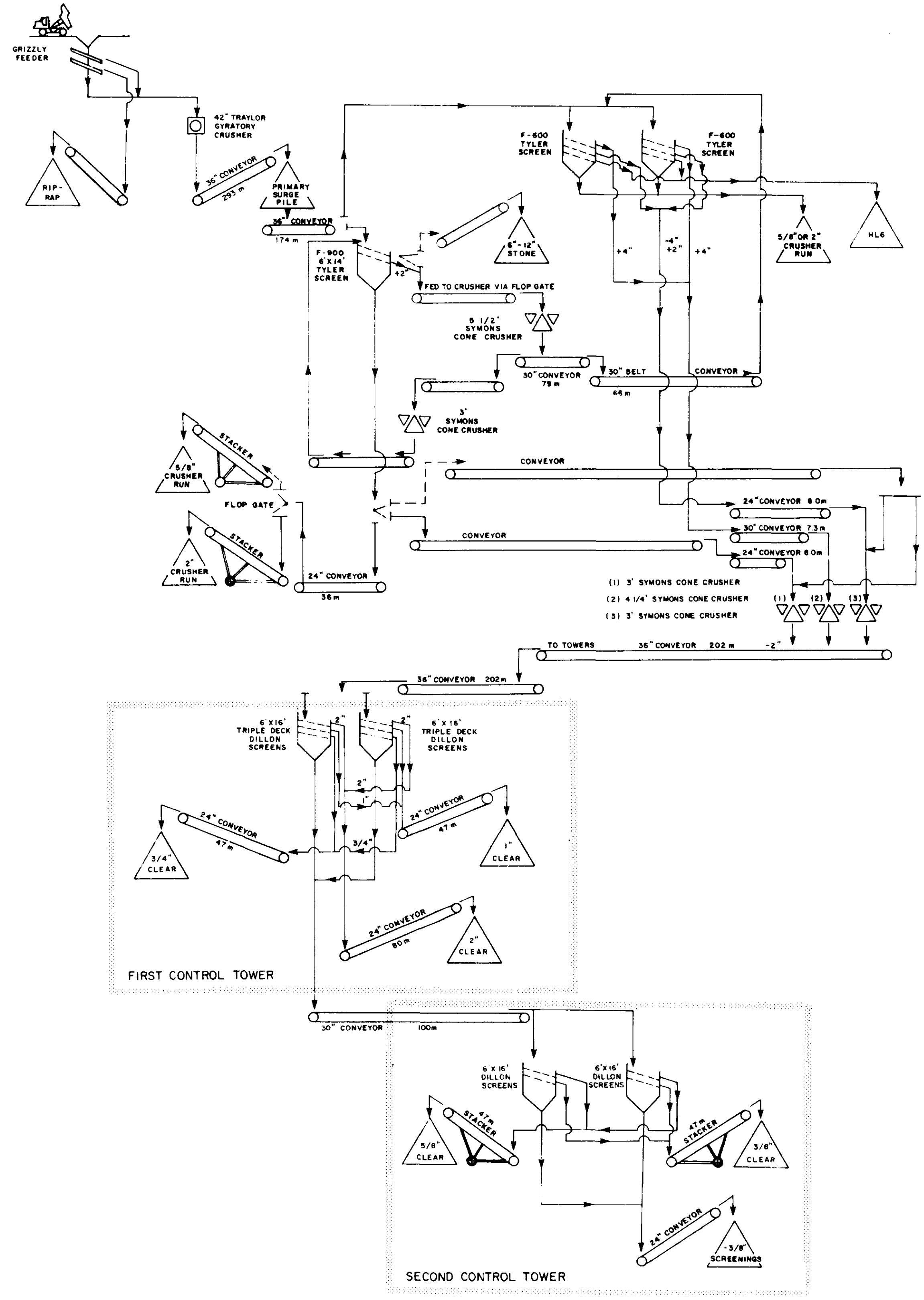


Figure 3.1. FLOW DIAGRAM OF TYPICAL LARGE, MODERN CRUSHED-LIMESTONE PLANT, FEATURING FLEXIBILITY IN SIZES AND GRADATIONS.

SECONDARY CRUSHING

Secondary crushing is employed to reduce material to more salable size distributions. There are a variety of secondary crushers on the market, most of which are smaller, lower capacity, higher speed variations of primary crushers. The most common secondary crushers are hammermills and cone crushers, a type of gyratory crusher. Cone crushers are available which can crush stone to 100% passing 10 mesh at rates up to 1,000 tonnes per hour.

Pulverized stone is processed in either wet or dry grinding circuits using hammer mills, cage mills, roller mills and ball, tube, rod and pebble mills. The choice of mill depends on the type of stone being processed, the degree of fineness desired, and the particle size distribution desired. Details of these mills are to be found in the section on Fillers and Extenders.

CONVEYING AND SCREENING

After crushing, the stone is generally conveyed by belt conveyor to a series of single, double and triple–deck screens which are used to separate products by size range. Vibrating screens are generally employed to prevent clogging. Screen materials vary from punched metal plates to woven wire, rubber or urethane. Urethane screens are enjoying increased use because of their resistance to wear, and their lower tendency to clog with fine particles. Screened product may be conveyed to surge piles for subsequent reclaiming and stockpiling or sale, or to a wash plant.

WASHING

Some quarries have wash plants to remove residual clay, shale, silt and stone dust from the crushed stone. The prevalence of washing has increased in recent years as customers increase their quality requirements for stone. Wash plants may incorporate scrubbing systems, water jets or sprays, or log washers, depending on the degree of washing required and the type of material to be removed. Very elaborate washing systems employing flotation processes are common in Europe. Washed stone is generally dried in rotary driers, a necessary step for some markets such as asphalt aggregate which require bone–dry stone.

STORAGE

Screened and/or washed stone is generally stored in uncovered stockpiles on the ground. Reclaim may be either by underground conveyor, sometimes with product mixing capabilities, or by front–end loader. In some cases the reclaimed product is moved to storage bins which empty directly into waiting trucks or rail cars. Plants may maintain a diverse range of product sizes; typically about 10 size gradations.

ENVIRONMENTAL CONTROL

The crushing, screening and conveying of stone necessarily creates significant amounts of dust. Techniques to reduce dust levels include the use of covered conveyors, water sprays and special surfactant compounds. Road dust is generally controlled by the use of water trucks and the application of calcium chloride solutions.

Waste wash water is generally discharged to settling ponds for subsequent re–use. Make–up water may be derived from special wells or from the surface run–off of the quarry.

In urban and semi–urban areas noise control is a serious concern. Special enclosures are generally required to reduce the noise from crushing and screening operations. Truck noise is often a significant problem and circuitous access roads and berms are often required.

Pit rehabilitation is a requirement for all operations in areas designated under the Pits and Quarries Control Act.. Increasingly stringent standards are adding substantially to quarry costs and thus to the costs of stone. However, operators recognize the value of rehabilitation as a wise corporate practice in light of increasing land use competition, especially in southern Ontario.

STONE SPECIFICATIONS

Specifications for crushed limestone for various uses have been developed based on the use of the material as either coarse or fine aggregate. The most important specifications deal with the use of limestone aggregates as road building materials and as concrete aggregate for building construction.

CLASSIFICATION

Aggregate is defined as coarse if it is retained on a seive that has openings with sides of 4.75 mm (No. 4 mesh). Fine aggregate is the material that passes. Typically, road construction requires 50% coarse and 50% fine aggregates; concrete and concrete products require 55% coarse and 45% fine aggregates. Crushed stone is interchangeable with gravel for many applications but not all. The most important specifications are those of particle size and distribution, and particle shape, although physical and chemical properties are also important.

The gradation of fine aggregate in asphalt and concrete mixes is critical. Specifications permit a fair range in gradation but require a high degree of uniformity in the continuing supply. In concrete, the colour and texture of the finished product is materially affected by the nature of the aggregate, particularly of the fine aggregate.

The proportion of fine material produced in a crushed stone operation depends on several factors, primarily the degree of crushing. Typical crushed limestone plants produce approximately 25% fine aggregate, not all of which is salable. Some plants, due to equipment factors and the physical characteristics of the stone may produce 35% or more fine aggregate. The unsalable proportion of this output can build quickly and create a costly storage problem. If it is never sold, the whole cost of the operation, including the cost of disposal of the unwanted material, must be borne by the revenue from other products.

The gradation and angularity of a typical quarry fine product, while generally resembling sand in its size range and quite consistent in its makeup, does not make its use in concrete or asphalt readily acceptable. Its best use is in base course materials where its nature contributes to compactability. However, problems are encountered when too much extreme fine content impedes the drainage of water from the base.

"Manufactured sand" can be produced by the crushing and grinding of stone. It is a practical method for increasing the proportion of fine aggregate within certain limits. However, the method is highly energy intensive and the product, while satisfactory for some uses such as mass concrete, is unsuitable for many uses due to its harsh angular shape. The most significant difficulty is caused by the large amount of extreme fine sizes, below 200 mesh, that is produced. The amount of this material can exceed 20% and its disposal is costly and difficult.

In fine aggregates the gradation is usually the most important quality factor. If that is controlled, the material is usually acceptable.

In coarse aggregate, the desired size can generally be produced by the degree of crushing, but many physical and chemical specifications must also be satisfied. Various deleterious materials such as chert, shale or siltstone may be present in a quarry face which may restrict or totally prevent the use of such materials. Specifications that do not permit the use of lower quality material result in higher prices. However, the cost of aggregate is usually such a small part of the total construction cost that compromising the expected life of the finished product by using cheaper materials is rarely a good practice.

CONSTRUCTION AGGREGATE SPECIFICATIONS

Considerations in the assessment of aggregate for construction purposes include the following:

☐ Strength and hardness

principally related to density, porosity, and homogeneity of a deposit

☐ Cleanness

free from dust and fines such as clay, silt and soil

☐ Particle shape

the particles should be as cubic shaped as possible with no laminations or incipient cracks. Flat elongate particles are not desirable as they exhibit poor interlocking and contribute to excessive voids.

☐ Chemical soundness

a minimum content of soluble minerals, impurities such as sulphates and susceptibility to alkali–reactivity – particularly important where aggregate is used in concrete

In Ontario, the use of limestone aggregate in road construction is governed by Ontario Provincial Standard Specifications (OPSS) developed by the Ministry of Transportation. The following specifications cover the main aggregate applications:

1001 – aggregates – general, fine and coarse
1002 – aggregates – concrete
1003 – aggregates – hot mix asphaltic concrete
1004 – aggregates – miscellaneous
1010 – aggregates – Granular A, B, and M and select subgrade material

These specifications are supplemented by specified test procedures and specifications developed by the Canadian General Standards Board (CGSB), the Canadian Standards Association (CSA), and the American Society for Testing and Materials (ASTM) for special situations. The OPSS prescriptions for aggregates are summarized in Table 3.1.

The most significant factors in the specifications relate to the following:

- gradation of fine and coarse aggregate
- percent of flat and elongate particles in the batch
- physical test requirements such as Los Angeles Abrasion, Magnesium Sulphate Soundness, Petrographic Number, Absorption and Plasticity Index
- chemical requirements such as alkali limits for alkali–silica and alkali–carbonate reactive rock

An additional criteria which is being developed relates to the skid resistance of aggregate. The Ministry of Transportation uses a measure of the ability of an aggregate to retain or develop microtexture called the Polished Stone Value (PSV) test. Wear resistance of the aggregate is measured by the Aggregate Abrasion Value (AAV).

Table 3.2 illustrates a typical section through a road. The thickness and composition of each layer will be dependent on the level of traffic and the nature of the traffic expected for the road, as well as the nature of the ground conditions and the climatic conditions.

Crushed limestone aggregate is used in road base below the asphaltic driving course. A well graded material results in greater interlock between particles thereby increasing the frictional strength and load bearing capacity of the road. Limestone particles must be resistant to freeze–thaw action. This avoids the generation of excess fines which results in decreased permeability and strength. Physical and gradation requirements for these materials are covered by OPSS 1010 and OPSS 1001 and refer to Granular A, B, M, and select subgrade material.

Table 3.1. ONTARIO PROVINCIAL STANDARD SPECIFICATIONS FOR ROAD CONSTRUCTION AGGREGATE.

OPSS 1002 - SPECIFICATIONS FOR CONCRETE AGGREGATES. Gradation Requirements For Fine Aggregates.*

MTO Sieve Designation	Percentage Passing
9.5 mm	100
4.75 mm	95-100
2.36 mm	80-100
1.18 mm	50-85
600 µm	25-60
300 µm	5-30
150 µm	0-10
75 µm	0-3 Natural Sand 0-6 Manufactured Sand

**MTO Lab Test No. LS 602.*

Gradation Requirements - Coarse Aggregates For Structural Concrete, Sidewalks, Curb & Gutter.*

Nominal Maximum Size	19.0 mm	13.2 mm	9.5 mm**
MTO Sieve Designation	**Percentage Passing**		
53.0 mm			
37.5 mm			
26.5 mm	100		
22.4 mm	-		
19.0 mm	90-100	100	
16.0 mm	65-90	-	
13.2 mm	-	90-100	100
9.5 mm	20-55	40-70	85-100
4.75 mm	0-10	0-15	10-30

**MTO Lab Test No. LS 602*

***Not more than 10% of 9.5 mm nominal maximum size material shall pass the 2.36 sieve.*

Gradation Requirements - Coarse Aggregates For Concrete Pavement Or Base.*

Nominal Maximum Size	37.5 mm	19 mm	Combined
MTO Sieve Designation	**Percentage Passing**		
53.0 mm	100	-	100
37.5 mm	90-100	-	95-100
26.5 mm	20-55	100	-
19.0 mm	0-15	90-100	35-70
13.2 mm	-	-	-
9.5 mm	0-5	20-55	10-30
4.75 mm	-	0-10	0-5

**MTO Lab Test No. LS 602.*

OPSS 1003 - SPECIFICATIONS FOR HOT MIX ASPHALTIC CONCRETE. Gradation Requirements For Total Fine Aggregate.*

MTO Sieve Designation	Percentage Passing HL 1 & 3	HL 2	HL 4 & 8
9.5 mm	100	100	100
4.75 mm	90-100	85-100	85-100
2.36 mm	70-100	70-90	60-100
1.18 mm	50-90	50-75	34-90
600 µm	30-70	30-55	17-70
300 µm	15-40	15-35	9-40
150 µm	5-15	5-15	3-15
75 µm	0-5	3-8	0-7

**MTO Lab Test No. LS 602.*

Gradation Requirements For Coarse Aggregate.*

MTO Sieve Designation	Percentage Passing HL 1 & 3	HL 4	HL 8
26.5 mm	-	-	100
19.0 mm	-	100	90-100
16.0 mm	100	96-100	65-90
13.2 mm	96-100	67-86	-
9.5 mm	50-73	29-52	20-55
4.75 mm	0-10	0-10	0-10

**MTO Lab Test No. LS 602.*

Physical Requirements For Coarse Aggregate.

MTO Lab Test	MTO Lab Test #	HL Type 1	3	4	8
Los Angeles Abrasion, % Maximum Loss	LS 603	15	35	35	35
Magnesium Sulphate Soundness, 5 cycles % Maximum Loss	LS 606	5	12	12	15
Absorption, % Maximum	LS 604	1.0	1.75	2.0	2.0
Petrographic Number, HL Max.	LS 609	100	135	160	160
Loss by Washing (Passing 75 µm Sieve), % Maximum	LS 601	*1.0	*1.3	*1.3	*1.3
Flat and Elongated Particles, % Maximum	LS 608	20	20	20	20
Percentage Crushed % Maximum	LS 607	100	60	60	60

**When quarried rock is used as a source of coarse aggregate, a maximum of 2 percent passing the 75 µm sieve shall be permitted.*

Table 3.1. CONTINUED.
OPSS 1002 - SPECIFICATIONS FOR CONCRETE AGGREGATES. Physical Requirements - Coarse Aggregates.

		Acceptance Requirement	
MTO Lab Test	MTO Lab Test Number	Concrete Pavement	Concrete Structures Sidewalk, Curb and Gutter, and Base
Material finer than 75 µm Sieve, by washing, % Maximum,	LS 601		
- for gravel		1	1
- for crushed rock		2	2
Los Angeles Abrasion, % Maximum Loss	LS 603	35	50
Absorption, % Maximum	LS 605	2	2
Magnesium Sulphate Soundness, 5 cycles, % Maximum Loss	LS 606	12	12
Flat and Elongated Particles, % Maximum	LS 608	20	20
Petrographic Number, Maximum	LS 609	125	140

OPSS 1010 - SPECIFICATIONS FOR ROAD BASE AGGREGATES. Physical Requirements.

Physical Test	Granular A	Granular B		Granular M	Select Subgrade Material	MTO Lab Test Number
		Type I	Type II			
Los Angeles Abrasion, Loss % Maximum	60	N/A	N/A	60	N/A	LS 603
Petrographic No., Granular, Maximum	200	*250	250	200	*250	LS 609
Plasticity Index	0	0	0	0	0	LS 704
Percentagae Crushed Minimum	50	N/A	100	50	N/A	LS 607

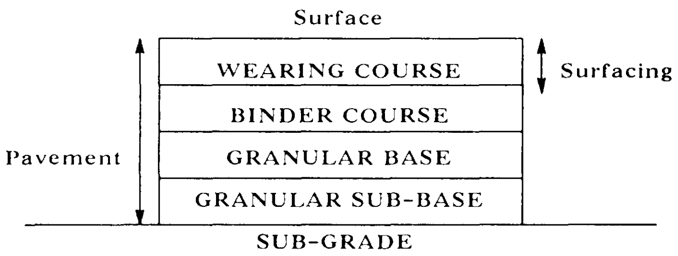
**The Petrographic No. requirements will be waived if the material has more than 80% passing the 4.75 mm sieve.*

Gradation Requirements***.

MTO Sieve Designation	Percentage Passing by Mass				
	Granular A	Granular B		Granular M	Select Subgrade Material
		Type I****	Type II****		
150 mm	N/A	100	100	N/A	100
37.5 mm	N/A	N/A	N/A	N/A	N/A
26.5 mm	100	50-100	50-100	N/A	50-100
19 mm	85-100 *(87-100)	N/A	N/A	100	N/A
13.2 mm	65-90 *(75-95)	N/A	N/A	75-95	N/A
9.5 mm	50-73 *(60-83)	N/A	N/A	55-80	N/A
4.75 mm	35-55 *(40-60)	20-100	20-55	35-55	20-100
1.18 mm	15-40	10-100	10-40	15-40	10-100
300 µm	5-22	2-65	5-22	5-22	5-95
150 µm	N/A	N/A	N/A	N/A	2-65
75 µm	2-8 **(2-10)	0-8 **(0-10)	0-10	2-8 **(2-10)	0-25

(*) Where the aggregate is obtained from an iron blast furnace slag source.
(**) Where the aggregate is obtained from a quarry or slag source.
(***) MTO Lab Test No. LS 602.
(****) When Granular B is used for granular backfill for pipe subdrains, 100% of the material shall pass the 37.5 mm sieve.

Table 3.2. A TYPICAL CROSS-SECTION THROUGH AN ASPHALT ROAD.



Wearing course	A stable weather resistant running surface which has to withstand the abrasive forces of traffic and provide a degree of skid resistance
Binder course	Provides strength to the pavement while providing an even, well regulated surface for the wearing course.
Granular base	The load-bearing and strengthening component of the pavement. Protects wearing and binder course from frost action.
Granular sub-base	Lowest layer of the pavement. Acts as the principal foundation for the subsequent road profile, and protects overlying pavement structure from frost.
Sub-grade	Usually natural soil, exposed rock formation, or rock fill.

Modified after Power, 1985.

Aggregates used in concrete pavement or base are governed by OPSS 1002. Coarse aggregate for this application has a nominal minimum size of 4.75 mm. Fine aggregate has a nominal maximum size of 9.5 mm and a nominal minimum size of 150 microns. The physical requirements for coarse aggregate require a maximum Los Angeles Abrasion and Impact Loss of 35% and a maximum Magnesium Sulphate Soundness Loss of 12%. The percent of flat and elongate particles should not exceed 20%.

Aggregate for use in asphaltic mixes for road surfaces must conform to the requirements of OPSS 1003. These aggregates are referred to as HL1, 2, 3, 4 and 8. Secondary highways with less than 2,500 AADT/lane (average annual daily traffic/lane) use HL3 (hot laid) and HL4. HL3 aggregates have a maximum size of 13.3 mm, allowing a minimum mat thickess of about 25 mm. HL4 aggregates have a maximum size of 16 mm, allowing a minimum mat thickness of about 30 mm, but normally 44 mm.

On highways with more than 2,500 AADT/lane the types of asphalt aggregates used are designated HL1, DFC (dense friction coarse) and OFC (open friction coarse). HL1 asphalt has the same gradation as HL3, only the nature of the stone is different. DFC has angular fine aggregate to increase stability. OFC is an open graded mix, allowing internal drainage through the matrix rather than over the pavement surface. It is used on very high volume, urban highways because of its low tire noise characteristics.

Aggregates for HL3 and HL4 have no requirements respecting their frictional properties, except for northern Ontario. In this region, most of the 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 in northern Ontario become accustomed to the good friction supplied by local aggregates and do not adjust their driving habits to accommodate poorer performing materials. As a result, in many parts of northern Ontario the use of aggregates containing more than 40% carbonates is prohibited.

The selection of the coarse aggregate for HL1, DFC and OFC pavements is based on the actual performance of the aggregate in test sites. 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. Table 3.3 illustrates the principal types and properties of surface coarse asphalt mixes used in Ontario.

The skid resistance of a road surface is determined by both its macrotexture; i.e., the projection of coarse aggregate particles above the matrix, and its microtexture, i.e., the surface texture of the particle. Good macrotexture is required to break the water film on the road surface at high speed and to provide bulk drainage. It is measured by the aggregate's ability to withstand abrasion, the Aggregate Abrasion Value (AAV) test. A good microtexture is needed at all driving speeds to penetrate the thin water film and come in contact with the tire. This is measured by the Polished Stone Value (PSV) test. Low AAV values and a minimum PSV of 50 have been reported as being desirable for high density roads in Ontario. In the United Kingdom high traffic volume road surfaces are constructed with aggregates having a maximum AAV of 12 and a minimum PSV of 55–65. Very few, if any, carbonate materials are able to pass these requirements, except for dolomitic sandstone (from the March Formation), which has been found to be the best, naturally occurring skid-resistant material in Ontario as determined by the PSV test. This rock is found in eastern Ontario. This material also appears to provide the

Table 3.3. PRINCIPAL TYPES OF SURFACE COURSE ASPHALT MIX USED IN ONTARIO.

Mix Type	Maximum Stone Size	Normal Stone Content %	Fine Aggregate Type	Annual Average Daily Traffic
HL4	16.0 mm	45-50	Natural sand	<2500
HL3	13.2 mm	45-50	Natural sand	<2500
HL1	13.2 mm	45-55	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 expressways)

Modified after Rogers, 1983.

lowest cost per tonne on a laid-down basis of any of the better skid-resistant materials, as shown in Figure 3.2.

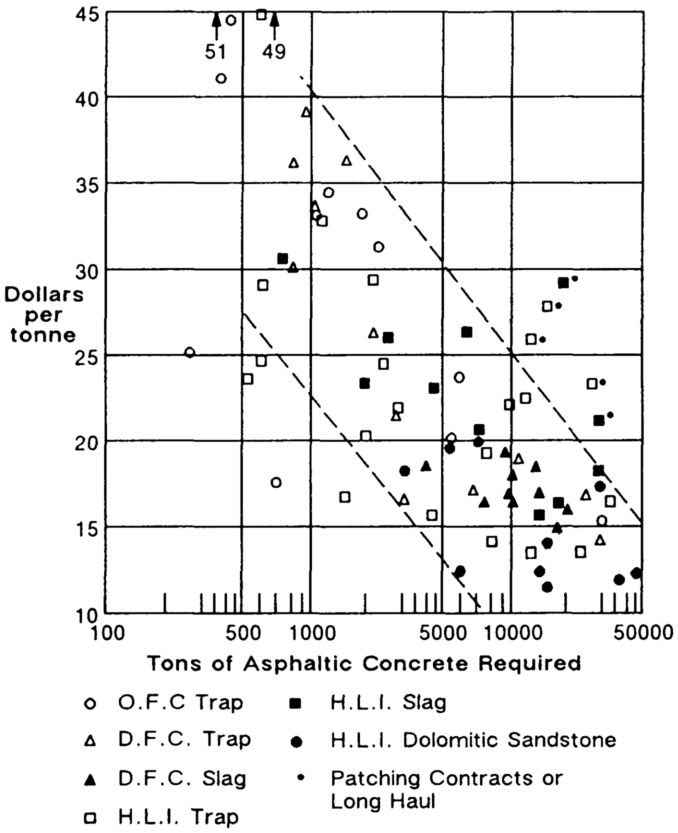


Figure 3.2. COST PER TON OF MIX PLOTTED AGAINST QUANITITY FOR 1979-1981 CONTRACTS. *Source: Rogers, 1983.*

CONCRETE AGGREGATE

Aggregates for use in concrete, exclusive of that for road building, are governed by OPSS 1002, CSA specification CAN3-A23.1-M77 and/or ASTM specification C33-82. The desirable properties of concrete aggregates are that they be essentially clean, and uncoated, consisting of properly shaped particles of strong, durable material. When incorporated in concrete, they should satisfactorily resist changes such as cracking, swelling, softening, leaching, or chemical alteration, and should not contain contaminating substances which might contribute to the deterioration, loss in strength, or unsightly appearance of the concrete.

Many carbonate rocks produce good quality aggregates. However, grain size or the presence of other materials can affect the overall quality. Carbonate rocks can have very porous structures due to leaching of soluble minerals (evaporites) or the weathering out of argillaceous impurities. They can also contain fossils which may increase the porosity of the rock.

Extremely fine grained limestones (lithographic limestones) can give reduced strength in concrete due to poor bond strength between the rock and cement paste.

The evaporite minerals gypsum and anhydrite can occur in calcareous rocks as nodules. Gypsum can delay the setting time of concrete and can also cause concrete expansion.

Anhydrite absorbs water readily causing volume increases as well as the formation of secondary gypsum. Gypsum nodules are found in some quarries within the Niagara Escarpment between Queenston and Hamilton.

Coarse crystalline marbles are weak when subject to stress. This is a result of poor intergranular bonds. Ultimately, the compressive and flexural strengths of a concrete containing these aggregate types will be reduced.

Some marbles may also have peculiar and uneven rates of thermal expansion and contraction which can make them incompatible with the cement paste in a concrete at low temperatures. This effect can lead to rapid deterioration of a concrete.

ALKALI-AGGREGATE REACTIVITY

Certain Ontario carbonate aggregates react with the alkalies of cement (Na_2O and K_2O) which produces an undesirable expansion leading to the cracking and deterioration of concrete. Cracking also creates channels for water movement in the concrete leading to an increase in saturation and reduced freeze–thaw durability. The higher the alkali content of the cement and the higher the cement content of the concrete, the greater the rate of expansion and cracking. It is possible to use special low alkali cement or other corrective measures but it is better to use non reactive aggregates. It is most important that potentially reactive aggregates are recognized, and are properly investigated before they are used in concrete.

These reactions can be grouped into two types with Ontario limestones (1) alkali–carbonate, and (2) alkali–silica.

Alkali–Carbonate Reaction

Rocks of the Gull River Formation (Lake Ontario Basin and Ottawa/St. Lawrence Lowlands) are alkali–carbonate reactive. They are comprised of beds of fine grained dolomitic limestone with a significant clay mineral content.

This reaction only occurs with coarse aggregate from quarries. Only certain beds or levels within the quarry may be reactive. A number of different techniques may be used to identify the potential reactivity of these materials, of which the simplest method is the Quick Chemical Test (MTO LS–615). This test measures the relative amount of dolomite and clay content within the rock. This test can be completed in a few days. The results allow the immediate acceptance of most aggregates.

If an aggregate fails the Quick Chemical Test, more lengthy testing is called for, specifically, the Concrete Prism Expansion Test (CAN3– A23.2–14A, 1986). This test usually takes one year before a final result is obtained.

Other techniques are also used, such as the Rock Cylinder Expansion Test (ASTM C586) or detailed examination under the microscope. These techniques are usually used in the exploration of new quarries and are not normally used for accepting aggregate stockpiles.

Alkali–Silica Reaction

The main alkali–silica reactive mineral found in Ontario limestones is chalcedony (SiO_2). Rocks of the Bobcaygeon Formation in the Lake Ontario Basin and Ottawa/St. Lawrence Lowlands are known to be alkali–silica reactive due to the presence of small amounts of chalcedony.

The Mortar Bar Test (ASTM C227) is employed with suspect aggregates. Results are usually obtained after 3 or 6 months. The Quick Chemical Test (ASTM C289) is not practical when significant amounts of carbonate materials are present so is not useful for evaluating the alkali–silica reactivity of these limestones.

The Ontario Ministry of Transportation has compiled information and performed research on the alkali reactivity of concrete aggregates. Several limited distribution reports have been published on the topic. For more detailed information, the reader is referred to the Soils and Aggregates Section of the Engineering Materials Office, Ministry of Transportation, Downsview, Ontario.

RAILWAY BALLAST

Specifications for railway ballast are generally established by the American Railway Engineering Association (AREA). The AREA specifies material in the size range 64–19 mm, although 5% to 10% of the ballast may be as small as 9.5 mm. The ballast must have an abrasive resistance value equal to or less than 40% based on the Los Angeles Abrasion test.

The increased use of concrete sleepers may force a gradual change from the use of limestone as ballast. Concrete sleepers reduce the relative resistance of the ballast to point loading by concentrating the vertical and horizontal forces on individual units. This creates too heavy a load on the aggregate resulting in the production of excess fines and a gradual rounding of the aggregate. Reduced particle interlock because of rounding, and the generation of fines which trap water, will result in decreased strength in the ballast and increase the incidence of frost heaving. Preferable materials in such cases are granitic rocks, trap rock, and blast furnace slag.

OTHER USES

Specifications for other uses of limestone aggregate such as roofing granules, stucco dash, poultry grit, etc., are generally set by ASTM. Roofing granules for built–up roofs are generally in the size range of 19.2 to 2.4 mm. Poultry grit varies from 9.5 mm coarse material to 3.2 mm fine aggregate. Crushed limestone for use in flue–gas desulphurization is generally specified to be 85% passing 325 mesh. Filter beds for sewage treatment plants use stone of 3.8 to 6.35 cm size (or 5.1–7.6 cm for high rate filters) with very low tolerances for plus or minus size material. Soundness requirements are very strict and low moisture absorption is required.

Cement

The term "cement" most commonly refers to hydraulic cement, especially portland cement. Hydraulic cements have the property of hardening under water and are the chief binding agents for concrete and masonry. Portland cement, originally patented by Joseph Aspdin in England in 1824, is the predominant variety of hydraulic cement, accounting for about 95% of all cement produced in North America; slag cement and masonry cement used for stucco and mortar account for most of the balance.

Hydraulic cements were originally discovered in ancient times. The Egyptians calcined an impure gypsum containing calcium carbonate to obtain a cementing material for use in the construction of the Great Pyramid about 2,600 B.C. The Greeks and the Romans pulverized volcanic material and mixed it with sand and lime to make a mortar which exhibited great strength and durability under water.

The art of producing cement was lost during the decline of the Roman Empire. In 1756, John Smeaton rediscovered the lost art when he found that clay, when contained in or added to limestone and the volcanic material pozzolana, produced a hydraulic cement. Joseph Parker, in 1796, patented a hydraulic cement produced from limestone containing nodules of clay, and pulverized old bricks and tiles. This material was called Roman cement. Finally, in 1824, Joseph Aspdin patented a process for the production of a hydraulic cement based on the mixing and calcination of clay, sand, and limestone. This material was called portland cement because the set material resembled the building stone quarried from the Isle of Portland in England.

In North America, testing of limestones for use as mortar in the construction of the Erie Canal led to the discovery of an argillaceous limestone in Madison County, N.Y. This material was called cement rock because it contained raw materials in proportions required for the production of "natural cement". Rapid expansion of the system of canals in eastern North America resulted in an expansion of the natural cement industry. In about 1850, however, concrete became a major building material and the superior qualities of portland cement resulted in it becoming an important import into North America.

In 1871, David Taylor of Pennsylvania patented a cement equal to the imported portland cement. The material was produced from argillo–magnesium and argillo–calcareous limestone burned at a high temperature to a state of vitrification. The ground clinker made an excellent cement. Portland type cement production increased rapidly in subsequent years and gradually displaced natural cement production. By 1920, most of the natural cement plants in North America had been closed or converted to portland cement production.

The first cement produced in Ontario was derived from natural cement rock. Production probably began in the early 1840s at Thorold at the quarry of John Battle, which was opened in 1841. This quarry was later called the Thorold Hydraulic Cement Works and operated until 1891. During the period from about 1880 to 1907 there were five natural cement producers in the province. In addition to the Thorold operation, natural hydraulic cement was produced by Rathbun and Company at its plant at Strathcona (Napanee Mills) beginning in 1880; by the Toronto Lime Company at Limehouse; by Queenston Cement Works at Queenston beginning in 1881; and by F. Schwendiman in Barton Township near Hamilton beginning in 1894.

Portland cement production based on marl began in 1886 at Strathcona, by Rathbun and Company. Marl–derived portland cement flourished from 1886 to 1919, with 14 plants being active. Most of the plants were located in Grey County (7), with other plants being located in Hastings, Lennox & Addington, Victoria, Peterborough, Perth, and Dufferin counties.

The first limestone–based portland cement plant in Ontario was built in 1905 by the Belleville Portland Cement Company at Point Anne near Belleville. In 1908, Lehigh Portland Cement Co. also built a plant at Point Anne. This was followed by plants at Port Colborne (1908, Canadian Portland Cement), St. Marys (1912, St. Marys Cement), Hanover (1920, Hanover Portland Cement), and Lakefield (1927, Canada Cement Company).

In 1909 severe competition and over capacity in the cement industry prompted the formation of the Canada Cement Company. This company was formed as the result of a merger of four of the marl cement producers and three of the limestone portland cement producers, plus two Quebec–based cement plants. Competition in the Ontario cement industry remained limited until the mid–1950s, when several new producers such as Lake Ontario Cement and St. Lawrence Cement Company entered the market.

Current North American clinker production capacity is approximately 136.5 million tonnes, distributed 63% (86.0 million tonnes) in the U.S., 12% (16.4 million tonnes) in Canada, 21% (28.7 million tonnes) in Mexico, and 4% (5.4 million tonnes) elsewhere.

TYPES OF CEMENTS

Portland cement is produced by heating a properly portioned mixture of finely ground raw materials containing calcium carbonate, silica, alumina and usually iron oxide, to a sintering temperature of about 1,480°C in a kiln. Partial fusion occurs at this temperature, resulting in a product called clinker. Chemically, clinker comprises four main phases of various proportions of tricalcium silicate ($3CaO.SiO_2$, abbreviated C3S), dicalcium silicate ($2CaO.SiO_2$, or C2S), tricalcium aluminate ($3CaO.Al_2O_3$, or C3A), tetracalcium aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$, or C4AF), minor amounts of calcium sulphate ($CaSO_4$), and usually, but not necessarily, magnesia (MgO), lime (CaO), and various alkalis, depending on raw materials used. The clinker is ground to a fine powder with a small amount, 2% to 5%, of calcium sulphate, usually gypsum or anhydrite, to make portland cement.

There are several varieties of portland cement which are classified mostly on the proportions of C3S, C2S, and C3A in the cement. The five most common types of portland cement are:

☐ Normal Portland – Type 10 (Canada); Type I (U.S.)

☐ High Early Strength Portland – Type 30 (Canada); Type III (U.S.)

similar to normal portland, but is normally ground finer and slightly altered in composition

☐ Sulphate Resisting Portland – Type 50 (Canada); Type V (U.S.)

composition is modified to provide increased resistance to sulphate–bearing waters

☐ Moderate Portland Cement – Type 20 (Canada); Type II (U.S.)

provides moderate sulphate resistance and moderate heat of hydration

☐ Low–Heat–of–Hydration Portland – Type 40 (Canada); Type IV (U.S.)

chemical composition is adjusted to reduce the heat of hydration and provide a slower rate of strength development than normal portland

Moderate portland and low–heat–of–hydration portland cements are for use in concrete to be poured in large volumes such as in dam construction.

Portland cements are also available in an air–entrainment formulation in which a small amount of an air–entrainment agent has been added during grinding. The agent produces minute, well–distributed, completely separated air voids that protect the concrete from freeze–thaw damage. The agents used are:

- alkali salts of wood resins, soluble in coal tar hydrocarbons (i.e. benzene, toluene, etc.) and insoluble in petroleum solvents
- synthetic detergents of the alkyl–aryl sulphonate type, the alkyl group being derived from a petroleum distillate and the aryl group usually being a sulphonated benzene or naphthalene ring. The usual product is the sodium salt
- calcium lignosulphonate from sulphite pulping
- sodium salts of cyclo–paraffin carboxylic acids such as naphthenic acid
- calcium salts of glues and other proteins obtained in the tanning process
- alkali or triethanolamine salts of fatty acids derived from fats and vegetable oils and from the alkali pulping process
- triethanolamine salts of sulphonated aromatic hydrocarbons derived from petroleum.

White cement is an ordinary portland cement made from iron–free materials so that its colour is white instead of grey. The clinker is burned in a reducing flame in the kiln and rapidly quenched in a water spray to keep any iron in the ferrous state to avoid coloration by ferric iron compounds. The clinker is ground with high purity gypsum using ceramic balls and liners in grinding mills, although there is a trend to the use of high–chromium alloys for use as liners and grinding media. White cement is used in decorative concrete including terrazzo, highway lane markers, and architectural concrete.

Masonry cement is a hydraulic cement for use in mortars for masonry construction. It contains one or more of the following materials: portland cement, portland–pozzolan cement, slag cement, or hydraulic lime, usually with hydrated lime, limestone, chalk, calcareous shale, talc, slag, or clay interground for plasticity. The material is marketed under the following proprietary names:

- mortar cement
- mortar mix
- mason's cement
- brick cement
- masonry cement.

Portland–blast furnace slag cement is an interground mixture of portland cement clinker and granulated blast furnace slag in which the amount of the slag constituent is between 25% and 70% of the total weight of the blended cement. It is used for general concrete construction.

Portland–pozzolan cement is an intimate and uniform blend of portland cement or portland–blast furnace slag cement and fine pozzolan. The pozzolan constituent ranges from 15% to 40% of the total weight of the blended cement and is a finely divided aluminous and siliceous material that reacts with calcium hydroxide in the presence of water to form a material with cement–like properties. Fly ash from coal fired power plants is a typical example. Natural pozzolanic materials include some diatomaceous earths, opaline cherts and shales, tuffs, volcanic ash, and pumices.

Slag cement is a finely divided material consisting of an intimate and uniform blend of granulated blast furnace slag and hydrated lime in which the slag constituent is at least 70% of the total weight of the blended cement.

Oil–well cement is used to seal oil and gas wells at pressure up to 18,000 psi and temperatures up to 180°C. The cements are required to remain fluid for up to 4 hours and then to set rapidly. Setting time is controlled by reducing C3A to nearly zero or adding to portland cement some retarder such as starches or cellulose products, sugars, and acids or salts of acids containing one or more hydroxyl groups.

Expansive cement is a hydraulic cement that expands slightly on hardening, or has no net shrinkage on subsequent air–drying. Three types of expansive cements are recognized in the American Society for Testing and Materials (ASTM) specifications, all of which depend upon the formation of calcium sulphoaluminate hydrate to cause expansion equal to or greater than shrinkage that would normally occur during the hardening process.

Set–regulated cement is a hydraulic cement where the setting time can be controlled from 1 to 10 minutes and very high early strengths develop. The cement contains from 1 to 30 weight percent of $11CaO.7Al_2O_3.CaF_2$. Slip–formed structures, highway repairs, underwater patching, and manufacture of pre–stressed, precast forms are principal applications.

Aluminous cement, also known as high–alumina cement, calcium aluminate cement, or "Ciment Fondu" is manufactured by heating until molten, or by sintering, a mixture of high–purity bauxite and limestone with a very low silica and magnesium content. The product is cooled and finely ground. Special applications of aluminous cement are based on its rapid–hardening qualities, resistance to sulphate action, and refractory properties when used as "castable refractories" and mortars for furnaces and kilns. The material is black in colour.

Specifications for portland cements used in Canada are published by the Canadian Standards Association (CAN 3–A5–M83). Masonry cement used in Canada should conform to the CAN 3–A8–M83 specification. Blended hydraulic cements are covered by CAN 3–A362–M83. Cement types manufactured in Canada but not covered by the CSA standards generally meet the appropriate specifications of the ASTM. A comparison of Canadian and U.S. cement specifications is provided in Table 3.4. It will be noticed that Canadian specifications allow for a larger percentage of alkali materials in the cement than do U.S. specifications. This difference in specifications has an impact on the operations and market opportunities available to some of the Ontario cement manufacturers.

Cembureau, the European Cement Association, has published Cement Standards of the World – Portland Cement and its Derivatives, in which standards are compared. Cembureau also publishes the World Cement Directory, which lists production capacities by country and by company.

CEMENT MANUFACTURE - MATERIALS

Portland cement is prepared by igniting a mixture of raw materials, one of which is mainly composed of calcium carbonate and the other of aluminum silicates. The most typical materials answering this description are limestone and clay, both of which occur in nature in a great number of varieties. In Canada limestone represents about 84% of the total raw material requirement, the balance being comprised of clay, shale, gypsum, sand or silica, and iron oxide.

Limestone for cement use is obtained from sedimentary formations of marine origin from virtually every geologic age. Argillaceous limestone, often called cement rock, and containing ingredients for cement manufacture in approximately the required amount, is extensively used in Ontario. The maximum magnesium oxide (MgO) allowed in portland cement is 5% in both Canada and the United States.

Noncalcareous materials necessary for manufacturing clinker are silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). Many limestone deposits contain chert, a form of silica, and some contain iron minerals. Sand, quartzite, and sandstones from sedimentary deposits are used to maintain the proper silica ratio, but most of the silica is added in the form of aluminum silicates in clay and shale. Iron ore and mill scale are the predominant sources of iron oxide. Fly ash is being increasingly used as a substitute argillaceous raw material. Blast furnace slag is utilized for both the silica and alumina content and as a source of iron oxide.

In addition to the raw materials used for making clinker, calcium sulphate ($CaSO_4$) in the form of gypsum or anhydrite, is added during the grinding of clinker in quantities up to 5%, to impart set–retardant properties to the finished cement.

Table 3.5 provides analyses of typical cement raw materials. Table 3.6 shows the distribution of cement raw materials used in Canada and the United States. It is assumed that Ontario cement manufacturers employ a mix of raw materials similar to that used in the rest of Canada in the production of their products.

CEMENT MANUFACTURE - TECHNOLOGY

EXPLORATION AND DEVELOPMENT

The relative abundance of limestone and other calcareous materials, shales, and clays narrows the prospecting and exploration work mostly to delineating the size and chemical uniformity of the deposits. Portland cement cannot contain more than 5% MgO as larger amounts promote the formation of periclase, which expands and

Table 3.4a. COMPARISON OF CEMENT SPECIFICATIONS.

	Canada					United States							
	Type					Type							
Factor	10	20	30	40	50	I	Ia	II	IIa	III	IIIa	IV	V
Chemical requirements													
SiO_2, min., %	-	-	-	-	-	-		20.0		-		-	-
Al_2O_3, max., %	-	-	-	-	-	-		6.0		-		-	-
Fe_2O_3, max., %	-	-	-	-	-	-		6.0		-		-	-
MgO, max., %	5.0	5.0	5.0	5.0	5.0	6.0		6.0		6.0		6.0	6.0
SO_3, max., %													
when C_3A <7.5%	3.0	3.0	3.5	2.5	2.5	3.0		3.0		3.5		2.3	2.3
when C_3A >7.5%	3.5	-	4.5	-	-	3.5		-		4.5		-	-
C_3A, max., %	-	7.5	-	5.5	3.5	-		8.0		15		7	5
C_3S, max., %	-	-	-	-	-	-		-		-		35	-
$C_4AF + 2(C_3A)$	-	-	-	-	-	-		-		-		-	25
L.O.I., max., %	3.0	3.0	3.0	3.0	3.0	3.0		3.0		3.0		2.5	3.0
Insoluble residue, max., %	1.0	0.7	0.7	0.7	0.7	0.75		0.75		0.75		0.75	0.75
Optional chemical requirements													
C_3A, max., %										8[1], 5[2]			
$C_3S + C_3A$, max., %								58[3]					
Alkalis (Na_2O + 0.658 K_2O), max., % (for low alkali cement)						0.60		0.60		0.60		0.60	0.60

[1]For moderate sulfate resistance [2]For high sulfate resistance [3]For moderate heat of hydration
Note: C_3A limit for SO_3 in U.S. is 8.0%
Source: Canadian Standards Association and ASTM

Table 3.4b. COMPARISON OF CEMENT SPECIFICATIONS.

	Canada					United States							
	Type					Type							
Factor	10	20	30	40	50	I	Ia	II	IIa	III	IIIa	IV	V
Physical requirements													
Air content of mortar, min./max. %	-	-	-	-	-	-/12	16/22	-/12	16/22	-/12	16/22	-/12	-/12
Fineness,													
Specific surface (m^2/kg)[1]						280		280		280		280	280
% passing 45 micron sieve, min.	72	72	-	-	72								
Autoclave expansion, max., %	1.0	1.0	1.0	1.0	1.0	0.80		0.80		0.80		0.80	0.80
Compressive strength (MPa) at: 1 day	-	-	12.5	-	-	-	-	-	-	12.4	10.0	-	-
3 days	12.5	10.0	22.0	8.5	10.5	12.4	10.0	10.3	8.3	24.1	19.3	-	8.3
7 days[2]	18.0	16.0	-	-	16.0	19.3	15.5	17.2	13.8	-	-	6.9	15.2
28 days[2]	26.5	26.5	-	25.0	26.5	27.6	22.1	27.6	22.1	-	-	17.2	20.7
91 days	-	-	-	33.0	-	-	-	-	-	-	-	-	-
Setting times[3]													
min., minutes	45	60	45	90	60	45		45		45		45	45
max., minutes	360	360	250	360	360	375		375		375		375	375
Heat of hydration													
7 days, kJ/kg, max.	-	300	-	275	-	-		290		-		250	-
28 days, kJ/kg, max.	-	-	-	-	-	-		-		-		290	-
Sulphate expansion 14 days, max, %	-	0.050	-	-	0.035	-		-		-		-	0.040

[1]Air permeability test, minutes [2]Vicat test
[3]Lower values prevail in the U.S. when the optional heat of hydration or sum of C_3S and C_3A is specified.
Source: Canadian Standards Association and ASTM.

Table 3.5. ANALYSES OF TYPICAL RAW MATERIALS.

	Chalk	Clay	Lime-stone	Shale	Marl	Typical raw mix
SiO_2	1.14	60.48	2.16	55.67	16.86	14.30
Al_2O_3*	0.28	17.79	1.09	21.50	3.38	3.03
Fe_2O_3	0.14	6.77	0.54	9.00	1.11	1.11
CaO	54.68	1.61	52.72	0.89	42.58	44.38
MgO	0.48	3.10	0.68	2.81	0.62	0.59
S	0.01	n.d.	0.03	0.30	nil	nil
SO_3	0.07	0.21	0.02	nil	0.08	0.07
L.O.I.	43.04	6.65	42.39	4.65	34.66	35.86
K_2O	0.04	2.61	0.26	4.56	0.66	0.52
Na_2O	0.09	0.74	0.11	0.82	0.12	0.13
	99.97	99.96	100.00	100.20	100.07	99.99
$CaCO_3$	97.6		94.1		76.0	79.3

Includes also P_2O_5, TiO_2 and Mn_2O_3.
Source: Lea, 1970.

hydrates slowly and can lead to unsound concrete. Problems involving limestones with excessive magnesia can sometimes be solved by drilling, sampling, and selective quarrying. Both core and rotary drilling and sampling techniques are employed to provide information about the composition and thickness of a deposit. Information obtained from exploration drilling and mapping is used as a basis for planning and developing methods of quarrying. In general, cement plant operators require a deposit with at least 50 years of readily accessible rock before they will consider it as a source of raw material.

Table 3.6. DISTRIBUTION OF CEMENT RAW MATERIALS, CANADA AND UNITED STATES, 1984.

	Canada %	U.S. %
Calcareous		
Limestone	69.42	63.97
Cement rock	14.38	19.99
Coral	-	1.05
Other	n.a.	0.20
Argillaceous		
Clay	0.05	4.64
Shale	3.73	2.62
Other	n.a.	0.10
Siliceous		
Sand & calcium silicate	2.11	1.59
Sandstone, quartzite, other	n.a.	0.50
Ferrous		
Iron ore, pyrite, mill scale	1.10	1.08
Other		
Gypsum & anhydrite	4.39	3.26
Blast furnace slag	0.85	0.08
Fly ash	-	0.66
Other	3.97	0.26
TOTAL	100.00	100.00

Source: Statistics Canada, 1984.
U.S. Bureau of Mines, 1985.

RAW MATERIAL EXTRACTION

Raw materials for cement manufacture are generally obtained by quarrying the rock. Depending on the nature of the materials, the limestone may be either blasted free or ripped using heavy machinery. Shales are generally loosely consolidated and can be readily ripped, while silica is obtained from loose sand deposits or from the crushing of sandstone. Silica and alumina are also obtained from the excavation and washing of clays.

Iron ore, mill scale, gypsum and anhydrite are generally purchased in the open market by cement manufacturers, as are other limestones necessary to bring the essential chemical components to the required levels.

PROCESSING

The process of cement manufacture consists of the incorporation of the raw materials to form an homogeneous mixture, the burning of the mix in a kiln to form a clinker, and the grinding of the clinker to a fine powder, with the addition of a small proportion of gypsum. About 1.8 tonnes of raw materials are required to manufacture 1 tonne of finished cement; 1.7 tonnes are used to make clinker, and the remaining 0.1 tonne is added during the clinker–grinding process.

Raw material grinding takes place using either the wet process or the dry process. In Ontario, and in North America generally, the dry process is predominant in terms of clinker production capacity. Dry process plants accounted for approximately 70% of Canadian clinker capacity and over 80% of Canadian cement production in 1984. In the United States dry process plants were responsible for approximately 60% of clinker production in 1984.

Wet process plants vary depending on the nature of the raw materials. In the U.K. and other areas where chalks and marls are used as the raw materials, these rocks are broken up and combined in wash mills. These usually consist of circular pits lined with bricks or concrete, and containing gratings in the walls through which the raw materials can pass when reduced to a sufficiently fine condition. The chalk and clay are fed in the required proportions to the wash mill together with sufficient water to form a liquid of creamy consistency that is pumped to slurry tanks or basins.

If the raw materials are harder limestones and shales, the wash mill is inadequate to reduce the materials to the required fineness. This situation generally prevails in North America and is the case for Ontario cement producers. The raw materials in such cases are crushed and fed to ball mills, and water added in an amount to form a slurry. Clay, if it is used, is usually fed to the ball mill already dispersed in the water. The finished slurry usually does not contain more than a few percent of material retained on a 170 mesh, and its water content varies from 35% to 45% with different raw materials. The slurry is pumped to slurry tanks or basins and agitated to keep the mixture homogeneous. The proportion of lime in the mix is controlled by analysis and adjusted periodically as required. Final adjustment of composition is often obtained by blending the slurry from two basins, one of which is kept slightly high and one slightly low in lime. In some plants more elaborate blending systems are practised, using a number of slurry basins, blending tanks, and final storage tanks. The finished slurry is fed to the kiln.

Dry process plants are now the most common type of cement plant in Canada. In the dry process the raw materials are crushed, dried in rotary driers, proportioned, and then ground in ball mills to a fineness ranging from 75% to 90% passing 200 mesh. The ball mills are continuous in operation, receiving raw material at one end and discharging ground material at the other. They are often divided into two, three, or even four compartments containing balls of different size. Two mixes, one high and one low in lime, are often prepared and blended in the required proportions in a silo with vigorous air circulation. The dry powder is fed to the kiln.

At many new dry process plants, roller mills are replacing ball mills. In roller mills, the material is dried during pulverization using waste heat from the kiln, significantly improving energy efficiency.

Figure 3.3 illustrates the wet and dry processes for the manufacture of cement.

Burning is the most important operation in the manufacture of cement. The strength and other properties of cement depend on the quality of the clinker produced. Fuel consumption is a major expense and several technologies have been introduced to improve energy utilization in cement manufacture. Rotary kilns are the only type of kiln used in Canadian cement manufacture.

Rotary kilns are used for both wet and dry process cement manufacture. The kiln is a refractory lined cylindrical steel shell that rotates around an inclined axis. Blended dry mix or slurry enters the upper or feed end of the kiln and is conveyed by the slope and rotation to the firing or discharge end of the kiln. The variations in wet and dry process cement kilns are described below.

Wet process kilns employ chains in the upper part of the kiln to assist in the transfer of heat from the kiln gases to the raw materials. The slurry is dried in the upper part of the kiln and water driven off as steam and then, as it descends the kiln, the dried slurry undergoes a series of reactions, forming hard granular masses known as clinker in the most strongly heated part of the kiln. The clinker is discharged into air coolers, which may consist of a series of cylinders arranged around the periphery of the kiln; or onto a traveling or reciprocating grate cooler where air passes through the slowly moving bed of hot clinker. If a traveling or reciprocating grate cooling system is used, the heated air drawn from the coolers is recovered and used for the combustion of coal (if a coal–fired plant) or passed back to the upper stage of the kiln for drying of the slurry.

Wet process kilns are typically quite long, and may be up to 213 m in length and 7.6 m in diameter. The long length of the kiln improves the thermal efficiency of the kiln and enables the exit gas temperature to be reduced to 93°C or even lower.

Numerous methods are used to improve the fuel–efficiency of wet process plants. The water content of the slurry may be reduced by slurry filters, which are large rotating discs or drums covered with filter cloth. These devices reduce the water content to 20%–30% from 35%–45% in the filter cake. Heat transfer devices such as spiral vanes or guides in the back–end of the kiln or additional rotating cylinders may also be used. The slurry is passed through these devices before being fed to the kiln.

Dry process kilns are of two types: a short kiln with a preheater, and a long kiln similar to a wet process kiln, but somewhat shorter and differing in that the gas exit temperature is lowered to about 87°C. The temperature of the clinker discharged from the kiln is thereby reduced and some of the clinker heat is recovered and used to heat combustion air inside the kiln.

Energy conservation is a major theme in dry process cement manufacture. In Canada in 1984 the average energy consumption per tonne of cement was 4,931 MJ (4.7 million Btu). This contrasts with an average energy consumption of 6,714 MJ (6.4 million Btu) for U.S. cement producers. These data show substantial declines from the energy consumption recorded 10 years ago in

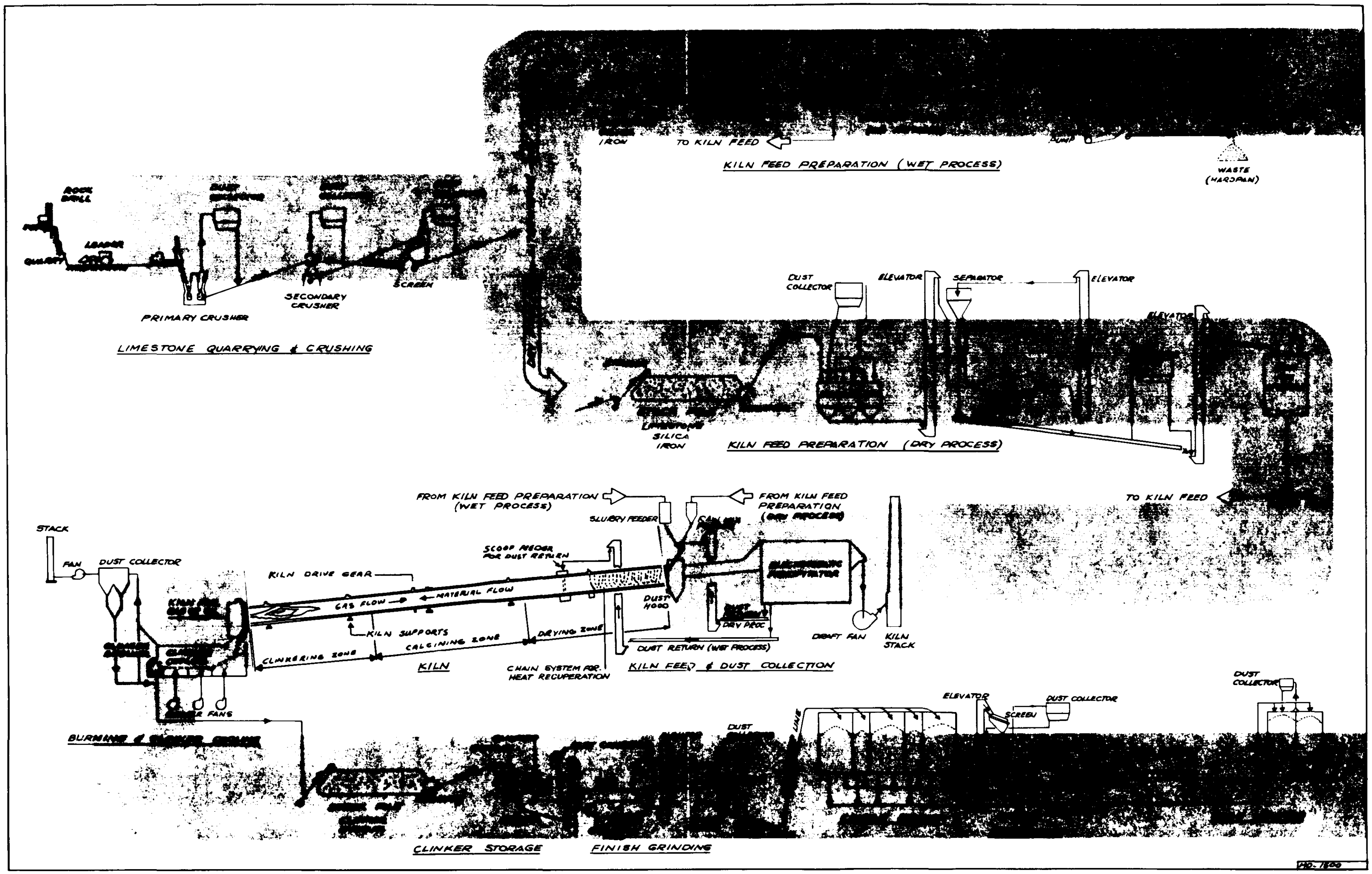


Figure 3.3. (TOP) WET CEMENT PROCESS. (MIDDLE) DRY CEMENT PROCESS. (BOTTOM) FINAL GRINDING OF CLINKER. (Figure courtesy of Lafarge Canada Inc.)

both countries. Figure 3.4 illustrates changes in energy consumption in Ontario. Energy efficiency has been a major factor in the success of Ontario cement producers in penetrating the U.S. market.

The most popular method of energy conservation has been to use a preheater. The suspension preheater is the most common and is composed of a system of multistage cyclones and riser ducts in which the kiln feed is heated in suspension and partially calcined when it comes into contact with kiln exit gases. Some preheaters are equipped with pre–calciners that, by using kiln exit gases together with separate burners, achieve up to 95% calcination of raw material before it enters the kiln. Thus, the preheater–precalciner system permits the use of shorter kilns with less loss of heat. By the end of 1985 there were 59 suspension and 18 grate type preheaters in operation out of a total of 275 cement kilns in the United States. Canadian cement plants operated 9 preheaters on a total of 49 kilns in 1985.

The Lepol kiln is a variant of the preheater–precalciner system and uses a travelling chain grate enclosed by a casing which is installed in advance of the kiln. The raw materials are prepared in the form of small nodules by the addition of a small amount of water to the dry mix. The nodules are piled in a layer approximately 15 – 20 cm thick on the travelling grate which conveys them to the kiln. The hot waste gases from the kiln are sucked through the raw mix and the heat transferred. Exit gas temperatures can be reduced to as low as 49 °C using this system in conjunction with a short kiln having a high exit–gas temperature.

Ontario cement plants employ gas, oil, and coal firing systems, with pulverized coal now being the preferred fuel. Several companies have also investigated the use of alternative fuels such as refuse, waste rubber and tires, electrical insulating oils, etc. The change in the distribution of fuel mix for cement production from 1980 through 1985 is shown in Figure 3.5 and Table 3.7. For Canada as a whole, the distribution of fuel mix was as follows:

	1974	1985
natural gas	49.5%	37.8%
petroleum products	39.7%	6.9%
coal and coke	10.8%	55.4%

Source: Canadian Minerals Yearbook, Cement, 1986.

A similar change in fuel mix distribution has taken place in the United States cement industry. Coal and coke accounted for 92% of fuel consumption on an energy content basis in 1983, and 95% in 1985. In 1972 coal and coke represented less than 39% of the energy requirements of U.S. cement plants. Figure 3.5 and Table 3.8 illustrate the distribution of energy sources for Ontario and U.S. cement producers in 1984 and 1985.

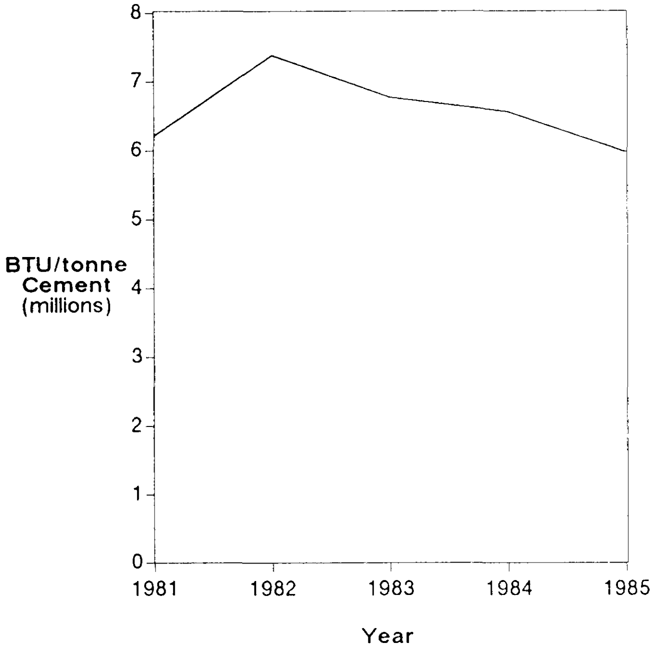


Figure 3.4. ENERGY ANALYSIS; ONTARIO CEMENT PRODUCERS.

Wet process plants are generally more energy intensive than dry process plants and typically require approximately 4% more energy per tonne of clinker. However, dry process plants equipped with suspension preheater systems will require only 70% of the energy required by a wet process plant. Dry process plants equipped with grate–type preheater systems require approximately 90% of the energy per tonne of clinker that wet process plants use. Data available for energy use in the U.S. cement industry indicate the following for 1985:

- ☐ wet process plants 6476 MJ/tonne clinker
- ☐ dry process plants 4857 MJ/tonne clinker
  - no preheater 6592 MJ/tonne clinker
  - suspension preheater 4513 MJ/tonne
  - grate type preheater 6244 MJ/tonne

These data are 26% less than 1972 for wet process plants and 17% less than 1972 for dry process plants in terms of energy consumption per tonne of clinker produced.

Finish grinding takes place in ball mills which are similar in design to the raw mills. Clinker from storage or directly from the coolers is fed to the mills, along with anhydrite or gypsum in amounts up to 5%. The material is ground to a particle size of approximately 10 microns. The fineness of the material is generally given in terms of the specific surface area in square metres per kilogram measured by the air permeability test, and is referred to as the Blaine number. Most cements are finished to a Blaine number ranging from 4200 to 4500. The fineness

Table 3.7. ENERGY ANALYSIS. ONTARIO CEMENT PRODUCERS.

Energy source	Energy consumption ($)					
	1980	1981	1982	1983	1984	1985
Coal and coke	12,241,928	18,688,449	20,376,991	19,286,487	23,326,575	31,166,125
Natural gas	10,231,159	10,848,681	9,088,615	7,544,562	8,451,778	8,799,205
Light fuel oil	217,106	374,858	313,392	296,170	524,627	225,671
Heavy fuel oil	7,522,686	6,333,950	3,067,768	2,768,052	2,938,060	4,410,979
Diesel oil	618,020	939,004	874,241	582,423	631,314	675,875
Electricity	12,343,839	14,033,355	13,798,068	14,438,896	17,333,984	20,703,566

Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986

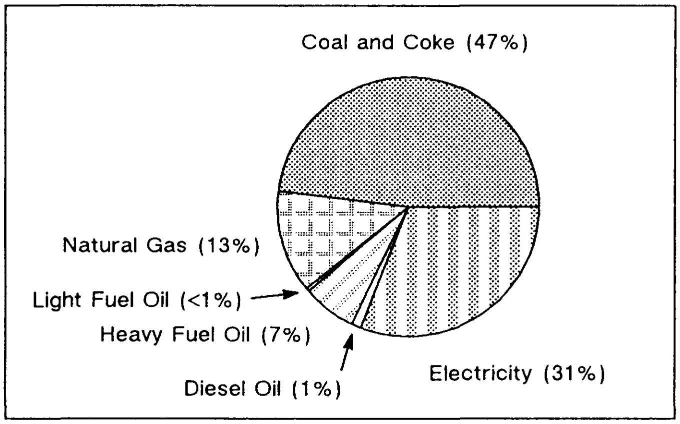


Figure 3.5. ENERGY COST/TONNE OF CEMENT 1985. *Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.*

Table 3.8. ONTARIO-UNITED STATES ENERGY CONSUMPTION PER TONNE CEMENT PRODUCED, 1984-1985.

1984	Ontario	U.S.
Coal (t)	0.1121	0.1814
Natural gas (m^3)	0.0149	5.9280
Fuel oils (1)	4.1312	1.7428
LPG (1)	0.0470	n.a.
Electricity (kWh)	136.5	154.6
1985		
Coal (t)	0.1414	0.1555
Natural gas (m^3)	0.0144	4.4532
Fuel oils (1)	4.5192	1.7728
LPG (1)	0.0728	n.a.
Electricity (kWh)	154.3	152.3

Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986
U.S. Bureau of Mines

is controlled with air separators in closed circuit with the grinding mills. When the proper fineness has been achieved the cement is passed to storage silos and/or to the pack house for shipment in bulk by rail car, truck, and boat, or in bags.

Electrical energy requirements for grinding (raw and finish) averaged approximately 138 kilowatt hours per ton, or about 1388 MJ per tonne of finished cement in the U.S. in 1985. Ontario cement plants consumed approximately 154 kWh per tonne of cement production in 1985 (Table 3.8).

Dust control is of major concern to the cement industry. In wet process plants the dust at the kiln exit varies up to about 5% of the clinker output and in dry process plants it can rise as high as 15%. Dust is also generated during the finish grinding process.

Electrostatic precipitators, cyclone separators, scrubbing towers and bag filters are used to trap the dust, which is usually returned to the kiln. The dust is relatively rich in the more volatile constituents of the charge, and this can cause problems with alkali buildup in the precipitators if the limestone is high in potassium, sodium, and chlorine. For this reason,most electrostatic precipitators are equipped with by–pass features to enable regulation of deleterious alkali buildup. Dust from the finish mills is generally captured by means of bag filters and cyclone towers and charged back to the mills.

CEMENT USES

By itself, cement has very little use. However, when combined with water, sand, and suitable aggregate material such as crushed stone or slag, in proper proportions it acts as a binder, cementing the materials together as concrete; one of the most versatile building materials known. Concrete finds use in all forms of construction and in the manufacture of concrete products such as pipe, building blocks, pre–stressed bridge piers and sections, etc. Cement can also be used in the manufacture of concrete (calcite) bricks which are between 20% to 30% less expensive than clay bricks. They have been improved in quality and colour to such an extent in recent years that they are very difficult to distinguish from the clay product. Concrete bricks enjoy strong demand in Ontario, accounting for about 25% of the total brick market in 1984. They are produced by several of the building materials subsidiaries of the cement producers such as Canada Building Materials (St. Marys Cement), Primeau

Argo Block (Lake Ontario Cement), and Richvale Building Materials (Lafarge Canada).

Pre–stressed and pre–cast concrete structures are enjoying increased demand. Such structures offer engineers and contractors lower cost alternatives for engineering construction such as bridges and highway piers and for commercial building construction. An interesting new development is the use of pre–cast panels faced with thin veneers of building stones such as limestone or granite. The combination of the materials allows the architect to design a very attractive building at competitive construction costs. An example of this technique is the recently completed Carleton County courthouse in Ottawa, which is faced with limestone.

TECHNOLOGY

Technical developments related to the use of cement and concrete include the following:

- The development of fibre–reinforced concretes using plastic, glass and ceramic–based fibres for reinforcements. The fibres are incorporated into the concrete to prevent crack propagation and increase the impact resistance of the concrete.
- The development of synthetic chemical additives to impart increased chemical resistance, crack resistance, impact resistance and workability.
- The development of high–shear processing techniques, together with rolling or pressing to remove pores from low– water calcium aluminate cement pastes. The pastes contain from 5% to 7% organic polymers to improve workability. The resulting paste is called macro–defect–free or MDF cement and, on hardening, has a strength similar to that of aluminium and much lower permeability than ordinary portland cement.
- The development of new cementitous aggregates such as fly ash and microscopic silica particles. The minerals help to fill the pores in the concrete and improve the bonding properties of the cement, resulting in greater strength and reduced permeability.
- The development of very high compressive strength concretes. Typical concretes have compressive strengths of approximately 34 MPa (5,000 psi). Concretes with compressive strengths of 69 to 103 MPa (10,000 to 15,000 psi) are becoming common, and concretes with strengths of at least 310 MPa (45,000 psi) have been developed. Even higher strengths should be possible. Higher compressive strength concretes will permit the use of smaller columns in high rise buildings with consequent savings in space and materials.
- The development of new non–calcareous concretes such as sulphur concretes may negatively affect the market for portland cement. Sulphur concrete, for example, offers superior corrosion resistance in acidic environments and can be recycled by remelting and recasting without loss of the mechanical properties.
- Use of portland cement as an anti–stripping agent in asphalt mixes may increase the consumption of cement and offer a lower cost alternative to sulphur in this application.
- New cement plant technologies include the use of compressed air cannons to remove material build–up in cement kiln pre–heaters, and the development of high efficiency air separators in the grinding circuit.
- Portland cement could be used as a sulphur removal agent in fossil fuel–fired power plants. The cement would be used in place of limestone, lime or other basic material, and could eventually prove to be a cheaper material to use.

Lime, Chemical and Metallurgical Stone

Limestone is one of the most widely used raw materials in industry. Starting with crude crushed stone, limestone is used to produce lime which is consumed in almost every branch of industry as a chemical and metallurgical intermediate, fluxing agent, additive, soil conditioner and stabilizer, building material, and a host of other uses.

LIME

Lime is the product of heating calcium and/or magnesium carbonate rocks to the dissociation temperature of the carbonates, and holding the material at that temperature for a sufficient period to release carbon dioxide. The process is referred to as calcination. The term "lime" should only be applied to calcined limestone and dolomitic materials, and their secondary products, hydrated and slaked lime. Hydrated lime is the product of mixing calcined lime, quicklime, with water; drying the resulting product, and (possibly) regrinding. Slaked lime is the product of mixing quicklime with excess water to form a slurry.

The principal Canadian markets for lime are the steel industry, the pulp and paper industry, and the mining industry. Lime is also used in water and sewage treatment, sugar refineries, glass and chemical production, fertilizer production, tanneries and in agriculture, road and soil stabilization, construction products, and other uses.

Lime is of two primary types. High calcium lime is produced by the calcination of high calcium limestone, and is by far the most important form of lime. Dolomitic lime is produced by the calcination of dolostone, $CaCO_3.MgCO_3$, and is more restricted in use than high calcium lime. Dead–burned dolomite is a special form of dolomitic lime that is produced by sintering a mixture of dolostone and 5%–10% iron oxide (mill scale) at high temperatures (1650°C) in the presence of low ash coal. The resulting product possesses good refractory properties and is employed as a lining in steelmaking and other high temperature industrial furnaces.

LIME MANUFACTURE

The manufacture of lime is accomplished by the calcination of crushed limestone or dolostone. Because of variations in limestone chemistry, crystal form, and other physical properties, no two limestones will produce identical limes; even when calcined under identical conditions in identical kilns (see Figure 3.6). As a result, most lime material specifications are quite general and liberal in their provisions.

CALCINATION

Lime manufacture begins in the calcination, a thermal process resulting in the release of carbon dioxide gas from limestone and dolostone. It is a reversible reaction and can be represented as follows:

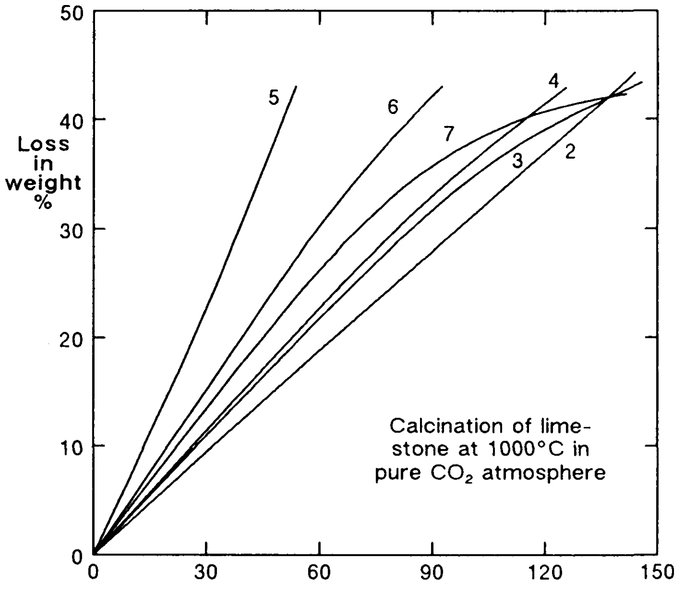
$$CaCO_3 \text{ (limestone)} + \text{heat} \Leftrightarrow CaO \text{ (h.c. quicklime)} + CO_2$$

$$CaCO_3.MgCO_3 \text{ (dolostone)} + \text{heat} \Leftrightarrow CaO.MgO \text{ (dol. lime)} + 2\ CO_2$$

The three essential factors in the reaction are:

1. The stone must be heated to the dissociation temperature of the carbonates.
2. This minimum temperature (but in practice a higher temperature) must be maintained for a certain duration.
3. The carbon dioxide gas that is evolved must be removed.

High calcium limestones have a dissociation temperature approximately that of pure calcite, which is 898°C at 1 atmosphere pressure (760 mm) for a 100% CO_2 atmosphere. Pure magnesium carbonate has a disso-



2 and 3: dense crystalline stone
4: finely crystalline stone
5, 6 and 7: fine grained crystalline stone

Figure 3.6. VARIABLE RATES OF DISSOCIATION FOR DIFFERENT SPECIES OF LIMESTONE. *Source Boynton, 1980.*

ciation temperature in the range 402 to 480°C. The proportions of calcium and magnesium carbonates in a particular dolostone will affect the dissociation temperature. A good "average" value for dissociation would be 725°C at 760 mm pressure and 100% CO_2 atmosphere, with the $CaCO_3$ component dissociating at the higher temperature for calcite, resulting in a dual-stage decomposition.

As a consequence, the MgO component in dolomitic lime is necessarily hard-burned before the CaO is formed. This problem can be alleviated by cooling the quicklime immediately after the $CaCO_3$ is calcined and by calcining at minimum and constant temperatures, but for a longer duration.

Critical parameters in the successful calcination of limestone and dolostone are the following:

- Regulation of CO_2 partial pressure. It is essential to have rapid and continuous evolution of CO_2 to reduce the dissociation temperature. The relationships between temperature, pressure, and CO_2 concentration are illustrated in Figure 3.7.
- Stone size. Moderate kiln stone sizes (1 1/2 in. – 8 in. diameter) are generally required to permit rapid and thorough heating. Stone should also be relatively uniform in size with a maximum size gradation of 1:3 to promote even calcination. It is desirable that stones have relatively uniform thickness as well as length and width as the rate of calcination is directly proportional to the square of the thickness of the stone.

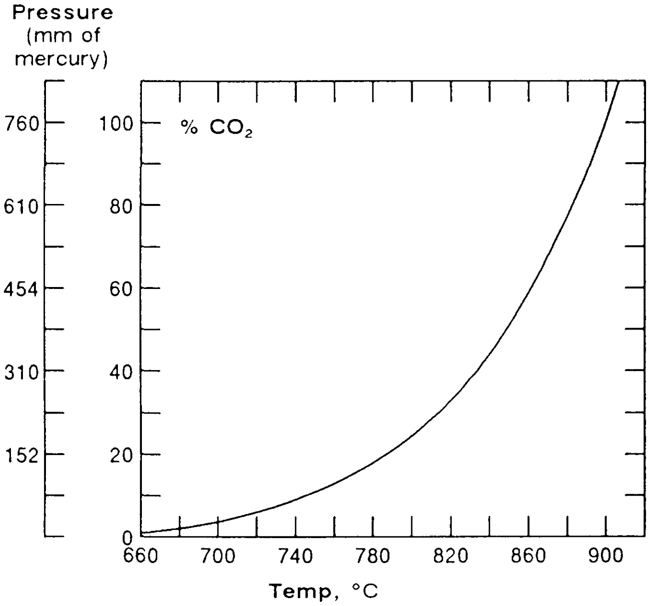


Figure 3.7. INFLUENCE OF CO_2 CONCENTRATION AND PRESSURE ON DISSOCIATION TEMPERATURE OF $CaCO_3$. *Source Boynton, 1980.*

- Porosity and density of the stone. High porosity is associated with low shrinkage and high lime reactivity. Dense, fine-crystalline stones tend to hard-burn and produce a less reactive lime with more core (uncalcined material).
- Rate of heating and final temperature. Generally, gradual preheating and a gradual increase in calcination temperature up to the point of complete dissociation results in the most reactive lime.

The relationships between stone size (surface area), calcination temperature, and duration of calcination are illustrated in Figure 3.8.

The heat consumed during dissociation is determined by the specific heat of the material. The theoretical heat requirements for dissociation of CO_2 are:

high calcium limestone:	1,696 MJ/tonne (1,458,814 Btu/ton)
dolostone:	1,450 MJ/tonne (1,247,103 Btu/ton)

To this heat requirement must be added the heat required for the retention of the dissociation temperature. These values are approximately 2,900 to 3,500 MJ/tonne (2.5 to 3.0 million Btu/ton) for high calcium lime and 3,025 to 3,220 MJ/tonne (2.60 to 2.77 million Btu/ton) for dolomitic lime. The total heat requirements are therefore:

high calcium quicklime:	4,605 to 5,190 MJ/tonne (3.96 to 4.46 million Btu/ton)
dolomitic quicklime:	4,475 to 4,675 MJ/tonne (3.85 to 4.02 million Btu/ton)

LIME KILNS

Figure 3.9 provides a simplified flow sheet for an integrated lime operation. The key component of a lime plant is the kiln, though few of the many types that have been developed over the past 100 years have proven to be commercial successes. All of these are variants of vertical and rotary kilns. The principal types of lime kilns are detailed below.

VERTICAL KILNS

All modern vertical kilns are divided into four principal zones: (1) stone storage; (2) preheating zone; (3) calcining zone; (4) cooling and discharge zone. Differences in the design of these zones constitute the "art" of vertical kiln design.

Traditional vertical kilns are of the mixed feed design, and the gas-fired cross-flow and centre burner type. Mixed feed kilns are fired with a low-ash coal or coke which is fed to the kiln in direct association with the kiln stone. The resulting lime is generally of inferior quality due to sulphur contamination, but the kiln offers very high thermal efficiency and generates substantial amounts of CO_2 gas, which can be recovered and used in

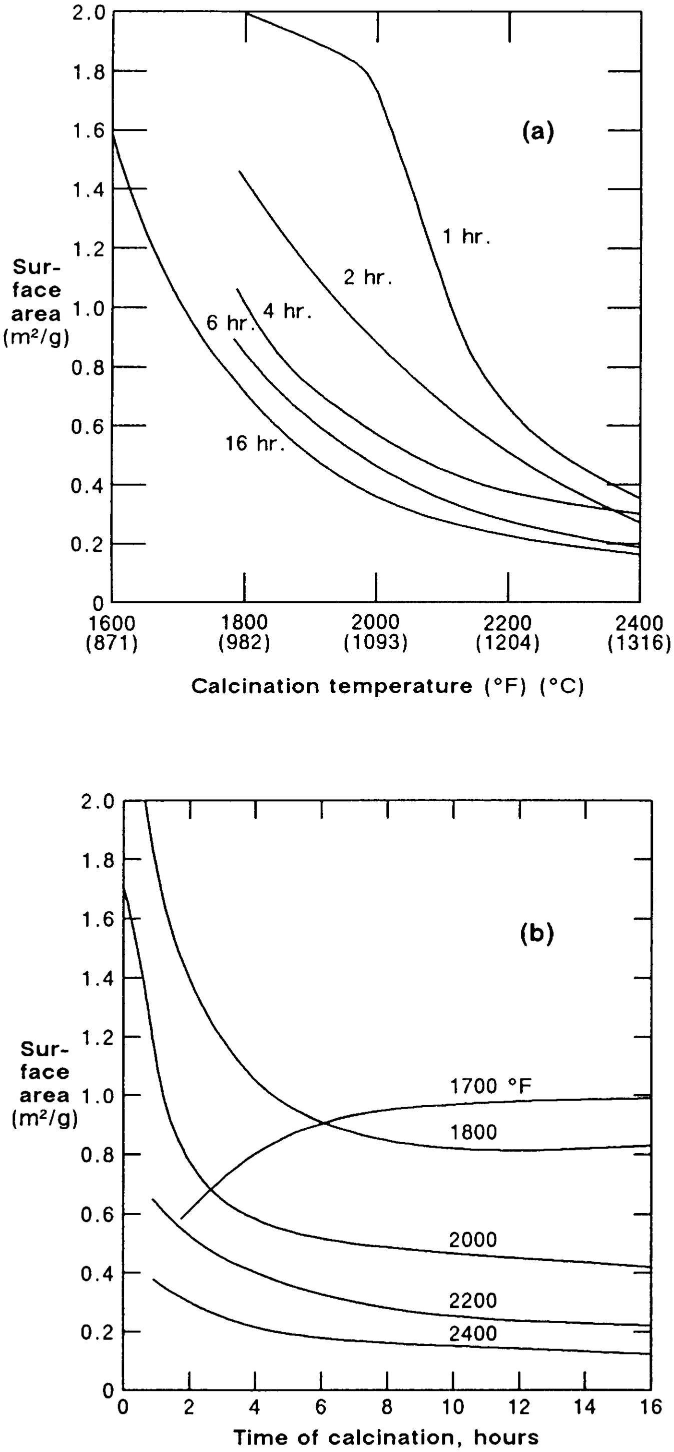


Figure 3.8. (a) RELATION OF SURFACE AREA TO CALCINATION TEMPERATURE. (b) RELATION OF SURFACE AREA TO DURATION OF CALCINATION. *Source Boynton, 1980.*

chemical processes such as soda ash manufacture and in sugar refining.

The centre burner kiln offers greatly increased production capacity and fuel efficiency over older vertical kiln designs. The Azbe kiln uses recirculation of the hot exit gases for calcination. The cross–flow kiln passes the gases at right angles through the stone. Union Carbide has developed a variant of the cross–flow kiln in which burner beams are used at two levels to provide more uniform calcining. The Union Carbide design is quite popular in the United States.

The latest versions of the vertical shaft kiln are of three types: parallel–flow or Maerz kiln, double–inclined kiln, and annular or ring kiln. These kiln designs offer very high thermal efficiency and yield a more reactive and pure lime (1–1.5% unburnt core) with lower levels of sulphur content than mixed feed kilns. Table 3.9 provides a comparison of experience with various vertical kiln designs.

ROTARY KILNS

The rotary kiln is by far the most popular design in North America. Despite its higher capital cost and lower thermal efficiency in comparison to modern vertical shaft kilns, the rotary kiln is preferred due to its ability to fire any fuel and its ability to handle a wide range of stone sizes. These factors enable rotary kiln operators to switch fuel sources relatively easily as conditions warrant,and to reduce the build–up of unusable stone fines. The modern rotary kiln is generally fired with pulverized coal, though most are also equipped with stand–by fuel facilities to fire oil and/or natural gas. Current designs incorporate numerous energy conserving devices such as preheaters, internal heat exchangers, and lime coolers, etc., many of which are common to cement plant kilns. Modern rotary kilns tend to have a low length:diameter ratio as opposed to the more traditional long rotary kiln. The short rotary kiln is generally more thermally efficient than the long rotary kiln. Energy conserving devices used in rotary kilns are detailed below:

PREHEATERS

Preheaters offer the most potential for improving thermal efficiency in lime manufacture. The most popular forms of preheaters are the following:

☐ travelling grate type (AC–Lepol)

this features a travelling grate which acts as a preheater and pre–calciner. The system can handle a very broad range of stone sizes from 4 mesh to 5 cm and offers good thermal efficiency of approximately 5,580 MJ/tonne (4.8 million Btu/ton).

☐ shaft preheaters

there are several varieties. The best performance in retrofit applications is with short rotary kilns (31 m to 53 m) of approximately 1:10 diameter:length. Traditional long rotary kilns of 76 m to 136 m have

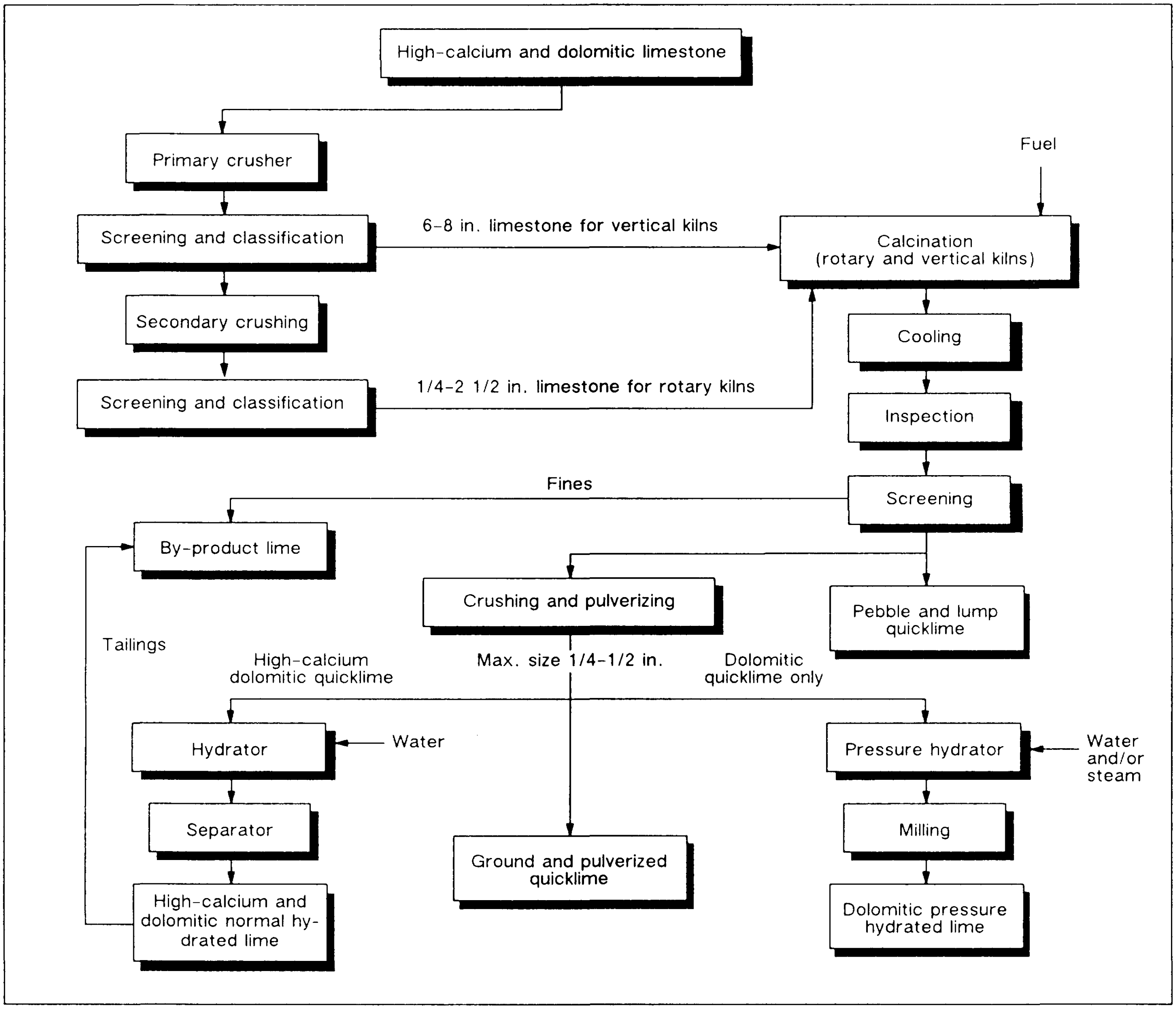


Figure 3.9. SIMPLIFIED FLOW SHEET OF INTEGRATED LIME OPERATION. *Source Boynton, 1980.*

been less successful. The two most popular types are by KVS, which makes standard shaft, rectangular, and polygon shaped units for kilns up to 900 tonnes/ day capacity; and by Parsons and Kraus– Maffei. Thermal efficiencies for both designs are in the 4,885 to 5,580 MJ/tonne (4.2 to 4.8 million Btu/ ton) range.

KILN INTERNALS

Internal kiln design features promoting thermal efficiency include heat exchanger cross section design enhancements such as trefoils, dams and lifters, chains, etc. The essential feature of all of these kiln internals is that they promote greater heat exchange with the stone and more even heating by constantly exposing all parts of the stone to the hot gases.

COOLERS

Coolers provide for heat recovery and the cooling of the lime. There are several types:

- Contact or Niems coolers
- Planetary coolers or satellite coolers

Table 3.9. COMPARISON OF SPECIFICATIONS OF SHAFT KILNS.

	Regular	Union Carbide	Cross Flow	Double Inclined	Annular	Parallel Flow Regenerative
Shaft	Round	Rectangular	Rectangular	Rectangular	Round	Round
Cross section area (ft^2)	43-323		42	56	99-315	25-172
Capacity (STPD)	50-500	150-600	200	120-175	100-500	100-600
Capacity (MTPD)	45-454	136-544	181	109-159	91-454	91-544
Feed size	2-1/2"-8"	1"-7"	3/4"-3"	1/2" to 2-1/2"	3/4"-5"	3/4"-7"
Fuel	Coke, oil, gas	Oil, gas	Oil, gas	Coke, oil, gas	Oil, gas, Pulverized coal*	Oil, gas, Pulverized coal*
Fuel rate (10^6 Btu gross per short ton)	3.38 to 4.50	4.9 to 5.2	4.0 to 4.4	3.78 to 4.18	3.78 to 4.18	3.38 to 3.78
Power (kwh/MT)	2.5-8	10-25	20-30	16-26	10-30	20-25

**Pilot installations in operation since 1981*
Source: Schwarzkopf, 1981.

- Rotary coolers
- Grate coolers

The most effective system for both heat recovery and lime cooling appears to be the contact cooler. The other types of cooler are less effective in heat recovery but approximately equal to the contact cooler in cooling performance.

Control of kiln stone feed size is critical to successful operation of rotary kilns. The maximum stone size is generally 2 in., although some operators use 2 1/2 in. stone. The minimum size is generally 1/4 in. or 3/8 in. Most plants operate with stone sizes in the range of 3/8 in. to 7/8 in.; 7/8 in. to 1 5/8 in.; 1 in. to 2 in.; and so on. Plants with multiple kilns may calcine two to four different gradations of stone to minimize the production of unusable stone fines.

Two other developments of note related to rotary kiln operation are the development of suspension preheater and flash calcining systems for lime kiln fines and limestone spalls; and the Maerz FK calcining method for limestone fines. The latter method uses a suspension preheater but not the flash calciner. These technologies, which have been adopted from the cement industry, allow lime producers to successfully calcine limestone fines and dust. The result is a significant increase in the size range of stone which can be converted into salable product, rather than stored as waste material or sold at very low prices. Both systems are also very thermally efficient.

OTHER KILN TYPES

Two other kilns used in North America are the Fluo-Solids kiln and the Calcimatic kiln. The Fluo-Solids kiln successfully calcines very small stone of 8-65 mesh at high energy efficiencies. The operation of the kiln is based on the fluidized bed principle and requires very precise control. The kiln produces a very reactive lime with almost no core, and is most successful with soft limestones or heavily crystalline stone that thermally decrepitates. The Calcimatic kiln features a large diameter circular refractory hearth that can be operated at various speeds up to 200 rpm; most units operate in the 27 to 85 rpm range. The hearth is divided into heating zones, and extensive instrumentation is used for precise temperature control. The kiln can successfully calcine a wide range of stone types and sizes, varying from 1/4 in. to 4 in., with a maximum recommended gradation of 1:4. There is one Calcimatic unit in operation in Ontario at BeachviLime Ltd. in Beachville, Ont. (site A-3 in the Aylmer District chapter, Volume III).

FORMS OF LIME

Quicklime is commercially available in the following forms:

1. Lump.

   Sizes range from 2 1/2 in. to 12 in., but usually a more restricted size range such as 3 in. x 6 in., 4 in.x 8 in., etc. These sizes are derived exclusively from vertical kilns.

2. Pebble.

   Sizes range from 1/4 in. to 2 1/2 in., but actual size distribution is more precise, such as 1/4 in. x 1/2 in., 1/2 in. x 1 in., etc. The product is available from both rotary and vertical kilns and the Calcimatic kiln.

3. Ground.

   Typical size range is 100% passing 8 mesh and 2%-4% passing 100 mesh. It is a secondary product resulting from the screening of fines or grinding and classifying coarser sizes.

4. Pulverized.

   Typical size range is 100% passing 20 mesh and 85%- 95% passing 100 mesh. It is produced by pulverization and classification of larger size material.

5. Briquettes (pelletized).

These are produced by compressing quicklime fines in special moulding equipment, to about 1 in. The volume of production is quite small.

LIME HYDRATION

Lime hydration refers to the addition of water to quicklime whereby approximately stoichiometric amounts of water and lime react to form a chemically combined dry hydrate. It contains less than 1% free moisture and is handled as a dry powder. If excess water is added slaking is said to take place, with the formation of a lime slurry. This product is handled as a liquid. The hydration process is strongly exothermic. This heat may be captured for use in the hydration process or used for other processes, or more usually is wasted. High calcium quicklime hydrates much more readily than dolomitic lime. Special procedures and equipment are required to economically hydrate dolomitic lime. The rate of hydration is dependent upon the purity of the lime, the MgO content, the size of the starting lime particles (smaller is faster), the temperature of the water, the amount of water, degree of agitation, and extent air–slaked lime is used.

SLAKING

Lime slaking may take place in either a batch or continuous mode. Batch slaking has largely been superceded by the continuous process. Paste slaking is the predominant method as it reduces the detention time by recovering some of the heat of hydration to increase the water temperature. The paste slaker also yields a more concentrated hydrate. Only large volume users such as pulp and paper mills employ slaking equipment today.

DRY HYDRATION

Hydration plants also operate in batch and continuous modes, the latter type predominating. All hydrate production takes place in closed–circuit systems to prevent recarburation. Plant layout and equipment selection varies widely. The hydrated product is generally ground in a ball mill to improve the plasticity of the product. The most significant factors affecting hydrating plant design are:

- porosity and slaking rate of the quicklime
- chemical purity of the quicklime
- physical size and gradation of the quicklime
- temperature of the hydration water
- particle size requirement of the hydrate

LIME SPECIFICATIONS

Specifications for lime are quite diverse due to the variations in the starting material. The ASTM has developed a series of specifications for both quicklime and hydrated lime for use in a wide range of applications. These specifications are summarized in Table 3.10. Canadian specifications for quicklime and hydrated lime generally follow the prescriptions of the ASTM.

USES

LIME

Lime is used in an extremely diverse range of applications. In industry it is the second largest volume basic chemical, next to sulphuric acid. It is used for neutralization, coagulation, causticization, dehydration, hydrolyzation, and absorption; in building construction as a cementitious material and as a plasticizer; in agriculture to supply calcium and magnesium as plant nutrients and for neutralization of acid soils; in highway construction for soil stabilization and as an anti–stripping agent in asphalt. High calcium and dolomitic lime may be used interchangeably for many of the listed applications. For certain applications, however, there are general preferences for one type over the other, and for some of these only one type of lime can be used. Similarly, both quicklime and hydrated lime may be used interchangeably for some applications. The selection will depend on the volume requirements and storage facilities as quicklime is the more reactive material and costs less per tonne. In other applications only quicklime or hydrated lime may be specified. A brief description of the uses of lime is provided in the following sections.

IRON AND STEEL

Lime is used as a basic fluxing agent in iron and steelmaking processes. It is used in iron making in the manufacture of sinter and in the production of self–fluxing sinters and iron agglomerates (pellets). In steelmaking it is used as a flux to assist in the removal of phosphorus, silica, and sulphur. The most important steelmaking processes using lime are the basic oxygen furnace (BOF) and the electric arc furnace (EAF), and their variants. The use of lime, as opposed to limestone, in the basic open hearth furnace is limited and is rapidly declining as these furnaces are being phased out in favour of the BOF and EAF.

Both high calcium and dolomitic lime are used in BOFs, with dolomitic lime accounting for 20% to 30% of the total lime charge in most BOFs. Some BOFs use up to 50% dolomitic lime in the fluxing charge. Typical size specifications for lime call for lump or pebble material. However, those steel plants using the more modern LD–AC or Q–BOP BOF processes tend to prefer 200 mesh and 150 mesh material as it is injected into the melt via lances. Quicklime accounts for most lime consumption, although hydrated lime may be used as a heat insulator in the ladle refining process, especially if calcium wire is used as the flux. Dead–burned dolomite is used as a refractory material to protect the basic lining of open hearth furnaces and of electric furnaces.

Table 3.10. ASTM LIME SPECIFICATIONS FOR QUICKLIME, HYDRATED LIME, AND LIMESTONE FOR CHEMICAL USES.

SPECIFICATION C911-87			Chemical Requirements, %										Physical Requirements			
													Dry Sieve	Wet Sieve		
Use	ASTM Specification[1]	Approved Types of Lime or Stone	CaO min	CaO,+ MgO min	SiO_2+ Fe_2O_3,+ Al_2O_3, max	MgO, max	CO_2, max	SiO_2+ Insoluble matter, max	Al_2O_3+ Fe_2O_3, max	Available CaO, min	Fe_2O_3, max	Chemical Other	% -12 mesh min	% -30 mesh min	% -200 mesh min	% -325 mesh min
Cooking rags	C 45	CH	-	-	-	-	-	-	-	64.3[3]	-	-	-	-	-	-
Cooking rags	C 45	CQ	-	-	-	-	-	-	-	90.0[3]	-	-	-	-	-	-
Sulfite pulp	C 46	CQ,MQ	-	95.0[2]	3.0[2]	-	-	-	-	-	-	-	-	-	-	-
Sulfite pulp	C 46	CL,ML	-	95.0[2]	3.0[2]	-	-	-	-	-	-	-	-	-	-	-
Silica brick	C 49	CH	90[2]	-	-	2.5[2]	2.5	3.0[2]	1.5[2]	-	-	Free CaO ≤1.5	-	99	95	-
Silica brick	C 49	CQ	90[2]	-	-	2.5[2]	2.5	3.0[2]	1.5[2]	-	-		-	-	-	-
Water softening	C53	CQ	-	-	-	-	-	-	-	90	-	-	-	-	-	-
Water softening	C53	CH	-	-	-	-	-	-	-	68.1		-	-	-	-	-
Other water treatment uses	C 53	CQ,DQ, MQ	-	93.0	-	-	-	-	-	-	-	-	-	-	-	-
Other water treatment uses	C 53	CH,DH MH	-	93.0[2]	-	-	-	-	-	-	-	-	-	-	-	-
Carbide	C 258	CQ	92[2]	-	-	1.75[2]	4.0	2.0[2]	1.0[2]	-	0.5	P ≤0.02[2] S 0.2[2]	-	-	-	-
Grease	C 259	CH	-	-	-	1.5	-	1.0	-	-	0.5	available $Ca(OH)_2$ ≥90	-	-	98	95
Calcium silicate product	C 415	CH	90[2]	-	-	1.3[2]	2.5	3.0[2]	1.5[2]	-	-	-	-	99	95	-
Calcium silicate product	C415	CQ	90[2]	-	-	1.3[2]	2.5	3.0[2]	1.5[2]	-	-	-	99	-	-	-
Hypochlorite bleach	C 433	CH	-	-	-	-	-	-	-	68	0.3[2]	-	-	-	-	-
Hypochlorite bleach	C 433	CQ	-	-	-	-	-	-	-	90	-	-	-	-	-	-
Industrial waste treatment	C 826	CH DH MH	-	95.0[2]	-	-	5.0	-	-	-	-	BF > 0.72[4] BF > 0.81[4] BF > 0.74[4]	-	-	85	-
Industrial waste treatment	C 826	BH	-	90.0[2]	-	-	-	-	-	-	-	-	-	-	70	-
Industrial waste treatment	C826	CQ DQ MQ	-	90.0	-	-	-	-	-	-	-	BF > 0.93[4] BF > 1.06[4] BF > 0.93[4]	-	-	85[5]	-
Industrial waste treatment	C826	CL DL ML	-	90[2]	-	-	-	-	-	-	-	BF > 0.45[4] BF > 0.56[4] BF > 0.48[4]	-	-	-	-

[1] *These designations refer to the following ASTM Methods.*

C 45 Specification for Quicklime and Hydrated Lime for Cooking of Rags in Paper Manufacture
C 46 Specification for Quicklime and Limestone for Sulfite Brick Manufacture
C 49 Specification for Quicklime and Hydrated Lime for Silica Brick Manufacture
C 53 Specification for Quicklime and Hydrated Lime for Water Treatment
C 258 Specification for Quicklime for Calcium Carbide Manufacture
C 259 Specification for Hydrated Lime for Grease Manufacture
C 415 Specification for Quicklime and Hydrated Lime for Calcium Silicate Products
C 433 Specification for Quicklime and Hydrated Lime for Hypochlorite Bleach Manufacture
C 826 Specification for Lime and Limestone Products for Industrial Waste Treatment

Limestone, high-calcium - CL
Limestone, dolomitic - DL
Limestone, magnesian - ML
Quicklime, high-calcium - CQ
Quicklime, dolomitic - DQ
Quicklime, magnesian - MQ
Hydrated lime, high-calcium - CH
Hydrated lime, dolomitic - DH
Hydrated lime, magnesian - MH
Hydrated lime, by-product - BH

[2] *On a nonvolatile basis.*

[3] *Standard composition.*

[4] *BF means Basicity Factor.*

[5] *Slaked basis.*

Table 3.10. CONTINUED.

QUICKLIME FOR STRUCTURAL PURPOSES
SPECIFICATION C5-79

	Calcium Lime	Magnesium Lime
Calcium oxide, min, %	75	-
Mgnesium oxide, min, %	-	20
Calcium and magnesium oxide, min, %	95	95
Silica, alumina, and oxide of iron, max, %	5	5
Carbon dioxide, max, %		
If sample is taken at place of manufacture	3	3
If sample is taken at any other place	10	10

FINISHING HYDRATED LIME
SPECIFICATION C206-84

	Type N	Type S
Calcium and magnesium oxides (nonvolatile basis), min, %	95	95
Carbon dioxide (as-received basis), max, %		
If sample is taken at the place of manufacture	5	5
If sample is taken at any other place	7	7
Unhydrated oxides (as-received basis), max, %	-	8

Type *N - Normal*
S - Special

HYDRAULIC HYDRATED LIME FOR STRUCTURAL PURPOSES
SPECIFICATION C141-85

	Min	Max
Calcium and magnesium oxides (CaO and MgO calculated to the nonvolatile basis), %	65	75
Silica (SiO_2 calculated to the nonvolatile basis), %	16	26
Iron and aluminum oxides (Fe_2O_3 and Al_2O_3 calculated to the nonvolatile basis), %	-	12
Carbon dioxide (CO_2 on an as-received basis), %	-	8

HYDRATED LIME FOR MASONRY PURPOSES
SPECIFICATION C207-79

	Hydrate Types			
	N	NA	S	SA
Calcium and magnesium oxides (nonvolatile basis), min, %	95	95	95	95
Carbon dioxide (as-received basis), max, %				
If sample is taken at place of manufacture	5	5	5	5
If sample is taken at any other place	7	7	7	7
Unhydrated oxides (as-received basis), max, %	-	-	8	8

Type *N - Normal*
NA - Normal air-entraining
S - Special
SA - Special air-entraining

Another technical development affecting the use of lime in the steel industry is increased use of hot iron desulphurization and the use of magnesium as the desulphurization agent. In hot metal desulphurization molten iron from the blast furnace is treated prior to entering the BOF. The fluxing agent may be lime, calcium carbide, or magnesium powder. Calcium carbide is typically employed in Japan and Europe, although there is a trend to the use of magnesium powder. In Canada and the United States the magnesium powder is often treated with a lime coating to yield a lower cost fluxing agent.

OTHER METAL SMELTING

Lime is used as a fluxing agent to promote slag formation in the smelting of copper, lead, zinc, and antimony. It is used in the flotation process for copper production for pH adjustment and as a settling agent, in the recovery of gold and silver in the cyanide flotation process, used in the recovery of nickel by precipitation after it is smelted. Lime is used in the Bayer process for the manufacture of alumina, where the lime causticizes sodium carbonate solutions to generate sodium hydroxide, and in the secondary desilification process. In acid–type uranium extraction, lime is used to neutralize waste acid liquors. Other uses of lime include the recovery of tungsten from scheelite and the recovery of high cost flotation agents such as xanthates in zinc, nickel, and lead flotation mills.

PULP AND PAPER

High calcium lime is used to causticize the "black liquor" (sodium carbonate solution) to sodium hydroxide in the sulphate pulping (kraft) process. Most kraft pulp mills recover the calcium carbonate sludge after the causticizing process by dewatering and calcining. Approximately 92% to 98% of the lime is recovered, the balance being made up by purchases of quicklime or high calcium stone.

Some lime is still used in the sulphite pulping process, although most bisulphite pulping liquors are now derived by reacting SO_2 with limestone or other alkaline bases such as ammonia, magnesia, and soda ash. Lime is also used for the production of calcium hypochlorite for pulp bleaching.

CHEMICAL MANUFACTURE

A diverse range of chemicals may be prepared from lime. The principal chemicals produced are the sodium alkalis (sodium carbonate, sodium bicarbonate, sodium hydroxide) by the Solvay process, which requires large quantities of salt brines and CO_2 as well as ammonia. The purpose of the lime is to causticize sodium carbonate to sodium hydroxide and to regenerate the ammonia catalyst in the manufacture of soda ash. The process used by General Chemical Canada Ltd., the only Solvay soda ash producer in Canada, is illustrated in Figure 3.10.

Lime is also used in the production of the following chemicals:

- calcium carbide for acetylene production
- calcium cyanimide, a nitrogen fertilizer
- inorganic insecticides and pesticides such as arsenates, Bordeaux mixtures, and lime–sulphur sprays and powders
- magnesium and calcium oxides and hydroxides, calcium chloride, inorganic salts, chrome chemicals, hydroxides of lithium, barium, etc., and the purification of brines for food grade sodium chloride
- ethylene glycol via the chlorohydrin process and the production of propylene oxide and glycol
- azo dyes
- napthol via the sulphuric acid process
- benzaldehyde and benzoic acid from dichlorotoluene and trichlorotoluene
- precipitated calcium carbonate from soda ash manufacture or carbonation of milk–of–lime.

ENVIRONMENTAL USES

Lime is extensively used for environmental purposes. These uses include the following:

- Neutralization of waste acid liquors and gases from ferrous and non–ferrous metals smelters and refineries;
- Neutralization of organic and inorganic acid wastes from chemical plants, pulp and paper mills, textiles plants, and food processing plants;
- Water softening, purification, and coagulation (turbidity removal) for potable and process water and boiler feed water;
- Sewage treatment and phosphate removal and sewage sludge neutralization and precipitation;
- Scrubbing of acid gas emissions from thermal power plants and boilers.

These uses are more advanced in the United States than in Canada. Water, gaseous, and sewage treatment accounted for approximately 29% of U.S. demand for lime in 1985 versus approximately 5% in Canada in 1983. The main differences are accounted for in scrubbing of acid gases and in sewage treatment.

GLASS AND CERAMICS

Dolomitic lime is used as the source of magnesium oxide in glass–making. Both high calcium and dolomitic limes are used to manufacture special refractories and silica brick for use in cement kilns, steel furnaces, and other high temperature industrial furnaces.

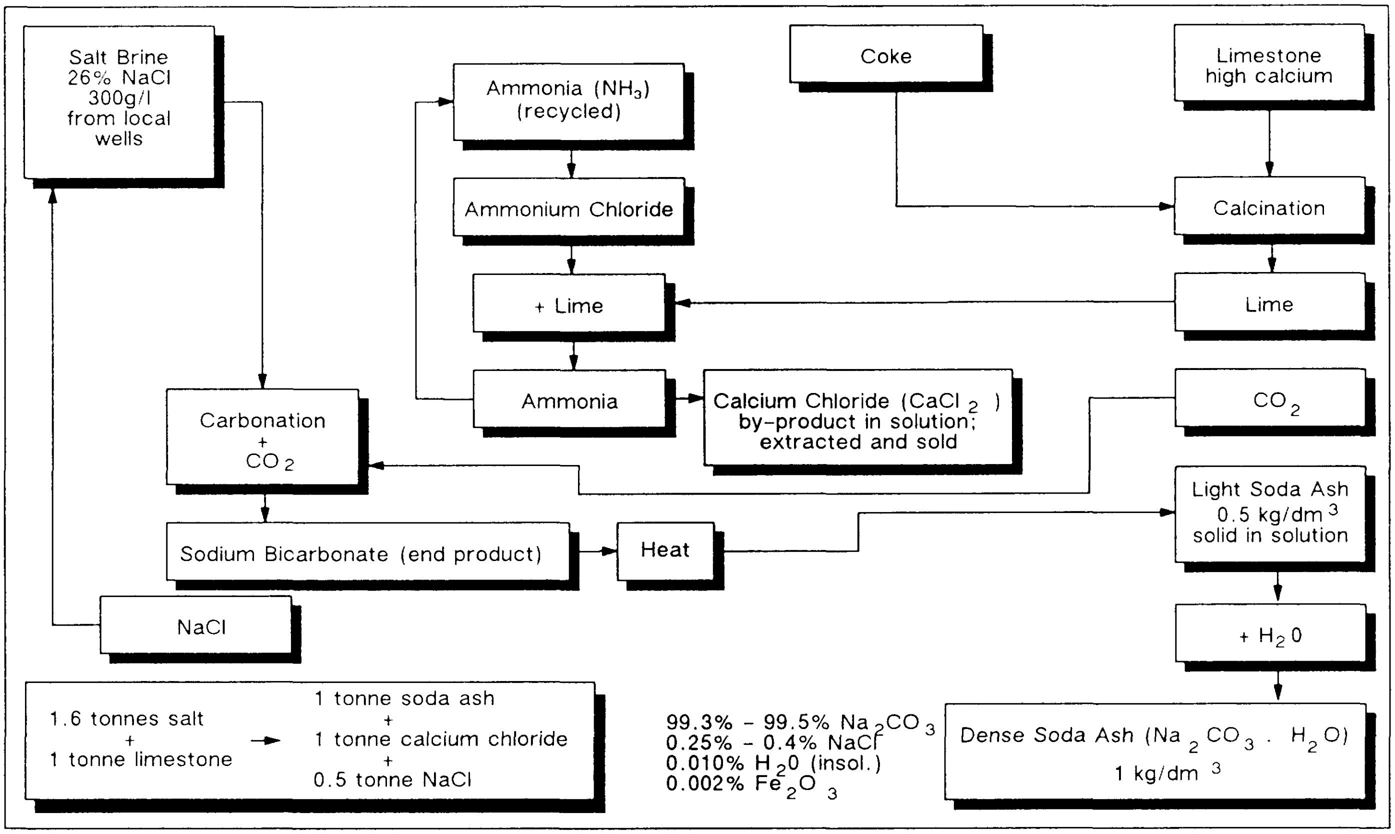


Figure 3.10. SOLVAY PROCESS FOR THE MANUFACTURE OF SODA ASH.

BUILDING PRODUCTS

Lime is used as the raw material for the manufacture of calcium silicate building products such as sand–lime brick, cellular concrete blocks, and silicate concrete. These products have achieved much greater market acceptance in Europe and Japan than in North America, where concrete is the primary building material.

FOOD PROCESSING

Lime is extensively used in the food processing industry as a precipitating agent and for waste disposal. The sugar refining industry is the major user, and many sugar mills have captive lime plants associated with them. This is especially true of sugar beet processing plants which produce large volumes of acid waste and require large amounts of lime for the clarification process.

Lime is used in the production of gelatin, in dairy processing, the baking industry, fruit processing, and controlled atmosphere apple storage.

OTHER INDUSTRIAL USES

Other uses of lime include the following:

- Petroleum refining; for mercaptan removal, SO_2 gas removal, lubricating grease production, "red lime mud", drilling mud conditioning, etc.;
- dehairing and plumping of hides in tanneries;
- paint, pigment, and varnish manufacture;
- rubber manufacture;
- chemical dehydration of organic chemical compounds.

AGRICULTURAL USES

Lime is used in agriculture for soil neutralization, composting, fertilizer manufacture, chicken litter disinfection, etc. These uses represent only a small portion of total demand.

CONSTRUCTION

Construction uses for lime include the following:

- masonry mortar, stucco, and base coat plaster;
- hydraulic lime;
- lime–cement mortar.

These uses are more common in Europe than in North America. Dolomitic rather than high calcium lime is generally preferred.

SOIL STABILIZATION

Soil stabilization is a significant use of lime in the United States, but is a limited end–use in Canada. The lime reacts with most types of clay soils by agglomerating the clay particles through base exchange and chemically reacting with the silica and alumina in the soil, forming complex calcium and aluminum silicates. Lime can also be used in deep soil stabilization projects such as underwater construction of bridge piers. In this case special injection equipment is required to inject the lime solution under high pressure. Finally, hydrated lime is used as an anti–stripping agent for asphalt mixes, especially siliceous aggregates.

CHEMICAL PROCESS STONE

Crushed limestone and dolostone are used to make glass more insoluble. During the glass–making process the limestone and/or dolostone acts as a flux for the melting sililca sand, forming chemically fused calcium and/or magnesium silicates. High calcium limestone is used in the manufacture of flat or window glass, while dolostone is used in the manufacture of glass containers and tumblers, and in the manufacture of glass fibre. The higher MgO content in glasses made from dolostone confers greater acid etching resistance and increases the thermal shock resistance of the glass.

Limestone and dolostone used in glass manufacture must be low in iron, at least below 0.06% FeO. Iron limits could be as low as 0.014% (or lower) for some glasses. Stone is crushed to sizes of 0.74 mm to 2.4 mm. Typical chemical specifications are given in Table 3.11.

Table 3.11. CHEMICAL SPECIFICATIONS FOR LIMESTONE AND DOLOSTONE IN GLASS MAKING.

	Limestone	Dolostone	Dolomitic Lime
SiO_2	0.5%–2.0%	1.0%	0.6%
Al_2O_3	0.2%–0.4%	0.1%–0.3%	
Fe_2O_3	0.05%–0.15%	0.15%–0.30%	0.2%
TiO_2	0.01%		
CaO	53.55%–56.0%	29%–31%	55%
MgO	0.4%–1.2%	19%–22.5%	38%
$Na_2O + K_2O$	0.03%–0.15%		
As_2O_3			0.01%
P_2O_5	0.01%–0.1%	0.10%	0.01%
L.O.I.	42.0%–44.0%		2.0%
Moisture	0.1%	0.1%–0.5%	

Source: Boyton, 1980.

PULP AND PAPER

Pulp and paper mills use limestone as supplementary material to make up their lime requirements for the recausticization of the spent sulphite pulping liquor. The stone is added to the lime kiln during the calcining of the sulphite sludge. Requirements are modest and vary from year to year depending on the performance of the kiln and the relative costs of lime and limestone. Very limited amounts of magnesia or dolostone are used in sulphite pulp mills to prepare magnesium sulphite.

SODA ASH (SODIUM CARBONATE) MANUFACTURE

High calcium limestone is used in the production of soda ash by the Solvay process. The process has largely been supplanted by the use of natural soda ash, trona, from Wyoming. There is only one Canadian producer of soda ash, General Chemical Canada Ltd. in Amherstburg (site CH–1 in the Chatham District chapter, Volume III), and only one remaining U.S. producer. General Chemical produces calcium chloride, sodium bicarbonate, and a range of other calcium and sodium compounds or by–products and co–products of the Solvay process. Approximately 1.6 tonnes of salt and 1 tonne of limestone are required to produce 1 tonne of soda ash, 1 tonne of calcium chloride and 0.5 tonne of sodium chloride. The salt is recycled in the production process.

METALLURGICAL STONE

Crushed limestone and dolostone are used as a flux in ferrous and non– ferrous smelting and refining as a cheap substitute for the more expensive lime. The crude crushed material is also preferred for technical reasons in some applications. The major use of crushed limestone and dolostone in the metallurgical industries is in the steel industry. High calcium stone or lime are used as a flux in open hearth steelmaking, though this use is rapidly declining as the last two open hearth furnaces in Canada will be closed by the end of 1989 with the conversion of Stelco's Hilton Works in Hamilton, Ontario, and Sysco Steel in Sydney, Nova Scotia, to full Basic Oxygen Furnace production. Limestone and dolostone are also used directly in the manufacture of self–fluxing sinter and pellets. The Iron Ore Company of Canada started production of self–fluxing pellets at Wabush and Labrador City in 1985, using calcium limestone and dolomitic stone shipped from Ontario. Algoma Steel Corp. Ltd. produces self–fluxing sinter at its Wawa sinter plant using high calcium stone and dolostone from U.S. and Canadian sources. Dofasco Inc. produces self–fluxing pellets at the Adams Mine in Kirkland Lake and the Sherman Mine in Temagami, Ontario, for its steel production facilities in Hamilton.

Magnesium and calcium metal production is the other major metallurgical market for dolostone and high calcium limestone. Timminco Ltd. produces both metals using a variant of the alumino–silicothermic Pidgeon process at its plant at Haley, Ontario (site PE–6 in the Pembroke District chapter, Volume II).

Fillers and Extenders

Fillers and extenders are finely ground mineral materials used in a wide range of industrial applications. They may be used as low cost additives to increase the bulk of many commercial products, to improve the physical properties of the product, or for both purposes, adding important properties of their own without seriously decreasing the important characteristics of the product. The materials are also known as mineral extenders because they extend (and usually enhance) the properties of the products in which they are used.

There are a wide variety of extenders and fillers. The principal materials used are:

- carbonate materials such as calcium carbonate and magnesium carbonate
- kaolin
- barytes
- mica
- silica
- talc
- aluminum trihydrate (ATH)
- glass, ceramic, and plastic beads

Other mineral and organic based materials may also be used in limited quantities.

Carbonate-based mineral fillers and extenders are by far the most widely distributed and used materials, and their market has expanded rapidly in recent years. The development of processing technologies for the production of ultrafine grind carbonate materials, combined with changes in the manufacturing processes for many end–use applications, has greatly extended the application scope for carbonate fillers and extenders. The development of new markets and new products has also resulted in a considerable increase in the value–added of many carbonate derived fillers and extenders.

Carbonate fillers and extenders may be derived from limestone, dolostone, marble, calcite and marl, or synthetically produced as precipitated calcium carbonate or hydrated magnesium carbonate. White, high purity marble is the most common source of carbonate mineral fillers. Calcitic carbonates are extensively used as a paper filler and in paint, plastics, linoleum, and rubber. Important properties of filler grade carbonates include whiteness, fineness, freedom from grit, low oil absorption, and particle shape. Transportation charges play a major role in determining the market opportunities available to a producer, as well as competition from substitute materials.

ONTARIO OCCURRENCES AND PRODUCERS

Ontario carbonate sources include limestone, dolostone, marble, carbonatite, marl, and vein deposits. Limestone dust, produced during the quarrying and processing of limestone and dolostone for cement, lime, or construction aggregate, can be used as a filler in asphalt and other applications where colour is not important. Marl and vein calcite have been used in limited amounts in the past, but are not being used today.

Marble is the principal source of filler grade carbonate in Ontario, and has the greatest potential for market expansion and new product development. Marble in Ontario is generally restricted to the southern portion of the Grenville area of the Precambrian Shield.

Steep Rock Calcite, a division of Steep Rock Resources Inc., is the principal producer of carbonate fillers in Ontario*. The company operates a large, high–purity calcite marble quarry at Tatlock in southeastern Ontario. Primary crushed material is transported to a modern crushing and grinding plant at Perth, where material suitable for a variety of end–uses is produced using both dry and wet grinding circuits. A description of the quarry and plant is given in site CP–25 of the Carleton Place District chapter, Volume II. Previous attempts to produce filler grade calcium carbonate from other Grenville deposits, as well as calcite veins and marl beds, have generally been unsuccessful. These earlier investigations and workings of deposits are described in Guillet and Kriens (1984), Guillet (1969), and Hewitt (1964).

There are several producers of low grade off–white calcitic fillers in southern Ontario. BeachviLime Limited (site A–3 in the Aylmer District chapter, Volume III) between Beachville and Ingersoll produces industrial fillers as a by–product of limestone aggregate and glass grade production. The material is a coarse (200 to 325 mesh) product used in carpet backing, caulking compounds, asphaltic roofing products, and automotive undercoatings. Steetley Lime and Aggregates, a division of Steetley Industries Ltd. (site CB–11 in the Cambridge District chapter, Volume III), produces dolostone fillers at its aggregate and pulverized stone plant near Dundas. The filler products are produced from fines resulting from the production of glass grade dolostone, fertilizer diluents, and agricultural dolostone. The fillers are sold primarily for use in asphaltic roofing. Owen Sound Dolomite, a division of E.C. King Contracting of Owen Sound (site O–10 in the Owen Sound District chapter, Volume

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* *At the time of printing, the operations and shares of Steep Rock Calcite were being purchased by MAS Minerals Corp., a wholly-owned subsidiary of Pluess-Stauffer AG of Switzerland.*

III) produces dolostone fillers in conjunction with glass grade dolostone. The fillers are used in asphaltic roofing and sealer applications.

EXTRACTION AND PROCESSING

Carbonate materials for filler and extender uses are normally mined by quarrying. In the United States, however, there are a large number of underground operations. These underground operations generally employ the room and pillar method and are usually higher cost operations than open pit producers. Open pit mining methods for fillers and extender grade materials are similar to conventional quarrying for limestone and dolostone aggregate. Selective quarrying may be required on occasion to avoid areas of waste rock and meet the stringent quality requirements. It is generally desirable to have a number of working faces in the quarry to provide flexibility to the operation and allow for blending where quality variations occur.

Development of a suitable deposit should include removal of overburden, including final clean–up by pick and shovel or hydraulic washing. Extensive diamond core drilling is usually necessary to adequately define the limits and quality variations of the deposit. Large uniform deposits may.lend themselves to contract mining. For example, the deposit of Steep Rock Calcite at Tatlock is worked only a few weeks each summer, when sufficient crushed material is stockpiled at the Perth processing plant for the year's needs.

Processing methods for carbonate fillers are dependent upon the mineralogical and chemical purity of the raw material and the product quality requirements of the consuming industries. Processing choices are generally directed to producing materials suitable for the broadest possible range of applications within the market area of the producer. Because of this there are a variety of processing plants, which can generally be classified into six categories:

1. Plants producing by–product fillers from fines generated during the production of aggregate and other non–filler products.
2. Plants producing aggregate and other non–filler products, but with dedicated filler production facilities using dry grinding and air classification.

These first two types of plants produce fillers of low quality from off- white limestone and dolostone for local markets.

3. Plants producing high quality fillers using dry grinding and air classification.
4. Plants producing high quality fillers using wet grinding, flotation, wet grinding classification using centrifuges or cyclones, and filtration and drying.

These plants are conventional filler producers which meet the requirements of most consumers except those requiring ultrafine particle sizes.

5. Plants producing fillers using a combination of wet and dry processing techniques.
6. Plants producing ultrafine grind fillers using special wet grinding techniques, classifying centrifuges, and spray dryers.

These plants produce ultrafine grind products of less than 5 microns particle size.

Recent technological developments have concentrated on improvements to both wet and dry grinding systems for the production of very fine grind materials. The processes employed are often proprietary and very little information is available on their exact nature. Another development of major interest is the increasing interest in coated calcium carbonate using stearates or coupling agents. Surface coating technology is developing rapidly and is enabling filler producers to enter new markets and/or significantly increase the value–added of their products in existing markets. Many carbonate filler producers now make customized products for dedicated customers.

Figure 3.11 illustrates the typical flow of carbonate materials in either a dry or wet process plant. Primary and secondary crushing generally employ the same type of equipment as is used in aggregate production. Primary crushing is usually accomplished using jaw or gyratory crushers. Impact crushers may be used if the material is soft and free from silica. Secondary crushing is generally conducted using cone or impact crushers, usually in closed circuit with vibratory screens. Autogenous or semi–autogenous mills may also be used if the material is suitable.

Tertiary crushing and primary grinding is accomplished using a variety of equipment. The choice depends upon the later processing requirements. Roll crushers, roller mills, cage mills, rod mills, and ball mills may be used to provide feed for a fine grinding circuit or for a froth flotation circuit.

Further processing of the material may include fine grinding and classification. Roller mills are typically used to produce medium to fine filler products (up to 99% passing 325 mesh, 44 microns). Ball mills, pebble mills, and vibratory mills are used for fine grinding. The equipment is usually operated in closed circuit with air classifiers. Conventional ball or pebble mills are used to grind products ranging from 100 to 325 mesh. Vibratory mills and the new agitator mills using air classifiers and cyclones or classifying centrifuges can grind to even finer sizes of less than 5 microns with very tight particle size distributions. Grinding aids based on organic liquids may be employed to assist in the ultrafine grinding process and prevent the formation of agglomerates. Surface coat-

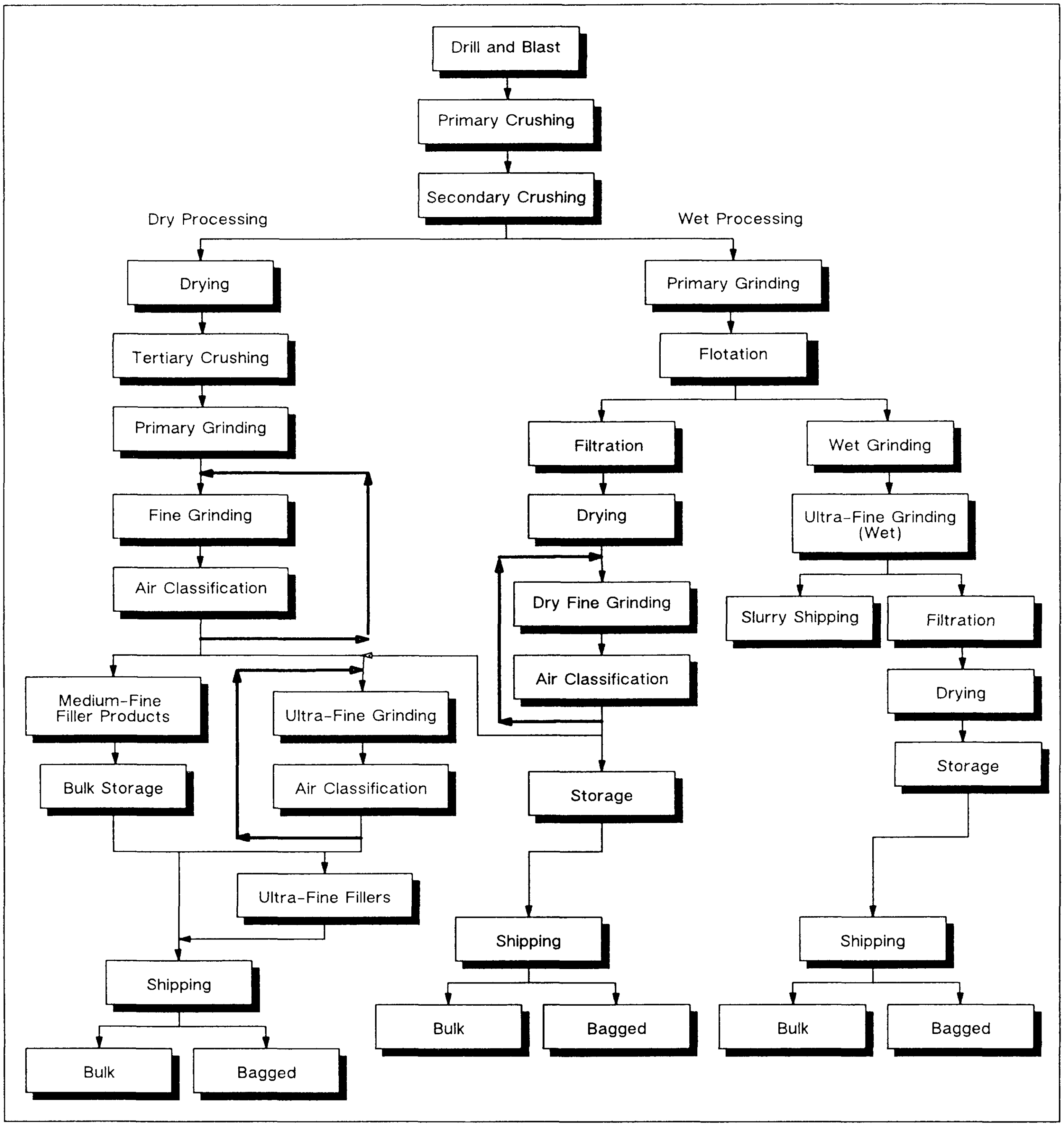

Figure 3.11. CONCEPTUAL FLOWSHEET - CALCIUM CARBONATE PRODUCTION, DRY OR WET PROCESSING ALTERNATIVES. *Source: Guillet and Kriens, 1984.*

Table 3.12. GRADE DESIGNATIONS AND TYPICAL PROPERTIES OF CALCIUM CARBONATE.

Grade (ASTM-D-1199)	Fine paint Grade I	Coarse paint Grade II	Grade II	Filler Grade III	Putty powder Grade IV	Superfine Grade V
Particle size analysis						
% Retained on 325 mesh	0.05	0.5	0.0	<25	<30*	0.0
Particle size range (microns)	0.5-20.0	0.5-45.0	0.5	10-45.0	40.0	0.05-5.0
Specific surface diameter (maximum, microns)	2.5	6.0		9.0	12.0	1.0
Mean particle size (microns)	3.0	7.0	13.0	17.5	36.0	
Hegman grind	6-6.25	4-4.25				
Physical properties						
Oil absorption	14.0-16.0	12.0-14.0				
Bulk density (lb/ft^3)	49.0	62.0	64.0	69.5	74.0	
Bulking value (gal/lb)	0.0443	0.0443	0.0443	0.0443	0.0443	0.0443
Specific gravity	2.71	2.71	2.71	2.71	2.71	2.71
Specific resistance (ohms)	20,000	20,000	20,000	20,000	20,000	20,000
pH	9.4	9.4	9.4	9.4	9.4	9.4
Hardness (Mohs)	3.0	3.0	3.0	3.0	3.0	3.0
Refractive index (mean)	1.59	1.59	1.59	1.59	1.59	1.59
Dry brightness (minimum)	96.0	94.0	93.0	85.0	90.0	96.0
Chemical composition						
% Calcium carbonate	98.00	98.00	98.00	95.00(min)	95.00(min)	98.50
% Magnesium carbonate	0.60	0.60	0.60	3.00(max)	3.00(max)	0.60
% Silica	0.50	0.50	0.50	1.00	1.00	0.40
% Iron oxide	0.06	0.06	0.06	0.06	0.06	0.02
% Alumina	0.36	0.36	0.36	0.36	0.36	0.20
% Moisture	0.02	0.02	0.02	0.15	0.15	0.02

**% retained on 200 mesh screen*

Applicable tests:

Moisture: Method A of method D-281.

Specific surface diameter: Practice D-1366.

Dispersed colour: Method D-718.

Oil absorption: Method D-281.

Particle size: Method D-3360.

Coarse particles: Method D-718.

Dry brightness: Method E-97.

Source: after Guillet and Kriens, 1984.

ings may also be employed to improve the properties of ultrafine grind fillers.

SPECIFICATIONS

The most significant considerations in selecting calcium carbonate as a filler are:

- particle size
- whiteness (brightness)
- mineralogical and chemical purity.

PARTICLE SIZE

Commercial grades of carbonate fillers cover the size range from 100 mesh (144 microns) to the sub-micron level. Five standard grades are recognized by the ASTM under standard D-1199. Within each grade are a number of filler products that fall within the specifications published for these grades. The ASTM specifications and some examples of grades falling within each grade division are provided in Table 3.12.

Many producers and consumers have developed their own specifications for carbonate fillers based upon the results of development work which identifies superior performance characteristics for such "non-standard" products. It is not unusual for a filler producer to provide exclusive grades to particular customers.

Particle size distribution is a critical parameter in most end-use applications. Changes in particle size distribution can cause a considerable change in product performance. For example, oil absorption of a filler is a function of its surface area. The packing density of the particles affects oil absorption as well as the viscosity of aqueous and organic systems. Particle size control is therefore one of the most important factors in the success of a filler manufacturer. Other significant physical and chemical parameters are bulk density, pH, bulking value, specific gravity, specific resistance, hardness, and refractive index.

WHITENESS

Whiteness and brightness are closely related factors and are important in carbonate fillers in applications such as paint, plastics, and paper. Other, less demanding, appli-

Table 3.13. PRIMARY USES FOR CARBONATE FILLERS.

Application	Function	General Specifications
Paint	Extender of prime pigments in interior and exterior paint formulations.	High whiteness; controlled particle size, 44 microns to 8 microns top size.
Plastics	As a resin extender in a wide range of polymer systems.	High whiteness; controlled particle size, 30 to 5 microns top size; fillers treated with coatings and coupling agents are used.
Paper	As a filler or for paper coating. Partial displacement of kaolin.	High whiteness; controlled particle size, low abrasion, very fine products with top sizes ranging from 10 to 4 microns.
Putty, caulking, sealing		White, medium to fine, 90-99% passing 325 mesh (44 microns).
Vinyl floor covering	As a filler in vinyl tile.	Coarse granular (-40 mesh) to fine (-325 mesh); good white colour; controlled particle size and bulk density.
Carpet backing		White to gray colour; 90%-99% passing 325 mesh.
Asphaltic products	Filler in roofing materials and asphalt sealers.	Off-colour buff to gray; coarse ranging from 80% passing 325 to 80% passing 200 mesh.
Rubber	Filler pigment in footwear, automotive goods, non-reinforced rubber, wire and cable coatings.	White to off-colour; fine to medium fine products.
Construction	Filler in jointing compounds for gypsum board.	Lower grade white products; 90-95% passing 325 mesh.
Other	Synthetic marble.	White, coarse products; 80-85% finer than 200 mesh, and granular grades.
	Coal dusting.	White to buff, coarse filler used in coal mining.

Source: Guillet and Kriens, 1984.

cations such as asphaltic roofing and sealers, carpet backing, jointing and caulking compounds, etc. can utilize off-white carbonate fillers, provided the material meets other specifications such as particle size, freedom from grit, oil absorption, etc.

There are a variety of methods to determine brightness and whiteness and producers usually state the method used to avoid confusion. Some industry groups such as the paper industry have developed their own standard test procedures, and filler producers generally employ these methods if selling to that market.

MINERALOGICAL AND CHEMICAL PURITY

Carbonate fillers should be as free as possible from deleterious materials such as quartz or other abrasive particles, arsenic, lead, water soluble salts, and dark minerals. If these materials are present additional and costly processing may have to be conducted to produce acceptable material.

USES

Calcium carbonate is used as an extender and filler in a broad range of applications. The principal end-use markets are plastics, paint, paper, adhesives and sealants, rubber, drywall compounds, and carpet backing. These applications are summarized in Table 3.13 and discussed in detail in the following sections.

PLASTICS

Mineral fillers are used in plastics as a resin extender and to improve some of the physical properties of the resin. Surface coatings and/or coupling agents have been employed in the development of new grades of fillers which considerably enhance the properties of the filler. Fillers are now used not only as low cost bulking agents, but also to impart beneficial properties to the resin. In most cases they are now regarded as functional fillers.

Calcium carbonate, however, is used to supply bulk at low cost and is mostly a non-functional filler. Typical size ranges used are in the 1 micron to 20 micron range. The more expensive ultrafine sizes may be used to provide functional properties such as improved mar and impact resistance, improved gloss, and improved cold flow properties in the compounding process. Precipitated calcium carbonate is included in the ultrafine sizes, but the volumes used are small.

The main uses in plastics for calcium carbonate are in PolyVinyl Chloride (PVC) and thermosetting polyesters. Calcium carbonate in PVC is found in both flexible and rigid materials. Calendered or flexible vinyl for applications such as furniture uses a 3.0 micron material at loadings of 15% to 20% or 20 to 60 phr (parts per hundred of resin). Thinner vinyls use finer grades of filler.

Table 3.14. SUMMARY OF APPLICATIONS FOR CALCIUM CARBONATE FILLER IN PLASTICS.

Polymer	Filler Level phr*	Particle Size Microns	Remarks
Flexible PVC	20-60	3	Compared with coarser grades, fine fillers cause less of a decrease in physical properties and provide better performance in thinner calendered films and coatings.
PVC plastisols and organisols	20-100	wide range	Coarse grades for carpet backings to ultra fine precipitated grades and coated chalk whiting for thixotropic viscosity control. Coarse particles lead to lower viscosity in plastisols.
Rigid PVC	1-5 40	2-3 1-3	Application in plastic for potable water pipe. Other pipe and conduit applications. Stearate-coated grades improve melt rheology and smoothness of extrusion; uncoated grades serve as antiplate-out agents.
PVC floor tile	80-400	small	Finest grind is about 12 microns; size distribution is wide; colour varies with feedstock.
Sheet moulding compound	250	3-6	Loadings are usually 250 phr for BMC, 100-150 phr for premix preform, and mat-over 400 phr is possible. Size distribution, and purity are selected to provide low-uniform-viscosity polyester.
Marine polyester	175-200	3-5	Meets standard requirements for this application of 0.15% maximum water absorption during a 24 hour immersion.
Polypropylene	43-67	1-3	For both polypropylene homopolymer and copolymers.

**parts per hundred of resin*
Source: Guillet and Kriens, 1984.

Rigid PVC applications for calcium carbonate include pipe and mouldings, windows and doors, floor tile, etc. Pipe producers currently use 2–3 micron material at loadings of 1–5 phr for potable water pipe and up to 40 phr for other pipe and conduit. There is a push by some manufacturers to increase calcium carbonate loadings in pipe by up to 50%, but this will require changes in government specifications for pipe. PVC floor tile calcium carbonate loading levels are in the range of 80 to 400 phr of small granular sizes (–40 to –325 mesh). In PVC plastisols and organosols such as carpet backing loading levels of 20 to 100 phr of (generally) 325 mesh material are common.

Polyesters have been the largest growth area for calcium carbonate in plastics. Typical mineral reinforced polyester formulations contain 20% chopped glass fibres, 35% to 40% resin, and 40% to 45% calcium carbonate by weight. Calcium carbonate is used in both sheet moulding compound (SMC) and bulk moulding compound (BMC), with higher loadings being found in BMC. The automobile industry is the principal end–user of these products, accounting for approximately 75% of the market, mainly for the front–end panels of cars (SMC) and truck hoods, fenders and front end panels (BMC). Calcium carbonate in these applications acts both as a filler and to control the viscosity, shrinkage, part weight, surface appearance, and maturation rate of the mix.

Calcium carbonate may also be used as a filler in other plastics, e.g. polypropylene. Typically, polypropylene for automotive applications is loaded with about 40% talc to increase the flexural modulus of the material to approximately 600,000 psi from the unfilled level of approximately 200,000 psi. A 40% loading of calcium carbonate gives a flexural modulus of about 400,000 psi. This provides a material competitive with Acrylonitrile Butadzene Styrene (ABS), but at reduced cost. The use of fine grade material in polypropylene will also increase its impact resistance. Table 3.14 summarizes the applications for calcium carbonate fillers in plastics.

PAINTS

Calcium carbonate is used as an extender in oil, alkyd, acrylic, and latex– based paint systems. The key parameters used by paint manufacturers to evaluate fillers are:

- oil absorption
- fineness
- particle size distribution
- whiteness (brightness)
- freedom from abrasive components such as silica

- pH
- water solubility
- chemical composition
- bulk density

Low oil absorption is of particular interest as this will allow for higher loadings while providing otherwise equivalent properties.

Coarse sized fillers of approximately 7.0 micron (44 micron top) are used in flat (low sheen) paints. Even coarser grades, 10 mesh and down, are used in textural paints and concrete block sealers. Semi-gloss and high gloss paints use finer grades of fillers. For example, a typical high gloss alkyd paint will use a 3.0 micron or less grade. Some high gloss paints use ultrafine fillers of 0.7 micron average particle size (90% below 2 microns). These ultrafine fillers are extremely efficient extender pigments and have substantial dry hide characteristics on their own. They have a lower oil absorption than calcined kaolin and can substitute to approximately 20% for the prime pigment, generally titanium dioxide (TiO_2). Loadings for paints are typically up to 300 mg per litre for flat and semi-gloss paints and 100 mg per litre for glossy paints.

PAPER

The use of calcium carbonate as a filler and coating material in paper manufacture is relatively new. Three developments opened up the market to natural ground calcium carbonate: first, a decline in the availability of precipitated calcium carbonate as the Solvay process for production of soda ash was displaced by high quality natural soda ash and trona. More recently, though, Pfizer, the largest precipitated calcium carbonate producer, has entered into arrangements to design, build and operate PCC plants at several paper companies. These plants utilize waste CO_2 from the lime reburn kiln and other raw materials. They thus provide a ready and relatively inexpensive source of high quality filler material. Second, the development of ultrafine wet grind technology to produce high solids carbonate slurry materials in the 0.6 micron to 0.8 micron size range; and third, the switch from acid sizing using alum to neutral and alkaline sizing materials, thus permitting the use of calcium carbonate as the filler material.

Alkaline sizing offers a number of advantages over acid sizing. Among these are:

1. It permits the use of less expensive hardwood pulps, which are more affected by acid media than are softwood pulps.
2. It permits higher filler loadings than does acid sizing using kaolin as the filler. Loadings up to 20% higher are possible, thus reducing fibre cost.
3. It allows for reduced maintenance costs by the elimination of corrosion causing acid constituents.
4. It allows for a reduction in effluent treatment as neutralization of effluent water is no longer required. White water from neutral and alkaline sizing operations can be recycled in the mill.
5. Energy costs are reduced due to lower water, steam, and heat consumption.
6. It provides for higher brightness and/or a reduction in the use of TiO_2 and optical brighteners.
7. It provides for higher strength paper by eliminating acid deterioration of the paper and by promotion of fibre hydration, resulting in easier processing and increased yield.
8. It provides for a more permanent paper which is less sensitive to ultraviolet light.

Filler grade calcium carbonates have an average particle size of 1.5 to 2.0 microns. The amount of filler used is dependent on the type of paper produced and whether it is coated or uncoated. Some types of paper such as newsprint use no fillers. Uncoated paper for printing may have filler levels ranging from 5% to 15%. Coated papers for magazines usually have filler levels in the 3% to 9% range.

Coating grade carbonates typically have particle sizes in the 0.6 micron to 0.8 micron range, with a top particle size of approximately 4 microns. High brightness (greater than 92 GE) is required. Coatings, of both precipitated and natural carbonates as supplements to the kaolin in the coating mixture, contribute to the whiteness of the paper and improve the ink receptiveness and smoothness. Particle morphology can have a decided impact on the optical properties of the paper, with rhombohedral and scalenohedral particles exhibiting the best performance.

PUTTY, CAULKS, AND SEALANTS

Calcium carbonate is widely used as a filler for putty, caulks, and sealants due to its low oil absorption, excellent availability, low cost, and whiteness. Calcium carbonates can be used at very high loadings (40% to 50% typical, up to 90% for putty) while maintaining good flow and viscosity. Typical particle sizes are 2 to 3 microns for Grade I to Grade III products with up to 20% retained on a 200 mesh screen. Sealants and caulking compounds generally use the finer grades, while putty uses the coarser Grade III material.

RUBBER

Calcium carbonate fillers are used in soft rubber goods such as floor coverings and auto mats. Kaolin is the primary filler with calcium carbonate used as a supplement to reduce product cost. Calcium carbonate fillers may also be used in wire and cable coatings, automotive weather stripping, and some footwear applications. Loading levels can be as high as 50% for some low performance rubber products. Grade II or Grade III products are used in low performance rubber products. Grade I fillers, often with surface treated particles, are required for wire and cable coatings.

CARPET BACKING

Carpet backing is the largest volume application for calcium carbonate where it is used to provide body and weight to the latex rubber, and can be loaded at levels up to 500 parts of filler per 100 parts of latex. Grade II and Grade III products are used, with particle sizes ranging from less than 44 microns to grades as coarse as 10% retained on a 200 mesh screen.

JOINTING COMPOUNDS

Coarse ground Grade II and Grade III calcium carbonate is used as a filler in drywall jointing compounds. Typical sizes are 90–99% passing 325 mesh and coarser 200 mesh products. Loadings can be as high as 80%. Critical characteristics of the formulated products are colour and application behaviour such as non–sagging and non–cracking.

ASPHALTIC PRODUCTS

Calcium and magnesium carbonate fillers are used in asphaltic roofing products such as shingles and rolled roofing, asphaltic sealers for driveways, and in automotive undercoatings. Standards in Canada allow for loadings of up to 50% in roofing shingles while in the U.S., loadings up to 60% in shingles are allowed. Coarse Grade III and Grade IV materials are used. The main requirements are controlled particle size, good flow properties, and high bulk density.

DOLOSTONE FILLERS

Except for asphaltic products, dolostone fillers are not used in North America. This is in contrast to Europe, where finely ground white dolomitic marble fillers are extensively used in paints, plastics and other applications where high whiteness, low oil absorption, and low abrasiveness are required. Possible reasons for the lack of use of dolostone fillers in North America are:

- lack of detailed performance characteristics
- ready availability of calcitic fillers
- tradition
- possible adverse chemical reaction with water to form magnesium sulphate as a result of the reaction of dolomite with sulphur dioxide to form sulphurous acid.

Building Stone

In recent years the building stone industry has undergone considerable development. The introduction of modern European cutting and polishing technology, the development of new fastening systems and favourable exchange rates have combined to make dimension stone an increasingly attractive building material. While the emphasis has been on granite, the limestone industry has also benefited from the renewed interest in building stone.

Building stone (also known as dimension stone) first became a significant industry in Ontario with the construction of the Welland and Rideau canals between 1824 and 1832. These major projects involved the extensive quarrying of limestone blocks for dams, locks and retaining walls. Many stone masons from Britain and elsewhere were hired for this work, and a lot of them settled permanently in Ontario where they encouraged the continued use of stone in both commercial and residential construction as well as in major public works. Early construction techniques relied on massive stone foundations and thick stone walls for their load–bearing capability; hence, evenly–bedded Paleozoic limestones were most frequently used.

Parks' (1912) report on "Building and Ornamental Stones of Canada" mentions 137 quarries actively producing building stone from Ontario's Paleozoic limestones and dolostones and 19 building stone quarries in the Grenville marble of eastern Ontario. However, by 1912 some former building stone quarries had already switched to the production of crushed stone, as a maturing portland cement industry encouraged the increased use of concrete and cement blocks. Goudge (1933) reported only 14 active Ontario quarries in his report "Canadian Limestones for Building Purposes". In 1986 there were 12 active limestone quarries producing building stone, but no marble quarries except those used for terrazzo and landscaping chips, and white industrial fillers.

The principal limestone building stone producing areas of Ontario are the Bruce Peninsula area around Wiarton and the Niagara Escarpment near Queenston and Thorold. Limestone mill blocks suitable for cut stone were produced by Queenston Quarries at Queenston and by Niagara Cut Stone at a quarry near Thorold. Mill blocks are produced at various locations on the Bruce Peninsula. The Adair Marble quarry (site O–1 in the Owen Sound District chapter, Volume III) of Arriscraft Corporation produces mill blocks which are processed at the company's plant at Cambridge (site CB–14 in the Cambridge District chapter). Thin–bedded limestone suitable for the production of flagstone, copings, sills and ashlar coursing is quarried at a number of small facilities near Wiarton and on Manitoulin Island. Building stone production in eastern Ontario, which had been a major factor in the development of Ontario's limestone industries, has largely disappeared, although mill blocks of black Bobcaygeon Formation limestone are produced at the Cornwall Gravel Company Ltd. quarry at Cornwall (site CW–14 in the Cornwall District chapter, Volume II).

Marble mill blocks were taken from several localities in eastern Ontario in the 1960s, principally the Tatlock and Sharbot Lake areas. Marble mill blocks are no longer produced, with most of the output being in the form of pulverized stone for terrazzo chips and other uses from quarries in the Madoc area. However, Karnuk Marble Industries Inc. in Cornwall does process imported mill blocks in a recently established, European–equipped plant and has conducted some exploratory work for the extraction of mill blocks.

The potential for building stone from Grenville marble in eastern Ontario has been discussed in Verschuren et al., (1985, p.24–34).

DEFINITIONS OF BUILDING STONE

Building stone is classified as either mill blocks or cut stone. Mill blocks are large rectangular blocks of stone measuring several metres on the side and weighing up to 40 tonnes, though typically 15 to 20 tonnes. Modern processing equipment and the economics of processing generally demand that mill blocks be as large as possible to increase the overall recovery rate. For maximum quarry recovery mill blocks should be at least 2 m x 1 m x 1.3 m and ideally 3 m x 1.3 m x 1.5 m.

Cut stone or finished stone is sawn from mill blocks to specific size specifications. The cut stone panels may range in thickness from 1.5 cm to 20 cm, depending on their use for exterior or interior requirements and the type of sawing equipment used. Cut limestone is now most commonly employed for interior applications, although certain exterior uses are not uncommon. Cut stone may also be used for sills, lintels, steps, coping, etc. Cut marble is employed for both interior and exterior uses. A variety of surface finishes are available for cut stone; limestone is supplied with gang–sawn finish, chat or shot–sawn finish, smooth machine finish, wet cobbed or hand finish, depending on the fineness of finish required. Marble for interior use is generally polished, while that for exterior uses has a sawn, rubbed, or honed finish.

Building stones are defined under a variety of names, depending upon their use and finish. Rectangular blocks of stone up to 30 cm or more in length and bounded by sawn, planed, or planar surfaces and used in walls or building faces are termed "ashlar" or "coursing ashlar". "Split–faced ashlar" has a natural rock face produced by splitting the rock by machine guillotine or other methods along the line of fracture on both sides of the stone. "Rock–faced ashlar" has a natural rock face pitched by hand tooling.

"Even–faced ashlar" uses blocks of equal height for each course, with the blocks of each course being equal or unequal in length. "Random coursed ashlar" uses blocks of differing size and height. Both types of ashlar are well represented in the limestone buildings of Queen's University and the Royal Military College in Kingston.

Ashlar may also have a finish referred to as "pointed face", "hammered face" and "pick face". The terms correspond to the method used to develop a planar face. Pointed ashlar is produced using a pointing chisel, hammered ashlar by the use of a hammer, and pick ashlar by the use of a mason's pick.

Ashlar may also have a sawn face and can be laid up with the bedding surface exposed. In this case it is termed "strataface ashlar" or coursing.

Rubble is a term applied to irregular building stones up to about 30 cm in length. The stones are not regularly rectangular and there is no even coursing.

Flagstone consists of thin beds of stone 2 cm to 8 cm in thickness. "Regular" flagstone is rectangular in shape with sawn or rock face edges. These are used for steps, paths, patios, etc. "Random flagstone" is irregular in shape with rock faces and is commonly used for walks, patios, etc. "Wall flagstone" is thin (0.5 cm to 2.5 cm) natural random flagstone used for interior wall applications. It is a variety of veneer.

Veneer is made from thin slabs of stone from 1.5 cm to 8 cm in thickness and may be even shaped or irregular. It is used as facing stone for buildings, walls, etc. The slabs are set on edge and present their large face to the viewer. New technology for the manufacture of large limestone veneer faces is revitalizing this market. Thin (1 cm to 2 cm thick) smooth–faced limestone veneers are adhesively and/or mechanically bonded to pre–cast concrete panels at the stone dressing plant, and these panels are then placed in position at the building site. The result is a very economic method of construction. An example of this technology is the recently completed county court house in Ottawa which is faced with "Adair Marble", a dolostone produced by Arriscraft Corporation in the Wiarton area.

Other uses of building stone are for copings, steps, sills, hearths, mantles, chimney caps, riprap and armour stone, and monumental stone. Granite is the most common stone used today for monumental stone; limestone is rarely used, and marble only occasionally.

PROPERTIES OF BUILDING STONE

The physical properties of building stone are important in evaluating the quality of a building stone deposit. Some of the key considerations are:

- geological features such as character of jointing, bedding, uniformity of colour and freedom from intrusion, shear zones, alteration zones and deleterious materials.
- chemical composition, especially as it may affect the weathering properties of the stone.
- petrographic examination to determine the mineralogical composition of the stone and its texture, grain size, alteration and type and character of cementation.
- colour and uniformity of colour, especially over time.
- staining and efflorescence due to deleterious materials such as pyrite and soluble salts.
- absorption and porosity of the rock, which influence the frost resistance of the rock.
- durability and soundness, freeze–thaw resistance and abrasive hardness.
- compressive strength and transverse strength.

QUARRYING METHODS

Geological features such as bedding, foliation, jointing, rift and grain are very important features to consider in planning a quarry operation. The thickness of the beds largely determines the thickness of mill blocks that can be removed from sedimentary formations. Foliation is frequently present to some degree in marble. The direction, dip, and frequency of joints is of primary importance in quarry development of all stones. Spacing of vertical joints may govern the size of mill blocks which can be removed and if vertical joints are spaced too closely they may render the stone commercially useless for building stone. The directions of easy breaking, rift and grain, should be used in laying out the quarry plan.

There are four main quarrying methods used in Ontario building stone quarries:

1. Hand quarrying
2. Knox method
3. Channelling by drilling and broaching
4. Wire saw method

HAND QUARRYING

Nearly all the small building stone quarries in Ontario, which produce ashlar, flagstone, sills, coping, steps, etc., are operated by hand quarrying methods. Hand quarrying is employed where the bedding planes are relatively closely spaced, usually from 5 cm to 25 cm apart. Equipment consists of air compressor, drills, crowbars, wedges, chisels, plugs and feathers and in some instances portable stone saws using diamond blades.

The quarries of the Wiarton area quarrying the thin Eramosa Member beds of the Amabel Formation employ portable diamond saws to cut the stone in place in the quarry. The diamond saws have blades of 30 cm to 45 cm in diameter and cuts are made as desired across a quarrying width of 4 to 5 m. The stone is lifted by bars and fork lift trucks.

KNOX METHOD

The Knox method of quarrying was employed at Queenston Quarries (site NI–4 in the Niagara District chapter, Volume III). The building stone occurs in a ledge 3 to 5 m thick with beds 0.3 to 2 m thick. When a sufficient area had been stripped of the overlying rock, the beds were examined for vertical joints which may occur 3 to 15 m apart. The Knox method requires three free faces and a bedding plane on the bottom. The free quarry face is established at right angles to the jointing by removal of a key block from one joint to the other. The block to be quarried is then bounded by the free quarry face on one side and by the two joints at either end, or by one joint and an open end where the adjacent block has been removed. Quarry blocks are split off parallel to the free face by making a back–wall cut parallel to the free face at a distance of 3 to 3.5 m from the face. A series of 3.5 cm holes are drilled, 3.5 to 4 m deep, on 0.6 m centres in a line parallel to the quarry face at the required distance from the face. Jackhammers or Joy wagon drills were used for drilling. The line of holes was from 3 to 15 m long depending on the joint spacing.

The drill holes are reamed by a Knox bit which grooves the hole on each side in the direction along which the break is to be made. The holes are loaded lightly with black powder and fired with caps. An air space is left in each hole between the charge and the tamping to allow the force of the explosion to be exerted on a relatively side surface. Where there are horizontal bedding planes in the block to be quarried, a charge is placed for each bed.

The quarry block is separated from the solid ledge by the blast and then drilled and split by plug and feather into random mill blocks. Horizontal holes may be drilled to lift the beds where necessary. Blocks are handled by derricks.

CHANNELLING BY DRILLING AND BROACHING

The method of channelling and broaching using quarry bars was formerly employed in some limestone quarries in Ontario. The method involves cutting out the block by closely spaced drill holes and breaking out the web of rock between the holes by a broaching tool. Two to four drills are mounted on each quarry bar and clamped to drill at the required angle. The drills can then be moved along the bar to drill a series of parallel holes. The channelling is usually carried out on the four vertical sides of the block. If necessary horizontal holes can be drilled to break out the block at the base. Mill blocks are handled by a derrick.

WIRE SAW METHOD

The wire saw was formerly used to quarry marble at the Tatlock quarry of Omega Tile and Terrazzo Ltd. Sawing was done by a three–strand steel wire 5 to 6 mm in diameter, using sand or carborundum as the abrasive. Modern wire saws use a diamond wire. Wire saws are also used in stone dressing plants for cutting stone.

Recent technological advances in drilling methods include the use of jet cutting and water assisted jet cutting torches and the use of multiple circular saws. Quarrying methods for building stone, however, will largely continue to rely on a considerable amount of hand labour in order to minimize breakage of the mill blocks.

STONE DRESSING

In many of the small limestone quarries the stone is dressed by hand cutting, using hammers and chisels for cutting and shaping the stone. In several quarries split faced ashlar is made by splitting the stone by guillotine, a hydraulic cutting machine whose cutting edge consists of a series of 2.5 cm teeth which will accommodate themselves to irregularities in the stone. Portable diamond saws are used in some limestone quarries for cutting stone to desired sizes.

Mill blocks are cut by gang saws using either steel blades with silica sand as the abrasive or diamond set saws. Diamond saws are considerably faster. Modern gang saws may have up to 120 blades and can be operated in either the horizontal or vertical direction in a fully automatic mode.

Stone cutting is also carried out by circular diamond saws and by wire saws. Planing machines are employed for giving the stone a smooth finish, making special shapes and mouldings. Polishing of marble is done on rubbing and polishing beds. Modern surfacing and polishing equipment consists of multiple–head (up to 8) grinders and polishers. This equipment is often fully automated and allows for the assembly line production of stone pieces.

For detailed information on a modern processing plant, refer to the description of the Karnuk Marble Industries Inc. plant (site CW–28) in the Cornwall District chapter, Volume II.

Pulverized Stone and Stone Chips

INTRODUCTION

A relatively small but specialized market has persisted in Ontario for many years for distinctly coloured marble and limestone chips and, particularly, for white marble chips. Markets for these products include terrazzo, landscaping and gardening, exposed aggregate in precast concrete panels, in sulphite pulp production, agricultural limestone, stucco, cultured marble, tile grout, poultry grit, animal feed additives, and sand traps for golf courses.

White Grenville marble of high chemical purity, either calcitic or dolomitic, is preferred for most uses. Terrazzo chips, however, are required in a variety of colours and are also derived from certain coloured Paleozoic limestones.

TERRAZZO CHIPS

Marble and limestone chips in various sizes and colours are used as coarse aggregates in floors and window sills, particularly in offices and institutional buildings. The chips are bonded by a fine-grained neutral or coloured cementing matrix, and are generally cast in place. After hardening, the exposed surface is ground and polished by portable electric equipment. The industry is represented in Canada by The Terrazzo, Tile and Marble Association of Canada with offices in Toronto.

The physical properties of a number of terrazzo aggregates from the Madoc area of Eastern Ontario have been favourably compared with imported ones by Hewitt (1964). Colour should be uniform, texture should be fine-grained and massive, absorption should be low, and abrasive hardness should be sufficient to withstand whatever wear is anticipated. While siliceous minerals improve the abrasive hardness of a marble, they are undesirable because of the difficulty of getting a uniform polish over the entire chip plus the increased polishing costs.

WHITE MARBLE CHIPS

Except for finely-ground white calcitic marble, which enjoys a substantial market in a variety of industrial filler applications, coarser marble products have a limited market in a variety of uses. Although good whiteness is generally essential, coarser marble products can be either calcitic or dolomitic in composition. Some of the principal uses are outlined as follows.

PULP AND PAPER

Blocks with diameters in the range of 20 cm to 35 cm, either calcitic or dolomitic in composition, are used in the Jensen tower system for making the sulphurous acid–bisulphite solution necessary in the production of sulphite wood pulp. The solution is made by bubbling sulphur dioxide gas through water towers packed with high–purity lump limestone or dolostone.

Although whiteness is desirable, chemical purity is more important. If limestone is used, the lime content should exceed 53 percent, the magnesia content should be less than 1.5 percent, combined silica, alumina and iron should be less than 1.5 percent, and organic matter less than 0.5 percent. If dolostone is used, the calcium carbonate content should be 54–59 percent, magnesium carbonate 35–44 percent, iron and alumina not more than 1 percent, and total insolubles not more than 2 percent (Hewitt, 1960, p.16).

LANDSCAPING AND GARDENING

White marble chips are enjoying a strong demand for decorative purposes in various gardening and landscaping uses, such as for surface dressing on driveways and garden paths, and as accent features in planters and gardens. At the retail level they are sold either in plastic bags or in bulk at most plant and garden nurseries.

Specifications are not critical. The stone can be either calcitic or dolomitic and not necessarily of high chemical purity as long as it is durable and of uniform whiteness. Coarse–grained marbles, although sometimes more friable, may be preferred because of the lustre on cleavage faces. Coloured impurities either as disseminated dark minerals, off–colour chips, or as foreign rock fragments should be minimal. Preferred chip size is –1 1/4 in. +3/4 in. and to a lesser extent –3/4 in. +3/8 in. A superior product is produced by washing away any fines adhering to the chips after crushing and screening.

POULTRY GRIT

A substantial market exists for poultry grit, and sand for tropical fish tanks, etc. Calcitic marble has generally been preferred, but dolomitic material and other less soluble rocks are sometimes used. At least three grit sizes are in demand: –3/16 in. +1/8 in., –6 mesh +12 mesh and –12 mesh +40 mesh.

STUCCO, CULTURED MARBLE, TILE GROUT

For these markets, both calcitic and dolomitic marbles are suitable. Whiteness and freedom from specking is essential. Products are generally required to be ground to about 200 mesh.

EXPOSED PRECAST AGGREGATE

White marble chips with similar specifications to gardening and landscaping stone are used in precast concrete panels in the construction of institutional buildings. The chips are normally only lightly imbedded in the concrete so that their exposed surfaces give an aesthetically pleasing exterior wall surface.

In addition to the specifications previously detailed, the chips should be free from discolouring impurities such as iron and sulphide minerals which might stain the surface through subsequent weathering.

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Part 4 — Production, Economics and Markets for Limestone Commodities

Limestone Aggregates

DEMAND

Construction and related uses account for the majority of crushed limestone demand, generally over 90% of the total. Reliable data on the distribution of demand within construction–related end uses are difficult to obtain. Data derived from analysis of production reports to the Ontario Ministry of Natural Resources indicate that significant shifts in the volume and value of production do occur. These shifts are principally due to the effects of the business cycle on construction activity. The data showing end use demand in recent years are provided in Figure 4.1 and Figure 4.2 and show the following:

- Ontario crushed stone production has remained relatively stable from 1980 to 1985, but with significant declines during the 1982–1983 recession;
- The distribution of stone demand by end use has also remained relatively constant, except for the influence of the business cycle. During the 1982–1983 period the percentage of stone consumed in road–related end uses increased significantly. Other end uses declined during this period. This shift in end use consumption patterns reflects the steady demand for road building aggregates, versus the more vulnerable demand for other uses such as non– residential construction.

On a regional basis there is some difference between Eastern and Central Ontario in terms of the demand for crushed limestone. Figure 4.3 illustrates 1985 demand patterns for stone. As can be seen, asphalt and concrete aggregate are more important products in Eastern Ontario than in Central Ontario. However, these differences may be accounted for by reporting errors and incomplete data. Overall, regional differences in end use distribution patterns are believed to be slight.

Approximately 50% of the road building aggregate used in Ontario is crushed stone, the balance being gravel and crushed gravel. Most of the crushed aggregate is consumed as Granular A, asphaltic hot mix and concrete aggregate material. Very little crushed limestone in Ontario is used as sub–base. In recent years there has been an increase in the use of crushed limestone in place of sand and gravel for road building aggregate. This results from cost and availability problems associated with sand and gravel production in certain parts of the Province as well as substitution of HL4 crushed limestone in place of HL3 crushed gravel for certain heavy traffic highway applications.

Imports and exports of crushed limestone vary considerably from year to year. The major importing centres are in southwestern Ontario, principally Sarnia, Windsor and Kingsville. Imports are almost exclusively by vessel from the large quarries in Michigan operated by the steel companies and the Standard Aggregates Inc. Mantoulin Island quarry. Imports of crushed limestone have averaged 590,000 tonnes per year, but have fluctuated from

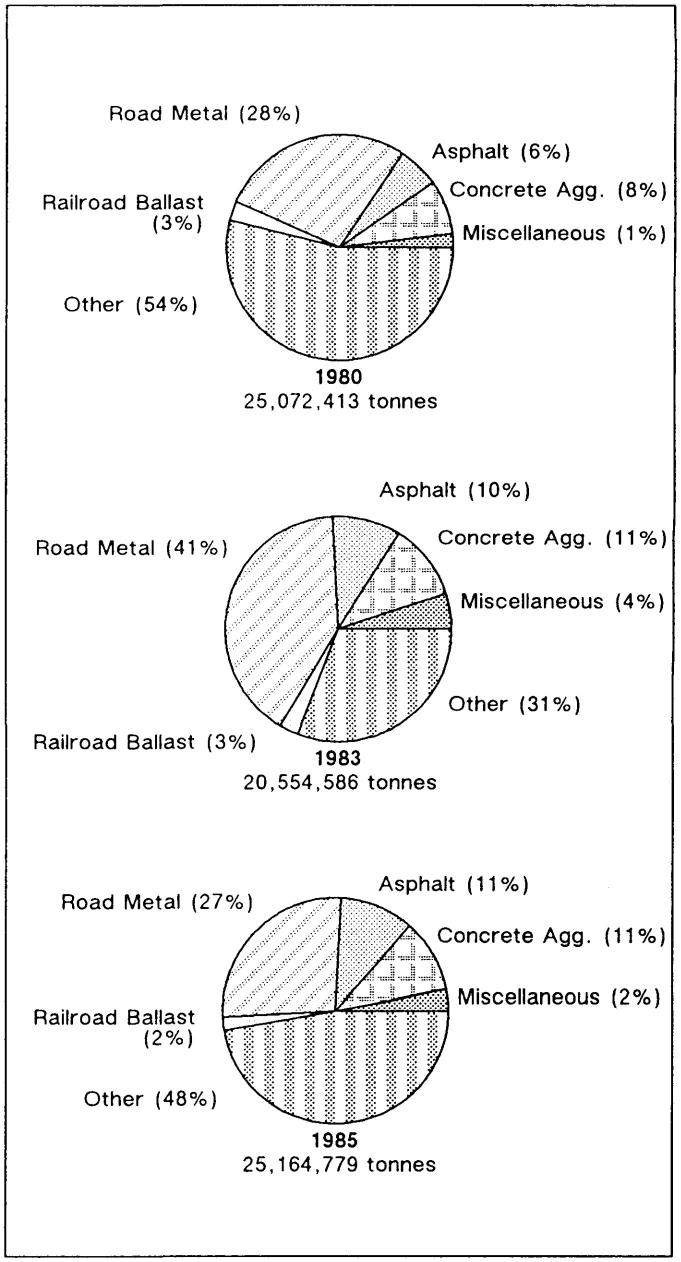


Figure 4.1. ONTARIO STONE PRODUCTION BY USE. *Data source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1981-1986 and Canadian Minerals Yearbook, 1986.*

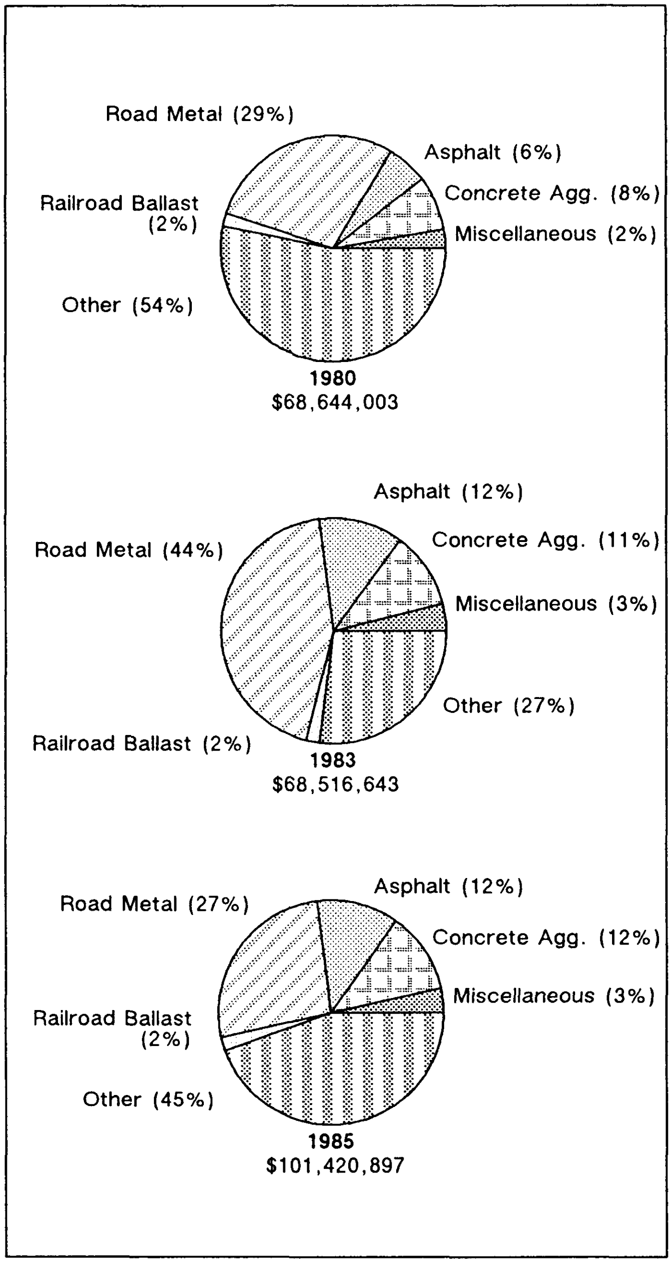


Figure 4.2. VALUE OF ONTARIO STONE PRODUCTION BY USE. *Data source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1981–1986 and Canadian Minerals Yearbook, 1986.*

a low of 451,000 tonnes to a high of 717,000 tonnes during the 1982–1985 period.

Exports of crushed limestone and dolostone have been from only two centres – Port Colborne Quarries Ltd. in Pt. Colborne, and Standard Aggregates Inc. on Manitoulin Island. Most of the stone has been exported for construction related uses, although the Manitoulin quarry has been successful in penetrating the US market for metallurgical stone. Data on imports and exports of crushed limestone are provided in Table 4.1.

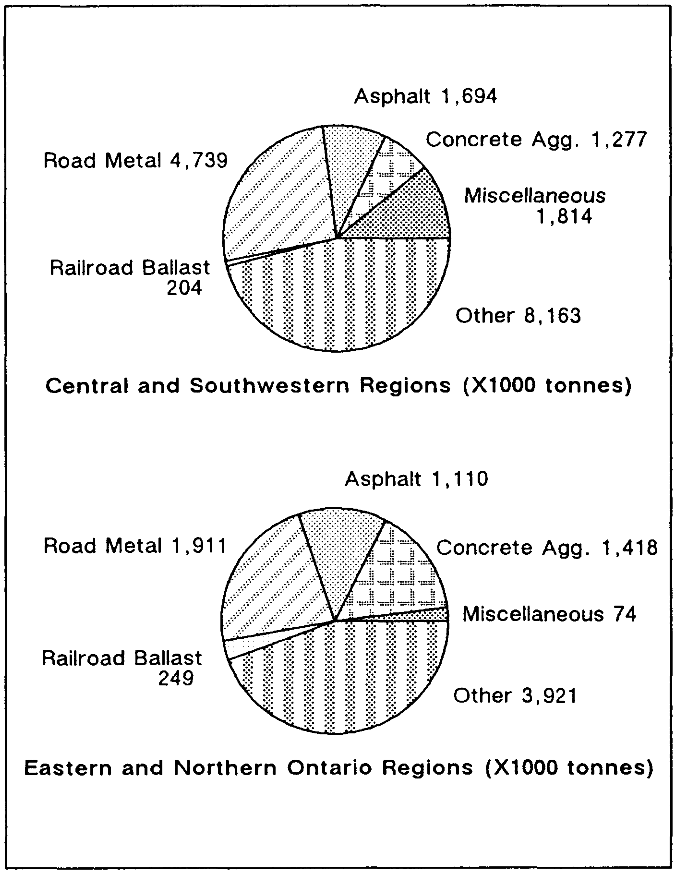


Figure 4.3. 1985 STONE PRODUCTION BY USE. *Source: derived from Ontario Mineral Score data.*

Data on total Canadian and US demand for crushed limestone are provided in Figure 4.4 and Figure 4.5. As can be seen, the distribution by end use is approximately the same in both countries.

Demand for crushed limestone for all uses is expected to increase in line with road building and construction activity. A simple linear regression model of demand is provided in Figure 4.6. This forecast predicts crushed limestone production will increase from the 1985 level of approximately 45 million tonnes to a level of approximately 65 million tonnes in 1996. This represents an average annual increase of 3.4%. Figure 4.7 provides a similar forecast for sand and gravel production. As can be seen, most of the increase in crushed stone production is attributable to the decline in sand and gravel production. Forecasts of limestone demand for chemical and metallurgical uses indicate relatively little change. Thus, one can conclude that the increased

Table 4.1. TRANS-BORDER MOVEMENTS OF STONE FROM ONTARIO.

	(tonnes)							
	1982		1983		1984		1985	
	Agg.	Chem/Met.	Agg.	Chem/Met.	Agg.	Chem/Met.	Agg.	Chem/Met.
Cdn.-US ports	26,308	203,157	518,028	299,198	333,558	163,400	821,775	357,831
US-Cdn. ports	451,059	893,917	683,068	946,150	512,544	1,127,329	717,271	1,052,579

Source: Statistics Canada, 1986

production of crushed limestone will be primarily attributable to the increased demand for construction– related aggregate. More detailed forecasts of the demand for construction aggregates have been prepared in conjunction with assessments of the supply of aggregate materials. These forecasts have been prepared on a provincial and on a regional basis.

- Proctor and Redfern Ltd. and Gartner Lee Associates Ltd. prepared several studies of aggregate supply and demand in the 1970s for various Ontario regions. These studies indicated that supplies of crushed stone from currently licensed quarries would be exhausted shortly after the year 2000 in many regions of the Province.
- Forecasts of aggregate demand in the Toronto, London, Windsor and Sarnia areas (Peat, Marwick and Partners and M.M. Dillon Ltd. 1980) predicted demand for crushed stone would exceed then currently licensed reserves in the early 1990s (London area) and approximately 2000 (Toronto area). Supply in the Windsor and Sarnia areas was already deficient.

All of the studies indicated that supplies of crushed stone would have to be obtained from more distant sources at considerably increased costs or that new quarries would have to be licensed within the regions under study if transportation costs were to be minimized.

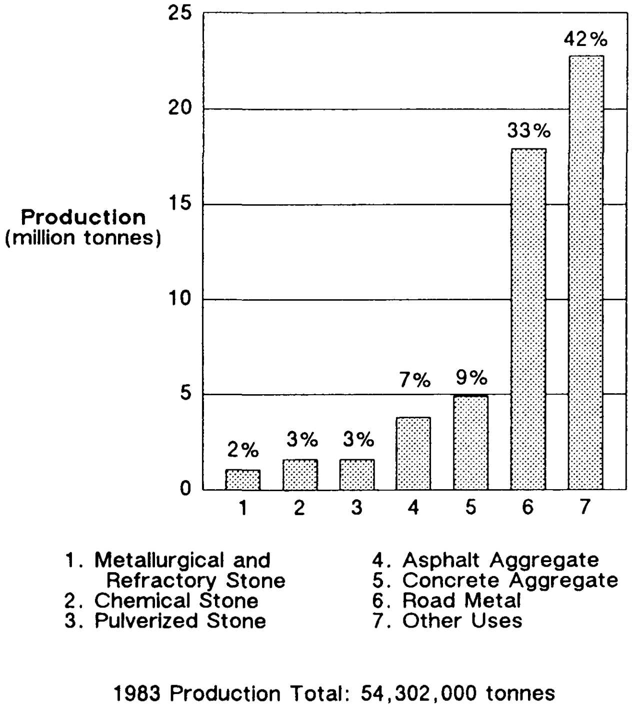


Figure 4.4. CANADIAN LIMESTONE AND MARBLE PRODUCTION. *Source: Canadian Minerals Yearbook, 1986.*

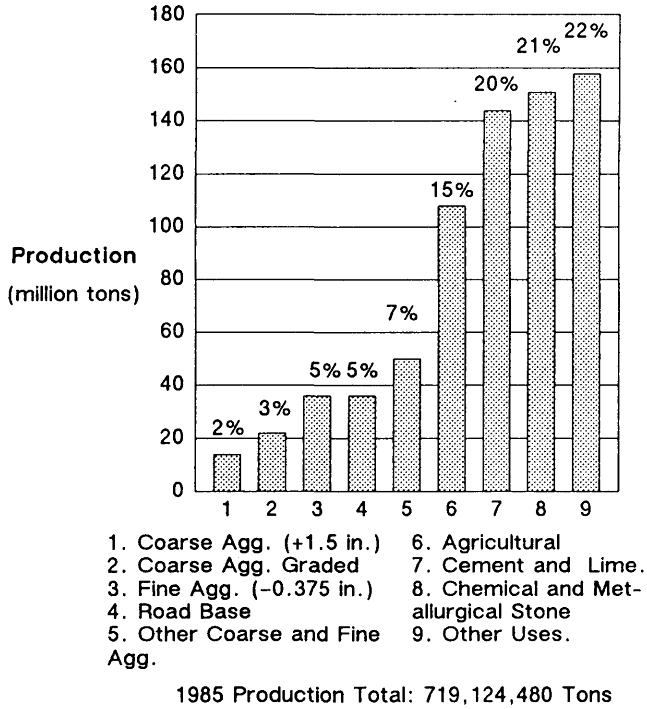


Figure 4.5. US LIMESTONE, DOLOSTONE AND MARBLE PRODUCTION. *Source: US Bureau of Mines Minerals Yearbook, 1985.*

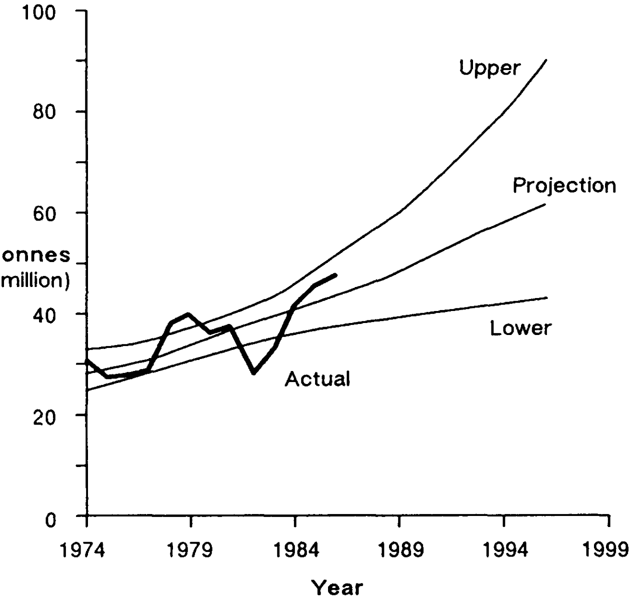


Figure 4.6. ONTARIO STONE PRODUCTION FORECAST, SHOWING ACTUAL DATA, PROJECTION AND 95% LIMITS.

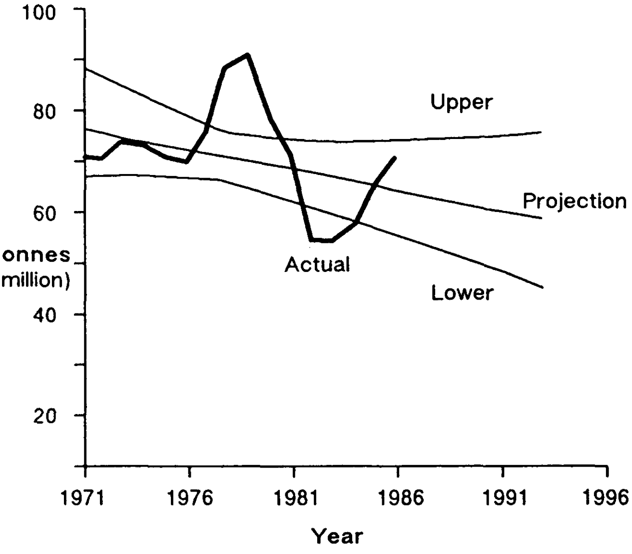


Figure 4.7. ONTARIO SAND AND GRAVEL PRODUCTION FORECAST, SHOWING ACTUAL DATA, PROJECTION AND 95% LIMITS.

AGGREGATE SUPPLY

Aggregate supply must be considered in terms of the quality of the available material, the quantity of the available material, and the costs of the material. Aggregates which are available only at very high prices should not be considered to be part of the current supply base. Several studies of the supply of aggregate materials have pointed out that aggregate shortages can be expected to develop around the year 2000 in most regions of the Province due to exhaustion of currently licensed reserves. In response to these concerns, the Government of Ontario has implemented new land use planning guidelines designed to protect aggregate sources from incompatible uses which would prevent future utilization. The Mineral Aggregate Resources Policy Statement is designed to balance the need for aggregate against other land uses within the local planning framework.

Possible new sources of supply of coarse limestone aggregate include Manitoulin Island and some of the quarries operated by the current cement producers such as St. Lawrence Cement Inc. at Colborne and Lake Ontario Cement Ltd. at Picton. The General Chemical Canada Ltd. quarry at Amherstburg is also a possible major source of aggregate. To some extent, these sources have been developed. For example, Standard Aggregates' Manitoulin quarry has displaced a considerable volume of imported stone in the Sarnia- Windsor market area. These new sources, however, will not meet requirements of all products due to either chemical or physical limitations of the stone or high delivered costs.

PRODUCTION COSTS

Production costs for crushed limestone are shown in Figure 4.8. In 1985 total costs of production averaged \$2.36/tonne. Of this cost, 40% was accounted for by items such as explosives, spare parts, etc. Energy, principally diesel fuel and electricity, accounted for 14% of costs, while direct and indirect labour accounted for 31% of costs. During the 1980–1985 period the fastest rising costs have been for energy and direct labour. Other costs have not changed significantly.

On a regional basis one can note differences in production costs. These are shown in Figure 4.9. The differences are believed to originate with the differences in the relative size of quarry operations in Eastern and Northern Ontario versus those in Central and Southwestern Ontario; the average size of operation being considerably larger in the Central and Southwest regions. In terms of the distribution of costs there are relatively few differences between the regions except for labour, with Eastern and Northern Ontario having a significantly higher labour cost per tonne. On an overall basis the Eastern and Northern region had a production cost of \$2.46 per tonne, versus a cost of \$2.32 per tonne for the Central and Southwest region.

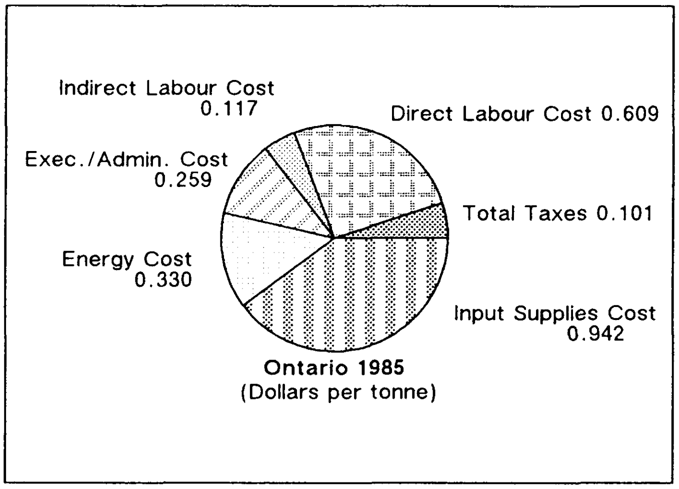


Figure 4.8. COSTS OF STONE PRODUCTION, ONTARIO 1985. *Derived from "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.*

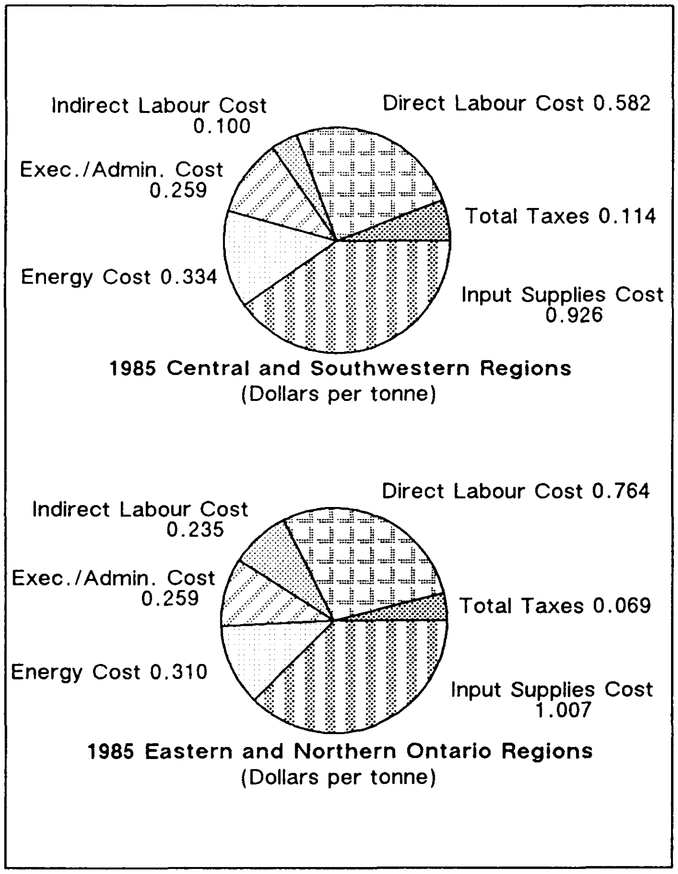


Figure 4.9. COSTS OF STONE PRODUCTION BY REGION - 1985. *Derived from "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.*

PRICES

There are no standard prices for crushed limestone. In addition to supply and demand factors, prices are determined regionally, or even locally, by production and transportation costs, by the degree of processing required for a particular end use and by the quantity of material required for a particular project. Transportation costs are particularly significant as the choice between two competing sources of supply is based on the delivered price of the stone.

Some guidance as to prices can be obtained from reference to Statistics Canada data which shows the following for Canadian limestone prices in 1983:

End Use	1983 Price/Tonne
Artificial Stone	$38.00
Roofing granules	9.87
Poultry grit	19.12
Stucco dash	28.00
Rubble & riprap	5.00
Concrete aggregate	3.79
Asphalt aggregate	4.02
Road metal	3.56
Railroad ballast	3.54
Other uses	3.33
Average value, all uses including chemical & metallurgical	4.02

As can be seen, the lower volume, more highly processed materials attract prices considerably in excess of those for other materials. Prices are expected to increase in line with production costs and the costs for quarry rehabilitation and taxes.

TRANSPORTATION COSTS

Transportation costs are a significant factor in determining the delivered price of stone and the markets available to a particular producer. Where access to cheap and efficient transportation is available, crushed stone can be delivered to sites several thousand kilometres distant at prices competitive with nearby sources. A good example of this occurs in the Strait of Canso area in Nova Scotia, where the local producer has been able to ship stone to points as far as Houston, Texas and to the Caribbean due to ready access to deep water shipping facilities. In Ontario, aggregate is moved by truck, ship and rail. Truck is by far the most important mode. The Aggregate Producers Association of Ontario estimates that over 2.5 million deliveries to Metro Toronto were made by truck in 1986. Water-borne movements of stone are relatively minor at present but are expected to increase in significance during the next decade. Rail transport of stone is rapidly declining in importance. It represents less than 5% of the total tonnage movement.

Trucking is expected to remain the dominant transportation mode. It offers the greatest flexibility to both producer and consumer in terms of frequency of delivery and average load size. It also requires the least amount of fixed investment for loading and unloading facilities and the least amount of double handling of the stone. For most quarry operators, trucking is the only possible transportation method. Representative truck operating costs as of mid–1986 for typical Ontario bulk operators are shown in Table 4.2. It is readily seen that transportation charges can rapidly exceed the FOB cost of the stone. In general, it is difficult for a quarry operator to be successful in selling to markets beyond a radius of 100 km from his plant.

Shipping costs by water are considerably below those for trucking. For example, typical 1985 costs for shipping 20,000 tonne loads from Manitoulin Island to various Ontario ports, depending on the line used, were:

Sarnia	\$2.73 – \$3.35 per tonne
Windsor	\$2.99 – \$4.10 per tonne
Sault Ste. Marie	\$2.63 – \$4.50 per tonne
Nanticoke	\$3.99 – \$6.00 per tonne

These rates are for self–unloading vessels delivering full loads; partial loads and drop–offs adding considerably to the freight charges. Water–borne movement of stone is generally not practical from the upper lakes to Lake Ontario ports due to the tolls on the Welland Canal and the extra transit time. Nevertheless, should trucking rates continue to escalate, and should the availability of nearby aggregate sources diminish, movement of stone from locations such as Manitoulin Island to southern Ontario ports must be considered a real possibility.

Rail shipping, while cheaper than trucking, is very inflexible. It requires very large volumes of stone and a large investment in terminal facilities at either end to be economic. Very few aggregate producers generate the required volumes to justify the expense. In addition, the stone must generally be moved by truck to its final destination. The extra handling adds considerably to the delivered cost of the stone.

TECHNOLOGICAL DEVELOPMENTS

Technological developments affecting the demand for aggregate include the following:

- Increased recycling of asphaltic hot mix. Currently about 9% of asphalt is recycled. This is expected to increase in the coming decade and to reduce the demand for Granular A and HL3 and HL4 material.
- Development of longer lasting asphaltic mixes using new additives such as sulphur, rubber, and other compounds. These mixtures are currently only in the test stage but show promise in substantially increasing the life of pavement.
- Increased use of aggregate substitutes such as blast furnace slag and nickel slag. These materials are currently being used as aggregate in road building, as concrete aggregate and as railroad ballast. It is expected supply will not increase and may even decrease due to a long–term reduction in blast furnace iron production and nickel production.
- Increased use of high alkali cements. This could create problems due to excessive sulphate expansion of concretes using alkali reactive aggregates. Many Ontario aggregates are not suitable for use in high alkali cements and significant shortages of suitable aggregates could result if higher alkali cements came into common use.

Table 4.2. ONTARIO BULK TRUCK OPERATING COSTS, (MID–1986).

Type of truck	Typical payload	Annual distance (km)	Cost/km		Cost/Tonne.km	
			Paved roads	Gravel roads	Paved roads	Gravel roads
5–axle semi trailer	22.6 t	80,000	\$1.422	\$1.662	\$0.0629	\$0.0735
		160,000	\$1.201	\$1.441	\$0.0531	\$0.0638
		240,000	\$1.128	\$1.368	\$0.0499	\$0.0605
7–axle semi trailer with pup	42.9 t	80,000	\$1.655	\$1.895	\$0.0386	\$0.0442
		160,000	\$1.378	\$1.621	\$0.0321	\$0.0378
		240,000	\$1.284	\$1.527	\$0.0299	\$0.0356

Source: "Operating costs of trucks in Canada", Transport Canada, 1986.

Cement

Ontario has five companies operating a total of seven portland cement manufacturing plants with a total installed capacity of 6.257 million tonnes of clinker. In addition, two slag cement manufacturing plants are operated in the province.

The Ontario portland cement industry is characterized by a high degree of both vertical and horizontal integration. Vertical integration refers to the ownership of aggregate, cement, ready–mix, concrete products, and construction companies within one corporate organization. Horizontal integration refers to the merging of one cement company with another. Horizontal and vertical integration usually have the effect of increasing economies of scale and thus reducing unit costs and increasing marketing and financing efficiencies. Vertical and horizontal integration may also have the effect of reducing competition and thus limiting price variations between competitors.

Vertical and horizontal integration in the cement industry has been prompted by the very high capital cost of new plant construction, high financing costs, the slow growth of the market, and the relatively low level of capacity utilization. Growth by acquisition is thus seen by the producers as the cheapest route to expansion and increases in cement plant operating rates. This is especially true in the case of expansion into the US market. Each of the major Ontario cement producers has significant operations in the US which receive clinker and/or finished cement from Ontario plants.

Ontario's cement industry produced 4,043,742 tonnes in 1985 and 4,843,000 tonnes in 1986. The value of production was $265 million in 1985 and $329 million in 1986. The industry directly employed 1,060 persons in 1985, and an unknown number of persons in associated industries such as ready–mix and concrete products manufacture, and haulage.

The Ontario cement operations are listed in Table 4.3. Significant characteristics of each of these companies are briefly noted in the following section.

ONTARIO CEMENT PRODUCERS

Lafarge Canada Inc. operates two cement plants in Ontario, at Bath and Woodstock. The Bath plant has a single dry process kiln with a capacity for 943,000 tonnes of clinker. The Woodstock plant has two wet process kilns with a total clinker capacity of 505,000 tonnes. Both

Table 4.3. ONTARIO CEMENT PRODUCERS, 1987.

				Capacity	
Company	**Plant Location**	**Process & Fuel type**	**No. of kilns**	**Clinker ('000 tpy)**	**Grinding**
		Portland Cement Producers			
Lafarge Canada	Bath	Dry, Coal, Oil, Gas preheater	1	943	1,000
	Woodstock	Wet, Coal, Gas	2	505	535
Federal White Cement	Woodstock	Dry, Oil	1	100	100
Lake Ontario Cement	Picton	Dry, Dry with preheater, Coal, Oil, Gas	4*	1,419	744
St. Lawrence Cement	Clarkson	2 Wet, Dry with preheater, Coal, Oil, Gas	3	1,700	2,400
St. Marys Cement	Bowmanville	Wet, Coal	2	600	790
	St. Marys	Dry, Coal preheater,	1	700	800
		Wet, Coal, Oil	2*	290	
		Slag Cement Producers			
Reiss Lime	Spragge				200
Standard Slag Cement Co.	Fruitland				200

**On standby, not normally used.*
Source: Canadian Minerals Yearbook, 1986, company contact.

plants obtain stone from quarries on site, the other raw materials being purchased.

Lafarge Canada is the largest cement company in Canada and the only company with cement production facilities in all regions of the country. Through its US operations, General Portland Cement, Lafarge Canada is the largest cement producer in North America. In Ontario, Lafarge Canada is integrated vertically through the ownership of Standard Industries Limited (aggregates, ready–mix, concrete blocks), Permanent Concrete (ready–mix, pre–cast concrete products, concrete blocks), Canfarge Limited (construction), and Richvale Block and Ready–Mix and McCord Co. (concrete block, ready–mix). The company is also involved in the reinforcing and structural steel business through its ownership of Francon Limited.

Lafarge Canada was formed as a result of the merger of the Canada Cement Company Ltd. and Lafarge Coppee S.A., a large French cement producer. The majority ownership of Lafarge Canada is held by Lafarge Coppee.

St. Lawrence Cement Inc. operates the largest cement plant in Canada at Clarkson (Mississauga), Ontario, with a total clinker capacity of 1.7 million tonnes from three kilns (two wet process and one dry process). Stone for the kilns is brought by boat from a quarry at Ogden Point, approximately 160 km east of Clarkson on the north shore of Lake Ontario.

St. Lawrence Cement is vertically integrated through its ownership of Dufferin Aggregates (aggregates), Dufferin Construction (construction), Dufferin Concrete Products (concrete blocks, ready–mix, pre–cast and pre–stressed concrete products), Boehmers Concrete (ready–mix), Custom Concrete (ready– mix, aggregates, concrete products), and Peninsula Ready–Mix & Supplies (ready– mix, concrete products), and other operations in the United States. The company is controlled by the Swiss–based Holderbank Financiere group.

Lake Ontario Cement Ltd. operates a plant and quarry at Picton on Lake Ontario. The plant has a clinker capacity of 1.419 million tonnes from 4 dry process kilns, although only two generally operate. The two operating kilns have a rated capacity of 4,000 tonnes per day. The controlling interest in the company has recently been purchased by Societe des Ciments Francais of France, that country's second largest cement producer.

Lake Ontario Cement is broadly diversified with interests in aggregate production (United Aggregates Ltd. and Maitland Concrete), ready–mix concrete and concrete block production (Premier Concrete, Primeau Argo, KVN Concrete, and Maitland Concrete), concrete products (Bestpipe, Duracon, Utility Vault, Soil Protection Systems), construction (KVN Construction), and cement chemicals (Euclid Chemical Canada). The company operates cement manufacturing and grinding plants in New York and Michigan in the United States.

St. Marys Cement Company is a privately held, Canadian–controlled company and operates two cement plants in Ontario. The Bowmanville wet process plant has two kilns with a total annual clinker capacity of 600,000 tonnes, while the St. Marys operation has a newly constructed (1981) single–kiln dry process plant and a two–kiln wet process plant. The latter plant is on stand–by and does not generally operate. Total annual capacity for the St. Marys plants is 1,590,000 tonnes. Stone for the plants is obtained from quarries on site. At the time of printing the company had announced an expansion of the Bowmanville plant.

St. Marys Cement is vertically integrated through its ownership of Canada Building Materials (ready–mix, concrete products), Pre–Con Company (pre– stressed and pre–cast concrete products and construction), Dominion Building Materials (ready–mix), Hancock Sand & Gravel (aggregates), and Hutton Transport Ltd. (bulk cement transportation). The company also owns cement grinding plants in the United States.

Federal White Cement Limited, a privately owned company, operates a white portland cement plant at Woodstock adjacent to the Lafarge Canada plant. The Federal White Cement plant was designed and constructed with the assistance of Lafarge Canada and has a kiln capacity of 100,000 tonnes per year. Stone for the plant is purchased from the Lafarge Canada quarry at Woodstock, or the nearby quarries of BeachviLime Ltd.

Reiss Lime Ltd. has recently started up a slag cement plant at Spragge, Ontario on the north shore of Lake Huron, with a capacity of 200,000 tonnes. Production is mainly used in backfill for the mines in Sudbury. Raw material for the plant is obtained from Algoma Steel in Sault Ste. Marie where the slag is crushed to minus 25mm. Reiss Lime Ltd. is 50% owned by Reiss Lime Inc. of the United States and 50% by Denison Mines Ltd. of Toronto.

Standard Slag Cement Co., a joint venture of Lafarge Canada, Koppers Co., and Steetley Industries Ltd., produces slag cement, slag aggregate, and expanded slag in Fruitland, near Hamilton from steel slag. The capacity of the plant is approximately 200,000 tonnes per year of slag cement.

ONTARIO CEMENT PRODUCTION

Ontario is the centre of cement production in Canada, accounting for 40% of clinker production capacity and 40% of cement production. The province is geographically situated to take advantage of the nearby US market. Trends in the production of cement in Ontario are illustrated in Figure 4.10. 1986 production totalled 4,843,000 tonnes with a value of $329 million or $70.66 per tonne. From 1950 through 1986, cement production in Ontario increased at an average annual rate of 4.27%, and the value of that production increased at an average annual rate of 8.79%. In constant 1986 dollars, however, the value of cement production increased at a rate of only 4.01% during the 1950 – 1986 period. The price received per tonne of production has declined slightly from 1950 through 1986 in terms of constant 1971 dollars from $23.70 in 1950 to $20.64 in 1986. Some of these trends are illustrated in Figure 4.11.

Exports represent a significant proportion of Ontario cement production, mostly destined for the US operations of the Ontario cement companies. Each of the Ontario portland cement producers (except for Federal White Cement) has clinker grinding and/or cement terminal facilities in the United States. In almost all cases these facilities are readily accessible by water transport from Ontario.

Canadian and specifically Ontario cement producers have historically operated at low levels of capacity utilization. The 1960s and early 1970s were periods of rapid expansion in Ontario cement production capacity, as was the late 1970s as the economy experienced rapid growth. Current Ontario clinker capacity is approximately 6,257,000 tonnes, while grinding capacity is approximately 6,270,000 tonnes. These data should be compared to 1985 and 1986 production of 4,043,742 tonnes and 4,843,000 tonnes respectively, indicating operating rates of 64.6% and 77.4% for 1985 and 1986. Operating rate data for Canada indicate that cement plant capacity utilization has ranged from a high of 83% in 1977 to a low of 46% in 1983, and was 57% in 1985. By way of contrast, US finished cement plant operating rates in 1985 and 1986 were 73.0% and 76.0% respectively. Clinker production capacity utilization was 77% in 1985 and 85% in 1986. Operating rates for both finished cement production and clinker production have consistently been above operating rates in Canada and Ontario for the past decade. Little change in this relationship is expected during the next several years.

CEMENT DEMAND

Demand for cement is a function of construction activity. Cement is used in all forms of construction but is a more prominent building material in commercial and engineering construction work. Table 4.4 illustrates construction activity in Ontario and the relative importance of the various types of construction activity. Figure 4.12 plots cement production ($ value) as a percentage of construction materials costs. As can be seen, cement represents

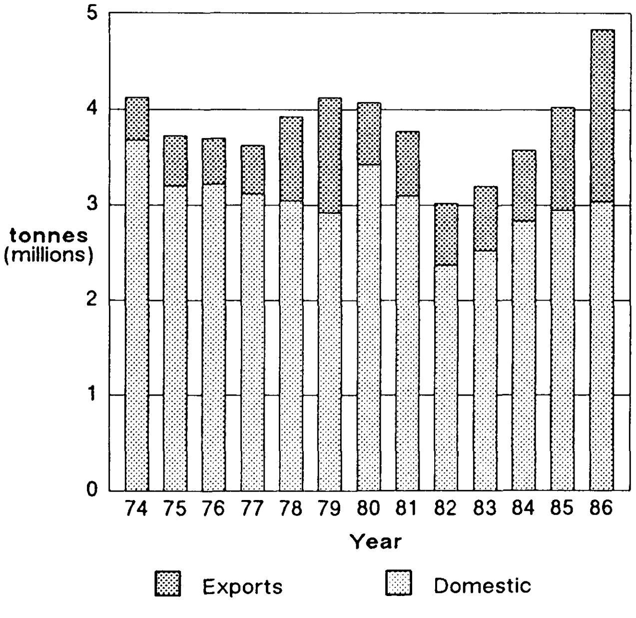


Figure 4.10. ONTARIO CEMENT, DOMESTIC AND EXPORT PRODUCTION. *Derived from data "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1987, and Statistics Canada, 1986.*

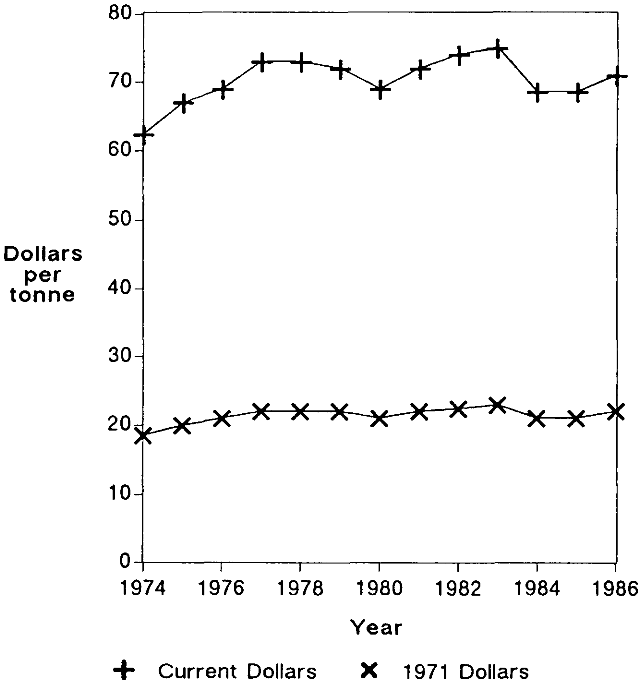


Figure 4.11. ONTARIO CEMENT, COST PER TONNE IN 1971 AND CURRENT DOLLARS. *Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.*

Table 4.4. ONTARIO CONSTRUCTION ACTIVITY, 1980-1986.

				($million)			
Type of construction	1980	1981	1982	1983	1984	1985	1986
Residential	4,229.8	4,998.8	4,475.3	5,875.4	6,313.5	7,463.2	8,775.9
Industrial	1,146.9	1,380.3	1,031.1	921.9	1,175.3	1,602.4	1,790.3
Commercial	1,682.6	1,865.3	2,166.6	2,102.6	2,612.6	3,151.4	3,546.5
Institutional	447.8	524.0	655.7	716.3	789.8	840.5	902.5
Other building	458.1	583.5	568.4	498.1	518.8	515.5	568.7
Engineering	4,042.3	4,836.5	5,510.6	4,856.5	5,359.6	5,378.9	5,394.4
Total	12,007.5	14,188.4	14,407.7	14,970.8	16,769.6	18,951.9	20,978.3

Source: Statistics Canada, 1986

between 3% and 4% of the total cost of construction materials.

Data on cement demand by type of construction activity is very difficult to obtain, though the results of some research conducted by the Canadian Portland Cement Association are shown in Table 4.5. Assuming these data to be correct, the estimated distribution of cement shipments in Canada and Ontario in 1985 and 1986 is as shown in Figure 4.13.

Data on US demand patterns by end-use for cement is provided in Table 4.6. It is seen that ready-mix and concrete products manufacturers are by far the largest users of cement. Similar end-use patterns are believed to prevail for Canada and for Ontario cement consumption.

A forecast of cement production is provided in Figure 4.14, based on a simple linear regression model and should be regarded as indicative only. The forecast predicts Ontario cement production will decrease to approximately 3,250,000 tonnes by 1995, but could range

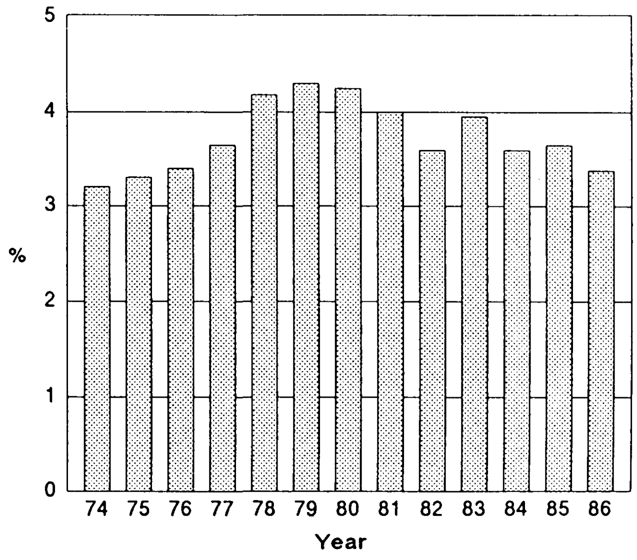


Figure 4.12. ONTARIO CEMENT, SALES AS % OF CONSTRUCTION MATERIAL COSTS. *Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986 and Statistics Canada, 1986.*

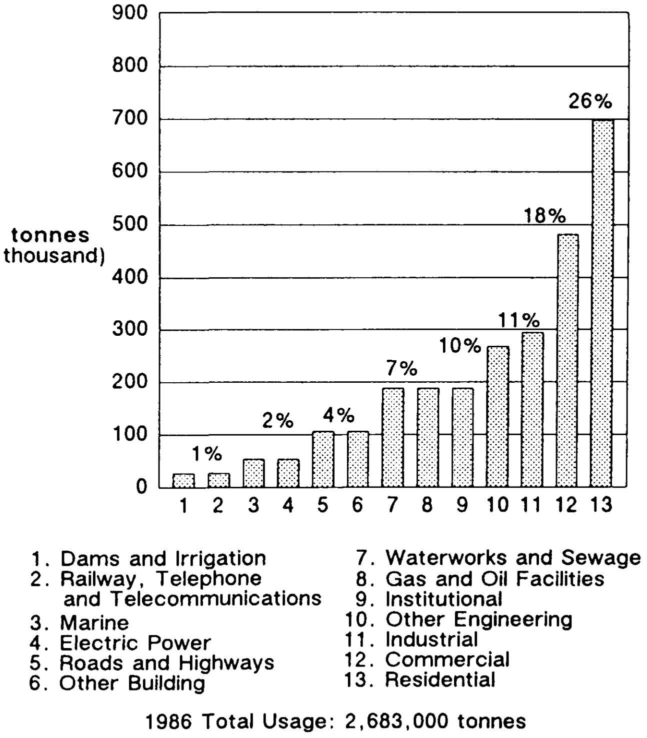


Figure 4.13. USE OF CEMENT IN ONTARIO, BY TYPE OF STRUCTURE. *Source: derived from Canadian Portland Cement Association and Statistics Canada data.*

Table 4.5 APPARENT USE OF CEMENT IN CANADA.

	tonnes (000)										
Type of structure	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Total Construction	9,016	8,566	8,441	8,282	8,368	8,428	7,962	7,758	5,994	5,847	6,000
Total Building Construction	6,779	6,149	6,010	6,363	8,928	6,000	5,480	5,280	3,743	3,850	3,987
Residential - Total	3,412	2,764	3,050	4,132	3,237	2,890	2,149	2,022	1,217	1,698	1,621
Single detached	2,233	1,800	1,948	1,763	2,073	1,776	1,342	1,340	644	1,156	1,093
Semi-detached, incl. duplexes	257	207	224	203	238	222	157	136	77	67	57
Apartments, incl. row housing	800	645	698	631	743	710	494	404	387	341	333
Other residential bldg.	76	70	135	100	131	129	108	99	71	92	92
Maintenance & repair	45	43	46	37	51	53	48	45	38	43	45
Industrial - Total	1,120	935	766	684	767	936	1,159	1,129	742	512	612
Factories, plants	1,048	862	697	633	723	873	1,088	1,053	683	450	557
Mining buildings	32	24	32	22	11	18	33	45	34	33	21
Railway stations, roadway bldgs.	17	23	14	13	12	16	7	8	6	5	6
Other railway bldgs.	9	13	8	5	7	13	14	7	8	13	15
Maintenance & repair	15	14	10	12	15	15	17	16	11	12	14
Commercial - Total	1,350	1,522	1,328	932	1,171	1,435	1,408	1,370	1,098	987	1,081
Warehouse & other storage	183	192	191	147	131	229	208	217	145	148	127
Grain elevators	9	11	14	18	21	21	19	18	20	44	39
Hotels, restaurants, clubs, etc.	181	128	84	45	94	136	134	137	109	101	110
Office bldgs.	412	448	467	347	436	447	502	509	451	403	418
Stores, retail & wholesale	248	232	240	191	286	383	343	305	194	156	165
Garages & service stations	94	84	75	57	72	43	51	54	43	44	59
Theatres, arenas & recr. bldgs.	188	397	244	98	117	141	138	115	125	108	148
Laundries & dry cleaning est.	2	1	1	1	1	2	1	1	1	1	1
Maintenance & repair	12	10	12	9	13	14	13	12	11	12	13
Institutional - Total	624	623	588	423	517	505	508	490	443	441	459
Schools & educational bldgs.	391	378	327	244	285	262	232	218	201	190	176
Churches & religious bldgs.	8	11	14	11	15	17	23	19	16	18	17
Hospitals, clinics, etc.	154	138	141	92	133	135	171	161	159	160	159
Other institutional bldgs.	68	93	101	72	79	86	78	87	82	89	102
Maintenance & repair	5	4	4	4	5	5	4	5	5	5	5
Other building construction - Total	273	304	278	192	236	234	257	269	223	191	214
Farm bldgs. (excl. dwellings)	100	95	98	83	113	119	131	129	107	90	104
Radio, T.V. & phone relay stations	35	42	42	25	29	34	35	41	31	17	21
Aircraft hangars	4	20	11	9	10	11	19	18	16	8	7
Passenger terminals	79	91	73	44	39	23	32	32	28	25	27
Armouries, barracks, etc.	3	7	5	3	6	6	3	3	2	6	9
Bunkhouses, dormitories, etc.	14	8	14	7	6	7	13	15	6	3	5
Laboratories	22	21	15	8	9	12	11	18	23	24	29
Other building construction	10	13	11	7	17	14	7	6	6	6	7
Maintenance & repair	6	6	6	5	7	7	6	6	5	6	5

Table 4.5. CONTINUED.

Type of structure	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
	tonnes (000)										
Total Engineering Construction	2,237	2,417	2,431	1,920	2,430	2,428	2,482	2,478	2,251	1,997	2,013
Marine construction - Total	182	144	115	111	127	123	122	133	151	133	140
Docks, piers, breakwaters, etc.	121	81	49	60	66	72	67	86	85	70	81
Retaining walls, embankments	12	10	11	9	11	7	6	8	3	6	6
Canals & waterways	10	4	7	8	8	8	8	8	7	6	8
Dredging & pile driving	10	7	5	7	10	5	14	9	15	13	10
Dyke construction	7	27	31	15	19	14	19	10	10	14	8
Logging booms	1	0	1	0	0	0	1	0	0	0	0
Other marine construction	9	13	10	11	10	14	6	8	30	22	24
Maintenance & repair	2	2	2	2	3	2	2	3	2	2	2
Roads, highways & runways - Total	362	353	352	279	384	356	337	296	255	252	268
Highway, road & street constr.	233	225	210	169	233	228	207	192	158	157	157
Parking lots	13	11	21	12	17	13	16	11	13	11	15
Sidewalks & paths	73	88	94	82	116	98	94	75	65	60	66
Runways, landing fields, tarmac	38	24	23	12	12	10	15	13	15	19	25
Maintenance & repair	5	5	5	4	5	6	6	5	5	5	5
Waterworks & sewage systems - Total	609	620	696	555	704	661	597	510	447	451	441
Drainage ditches, storm sewers	59	61	70	57	85	83	80	74	52	51	48
Water mains, hydrants & services	103	94	109	90	129	110	103	94	72	69	75
Sewage systems disposal plants	396	398	426	333	340	319	282	230	207	205	208
Water pumping stations, plants	36	53	77	62	132	133	117	99	102	113	96
Water storage tanks	6	5	5	5	8	7	7	6	6	6	7
Maintenance & repair	9	8	8	7	10	9	7	7	7	7	8
Dams & irrigation - Total	68	75	63	56	66	71	73	92	77	70	72
Dams & reservoirs	33	28	17	13	23	26	25	43	28	14	18
Irrigation & land recl. projects	33	46	44	42	41	43	48	48	48	55	53
Maintenance & repair	2	2	1	1	2	1	1	1	1	1	1
Electric power construction - Total	111	151	149	127	149	164	140	129	103	93	69
Electric power generating plants	86	121	122	105	136	131	110	102	79	71	45
Electric transformer stations	2	2	2	1	2	1	3	2	2	2	2
Power trans. & distr. lines	17	21	9	15	23	25	21	19	18	14	17
Street lighting	2	3	3	2	3	2	2	2	1	1	1
Maintenance & repair	4	4	5	4	5	5	5	4	3	3	4
Railway, telephone, telegraph - Total	48	45	48	35	44	47	48	46	48	49	47
Railway tracks & roadbeds	26	26	26	19	22	26	29	29	35	37	35
Signals & interlockers	2	2	2	2	2	2	1	1	1	1	1
Telephone & telegraph lines	18	15	17	13	17	17	15	14	11	8	9
Maintenance & repair	3	3	3	2	3	3	3	3	2	3	3

Table 4.5. CONTINUED.

Type of structure	tonnes (000) 1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Gas & oil facilities - Total	226	224	194	176	235	297	402	593	566	358	349
Gas mains & services	24	20	18	14	19	14	16	23	22	24	27
Pumping stations, oil	6	6	2	2	0	0	0	1	3	0	1
Pumping stations, gas	7	2	1	2	0	0	0	3	2	1	2
Oil storage tanks	4	9	5	3	2	2	1	4	4	4	3
Gas storage tanks	2	2	2	1	3	1	0	1	1	1	1
Oil pipe lines	20	49	7	1	2	7	12	23	10	16	34
Gas pipe lines	26	17	7	14	3	14	70	239	251	59	50
Oil & gas wells	84	71	95	91	152	208	252	217	181	192	204
Oil refinery - processing units	27	23	26	24	24	11	14	46	55	42	25
Natural gas processing plants	19	16	20	14	19	27	22	25	29	11	14
Maintenance & repair	8	8	10	8	11	12	14	11	8	8	7
Other engineering construction - Total	631	805	812	581	703	709	762	679	603	591	607
Bridges, trestles, overpasses	209	302	255	157	279	231	222	181	155	138	191
Tunnels & subways	14	36	57	33	31	24	22	19	23	46	26
Incinerators	2	2	1	1	1	2	2	1	1	1	2
Park systems, landscaping	29	17	21	26	36	34	35	31	32	29	31
Swimming pools, tennis courts	9	14	8	7	13	13	11	12	8	10	14
Mine shafts	256	251	296	235	267	311	358	355	320	303	284
Fences, signs, guardrails	15	15	14	13	19	20	22	20	17	16	16
Other engineering construction	91	162	151	102	100	68	82	56	44	43	39
Maintenance & repair	6	5	6	6	7	7	7	4	4	4	5

Source: Canadian Portland Cement Association, used by permission.

Table 4.6. UNITED STATES. PORTLAND CEMENT SHIPMENTS IN 1985, BY DISTRICT OF ORIGIN AND TYPE OF CUSTOMER.[1]

District of origin	Building material dealers tons (1000's)	Building material dealers %	Concrete product manufacturers tons (1000's)	Concrete product manufacturers %	Ready-mixed concrete tons (1000's)	Ready-mixed concrete %	Highway contractors tons (1000's)	Highway contractors %	Other contractors tons (1000's)	Other contractors %	Federal, State, and other government agencies tons (1000's)	Federal, State, and other government agencies %	Miscellaneous including own use tons (1000's)	Miscellaneous including own use %	Total[2] tons (1000's)
New York and Maine	226	6.2	559	15.4	2,517	69.2	198	5.4	120	3.3	1	-	20	0.5	3,369
Pennsylvania, eastern	377	8.8	1,072	25.1	2,692	63.0	38	0.9	30	0.7	(3)	-	63	1.5	4,272
Pennsylvania, western	227	18.0	21.4	16.9	703	55.6	72	5.7	48	3.8	-	-	-	-	1,268
Maryland, Virginia, West Virginia	177	5.2	599	17.6	2,395	70.5	72	2.1	78	2.3	40	1.2	30	1.1	3,399
Ohio	134	7.5	270	15.2	1,244	70.3	115	6.5	6	0.3	-	-	1	0.1	1,769
Michigan and Wisconsin	148	3.2	619	13.2	3,581	76.3	285	5.0	88	1.9	7	0.1	16	0.8	4,695
Indiana and Kentucky	129	5.4	382	13.9	1,724	72.2	128	5.2	37	1.5	-	-	44	1.8	2,389
Illinois	66	3.1	202	9.6	1,647	78.4	102	4.9	51	2.4	-	-	33	1.6	2,101
Georgia and Tennessee	166	7.7	561	25.9	1,274	59.0	31	1.4	119	5.5	2	0.1	8	0.4	2,162
South Carolina	57	2.6	386	17.5	1,662	75.3	23	1.0	52	2.4	3	0.1	25	1.1	2,307
Florida	425	13.0	395	12.0	2,232	68.0	81	2.5	101	3.1	14	0.4	32	1.0	3,282
Alabama	328	8.8	545	14.7	2,481	66.7	187	5.0	91	2.4	19	0.5	70	1.9	3,721
Arkansas, Louisiana, Mississippi	134	6.3	200	9.4	1,223	57.3	115	5.4	301	14.1	14	0.7	145	6.8	2,188
South Dakota	9	1.3	28	4.3	347	52.9	136	20.8	12	1.8	-	-	124	18.9	656
Iowa	53	3.3	295	18.2	963	59.5	277	17.1	8	0.5	6	0.4	16	1.0	1,618
Missouri	104	2.8	377	10.3	2,813	76.6	22	6.0	76	2.1	-	-	79	2.2	3,669
Kansas and Nebraska	63	2.5	136	5.3	1,756	68.9	283	11.1	271	10.6	1	-	42	1.6	2,550
Oklahoma	48	3.0	70	4.4	1,103	69.4	148	9.3	192	12.1	2	0.1	25	1.6	1,589
Texas, northern	314	5.9	410	7.8	2,710	51.3	394	7.4	1,239	28.4	98	1.9	122	2.3	5,287
Texas, southern	277	5.6	468	9.4	3,245	65.5	286	5.4	619	12.5	22	0.4	58	1.2	4,955
Idaho, Montana, Utah	52	3.0	130	7.5	1,085	62.2	179	10.3	268	15.4	-	-	28	1.6	1,743
Colorado and Wyoming	46	2.9	173	10.9	1,156	73.1	144	9.1	58	3.7	-	-	5	0.3	1,582
Alaska, Oregon, Washington	35	2.1	113	6.6	1,320	77.7	158	9.3	32	1.9	-	-	41	2.4	1,700
Arizona, Nevada, New Mexico	79	3.6	364	16.1	1,456	66.4	45	2.1	239	10.9	2	0.1	17	0.8	2,192
California, northern	163	6.3	298	11.5	2,007	77.4	27	1.0	75	2.9	7	0.2	18	0.7	2,596
California, southern	439	6.4	883	12.9	5,060	73.6	12	0.2	387	5.6	17	0.2	68	1.0	6,868
Hawaii	14	6.5	30	14.0	152	70.7	2	0.3	11	5.1	2	0.9	4	1.9	215
Foreign imports[4]	73	2.0	52	1.5	5,402	96.3	3	0.1	-	-	-	-	3	0.1	5,532
Total[2] or average	4,363	5.5	9,771	12.2	55,950	70.1	3,687	4.6	4,609	5.8	257	0.3	1,145	1.5	79,781
Puerto Rico	467	48.5	44	4.6	430	44.7	-	-	18	1.9	2	0.2	1	0.1	962

[1] *Includes Puerto Rico.*

[2] *Data may not add to totals shown because of independent rounding.*

[3] *Less 1/2 unit.*

[4] *Cement imported and distributed by domestic producers only. Source of imports withheld to avoid disclosing company proprietary data.*

Source: U.S. Bureau of Mines, Minerals Yearbook, Cement, 1985.

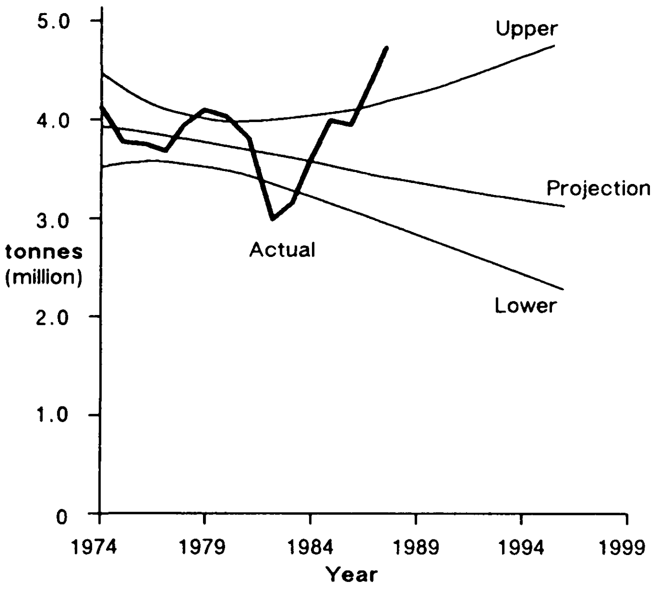


Figure 4.14. ONTARIO CEMENT PRODUCTION FORECAST, DATA, PROJECTION AND 95% LIMITS.

from a high level of approximately 4,400,000 tonnes to a low level of approximately 2,400,000 tonnes by that date. In all cases though, cement production capacity will significantly exceed the forecast demand level. Estimates of US cement demand in the year 2000 range from a low of 85 million tons to a high of 115 million tons, with 100 million tons being the most probable demand level. The data are provided in Table 4.7. These data should be compared to total US demand for cement of 91.8 million tons in 1986 and US clinker production capacity of approximately 90.0 million tons. It is obvious that imports will continue to fulfill a significant proportion of US cement demand for the foreseeable future.

Factors which could have an impact on cement demand, exclusive of variations in construction activity, include the following:

- A change in commercial construction to the use of reinforced and pre–cast concrete in place of structural steel. Much of the construction activity in southern Ontario is now of reinforced and pre–cast concrete. There has been a decided shift away from structural steel construction for many large office buildings. An example is the new Scotia Plaza tower in Toronto, a 68 storey reinforced concrete building. This building would have been constructed of structural steel if built 20 years ago.

Table 4.7. PROJECTIONS AND FORECASTS FOR US CEMENT DEMAND BY END USE-2000.

		2000			
			Contingency forecast for US		
		Statistical	Forecast range		
End use	1983	projections[1]	Low	High	Probable
		(Million short tons)			
Ready-mixed concrete	47	72	60	80	70
Concrete product manufacturers	8	14*	11	15	14
Highway contractors	4	0*	1	1	1
Building material dealers	5	4*	4	5	4
Other	10	14*	9	14	11
Total	74	-	85	115	100

[1] *Statistical projections, provided by the Branch of Economic Analysis, are derived from regression analyses based on historical time series data and forecasts of economic indicators such as GNP, and FRB index. A statistical projection of zero indicates that demand will vanish at or before the year 2000, based on the historical relationship. Projection equations with a coefficient of determination (R-squared) less than 0.70 are indicated by an asterisk (*).*
Source: US Bureau of Mines, Minerals Yearbook, Cement.

- Increased use of large reinforced pre–cast, pre–stressed structures for engineering construction for bridges, highways, buildings, etc.
- Increased use of concrete products such as pipe and blocks and development of new cement products such as cement bricks. Cement bricks now have 25% of the Ontario brick market, and are increasing rapidly in market share.
- Increased use of cement in highway construction. At present, cement is not used to any extent as the primary road surface in Canada. This is in contrast to the US, where cement is much more frequently employed in highway construction and repair.

CEMENT TRADE

Cement is a low cost bulk commodity and traditionally has not traded more than about 500 km from a producer's plant if land transportation is required. Ontario is in a unique position with regard to cement trade in that the Great Lakes offer the possibility of low cost shipment to almost all of the major markets in Ontario, and to a large part of the US market.

Data on Canadian imports and exports of cement and concrete basic products are provided in Table 4.8. As can be seen, Canada is a large net exporter of clinker, finished cement, and concrete products. The United States is by far the largest customer for Canadian cement, accounting for approximately 98% to 99% of exports in any given year. Contributing factors to the export success of Canadian and Ontario cement producers are the following:

- Lower production costs than U.S plants, especially for energy and labour. US plants tend to be older and less efficient than Ontario cement plants. This is especially true for the plants bordering the US side of the Great Lakes.
- A high degree of market integration. Much of Ontario's cement exports are destined for captive consumption in the US. Major facilities operated in the US by Ontario based cement producers are listed in Table 4.9.
- Low cost water transport of clinker and cement. Canadian ships are generally cheaper to operate than US ships. Specialized ships are employed on either an owned or long– term charter basis. This provides Ontario producers a significant degree of control over transportation costs.

Canadian and Ontario imports of clinker, cement, and concrete products primarily relate to cements not produced in Canada. For example, there is no domestic manufacture of aluminous cement and limited domestic manufacture of refractory cements and mortars. Imports of clinker are restricted to coastal regions such as the Maritimes where low ocean freight rates allow offshore material to be competitive with domestic cement. The principal sources of imported clinker are Spain, Belgium, and Venezuela, though the quantities imported from these countries are limited at present.

The United States is now the world's largest importer of cement and clinker. Imports of cement into the US have increased rapidly in recent years, accounting for 4% of US cement demand in 1982 and 19% of demand in

Table 4.8. CANADIAN CEMENT AND CONCRETE PRODUCTS TRADE.

	($'000)					
Imports	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**
Clinker	30	1,963	92	2	4	2,975
Cement	8,959	32,508	14,451	16,132	16,801	16,138
White cement	603	475	694	458	547	396
Aluminum cement	2,795	2,844	926	1,173	2,005	1,999
Other cements	6,289	19,286	4,856	2,835	2,438	5,431
Cement & concrete basic products	2,701	3,045	2,801	4,001	4,000	4,181
Total	21,377	57,561	23,820	24,601	25,795	31,120
Exports						
Cement	65,066	68,687	79,523	74,707	105,912	128,356
Prestressed concrete structural products	12,393	13,605	19,051	10,976	13,131	26,100
Cement & other concrete basic products	40,005	35,588	31,973	46,378	59,686	55,976
Total	117,464	117,880	130,547	132,061	178,729	210,432

Source: Statistics Canada, 1986.

1986. The rapid rise in imports is attributable to the following:

- A strategic decision by some US producers to utilize low cost imported clinker in place of high cost clinker produced in their own kilns.
- A rapid expansion in the degree of foreign ownership of the US cement industry, and a shift to the use of clinker from parent company kilns in Europe. Foreign ownership now accounts for approximately 41% of US cement production capacity.
- A general lack of investment in plant modernizations and expansions, resulting in higher cost domestic facilities.
- A significant expansion in cement production facilities in low cost countries such as Spain and Mexico. Producers in these countries are seeking markets for their product, and the United States represents the most remunerative market.

Table 4.9. US CEMENT FACILITIES OWNED BY ONTARIO-BASED CEMENT COMPANIES.

Lake Ontario Cement

Rochester Portland Cement
cement terminals at Rochester and Rome, N.Y.

Aetna Cement Corp.
clinker grinding and cement terminal at Essexville, Michigan

Universal Concrete Products
concrete pipe and products manufacturing operations in Pennsylvania, Ohio, Kentucky, Tennessee, N. Carolina, S. Carolina

St. Marys Cement

St. Marys Wyandotte Cement Inc.
clinker grinding and cement terminal at Wyandotte, Michigan

St. Marys Wisconsin Cement Inc.
clinker grinding plant at Milwaukee, Wisconsin and distribution terminals at Green Bay, Wisconsin and Waukegan, Illinois

St. Lawrence Cement

Independent Cement Corp.
cement plants at Catskill, N.Y. and Hagerstown, Md.

Distribution terminals in Connecticut, Maine, Maryland, Massachusetts, Minnesota, New York, Pennsylvania, Rhode Island

Lafarge Canada

Owns General Portland Cement, second largest cement producer in US, with operations throughout US.

Huron Cement Corp.

Source: Company reports.

Canada has supplied approximately 40% of US cement imports in the recent past. Imports from other countries such as Spain, Mexico, and Japan have been increasing rapidly, and the Canadian share of the market has declined accordingly. The Canadian share of the US import market stood at 52% in 1983 and 23% in 1985. However, within the area accessible by Great Lakes vessels, US imports from Canada have increased. Table 4.10 illustrates recent patterns in US imports of cement and clinker.

The outlook for US cement and clinker imports is for a continuation of recent patterns. Imports are expected to increase in concert with US cement demand and the closure of high cost domestic production facilities. The recent passage of the revised U.S Surface Transportation Assistance Act (Highway Act) should do much to stimulate demand for cement. Major US interstate highways and bridges are in need of significant repair in the next few years. The revised act eliminates the Buy America provisions which precluded the use of foreign cement in highway construction. Thus there are now no significant tariff and non– tariff barriers to the use of imported cement in the US.

CEMENT PRICES

Recent prices for cement are illustrated in Table 4.11.

It is seen that the average price for cement in Ontario has been consistently below the average price for Canada as a whole. The lower price for Ontario is believed to reflect a combination of the more competitive nature of the Ontario market and a greater reliance on standard Type I and II cements rather than the premium priced specialty cements.

Price data for the various types of cement are not readily available for Canada or for Ontario. Price data for the US is given in Table 4.12.

US prices for cement have been consistently above those in Ontario, the price differential sufficient to have attracted Ontario cement producers to the US market. A detailed analysis of cement prices in the US market area bordering the Great Lakes is provided in Table 4.13, the data indicating the marked geographic differences in cement prices. The data also indicate that Ontario cement prices are quite similar to prices in the region accessible by water transport. Despite the similarity in prices Ontario cement producers are attracted to the US market for several reasons. Among these are:

- The US market offers an opportunity to sell additional volume at what is essentially variable cost. Without this additional volume most of the Ontario cement industry would be significantly less profitable.
- The business cycles in Ontario and the US region bordering the Great Lakes have often been different.

Table 4.10. US IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY COUNTRY.

(Thousand short tons and thousand dollars)

	1983			1984			1985		
	Quantity	Value		Quantity	Value		Quantity	Value	
Country		Customs	C.i.f.		Customs	C.i.f.		Customs	C.i.f.
Canada	2,201	86,198	92,851	2,945	116,815	128,920	3,393	181,117	145,005
Colombia	68	8,845	4,169	227	5,138	6,927	662	16,430	20,244
France	158	6,435	7,507	225	7,044	9,180	552	13,866	18,319
Greece	-	-	-	-	-	-	511	9,760	12,202
Japan	(2)	100	118	183	5,287	7,595	1,184	28,786	37,105
Korea, Republic of	69	3,228	4,144	882	10,046	12,129	484	26,194	29,738
Mexico	826	30,844	33,539	2,003	64,574	74,877	2,502	75,755	87,839
Spain	787	28,883	29,303	1,760	49,584	61,218	3,383	80,448	103,353
Venezuela	60	1,705	2,138	1,022	25,281	32,224	1,569	38,282	50,320
Other	154	5,751	7,756	149	10,498	10,412	298	16,791	20,148
Total	4,268	161,439	181,525	8,846	294,207	343,482	[3]14,487	437,429	523,773

[1] *Cost, insurance and freight.*
[2] *Less than 1/2 unit.*
[3] *Data do not add to total shown because of independent rounding.*
Source: Bureau of the Census, US Department of Commerce.

US IMPORTS FOR CONSUMPTION OF CLINKER, BY COUNTRY.

(Thousand short tons and thousand dollars)

	1983			1984			1985		
	Quantity	Value		Quantity	Value		Quantity	Value	
Country		Customs	C.i.f.[1]		Customs	C.i.f.		Customs	C.i.f.
Canada	446	14,786	16,534	485	16,947	19,406	746	22,156	25,763
France	152	6,389	7,489	225	7,491	9,180	414	9,434	11,789
Greece	-	-	-	-	-	-	407	7,900	9,390
Japan	-	-	-	69	2,927	2,698	291	6,897	7,840
Mexico	192	6,899	7,373	477	11,608	13,077	581	14,671	16,387
Spain	214	5,559	6,437	528	11,885	14,860	1,656	31,877	39,917
Venezuela	-	-	-	294	5,623	7,484	290	5,570	7,022
Other	-	-	-	*141	*3,319	*3,985	248	5,062	6,305
Total[2]	1,006	33,688	37,784	2,215	59,801	70,635	4,683	103,067	124,418

**Revised*
[1] *Cost, insurance and freight.*
[2] *Data may not add to totals shown because of independent rounding.*
Source: Bureau of the Census, US Department of Commerce.
US Bureau of Mines, Minerals Yearbook, Cement, 1985.

Table 4.11. CEMENT PRICES.

	($/tonne) 1981	1982	1983	1984	1985
Canada	$77.00	$77.63	$79.83	n/a	n/a
Ontario	$54.15	$61.52	$66.32	$62.89	$65.55
US ($US/ton)	$52.46	$51.43	$50.45	$52.24	$51.87
US ($Cdn/tonne)	$69.35	$69.97	$68.55	$74.58	$78.10

Table 4.12. US CEMENT PRICES BY CEMENT TYPE.

Cement Type	($US/tonne) 1984	1985
Types I and II	$55.82	$55.35
Type III	60.02	60.10
Type V	53.51	66.93
Oil Well	64.88	64.59
White	186.35	190.57
Portland slag & Portland pozzolan	59.99	60.77
Expansive	86.20	106.47
Miscellaneous	69.11	73.36

Source: *US Bureau of Mines Minerals Yearbook, Cement, 1985. It is believed similar price differentials prevail in the Ontario and Canadian cement markets.*

Table 4.13. AVERAGE CEMENT PRICES.

Type of cement and region	($US/tonne) 1984	1985
Portland Cement		
New York and Maine	55.26	53.10
Pennsylvania	54.13	57.26
Ohio	50.47	52.92
Michigan and Wisconsin	49.80	48.63
Illinois	45.61	45.24
Average for region	51.86	52.27
Masonry Cement		
New York and Maine	71.90	73.61
Pennsylvania	77.39	76.05
Ohio	88.34	104.36
Michigan and Wisconsin	72.81	71.95
Illinois	n/a	n/a
Average for region*	76.94	79.00

**Excludes Illinois*

Source: US Bureau of Mines, Minerals Yearbook, Cement, 1985.

Such differences have allowed Ontario producers to offset declines in one market with advances in the other.

- The US region bordering the Great Lakes is one of declining domestic clinker capacity. Prices are expected to increase at a more rapid rate in the region than in Ontario.

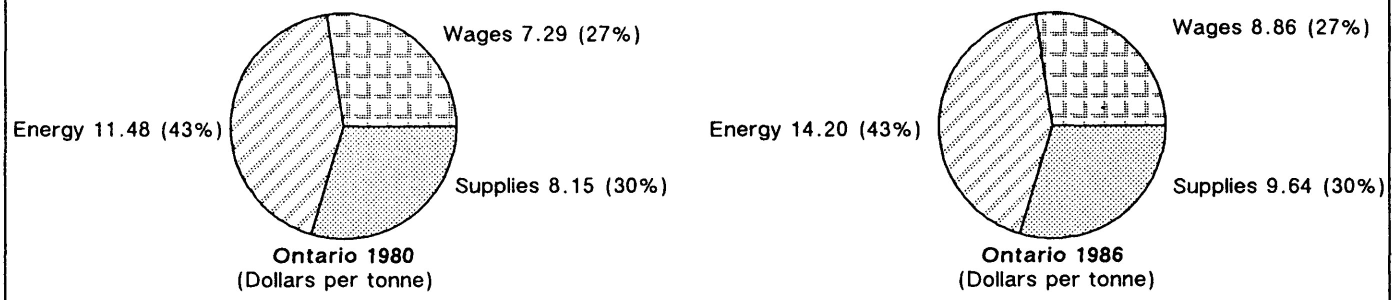
CEMENT PRODUCTION COSTS

The principal cost factors in the production of cement are fuel (45%), labour (30%), maintenance (10%), raw materials (10%), and overhead (5%). Direct costs for Ontario cement production for the period 1980–1986 are illustrated in Figure 4.15. Over that time period direct costs have increased by 6.3% per annum. During the same period cement prices increased at a compound annual rate of over 4%, while production increased at a rate of 2.7% per annum. These data would tend to indicate that cement prices in Ontario respond more to cost factors than to supply/demand factors. Such a pattern is characteristic of a mature industry with significant excess capacity.

The Ontario cement industry has taken significant efforts to reduce its unit costs of production. For example, Lafarge Canada stated in its 1986 annual report that unit costs were reduced 5% in 1986 over 1985 costs, and that unit costs were reduced by 3% in 1985 and 4% in 1984. The other cement producers are undertaking similar cost reduction programs.

CEMENT DISTRIBUTION

The integrated nature of Ontario's cement producers has had an impact on cement distribution patterns and methods. Whereas cement used to be shipped primarily in small lots in bags and drums to end users, it is now primarily shipped in bulk by ship, truck and rail car to distribution terminals and ready–mix plants owned by the cement companies. All of the Ontario cement producers operate large fleets of specialized bulk trucks equipped with pneumatic loading and discharge equipment. Rail cars are also specialized for the transport of cement, and



DIRECT COSTS OF CEMENT PRODUCTION

	1980	1981	1982	1983	1984	1985	1986
				($000)			
Wages	29,634	34,896	34,360	35,203	37,229	38,464	42,889
Energy	46,702	51,387	47,681	45,230	53,361	66,130	68,753
Supplies	33,162	33,436	29,762	31,802	35,474	45,768	46,670
TOTAL	109,498	119,719	111,803	112,235	126,064	150,362	158,312
				$/TONNE OF CEMENT			
Wages	7.286	9.214	11.426	10.998	10.391	9.511	8.856
Energy	11.483	13.569	15.857	14.130	14.893	16.353	14.196
Supplies	8.153	8.829	9.896	9.936	9.901	11.318	9.637

Figure 4.15. COST OF CEMENT PRODUCTION, ONTARIO 1980 TO 1986. *Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1987.*

Table 4.14. ONTARIO MOVEMENTS OF CEMENT BY WATER.

	('000 tonnes) Destination											
	Canadian Ports						Foreign Ports					
Origin	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**
Bath	174.9	308.3	204.4	262.5	238.4	163.7	52.8	63.8	20.4	31.7	32.3	18.4
Picton	256.7	218.9	202.8	252.5	304.0	285.5	556.3	545.3	366.9	449.3	526.0	507.8
Clarkson		5.0			13.2	28.8	83.5	174.5	116.0	193.0	234.2	308.2
Hamilton								5.5	3.3	1.5		18.0
Toronto		0.5					7.3					
Oshawa							23.5					
Windsor							0.7	0.4	0.4		0.4	
Bowmanville							59.2	60.1	13.7	165.6	107.2	
Kingston								5.3				21.8
Port Stanley									24.7	41.7	50.4	51.7
St. Catharines									1.6			
Thorold									1.6			
Trenton												48.7

Source: Statistics Canada, 1986.

Table 4.15. EXPORTS OF CEMENT AND CONCRETE PRODUCTS FROM ONTARIO, METHOD OF SHIPMENT.

	($'000)					
Mode	1980	1981	1982	1983	1984	1985
Water	40,550	38,087	33,115	37,302	41,564	40,975
Road	21,612	24,945	29,479	32,850	38,042	64,561
Rail	3,223	6,531	7,276	7,481	8,466	9,222
Air	124	12	1	149	19	31
Other				95	121	
Total	65,510	69,575	69,781	77,876	88,212	114,789

Source: Statistics Canada, 1986.

are generally under long term lease. Water shipment is now a major means of cement distribution in Ontario. Lafarge Canada, Lake Ontario Cement, and St. Lawrence Cement operate fleets of specialized cement carriers to move product from their plants at Bath, Picton, and Clarkson to terminals in Ontario and the United States. Lafarge Canada at Woodstock has used specialized barges and trailers to move cement via Port Stanley on Lake Erie to its US customers. St. Marys Cement in Bowmanvile has recently constructed a dock, for handling inbound shipments of coal and gypsum, that has the capability of handling outbound shipments of cement. Prior to the construction of the dock the Bowmanville plant used the nearby port facilities in Oshawa to load cement. Bulk shipments from St. Marys Cement in St. Marys and Federal White Cement in Woodstock are by truck and rail, with truck shipments predominating. All of the cement plants have facilities for the packing and shipment of cement in bags, which now, however, represent a small proportion of the shipments for all of the companies, generally less than 10%.

The relative importance of water transport in Ontario's cement industry is illustrated in Table 4.14 and Table 4.15. Out of total cement production of 4,043,742 tonnes in 1985 1,452,734 tonnes, or 36% was moved by water. For some companies such as Lake Ontario Cement water shipment is the principal transportation mode. In 1985 the company shipped approximately 80% of production by water.

Water is the principal means of transport for cement exports from Ontario, with 974,675 tonnes or 90% of the total 1985 Ontario exports of 1,085,000 tonnes of cement being moved by water. However, as can be seen from Table 4.15, road transport has now become the dominant mode of shipment in terms of value of exports. This shift in the relative importance of water and road is indicative of increased exports of higher value-added concrete products.

Lime, Chemical and Metallurgical Stone

LIME

ONTARIO LIME PRODUCTION

Ontario–based producers of lime are listed in Table 4.16. Some lime is also recovered by pulp and paper mills during the recausticization process to recover the spent pulping liquor in sulphite pulp mills. Of the eight major lime producers in the province three operate totally captive plants while two operate combined captive and merchant plants. Stelco Inc. in Ingersoll and Dofasco Inc. (BeachviLime Ltd. and Guelph DoLime Ltd.) produce lime for their own use and for commercial sale; General Chemical Canada Ltd. operates a lime plant as part of its sodium carbonate, calcium chloride, and hydrofluoric acid production operations in Amherstburg; Timminco Ltd. calcines a high purity dolomite for use in the production of magnesium metal by the Pidgeon process at Haley; Algoma Steel Corp. Ltd. produces lime for use in its iron and steel making operations at Wawa and Sault Ste. Marie; Reiss Lime Company of Canada Ltd. operates a lime plant at Spragge on Georgian Bay, though it imports almost all of its stone requirements from quarries in Michigan; and Steetley Industries Ltd. produces dolomitic lime for use in the steel and glass industries at its plant in Dundas.

Figure 4.16 and Figure 4.17 illustrate changes in the production of lime in Canada and Ontario. Quicklime represents over 90% of total lime production in any given

Table 4.16. ONTARIO LIME PRODUCERS.

Algoma Steel Corp. Ltd.	Sault Ste. Marie	High calcium and dolomitic captive use
General Chemical Canada Ltd.	Amherstburg	High calcium captive use
BeachviLime Ltd.	Beachville	High calcium captive and market
Guelph DoLime Ltd.	Guelph	Dolomitic (quick and hydrated) captive and market
Timminco Ltd.	Haley	Dolomitic captive use
Reiss Lime Co. of Canada Ltd.	Spragge	High calcium market
Stelco Inc.	Ingersoll	High calcium captive and market
Steetley Industries Ltd.	Dundas	Dolomitic market

BeachviLime and Guelph DoLime are subsidiaries of Dofasco Inc.

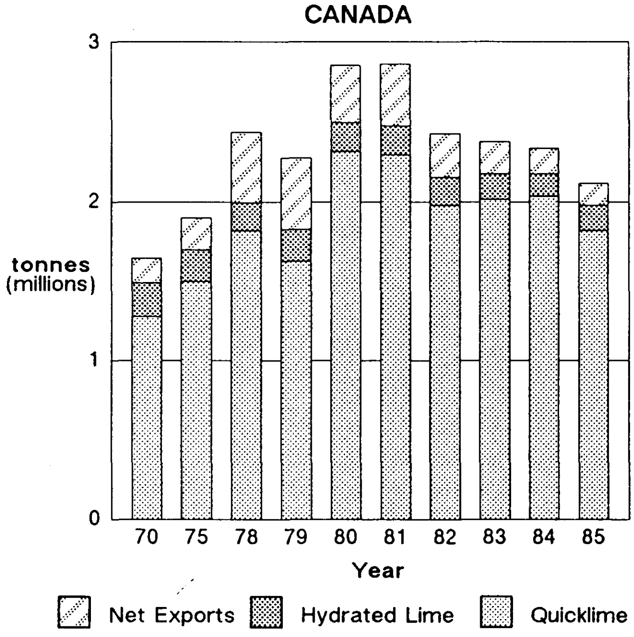


Figure 4.16. CANADIAN LIME PRODUCTION. *Source: Canadian Minerals Yearbook, 1986.*

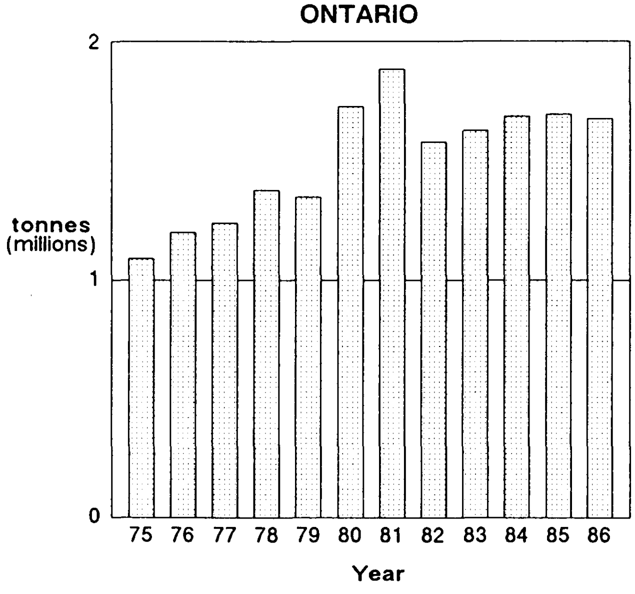


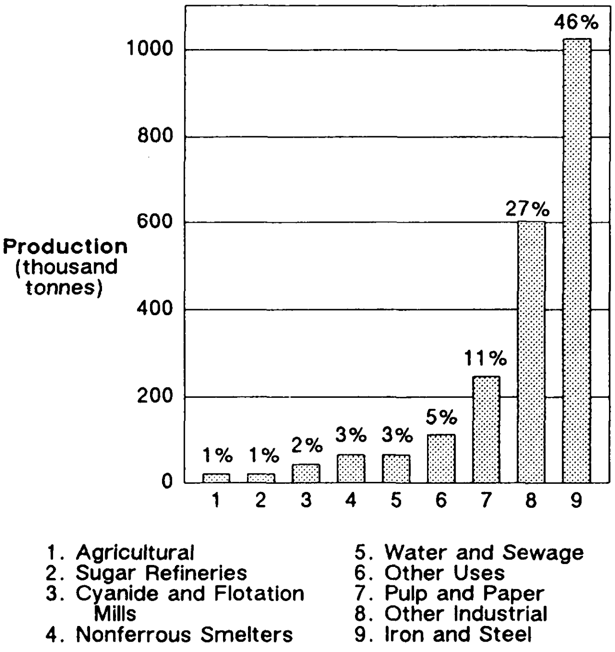
Figure 4.17. ONTARIO LIME PRODUCTION. *Source: Canadian Minerals Yearbook, 1986.*

year. Ontario production represents 70%–75% of total Canadian production, and is the principal source of lime exports. Almost all exports and imports of lime are connected with trade with the United States. There are no data available regarding dolomitic lime production. Production capacity for lime in Canada totals approximately 12,000 tonnes per day and, assuming an average availability of 330 days, total annual lime production capacity is approximately 3.96 million tonnes. These data indicate that Canadian lime producers have considerable excess production capacity and have experienced operating rates of 50%–55% in recent years. Most of the excess capacity is located in Ontario.

LIME CONSUMPTION

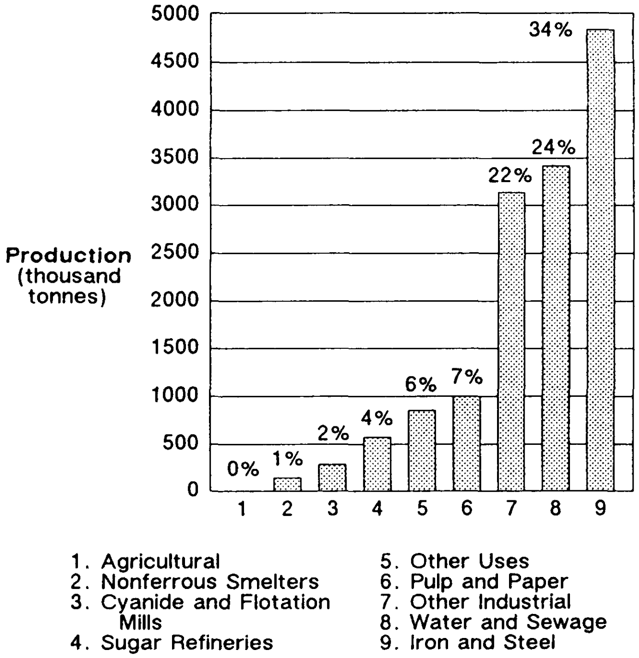
Figure 4.18 and Figure 4.19 detail lime consumption in Canada and the United States, and show a greater diversity of use in the US. The much greater use of lime in the US for environmental and soil stabilization purposes is especially noticeable. Factors affecting the use of lime in Canada include the following:

- Phase–out of open hearth steel production in favour of BOF and EAF steel production. By the end of 1989 there will be no open hearth steel furnaces in operation in Canada. Lime consumption will increase at the expense of limestone consumption in the steel industry.



1983 Consumption: 2,232,000 tonnes

Figure 4.18. CANADIAN LIME CONSUMPTION. *Source: Canadian Minerals Yearbook, 1986.*



1985 Consumption: 14,254,000 tonnes

Figure 4.19. UNITED STATES LIME CONSUMPTION. *Source: US Bureau of Mines Minerals Yearbook, 1985.*

- Significantly less use of flue gas scrubbers for desulphurization in Canada than in the United States;
- Significantly lower levels of industrial and municipal waste water treatment in Canada than in the United States;
- Rapid expansion of mechanical pulping technologies to replace chemical pulping, thus reducing the demand for lime.

The most significant factor affecting demand for lime is expected to be the imposition of much more stringent air pollution standards. Mandatory requirements for scrubbers to remove SO_2 and NOx emissions would require greatly increased lime production. An example of the potential impact of more stringent standards was provided in a study performed in the United States (Subhash, 1985). The study indicates complete installation of scrubbers on US thermal power plants would increase lime consumption by a factor of 4.9 to 13 times the level of use in 1982, depending upon the severity of the air quality standards. In the case of Ontario, removal of sulphur emissions from flue–gases would require approximately 500,000 tonnes of lime per year at current sulphur dioxide generation levels. Figure 4.20 provides a forecast of Ontario lime production to 1996. The forecast indicates a slight reduction in production over the next several years. This reduction is attributable to

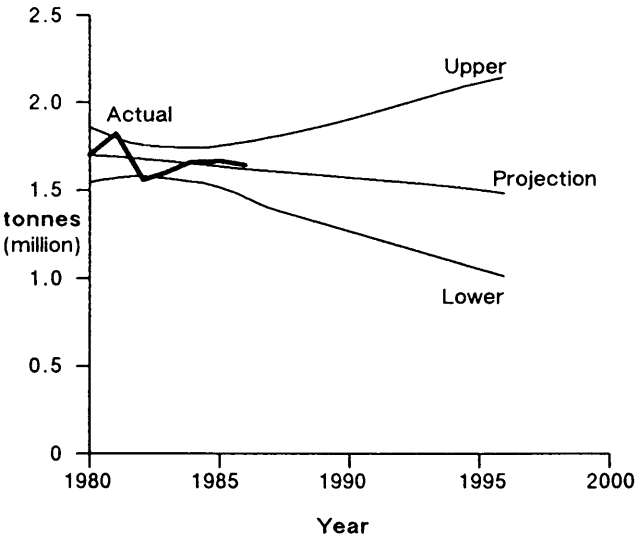


Figure 4.20. ONTARIO LIME PRODUCTION FORECAST, DATA, PROJECTION AND 95% LIMITS.

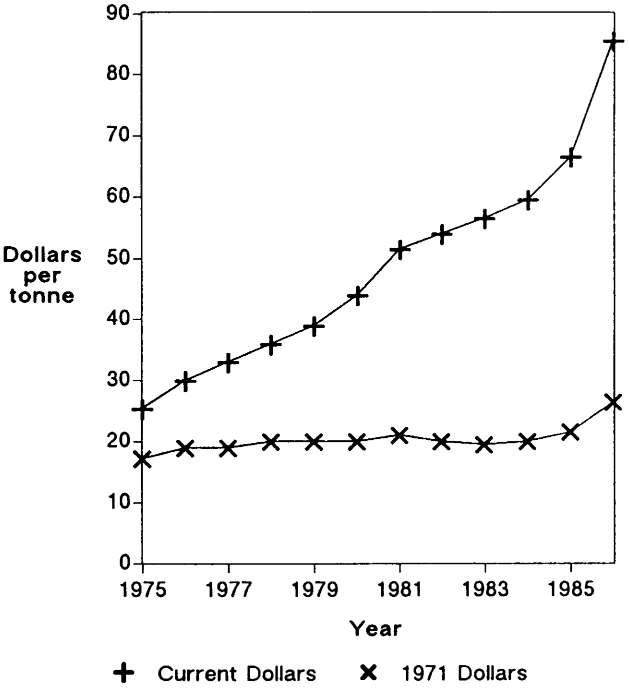


Figure 4.21. ONTARIO LIME PRODUCTION, UNIT VALUE IN CURRENT AND 1971 DOLLARS. *Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.*

changes in lime demand from the major consuming industries such as the steel and pulp and paper mills, and to a levelling off in demand for lime for other chemical and metallurgical purposes. The upper projection assumes increased demand for lime for environmental purposes.

PRICES

Prices for lime are a factor of market competition, end–use requirements, and transportation costs. In Canada average prices for quick and hydrated lime are shown in Table 4.17.

Significant variations in price by end–use and geographic area are common. For example, average lime prices declined from $69.20 per tonne in 1983 to $66.50 per tonne in 1985 in Ontario but remained stable in Alberta at $70.60 per tonne in 1983 and $70.25 per tonne in 1985. It is also known that producers located in areas providing a transportation barrier, such as New Brunswick, are able to secure significantly higher prices than producers in a more competitive market such as southern Ontario.

Table 4.17. CANADIAN LIME PRICES.

	$/tonne	
	Quicklime	Hydrated Lime
1982	$63.63	$76.38
1983	68.87	86.70
1984	68.75	86.13
1985	68.18	n/a

Source: Energy, Mines and Resources Canada, 1986

Figure 4.21 details Ontario lime prices. Prices have increased 10.7% per annum since 1975 in current dollar terms but only 5.5% per annum in constant 1971 dollar terms. The low level of real price increase and the excess capacity in the industry has not been conducive to major expansion and modernization projects. US prices for lime are listed in Table 4.18. The wide variation in price by end–use is noticeable.

LIME PRODUCTION COSTS

Lime production is a highly energy intensive business. On average, Canadian lime producers use about 6.4 GJ of energy per tonne of production. Newer plants make use of preheater systems, energy efficient large diameter short rotary kilns, and modern vertical kiln designs to reduce fuel requirements. In Ontario average energy consumption per tonne of lime was 5.4 GJ (5.16 million Btu). There has been relatively little change in average energy consumption per tonne of product in recent years, as illustrated by Figure 4.22. The cost of energy, however, has increased significantly, and stood at

Table 4.18. US LIME PRICES.

End-Use	($US/ton) 1984	 1985
BOF Steel	46.02	49.80
Water purification	51.38	49.88
Pulp & paper	47.41	49.78
Sewage treatment	55.16	50.11
Alkalis	48.93	49.80
Sugar refining	67.86	49.87
Road stabilization	55.10	65.62
Masons' lime	63.68	65.59
Refractory dolomite	60.35	64.69
Flue-gas desulphurization	46.47	49.80
Average for all lime	51.12	51.69
Average for quicklime		46.46
Chemical lime		45.88
Agriculture		49.02
Construction		54.88
Average for hydrated lime		67.56
Chemical lime		65.96
Agriculture		65.96
Construction		69.32

Source: US Bureau of Mines, Minerals Yearbook, Lime, 1985.

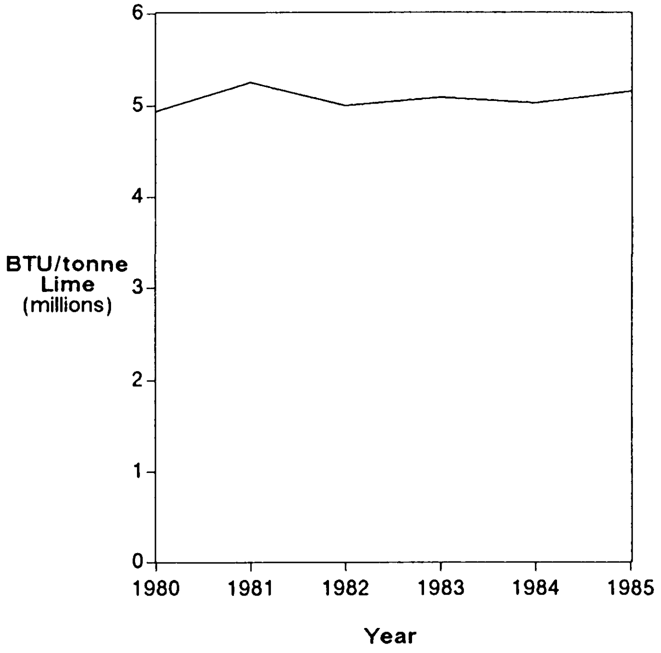


Figure 4.22. ENERGY CONSUMPTION/TONNE OF LIME. *Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.*

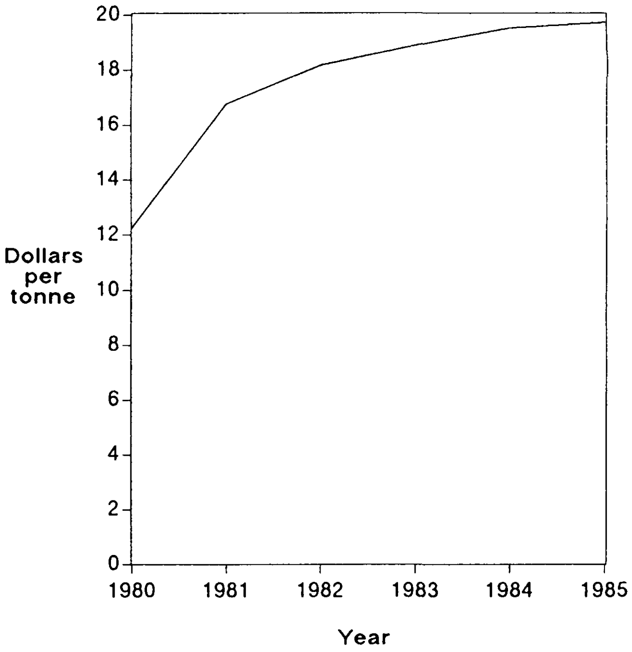


Figure 4.23. ENERGY COST/TONNE OF LIME. *Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.*

$19.70/tonne in 1985 versus $12.24/tonne in 1980. This is illustrated in Figure 4.23.

In an effort to reduce fuel costs Ontario lime producers have switched to burning coal and coke and reduced their reliance on fuel oil. Coal and coke represented 48% of the energy requirements and 29% of the energy dollars in 1985, versus 18% of energy requirements and 11% of energy dollars in 1980. These changes are illustrated in Figure 4.24.

Total direct costs for lime production in Ontario have increased at a rate of 5.45% per annum during the 1980–1985 period. Prices have increased at a rate of 7.06% per annum during the same period. The distribution of direct production costs has remained stable at 54% for energy in 1980 and 1985; 25% and 23% for wages; and 21% and 23% for supplies in 1980 and 1985 respectively, as shown in Figure 4.25.

CHEMICAL PROCESS STONE

Chemical process stone refers to limestone and dolostone used in the production of various chemicals. It is distinguished from lime used for similar purposes in that chemical stone is used directly rather than separately calcined first. The principal end-use markets for chemical process stone in Ontario are the glass industry, the pulp and paper industry, and in soda ash manufacture. Minor amounts of stone are used in paint manufacture.

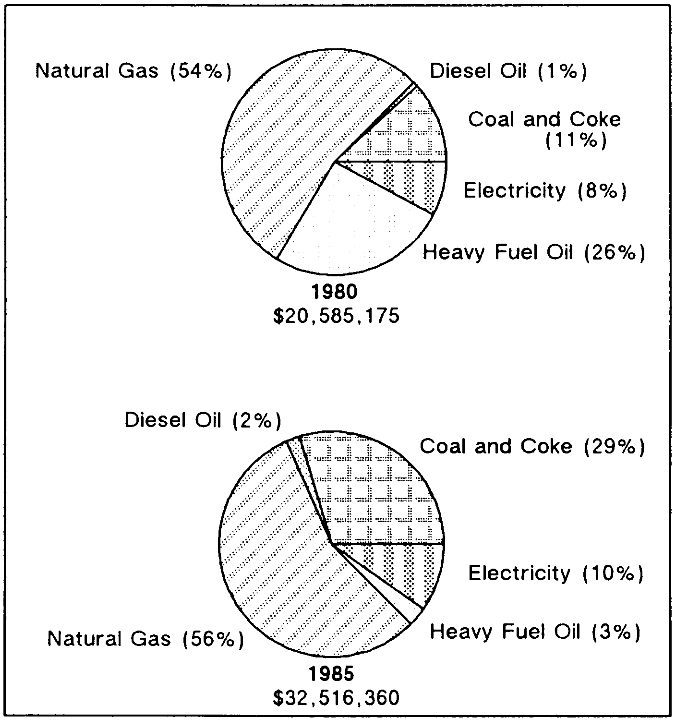


Figure 4.24. ENERGY COST/TONNE OF LIME. *Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.*

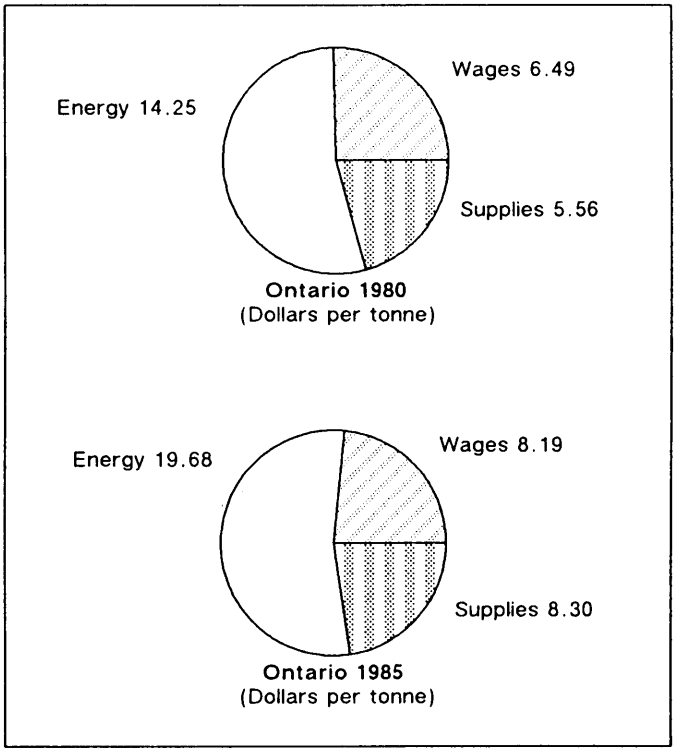


Figure 4.25. COSTS OF LIME PRODUCTION. *Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.*

GLASS MANUFACTURE

Crushed limestone and dolostone are used in glass manufacture to make the glass more insoluble. Limestone and dolostone used in glass manufacture must be low in iron, at least below 0.06% FeO.

Consumption of limestone and dolostone in the Canadian glass industry in recent years is given in Table 4.19.

Ontario glass plants were reported to have used 128,553 tonnes of Ontario limestone and dolostone in 1984 and 149,143 tonnes in 1985.

PULP AND PAPER

Pulp and paper mills use limestone as supplementary material to make up their lime requirements for the recausticization of the spent sulphite pulping liquor. Requirements are modest and vary from year to year depending on the performance of the kiln and the relative costs of lime and limestone. Very limited amounts of magnesia or dolostone are used in sulphite pulp mills to prepare magnesium sulphite. The total Canadian limestone and magnesia requirements in recent years are given in Table 4.20.

SODA ASH (SODIUM CARBONATE) MANUFACTURE

High calcium limestone is used in the production of soda ash by the Solvay process, though this has largely been supplanted by the use of natural soda ash, named trona, from Wyoming. There is only one Canadian producer of soda ash, General Chemical Canada Ltd. (formerly Allied Chemical Canada Ltd.) in Amherstburg, and only one remaining US producer. General Chemical produces calcium chloride, sodium bicarbonate, and a range of

Table 4.19. LIMESTONE AND DOLOSTONE CONSUMPTION IN THE GLASS INDUSTRY.

	Limestone	Dolostone
	('000 tonnes)	
1979	176.2	n/a
1980	173.3	n/a
1981	176.1	n/a
1982	168.7	n/a
1983	175.9	n/a
1984	178.0	112.0
1985	138.0	n/a

Source: Statistics Canada, 1986

Table 4.20. LIMESTONE AND DOLOSTONE CONSUMPTION IN THE PULP AND PAPER INDUSTRY.

	Limestone	Magnesia
	(tonnes)	
1980	25,560	7,496
1981	22,658	9,330
1982	97,372	4,584
1983	114,671	2,109
1984	n/a	n/a
1985	n/a	n/a

Source: Statistics Canada, 1986

Table 4.21. STEEL INDUSTRY LIME CONSUMPTION, CANADA/UNITED STATES.

	(tonnes)	
Canada	**1983**	**1984**
Quicklime	325 511	329 214
Other lime	205 802	242 522
Limestone	980 000	
United States	**1984**	**1985**
Limestone	3 481 973	3 689 676
Dolostone	64 850	19 047
Burnt lime	3 036 636	2 696 511
Other	243 983	175 051

Source: Statistics Canada, 1985
US Bureau of Mines, Minerals Yearbook, 1985.

Table 4.22. ONTARIO MAGNESIUM AND CALCIUM PRODUCTION.

	Magnesium		Calcium	
Year	('000 kg)	($ 000)	('000 kg)	($ 000)
1978	8,311.2	20,155.4	574.8	2,397.5
1979	9,015.0	24,444.0	455.7	2,152.1
1980	9,252.0	27,821.8	530.6	3,421.6
1981	8,548.0	29,439.5	469.4	4,512.1
1982	7,630.2	27,811.9	329.1	2,567.3
1983	5,980.3	21,978.1	398.9	3,306.5
1984	7,587.5	30,926.7	515.4	4,559.6
1985	8,446.3	36,369.6	738.5	7,778.9

Source: "Ontario Mineral Score", Ontario Ministry of Northern Development and Mines, 1986.

other calcium and sodium compounds or by-products and co-products of the Solvay process. Production is sold in Canada and the mid-western US. Stone requirements were reported to be over half a million tonnes in 1984 and 1985.

METALLURGICAL STONE

Crushed limestone and dolostone are used as a flux in ferrous and non- ferrous smelting and refining as a cheap substitute for the more expensive lime. The crude crushed material is also preferred for technical reasons in some applications. Table 4.21 illustrates changes in the demand for limestone and dolostone in the US and Canadian iron and steel industries in recent years.

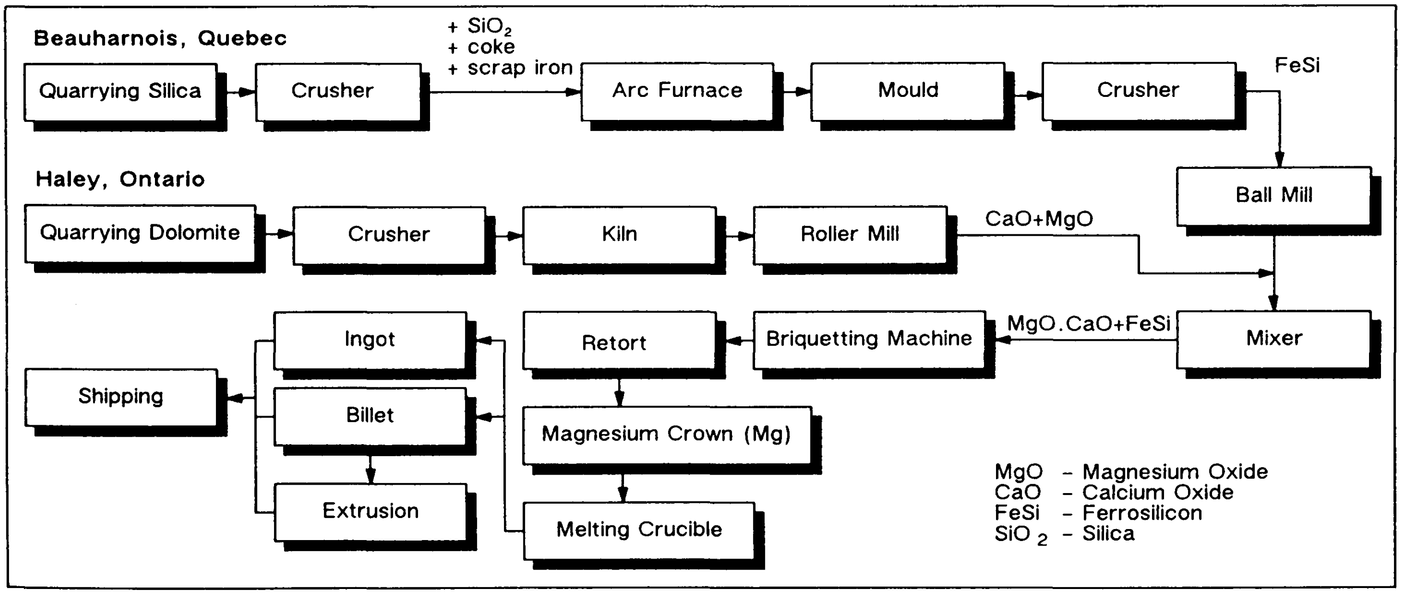


Figure 4.26. MAGNESIUM PRODUCTION AT TIMMINCO LTD. USING PIDGEON PROCESS. *Source: company literature.*

Limestone and dolostone are also used in non–ferrous smelting, but the quantities employed are relatively low, as lime is the primary flux. Actual usage depends on the relative delivered costs of stone and lime. Ontario production of stone for this purpose was reported to be 143,605 tonnes in 1984 and 149,143 tonnes in 1985.

Magnesium and calcium metal production is the other major metallurgical market for dolostone and high calcium limestone. Timminco Ltd. produces both metals using a variant of the alumino–silicothermic Pidgeon process at its plant at Haley, Ont. The Pidgeon process is illustrated in Figure 4.26.

Timminco recovers magnesium from a high quality Precambrian dolomitic marble quarried on site; calcium from high calcium stone obtained from quarries in southern Ontario; and strontium from imported celestite.

Dolomitic marble requirements for magnesium production were 106,267 tonnes in 1984 and 109,257 tonnes in 1985. Data on magnesium and calcium metal production are provided in Table 4.22. Timminco has announced plans to increase magnesium production capacity to approximately 15,000 tonnes per year from the current level of 10,000 tpy.

MARKETS

The principal end–use markets for calcium carbonate fillers are in plastics, paint, paper, adhesives and sealants, rubber, drywall compounds, and carpet backing.

PLASTICS

The relative growth rates of resin and fillers for the 1976–1985 period in the United States are illustrated in Figure 4.27. As shown, resin production increased 5.2% per annum during the 1980–1985 period. During the same period, the consumption of fillers and reinforcing materials in polymer–based materials increased at an average annual rate of 8.9%. Calcite itself exhibited an average annual growth rate of 10.4% during the 1980–1985 period in the US. The rapid growth rates for fillers are expected to continue for the next several years.

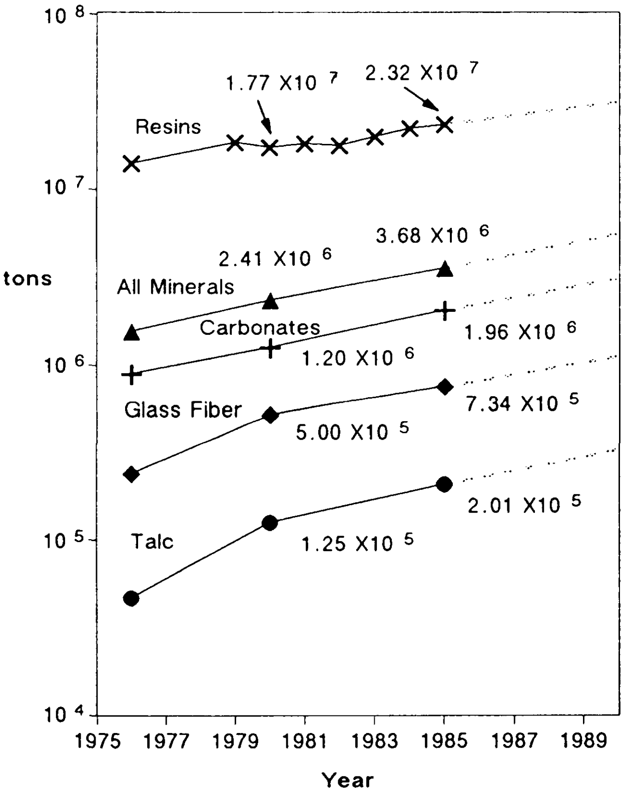


Figure 4.27. US CONSUMPTION OF RESINS AND OF FILLER, EXTENDER AND REINFORCING MINERALS FOR POLYMER–BASED COMPOSITES (TONS). *Source: Plumpton et al., (1987), Clifton, SME–AIME annual meeting, N.Y., Feb. 1985; Dickson, Industrial Minerals, Feb. 1987.*

Calcium carbonate is by far the main filler used in plastics, and represents approximately 50% of the market for all mineral fillers and reinforcements. C.H. Kline and Co. estimates that carbonate fillers accounted for 662,200 tonnes of the 1,452,000 tonnes of mineral reinforcements and fillers used by the US plastics industry in 1986.

The most important plastics markets for calcium carbonate are PVC and thermosetting polyesters. Of the total volume of 662,200 tonnes of calcium carbonate consumed in plastics in 1986 in the US approximately 65%, or 430,900 tonnes, was used in PVC. Polyesters accounted for a further 30%, or 198,700 tonnes. The balance of approximately 32,700 tons was used in other plastics such as polypropylenes, polyurethanes, ABS, and phenolics. Data on consumption patterns is provided in Table 4.23.

Calcium carbonate consumption trends are expected to parallel the growth rates for the plastics.

Calcium carbonate in PVC is found in both flexible and rigid materials. The market for flexible PVC faces stiff competition from cheap offshore calendered vinyl producers and is not expected to show much growth.

Rigid PVC applications for calcium carbonate include pipe and mouldings, windows and doors, floor tile, etc. There is a push by some manufacturers to increase calcium carbonate loadings in pipe by up to 50%, but this will require changes in government specifications for pipe.

Polyesters have been the largest growth area for calcium carbonate in plastics, typical mineral reinforced polyester formulations containing 40% to 45% calcium carbonate by weight. The automobile industry is the principal end–user of these products, accounting for approximately 75% of the market, mainly for the front–end panels of cars (sheet moulding compound (SMC)) and truck

Table 4.23. CALCIUM CARBONATE CONSUMPTION IN PLASTICS, UNITED STATES.

	(tonnes)	
	1983	1986
PVC	268 000	431 000
Polyesters	100 000	199 000
Others	18 000	33 000
Total	380 000	663 000

Source: Industrial Minerals, various issues.

hoods, fenders and front–end panels (bulk moulding compound (BMC)).

Calcium carbonate may also be used as a filler in other plastics; polypropylene is a major potential market, with calcium carbonate as a low cost replacement for talc.

PAINTS

Calcium carbonate is used as an extender in oil, alkyd, acrylic, and latex– based paint systems. The US paint industry consumed approximately 222,200 tonnes of carbonate fillers in 1983. The market is characterized by slow growth, although recent technological developments related to product form and particle size may increase the level of use.

PAPER

Calcium carbonate for use as a filler and coating material in paper manufacture is a relatively new development, with a potential annual market available in excess of 450,000 tonnes in North America. In particular, the market has been opened up by the switch from acid sizing to alkaline sizing, permitting the use of calcium carbonate as the filler material.

The overall cost advantages of alkaline sizing are estimated at approximately $20.00 per tonne. Despite the cost advantages, alkaline sizing is still not widely used in North American paper mills, although its use is increasing.

PUTTY, CAULKS, AND SEALANTS

Calcium carbonate is widely used as a filler for putty, caulks, and sealants. Consumption in the US in 1983 amounted to approximately 113,000 tonnes.

RUBBER

Calcium carbonate fillers are used in soft rubber goods such as floor coverings and auto mats. Kaolin is the primary filler with calcium carbonate used as a supplement to reduce product cost. Calcium carbonate fillers may also be used in wire and cable coatings, automotive weather stripping, and some footwear applications.

CARPET BACKING

Carpet backing is the largest volume application for calcium carbonate, consuming about 475,000 tonnes in 1983 in the US.

JOINTING COMPOUNDS

Calcium carbonate is used as a filler in drywall jointing compounds and in 1983 approximately 445,000 tonnes were used in this application in the United States.

PRICES

Prices for various grades of calcium carbonate are listed in Table 4.24. The prices listed show that there is considerable value–added as the fineness of the product increases and as other treatments such as surface coatings are incorporated in the products. Increasing the fineness of the material from an average particle size of 4 to 9 microns to one of 0.5 to 4 microns adds approximately 66% to the price of the product; manufacture of an ultrafine grade in slurry form will yield more than double the price of the medium grind product; while coated ultrafine calcium carbonates are worth approximately 4.5 times the value of a standard 325 mesh (44 micron) product. The increased value associated with the production of ultrafine grind and surface treated calcium carbonates is an obvious attraction. Nevertheless, there are only a few North American producers of ultrafine grind calcium carbonates, and no producers of surface treated calcium carbonates in Canada.

Prices for calcium carbonate fillers and extenders are generally quoted on an FOB producer basis. Accordingly, transportation costs can play a major role in determining the market opportunities available to a producer. Figure 4.28 illustrates the location of producers of fine grind (below 325 mesh, 44 micron) calcium carbonate as of 1984, and shows most of them to be concentrated in the eastern part of North America. Freight costs from producing plants to consumers may offset the advantages

Table 4.24. CALCIUM CARBONATE PRICES, NEW YORK BASIS.

($US/ton), May 1987	
Dry, coarse (9–17 microns),	
325 mesh, bags or bulk,	
fob works	$49.00 - $90.00
medium (4–9 microns)	70.00 - 100.00
fine (0.5–4 microns)	123.00 - 166.00
Slurry, fine (2–4 microns)	125.00 - 139.00
ultrafine	166.00 - 177.00
Coated, fine (2–3 microns)	167.00
ultrafine (1 micron)	228.00
Precipitate, technical (0.5 microns)	212.00 - 217.00
ultrafine (0.05–0.5 microns)	540.00
surface treated	320.00
USP, very fine, high purity	385.00 - 400.00
extra light	395.00
light to medium	400.00
heavy	445.00

Source: Chemical Market Reporter, May 29, 1987.

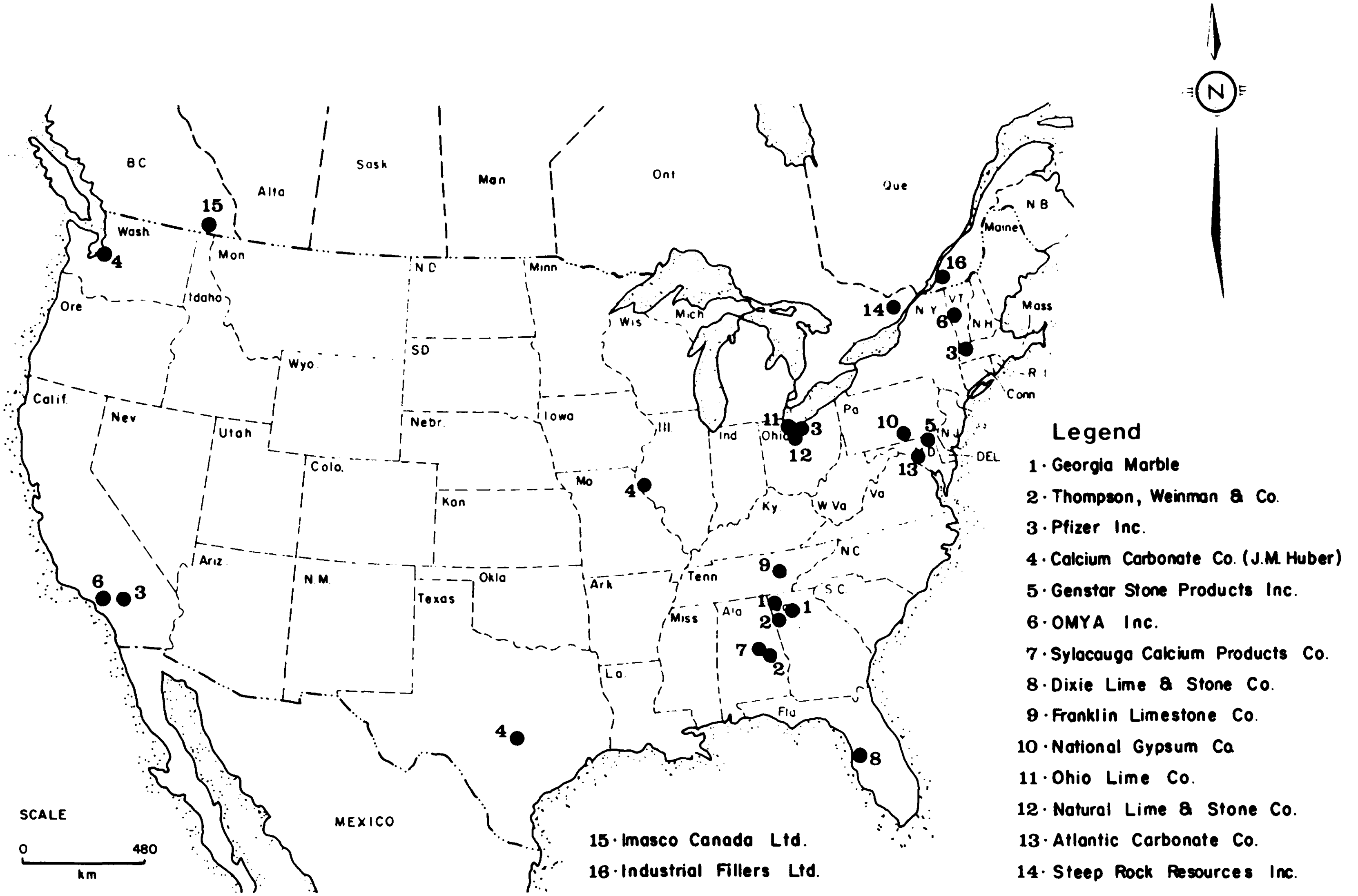


Figure 4.28. LOCATION OF PRODUCERS OF FINE-GROUND CALCITIC AND DOLOMITIC CARBONATE. *Source: Guillet And Kriens, 1984.*

Table 4.25. CANADIAN CALCIUM CARBONATE DEMAND.

	(tonnes)				
	1980	1981	1982	1983	1984
Pulp & Paper	1,660	45,018	18,928	4,473	n/a
Paint	30,968	22,318	18,669	22,190	18,532
Rubber ($M)	1,028	1,296	1,237	1,561	n/a
Asphalt Filler	n/a	n/a	31,000	33,000	n/a
Plastics	n/a	n/a	n/a	n/a	n/a

Source: *Statistics Canada, 1985.*

of using a higher quality product in some markets. For example, material from deposits in Maryland and Vermont generally has a 3 to 5 GE brightness advantage over material from the area around St. Louis. Despite this quality advantage, paint producers in the the Midwest prefer to use local calcium carbonate due to its lower delivered cost. Adjustment of pigment levels to overcome the brightness differential is less costly than using the higher quality stone.

CANADIAN DEMAND

Demand for calcium carbonate fillers in Canada has been estimated at approximately 150,000 tonnes for 1983. Domestic production has been estimated at 125,000 tonnes, with exports of 25,000 tonnes and imports of 50,000 tonnes. Data on end–use consumption are incomplete, and reliable market volume determinations are difficult to make. Table 4.25 provides some limited information on the demand for calcium carbonate in some of the principal end–use markets.

CANADIAN DEVELOPMENTS

Significant Canadian developments related to the supply of calcium carbonate fillers include the following:

- Expansion of the Steep Rock Calcite plant at Perth to include production of ultrafine grind products using wet grinding technology. This is a joint venture with Georgia Kaolin of the United States.
- Development of a fine grind calcium carbonate plant by Calcite et Dolomie de Mattawin in Quebec.
- Development of a calcite filler plant by Calcite du Nord in Quebec.

Canadian production capacity for standard and medium grind calcium carbonate filler grades would appear to be sufficient at present. Canadian capacity and demand for production of ultrafine grind grades still indicates room for expansion. As there is no domestic capacity for the supply of surface treated ultrafine grind calcium carbonates, there would appear to be an obvious opportunity for enhanced value added.

Building Stone

BUILDING STONE MARKETS

Data for Ontario limestone building stone production for the 1981 to 1986 period is given in Table 4.26.

Table 4.26. PRODUCTION OF LIMESTONE BUILDING STONE.

	Production (tonnes)	Value ($)	$/Tonne
1981	277,291	1,234,326	4.45
1982	130,112	998,022	7.67
1983	141,322*	1,214,209*	8.78
1984	154,084*	1,578,594*	10.24
1985	168,023	1,787,186	10.64
1986	198,847	2,424,339	12.19

Source: Ontario Ministry of Northern Development and Mines.
*Estimated figures.

The significant increase in value in recent years is attributed to the strong demand for building stone facing on commercial and multi-unit residential developments. In addition, Ontario stone has been used for several large institutional projects such as the new Canadian embassy in Washington D.C. Part of the increase in value results from the development of new technology for the bonding of limestone veneers to pre-cast concrete panels. This allows the stone plant to produce a very high value-added product, yet one which remains competitive with other building systems.

The market for building stones has traditionally been limited by transportation charges. Until very recently, relatively little building stone was shipped out of the province. For example, in 1980 92.5% of the stone was used in Ontario. This increased to 98.8% in 1981 and stood at 91% in 1982. In 1984 and 1985, however, Ontario accounted for only 81.5% and 66.6%, respectively, of building stone shipments.

Quebec and the United States represent the most significant destinations for Ontario building limestone. In 1985 3,220 tonnes were shipped to Quebec and 1,130 tonnes to the US.

It is expected that markets for building stone, especially for commercial use, will increase in the next few years as architects reacquaint themselves with the material and more modern production technology is installed by the stone producers. Another factor contributing to the growth in the market will be restoration of many of Ontario's historic limestone buildings and public structures such as the Rideau Canal. These trends may help to restore Ontario's limestone industry to the status it once enjoyed as a major source of building materials.

The potential for building stone from Grenville marble in Southeastern Ontario has been discussed by Verschuren et al. (1985), who emphasize that attempts should be made to develop markets for unique Ontario stones rather than to reproduce popular European marbles.

Pulverized Stone and Stone Chips

TERRAZZO CHIPS

The production of terrazzo chips in Ontario was started by Carl Stoklosar in the early 1930s, using a small jaw crusher and screen mounted on the back of a truck, at a site east of Eldorado. In 1935 he took over an old slate mill which had operated in the 1920s on the east side of Highway 62 several kilometres north of Madoc, and this is still the main plant site for Stoklosar Marble Quarries Ltd. Two other terrazzo producers subsequently commenced production at Madoc: Hastings Marble Products Ltd. and Madoc Marble Quarries Co. (Hewitt, 1964, p.12), and these were merged in 1965 to form Grenville Aggregate Specialities Ltd. The sale of white Grenville dolomite chips for terrazzo was also started about this time from the nearby underground mine of Canada Talc Industries Ltd. Grenville Aggregates continued to operate the Hastings plant on old Highway 7 on the west fringe of Madoc village, and in 1983 the company merged with Stoklosar. In 1986 both plants were still being operated by Stoklosar Marble Quarries Ltd., currently the only significant producer of terrazzo chips in Ontario.

Domus Engineering Company of Toronto is the exclusive sales agent for Stoklosar products in Canada. Sales in the United States, which once accounted for 40 percent of the company's volume but now only 5 percent, are made directly from Madoc. Prices quoted in 1986 were:

Products	Price
0, 1, 2	$160 per ton in 50 lb. plastic bags
0, 5, 2	$150 per ton in 100 lb. plastic bags
3, 5, 7	$165 per ton in 100 lb. plastic bags
All chip sizes	$120 per ton in bulk
White dust	$75 per ton in bulk
Coloured dust	$60 per ton in bulk

It is interesting to note that the 1965 price for a 100 lb. bag of chips was 83 cents; the 1986 price was $7.50. Sales in 1965 were about 5,000 tons, but were significantly less in 1986. Twelve men are employed, and their wages represent more than half of total operating costs.

WHITE MARBLE CHIPS

White marble chips were produced in Ontario by three companies in 1986. Steep Rock Resources Inc. produced a range of chip products at its Perth plant, using coarse grained calcitic marble from its Tatlock quarry. Bolenders Ltd. produced chips from its coarse–grained dolomitic marble at Eagle Lake near Haliburton, and Canada Talc Industries Ltd. produced fine–grained dolomitic marble chips from its talc mine at Madoc, principally for terrazzo. Other recent producers, currently dormant, are mentioned by Hewitt and Vos (1972, p.6) and Hewitt (1964, p.12).

Annual consumption within reach of Ontario producers is in the order of 50,000 tonnes, most of it in neighbouring US states as far west as Chicago. Ontario producers enjoy about half of this market, much of the rest being supplied by Georgia Marble Company from a quarry in northern New York State. Value of the chips in bulk FOB producing plant is about $20–25 per tonne.

The market for exposed aggregate is very much dependent on prevailing fashions in architecture. In 1986, North American demand was probably in the order of 10,000 tonnes.

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Appendices

Appendix I
Glossary Of Geological Terms

Note: The following terms were referenced from: Bates and Jackson (1980) and American Geological Institute (1976).

anhydrite: A mineral, $CaSO_4$, anhydrous calcium sulfate. Orthorhombic, commonly massive in evaporite beds.

argillaceous: Rocks or substances composed of clay minerals, or having a notable proportion of clay in their composition, such as shale, slate, etc.

ball–and–pillow structure: A primary sedimentary structure found in sandstone and some limestones characterized by hemispherical or kidney–shaped masses resembling balls and pillows.

basement: 1) The undifferentiated complex of rocks that underlies the rocks of interest in an area. 2) The crust of the earth below sedimentary deposits, extending downward to the Mohorovicic discontinuity. In many places the rocks of the complex are igneous and metamorphic and of Precambrian age, but in some places are Paleozoic, Mesozoic, or even Cenozoic.

bedding plane: In sedimentary or stratified rocks, the division planes which separate the individual layers, beds, or strata.

bedding: A collective term signifying existence of beds or laminae. Planes dividing sedimentary rocks of the same or different lithology.

bedrock: A general term for the rock, usually solids, that underlies soil or other unconsolidated, superficial material.

bioclastic rock: A sedimentary rock consisting of fragmental or broken remains of organisms, such as limestone composed of shell material.

bioherm: A mound–like or circumscribed mass built exclusively or mainly by sedentary organisms such as corals, stromatoporoids, algae, etc., and enclosed in normal rock of different lithologic character.

biostrome: A bedded structure composed of shell beds, crinoid beds, coral heads, etc., which was built by sedentary organisms grown and preserved in place. In contrast to bioherms they lack mound–like or lens–like form.

bioturbation: The churning and stirring of a sediment by organisms.

birdseye: (Texture) Microcrystalline to very fine–crystalline limestone containing spots or tubes of crystalline calcite.

bitumen: A general name for various solid and semi–solid hydrocarbons which are soluble in carbon bisulfide, whether gases, easily mobile liquids, viscous liquids or solids. The term is often used interchangeably with hydrocarbons.

bituminous: 1) Yielding bitumen, or having bitumen in composition. This term is also commonly used for certain varieties of coal which burn freely with flame, although they really contain no bitumen. 2) Containing much organic or at least carbonaceous matter, mostly in the form of tarry hydrocarbons which are usually described as bitumen. 3) Having the odour of bitumen.

bivalve: A common term for pelecypods.

Brachiopoda: A phylum of marine, shelled animals with two unequal shells or valves, each of which normally is bilaterally symmetrical. Also called lamp shells.

breccia: Fragmented rocks whose components are angular and therefore, are distinguished from conglomerates, and are not water–worn. A rock made up of highly angular fragments. May be sedimentary or formed by crushing or grinding along faults.

Bryozoa: Phylum of small colonial animals, equipped with a lophophore, and that build calcareous structures of many kinds, mostly marine.

burrow: A cylindrical or near cylindrical tube, often filled with clay or sand, which may lie along the bedding plane or penetrate the rock, made by an animal that lived in the sediment.

calcarenite: A deposit composed of cemented sand–size grains of calcium carbonate ($CaCO_3$); usually a biosparite or a grainstone.

calcilutite: A name for limestone and dolostone made up of calcareous rock flour, the composition of which is typically nonsiliceous, though many calcilutites have an intermixture of clayey material. Grains or crystals average 0.0625 mm in diameter.

calcisiltite: Limestone composed of calcareous sediment of silt size.

calcite: A mineral, $CaCO_3$, hexagonal, rhombohedral, trimorphous with aragonite and vaterite; the principal constituent of limestone.

carbonatite: Intrusive carbonate rock which are associated with alkaline, igneous intrusions in many localities.

celestite: A mineral, $SrSO_4$. Orthorhombic. The principal ore of strontium.

Cephalopoda: Most highly developed class of mollusks that swam by ejecting a jet of water from the mantle cavity through a muscular funnel. Most of those preserved as fossils had straight to symmetrically coiled shells divided into chambers by transverse septa.

chalk: A very soft, white to light grey, unindurated limestone composed of the tests of floating microorganisms and some bottom dwelling forms in a matrix of fine–crystalline calcite. Usually siliceous.

chert: 1) Mineral: A cryptocrystalline variety of quartz. Composed of inter–locking grains generally not discernable under the microscope. 2) Rock: A compact siliceous rock of varying colour composed of microorganisms or precipitated silica grains. Occurs as nodules, lenses, or layers in limestones and shales.

conchoidal: A type of rock or mineral fractures giving smoothly curved surfaces. Characteristic of quartz and obsidian.

conglomerate: Rounded, water worn fragments of rock or pebbles, cemented together by another mineral substance. A cemented clastic rock containing rounded fragments corresponding in their grade sizes to gravel or pebbles.

coquina: Limestone composed of broken shells, corals, and other organic debris.

coral, colonial: A coral in which the individuals are attached together as a unit and do not exist as separate animals.

coral: A bottom–dwelling, sessile, marine coelenterate; some are solitary individuals, but the majority grow in colonies; they secrete external skeletons of calcium carbonate. The calcareous skeleton of a coral or group of corals.

coralgal: Refers to carbonate sediment derived from corals and algae.

coralline: Any organism that resembles a coral in forming a massive calcareous skeleton or base, such as certain algae or stromatoporoids. Pertaining to, composed of, or having the structure of corals, as coralline limestones.

crenulations: Wrinkles. Small folds, with a wavelength of a few millimetres.

Crinoidea: A type of echinoderm consisting of a cup or "head" containing the vital organs, numerous radiating arms, an elongate, jointed stem, and roots by which it is attached to the sea bottom while the body, stem, and arms float.

cross–bedding: The arrangement of laminations of strata transverse or oblique to the main planes of stratification of the strata concerned; inclined, often lenticular, beds between the main bedding planes.

crystal: A homogeneous, solid body of a chemical element, compound, or isomorphous mixture, having a regularly repeating atomic arrangement that may be outwardly expressed by plane faces.

dolomite: A mineral, CaMg $(CO_3)_2$, commonly with Fe replacing Mg to produce ankerite. Hexagonal rhombohedral. It occurs in a great many crystalline and noncrystalline forms in carbonate rock, and among rocks of all geological ages.

dolostone: The name for a sedimentary rock composed of fragmental, concretionary, or precipitated dolomite of organic or inorganic origin.

eurypterid: One of a group of very large, extinct arthropods related to the trilobites.

fault: A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

fissility: A property of splitting easily along closely spaced parallel planes.

flame structure: A load cast showing evidence of some horizontal slip. A load cast in which part of an underlying layer has been squeezed irregularly upward into the overlying layer.

fossil: The remains or traces of animals or plants which have been preserved by natural causes in the earth's crust.

Gastropoda: A class of the phylum Mullusca; commonly known as gastropods or snails.

glauconite: A green mineral, closely related to the micas and essentially a hydrous potassium iron silicate. Commonly occurs in sedimentary rocks of marine origin.

gypsum: A mineral, $CaSO_4$ $2H_2O$. Monoclinic. A common mineral of evaporites. Used in manufacture of plaster of Paris and drywall. Also called satin spar (fibrous gypsum).

hematite: A mineral, Fe_2O_3 hexagonal rhombohedral. The principal ore of iron.

horn coral: A solitary coral, conical in shape, and generally belonging to the subclass *Rugosa*.

hydrocarbon: A compound containing only the two elements carbon and hydrogen (see bitumen).

inlier: An area or group of rocks surrounded by rocks of younger age, e.g. an eroded anticlinal crest.

interbedded: Occurring between beds, or lying in a bed parallel to other beds of different material.

interformational conglomerate: Those gravels and their indurated equivalents that often are present within a formation of which the constituents have a source external to the formation.

intraclast: A broad, general term for a component of a limestone, representing a torn–up and reworked fragment of a penecontemporaneous sediment (usually weakly consolidated) that has been eroded within the basin of deposition (such as the nearby sea floor or an exposed carbonate mud flat) and redeposited there to form a new sediment.

intraformational conglomerate: A conglomerate, the clasts of which are derived from the formation of which the conglomerate is a part.

joint: Fracture in rock, generally more or less vertical or transverse to bedding, along which no appreciable movement has occurred.

karst: A type of topography that is formed over limestone, dolostone, or gypsum by dissolving or solution, and that is characterized by closed depressions or sinkholes, caves, and underground drainage.

laminations: The layering or bedding less than 1 cm in thickness in a sedimentary rock. The more or less distinct alternation of materials, which differ one from the other in grain size or composition.

limestone: A bedded sedimentary deposit consisting chiefly of calcium carbonate ($CaCO_3$) which yields lime when burned. It is the consolidated equivalent of limy mud, calcareous sand, or shell fragments.

lithographic limestone: An exceedingly fine–crystalline limestone used for lithography. Texture: a term used to denote grain size in calcareous sedimentary rocks. The grain size corresponds to that of clay, or less than 0.004 mm.

marble: A metamorphic rock composed essentially of calcite and/or dolomite.

metabentonite: Metamorphosed, altered or somewhat indurated bentonite characterized by minerals that are not normally found in bentonites. Does not possess the swelling and absorptive properties of bentonite.

micrite: A limestone with very fine–subcrystalline texture, such as a lithographic limestone.

Mullusca: A phylum of unsegmented, invertebrate animals that includes the gastropods, pelecypods, cephalopods, etc.

mottled: Irregularly marked with spots of different colours.

mudcrack: Desiccation crack, formed when a thin layer of mud dries, usually in a polygonal pattern.

mudstone: An indurated mud having the texture and composition of shale, but lacking its fine lamination or fissilty; a blocky or massive, fine–grained sedimentary rock in which the proporations of clay and silt are approximately equal.

nodular: Having the shape of or being composed of nodules. Said of certain ores or strata.

nodule: A small, irregular rounded knot, mass or lump of a mineral aggregate, normally having a warty or knobby surface and no internal structure, and usually exhibiting a contrasting composition from the enclosing sediment or rock matrix in which it is embedded. Most nodules appear to be secondary features.

oolite: 1) A spherical to ellipsoidal body (0.25–2.0 mm in diameter) which may or may not have a nucleus, and has concentric or radial structure or both. It is usually calcareous, but may be siliceous, hematitic, or of another composition. 2) A rock composed chiefly of ooliths.

oolith: The individual spherite of which an oolite (rock) is composed.

ostracodes: Any aquatic crustacean belonging to the subclass Ostracoda, characterized by a bivalve, generally calcified carapace with a hinge along the dorsal margin. Most are of microscopic size (0.4 – 1.5 mm long) although freshwater forms up to 5 mm long and marine forms up to 30 mm long are known.

outcrop: That part of a geologic formation or structure that appears at the surface of the earth.

outlier: An area or group of rocks surrounded by rocks of older age, e.g. an isolated hill or butte.

parting: A small joint or bedding plane in a layer of rock.

Pelecypoda: A division (class) of uncoiled, bivalve mollusks, with straight intestine and sometimes with a foot utilized in locomotion, also referred to as bivalves, commonly known as clams.

pellet: Small aggregation of sedimentary material, usually fecal in origin. In size, pellets are approximately 0.1–0.3 mm in diameter, and in few cases are several mm in length.

pentamerid: An articulate brachiopod assigned to the superfamily Pentameracea; characterized in general by large, strongly biconvex shell with a smooth, costellate, or costate exterior, and by spondylium in the pedicle valve.

peridotite: A coarse–grained, ultramafic rock consisting of olivine and pyroxene with accessory constituents.

petroleum: A naturally occurring, complex liquid hydrocarbon that may contain varying degrees of impurities (sulphur and nitrogen) which after distillation yields a range of combustible fuels, petrochemicals and lubricants.

petroliferous: Containing or yielding petroleum.

platy: 1) Said of a sedimentary particle whose length is more than three times its thickness. 2) Said of a sandstone or limestone that splits into laminae having thicknesses in the range of 2 to 10 mm.

pyrite: (FeS_2): Iron pyrites. "Fool's gold", Dimorphous with marcasite. Isometric, commonly in striated cubes or in pyritohedrons. Brass yellow. An important ore of sulfur, sometimes mined for the associated gold or copper.

quartz: A mineral, SiO_2. Hexagonal, trigonal–trapezohedral. A common constituent in clastic sediments.

reed cast: A vertical and cylindrical cast of sand presumably representing the filling of a mold left by a reed.

reef: A rock structure, either mound–like or layered, built by sedentary organisms such as corals, etc., and usually enclosed in a rock of differing lithologies.

rip–up: 1) Said of a sedimentary structure formed by shale clasts (usually of flat shape) that have been "ripped up" by currents from a semi–consolidated mud deposit and transported to a new depositional site. 2) Said of a clast in a rip–up structure.

ripple mark: An undulatory surface sculpture produced in non–coherent granular materials by the wind, by currents of water, or by agitation of water in wave action.

Rugosa: See horn coral.

sandstone: A cemented or otherwise compacted detrital sediment composed predominantly of quartz grains, the grades of the latter being those of sand.

selenite: A clear, transparent variety of gypsum, $CaSO_4$ $2H_20$.

shale: A laminated sediment in which the constituent particles are predominantly of the clay grade.

shear zone: A zone in which shearing has occurred on a large scale so that the rock is crushed and brecciated.

siltstone: A very fine–grained consolidated clastic rock composed predominantly of particles of silt grade.

soft–sediment deformation: Deformation of sediment laminae and bedding due to density irregularities in the sediment over– and underlying a unit.

spicules: 1) One of the numerous minute calcareous or siliceous bodies, having highly varied and often characteristic forms, occurring in and serving to stiffen and support the tissues of various invertebrates, and frequently found in marine–sediment samples and in Paleozoic and Cretaceous cherts. 2) The empty siliceous shell of a diatom.

stromatolite: Laminated, but otherwise structureless calcareous objects, commonly fossil calcareous algae.

Stromatoporoidea: Laminated, organic bodies made of calcium carbonate and probably by a hydrozoan.

stylolite: A term applied to parts of certain limestones which have a column–like development; the "columns" being generally at right angles or highly inclined to the bedding planes, having grooved, sutured or striated sides, and irregular cross–section. Due to pressure solution the solution contact usually possesses insoluble residues such as bitumen, clays, etc.

subcrop: Occurrence of strata on the undersurface of an inclusive stratigraphic unit that succeeds an important unconformity where overstepping is conspicuous. Area within which a formation occurs directly beneath an unconformity. In this report, usually the Paleozoic strata underlying Pleistocene deposits.

sublithographic: Said of a limestone whose texture approaches the exceedingly fine grain of lithographic limestone. Also, said of the texture of such a rock.

sucrosic (saccharoidal): A granular or crystalline texture resembling that of loaf sugar, or of the crystalline granular texture seen in some sandstones, evaporites, marbles, and dolostones.

tabulate: 1) Having tabulae, specifically said of a coral characterized by prominent tabulae.

tentaculitids: A marine invertebrate animal characterized by radial symmetry, a small conical shell with transverse rings of variable size and spacing, longitudinal striae, an embryonic chamber with bluntly pointed apex, and small pores in the shell wall.

tetracoral: A coral with four–fold symmetry.

trace fossil: A sedimentary structure consisting of a fossilized track, trail, burrow, tube, boring, or tunnel resulting from the life activities (other than growth) of an animal, such as a mark made by an invertebrate moving, creeping, feeding, hiding, browsing, running, or resting in soft sediment. It is preserved as a raised or depressed form in sedimentary rock.

Trilobita: Class of extinct arthropods with a dorsal skeleton consisting of a cephalon, thorax, and pygidium, and divided longitudinally into a central axis and two pleutral regions.

vug/vuggy: An empty cavity, often with a mineral lining of different composition from that of the surrounding rock.

wavy bedding: Bedding that is characterized by undulatory bounding surfaces.

Appendix II
Crystallinity Classification

Coarse crystalline	over 5 mm
Medium crystalline	1–5 mm
Fine crystalline	0.2–1 mm
Very fine crystalline	under 0.2 mm; not detectable with the naked eye.
Subcrystalline	0.05–0.2 mm; crystals detectable under 10X hand lens (= lithographic)
Microcrystalline	under 0.05 mm; crystals only detectable under microscopic examination (= lithographic).

GRAIN-SIZE CLASSIFICATION

Boulder	Over 256 mm
Cobble	64–256 mm
Pebble	4–64 mm
Granule	2–4 mm
Very coarse grained sand	1–2 mm
Coarse grained sand	0.5–1 mm
Medium grained sand	0.25–0.5 mm
Fine grained sand	0.125–0.25 mm
Very fine grained sand	0.0625–0.125 mm
Silt	0.004–0.0625 mm
Clay (mud)	Less than 0.004 mm

BEDDING CLASSIFICATION

Massive bedded	over 100 cm
Thick bedded	30–100 cm
Medium bedded	10–30 cm
Thin bedded	3–10 cm
Very thin bedded	1–3 cm
Thick laminated	0.3–1 cm
Thin laminated	less than 0.3 cm

Appendix III
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Appendix IV
Inventory of All Known Paleozoic Limestone Quarries in Ontario

Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick–ness	Geological Formation(s) (Members)
A-01	Zorra Qy	Lafarge Canada Inc.	YES	17T	507750E 4771500N	W Zorra	II, III, IV	2–5, 2–4, 1–3	Aylmer	Y	48.8 m	Amherstburg, Lucas (Anderdon)
A-02	Beachville Qy	Beachvilime Ltd.	YES	17T	512000E 4769000N	N Oxford	II, III	17–18	Aylmer	Y	20.0 m	Lucas
A-03	Beachville Qy	Beachvilime Ltd.	YES	17T	511100E 4767750N	N Oxford	II, III, IV, B.F.	13–16, 15–18	Aylmer	Y	24.1 m	Lucas
A-04	Stelco Qy –Beachville	Stelco Steel Inc.	YES	17T	510600E 4766450N	N Oxford	II, III, B.F.	16–18, 5–17 & 12, 14, 15	Aylmer	Y	33.4 m	Lucas (sandy Anderdon)
A-06	Strathroy Qy #1	unknown	NO	17T	445400E 4758300N	Adelaide	II–III	16	Aylmer	N	1.0 m	Widder
A-07	Strathroy Qy #2	unknown	NO	17T	445950E 4759400N	Adelaide	II	17	Aylmer	N	unknown	Widder
A-08	Beachville Qy	Toronto Cement Corp.	NO	17T	514200E 4771200N	W Oxford	Broken Front	6	Aylmer	N	unknown	Lucas
A-09	Rapson Qy	unknown	NO	17T	517800E 4773800N	W Oxford	Broken Front	Gore	Aylmer	N	3.0 m	Lucas
A-10	Wier Qy	unknown	NO	17T	518200E 4775800N	E Zorra	XI	2	Aylmer	N	2.0 m	Bois Blanc
A-11	Callan Estate Qy	unknown	NO	17T	524800E 4782700N	E Zorra	XVII	9	Aylmer	N	2.0 m	Bertie
A-12	Innerkip Qy	Innerkip Quarries, Ltd.	NO	17T	524600E 4782900N	E Zorra	XVII	9	Aylmer	N	4.3 m	Bertie, Bois Blanc
A-13	Innerkip Park Qy	unknown	NO	17T	524300E 4783300N	E Zorra	XVII	10	Aylmer	N	3.5 m	Bois Blanc
BR-01	Wport Qy	Griffin Brothers Constr.	YES	18T	387650E 4947350N	N Crosby	VII	12	Brockville	Y	16.7 m	Gull River
BR-02	Harlem Qy	Tackaberry & Sons	YES	18T	411200E 4946700N	Bastard	VI	15	Brockville	I	3.7 m	March, Oxford
BR-03	Newboyne (O'Grady) Qy	Tackaberry & Sons	YES	18T	414050E 4951050N	Bastard	V	6	Brockville	I	3.8 m	March
BR-04	O.Shirley & Sons Qy	O. Shirley & Sons	YES	18T	416450E 4968150N	S Elmsley	III	9–10	Brockville	I	11.0 m	March
BR-05	Newbliss (Willows) Qy	Tackaberry & Sons	YES	18T	420700E 4961800N	Kitley	III	14–16	Brockville	N	8.0 m	Oxford
BR-06	Leeds (Ronan) Qy	Tackaberry & Sons	YES	18T	422100E 4961700N	Kitley	III	13	Brockville	I	10.4 m	Oxford
BR-07	Frankville (Mercier) Qu.	Tackaberry & Sons	YES	18T	423650E 4952650N	Kitley	VIII	19–20	Brockville	I	4.5 m	March
BR-08	Athens (Lawson) Qy	Tackaberry & Sons	YES	18T	422300E 4944350N	Rr Yonge & Escott	X	15	Brockville	Y	12.5 m	March
BR-09	Jasper Qy	Tackaberry & Sons	YES	18T	425950E 4965800N	Wolford	I	29–30	Brockville	Y	11.0 m	Oxford
BR-10	Sherwood Springs Qy	William Clow	YES	18T	436800E 4929300N	Frnt Yonge	I	2–3	Brockville	Y	4.5 m	March
BR-11	Woods (Tincap) Qy	Tackaberry & Sons	YES	18T	438200E 4942000N	Elizabethtown	V	20	Brockville	Y	10.0 m	Oxford
BR-12	Brockville Qy	Permanent Concrete	YES	18T	447500E 4939800N	Elizabethtown	I	3–5	Brockville	Y	20.1 m	March, Oxford
BR-13	Brockville Qy	Dibblee Constr.	YES	18T	447350E 4940750N	Elizabethtown	I	3–4	Brockville	Y	5.6 m	Oxford
BR-14	Maitland (Wings) Qy	Tackaberry & Sons	YES	18T	450500E 4948250N	Augusta	III	24–26	Brockville	I	6.0 m	Oxford
BR-15	Kemptville Qy	Maple Grove (Kemptville)	YES	18T	452500E 4986000N	S Gower	VI	10	Brockville	I	7.0 m	Oxford
BR-16	Wport Qy # 2	unknown	NO	18T	387800E 4946200N	N Crosby	VIII	10	Brockville	N	1.0 m	Gull River
BR-17	Freeland Qy	unknown	NO	18T	404500E 4950150N	Bastard	II	21	Brockville	N	2.5 m	March
BR-18	Lombardy Qy # 2	unknown	NO	18T	413300E 4961600N	S Elmsley	II	22	Brockville	N	3.0 m	Oxford
BR-19	Lombardy Qy	unknown	NO	18T	416150E 4966400N	S Elmsley	III	12	Brockville	N	2.5 m	Oxford
BR-20	Shanes Qy	unknown	NO	18T	420200E 4965250N	S Elmsley	I	8	Brockville	N	0.2 m	Oxford
BR-21	Toledo Qy	unknown	NO	18T	421400E 4954850N	Kitley	VI	21	Brockville	N	1.0 m	Oxford
BR-22	Brandy Hill Qy	unknown	NO	18T	428050E 4958600N	Kitley	VII	8	Brockville	N	1.8 m	March
BR-23	Lehighs Corners Qy	unknown	NO	18T	425600E 4949900N	Kitley	X	21	Brockville	N	2.0 m	Oxford
BR-24	Eastons Corners Qy	unknown	NO	18T	429600E 4964900N	Wolford	II	25	Brockville	N	0.5 m	Oxford
BR-25	Oxford Mills Qy	Grenville Crushed Rock	NO	18T	441250E 4978250N	Oxford	III	8–9	Brockville	N	6.0 m	Oxford
BR-26	Main Qy	Tackaberry & Sons	YES	18T	419800E 4943800N	Rr Yonge & Escott	X	21–22	Brockville	I	8.3 m	March
BR-27	Wights Corners Qy	unknown	NO	18T	423100E 4943700N	Rr Yonge & Escott	IX	14	Brockville	N	1.0 m	March
BR-28	Athens Qy	Brundige Constr. Co.	NO	18T	423500E 4943000N	Rr Yonge & Escott	IX	14	Brockville	N	0.0 m	March
BR-29	Athens Qy	unknown	NO	18T	423100E 4941800N	Rr Yonge & Escott	IX	16–17	Brockville	N	6.7 m	March
BR-30	Hawkes Qy	unknown	NO	18T	427200E 4947700N	Rr Yonge & Escott	X	1	Brockville	N	1.1 m	March
BR-31	Brown's Bay Prov. Park	St. Lawrence Parks Commission	NO	18T	435500E 4927000N	Frnt Yonge	Broken Front	7	Brockville	N	3.0 m	March
BR-32	Jones Creek Qy	unknown	NO	18T	435950E 4928050N	Frnt Yonge	Broken Front	5	Brockville	N	4.0 m	March
BR-33	Forthton Qy	unknown	NO	18T	431400E 4943800N	Elizabethtown	VII	33	Brockville	N	3.6 m	March
BR-34	Bellamy Qy	unknown	NO	18T	435400E 4950300N	Elizabethtown	VIII	17	Brockville	N	3.5 m	March
BR-35	New Dublin Qy	Brundige Constr. Co.	NO	18T	436600E 4943900N	Elizabethtown	VI	22	Brockville	N	7.0 m	Oxford
BR-36	Fairfield E Qy	unknown	NO	18T	441600E 4947300N	Elizabethtown	V	8	Brockville	N	0.8 m	March
BR-37	Tincap Qy	Tackaberry & Sons	NO	18T	437200E 4941900N	Elizabethtown	V	20	Brockville	I	10.1 m	Oxford
BR-38	Tincap Qy	Dodge Constr.	NO	18T	440500E 4940650N	Elizabethtown	III	17	Brockville	N	2.0 m	Oxford

* Y = yes; N = no; I = intermittent

Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick-ness	Geological Formation(s) (Members)
BR-39	Prescott Qy	unknown	NO	18T	457000E 4951300N	Augusta	I	7	Brockville	N	1.8 m	March
BR-40	Plums Qy	unknown	NO	18T	461300E 4952000N	Edwardsburgh	I	33–34	Brockville	N	0.5 m	Oxford
BR-41	Mills Qy	unknown	NO	18T	460500E 4959050N	Edwardsburgh	III	26	Brockville	N	12.0 m	Oxford
BR-42	Cardinal Qy # 2	unknown	NO	18T	466500E 4960500N	Edwardsburgh	I	11	Brockville	N	0.0 m	Oxford
BR-43	Cardinal Qy # 1	unknown	NO	18T	467900E 4958500N	Edwardsburgh	I	11	Brockville	N	3.0 m	Oxford
CB-01	Guelph Reformatory Qy	Guelph Reformatory	NO	17T	564500E 4822000N	Guelph	City of Guelph	–	Cambridge	N	11.9 m	Amabel (Eramosa), Guelph
CB-02	Guelph Qy	Guelph Dolime Ltd.	YES	17T	559800E 4818500N	Guelph	IV–V, Div G	1–5	Cambridge	Y	19.0 m	Amabel (Eramosa), Guelph
CB-03	Acton Qy	United Aggregates Ltd.	YES	17T	580200E 4830500N	Esquesing	III–IV	21–24	Cambridge	Y	41.2 m	Reynales, Amabel
CB-04	Milton (Dufferin) Qy	Dufferin Aggregates	YES	17T	584100E 4821300N	Esquesing & Nassagaweya	I & VII	8–10 & 7–13	Cambridge	Y	30.8 m	Cabot Head, Reynales, Amabel
CB-05	Halton (Milton) Qy	Halton Crushed Stone	YES	17T	583900E 4819000N	Nassagaweya	VI	7–8	Cambridge	Y	23.5 m	Cabot Head, Reynales, Amabel
CB-06	Milton Qy	Milton Limestone	YES	17T	587000E 4817450N	Nassagaweya	VII	1–2	Cambridge	Y	24.1 m	Reynales, Amabel
CB-07	Nelson (Mt. Nemo) Qy	Nelson Aggregate Co.	YES	17T	590500E 4807200N	Nelson	II–III	1–2	Cambridge	Y	18.9 m	Reynales, Amabel
CB-08	Old Nelson (Kerns Rd) Qu.	Nelson Crushed Stone	NO	17T	592500E 4800050N	Nelson	I S.D.S.	24	Cambridge	N	15.7 m	Reynales, Irondequ., Rochr., Amabel
CB-09	W Flamborough Qy	Flamboro Quarries Ltd.	YES	17T	579800E 4795500N	W Flamborough	IV	5–6	Cambridge	Y	9.4 m	Lockport (Eramosa), Guelph
CB-10	Clappisons Corners Qy	Armstrong Brothers	NO	17T	588600E 4796000N	E Flamborough	III	12	Cambridge	N	9.7 m	Reynales, Irondeq., Roches., Lockpt.
CB-11	Dundas (Steetley) Qy	Steetley Industries	YES	17T	582000E 4794000N	W Flamborough	II–IV	7–11	Cambridge	Y	20.0 m	Lockport (Eramosa), Guelph
CB-12	Stoney Creek Qy	Taro Aggregates	YES	17T	600000E 4783200N	Saltfleet	VI	new 25–26; old 27–28	Cambridge	Y	19.4 m	Lockport (Vinemount, Eramsoa)
CB-13	Vinemount Qy	Waterford Sand & Gravel	YES	17T	608500E 4781100N	Saltfleet	V	5	Cambridge	Y	19.5 m	Lockport(Goat Is., Vinemount, Eramosa)
CB-14	Irvine Creek Qy	unknown	NO	17T	545400E 4836600N	Nichol	XI	18–19	Cambridge	N	unknown	Guelph
CB-15	Elora Qy	Gypsum, Lime, & Alabast.	NO	17T	547125E 4837475N	Nichol	XII	21	Cambridge	N	18.0 m	Guelph
CB-16	Fergus Qy	James Gow	NO	17T	450100E 4838900N	Nichol	XV	23	Cambridge	N	7.6 m	Guelph
CB-17	O.H. Gow Qy	O.H. Gow	NO	17T	551500E 4839850N	W Garafraxa	I	6	Cambridge	N	7.0 m	Guelph
CB-18	Shands Qy	unknown	NO	17T	553100E 4842000N	W Garafraxa	III	6	Cambridge	N	unknown	Guelph
CB-19	Erin Qy	W.J. Smith	NO	17T	571500E 4842400N	Erin	V	15	Cambridge	N	unknown	Guelph
CB-20	Erin Qy	Ritchie Cut Stone Ltd.	NO	17T	572900E 4842900N	Erin	VI	15	Cambridge	N	4.0 m	Guelph
CB-21	Pearson (Erin) Qy	Wm. Pearson (1938)	NO	17T	576400E 4846900N	Erin	X	13	Cambridge	N	unknown	Amabel
CB-22	Rockwood Qy # 2	Rockwood Lime Co. Ltd.	NO	17T	569500E 4830950N	Eramosa	V	7	Cambridge	N	unknown	Amabel
CB-23	Rockwood Qy	Rockwood Lime Co. Ltd.	NO	17T	569100E 4830300N	Eramosa	V	6	Cambridge	N	12.1 m	Amabel
CB-24	W Rockwood Qy	unknown	NO	17T	568100E 4829100N	Eramosa	IV	6	Cambridge	N	unknown	Amabel
CB-25	Rockwood Qy # 3	E. Harvey Ltd.	NO	17T	569400E 4828900N	Eramosa	IV	4	Cambridge	N	3.5 m	Amabel
CB-26	Silver Creek N Qy	unknown	NO	17T	582950E 4838250N	Esquesing	IX	28	Cambridge	N	unknown	Amabel
CB-27	Glen Williams Qy	Industrial Sand & Gravel	NO	17T	583900E 4837750N	Esquesing	IX	26	Cambridge	N	12.0 m	Amabel, Reynales
CB-28	Georgetown Qy	Limehouse Crushed Stone	NO	17T	582200E 4836100N	Esquesing	VIII	27	Cambridge	N	5.6 m	Amabel
CB-29	Georgetown Qy	Armstrong Brothers	NO	17T	582800E 4833800N	Esquesing	VII	24	Cambridge	N	7.4 m	Amabel
CB-30	Limehouse Qy	Toronto Lime Co.	NO	17T	582600E 4832000N	Esquesing	VI	22	Cambridge	N	3.0 m	Decew, Amabel
CB-31	Speyside Qy	Standard Industries Ltd.	NO	17T	583500E 4824300N	Esquesing	II	13	Cambridge	N	3.2 m	Amabel
CB-32	Guelph Qy # 3	unknown	NO	17T	561850E 4821700N	Guelph	City of Guelph	–	Cambridge	N	unknown	Guelph
CB-33	Guelph Qy	Standard Aggregates	YES	17T	558800E 4815800N	Guelph	S.E. of Div B	6	Cambridge	N	2.7 m	Guelph
CB-34	Glenchristie Qy	Guelph Dolime Ltd.	YES	17T	557100E 4813600N	Puslinch	IV	1–3	Cambridge	N	15.0 m	Guelph
CB-35	Campbellville Qy	Fermar Paving Ltd.	NO	17T	581800E 4816950N	Nassagaweya	IV	8	Cambridge	N	9.7 m	Amabel
CB-36	Milton Qy	Gypsum, Lime, & Alabast.	NO	17T	586500E 4817500N	Nassagaweya	VI–VII	4	Cambridge	N	15.5 m	Amabel
CB-37	Kelso Qy	Gypsum, Lime, & Alabast.	NO	17T	585100E 4816600N	Nassagaweya	VI	3–4	Cambridge	N	20.7 m	Reynales, Amabel
CB-38	Rattlesnake Point Qy	unknown	NO	17T	587100E 4814600N	Nelson	VI	14	Cambridge	N	unknown	Amabel
CB-39	Lowville Qy	Bay Crushed Stone–Lowville Quarries	NO	17T	591100E 4808400N	Nelson	IV	3	Cambridge	N	17.7 m	Amabel
CB-40	Nelson Qy	unknown	NO	17T	592100E 4804600N	Nelson	II	16	Cambridge	N	unknown	Amabel
CB-41	Devil's Glen Qy	City of Cambridge	NO	17T	554300E 4802300N	N Dumfries	XII	W of Grand River	Cambridge	N	10.4 m	Guelph
CB-42	S Galt Qy	Chritie, Henderson, & Co.	NO	17T	555600E 4799450N	N Dumfries	X	9	Cambridge	N	12.0 m	Guelph
CB-43	Emerald Lake Qy	Gypsum, Lime, & Alabast.	NO	17T	570300E 4807000N	Puslinch	Puslinch Gore	29	Cambridge	N	2.9 m	Guelph
CB-44	Puslinch Qy	Steetley Industries	NO	17T	572500E 4807700N	Puslinch	Gore	35	Cambridge	N	6.7 m	Guelph
CB-45	Valens Qy	unknown	NO	17T	567300E 4802600N	Beverly	VIII or IX	17 or 18	Cambridge	N	1.2 m	Guelph

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CB-46	Sheffield Qy	unknown	NO	17T	563200E 4797800N	Beverly	VII	5	Cambridge	N	5.5 m	Guelph
CB-47	Rockton Qy	George Collins	NO	17T	567650E 4794600N	Beverly	V	14	Cambridge	N	2.2 m	Guelph
CB-48	Rockton Qy	Township of Flamborough	YES	17T	567700E 4795700N	Beverly	IV	18	Cambridge	N	3.9 m	Guelph
CB-49	Troy Quarries	unknown	NO	17T	566800E 4790800N	Beverly	III	8 & 9	Cambridge	N	2.0 m	Guelph
CB-50	Freelton Qy	unknown	NO	17T	576600E 4804700N	W Flamborough	VIII	3	Cambridge	N	8.0 m	Amabel
CB-51	Hayesland Qy	unknown	NO	17T	579000E 4798000N	W Flamborough	V	5–6	Cambridge	N	2.7 m	Guelph
CB-52	Greensville Qy	unknown	NO	17T	490600E 4891900N	W Flamborough	II	6 or 7	Cambridge	N	12.0 m	Lockport (Eramosa)
CB-53	Dundas Qy	Canada Crushed Stone	NO	17T	584000E 4791600N	W Flamborough	I	13–14	Cambridge	N	13.4 m	Lockport (Eramosa), Guelph
CB-54	Ancaster Quarries	unknown	NO	17T	584000E 4787800N	Ancaster	II	48	Cambridge	N	10.0 m	Lockport
CB-55	Old Barton Twp. Qy	incl. Gallager Lime & Hamilton Lime	NO	17T	591000E 4785000N	Barton	VI–VII	13–15	Cambridge	N	unknown	Lockport
CB-56	Rhymal Sta Qy # 1	unknown	NO	17T	593950E 4783300N	Barton	VII	5	Cambridge	N	unknown	Lockport
CB-57	Rhymal Sta Qy # 3	unknown	NO	17T	593850E 4782900N	Barton	VII	5	Cambridge	N	unknown	Lockport
CB-58	Rhymal Sta Qy # 4	unknown	NO	17T	594700E 4787700N	Barton	VII	5	Cambridge	N	4.0 m	Lockport
CB-59	Hannon Qy	Wentworth County	NO	17T	595200E 4782050N	Barton	VIII	1	Cambridge	N	6.7 m	Lockport (Eramosa)
CB-60	Rhymal Sta Qy # 2	unknown	NO	17T	594200E 4781900N	Glanford	I	14	Cambridge	N	unknown	Lockport
CB-61	Rhymal Sta Qy	S.W. Miles	NO	17T	594300E 4781400N	Glanford	I	14	Cambridge	N	9.5 m	Lockport (Eramosa), Guelph
CB-62	Mount Hope Qy	unknown	NO	17T	588000E 4779000N	Glanford	IV	5	Cambridge	N	unknown	Guelph
CB-63	Saltfleet Township Qy	Township of Saltfleet	NO	17T	599950E 4783700N	Saltfleet	V	26	Cambridge	N	unknown	Lockport
CB-64	Tapleytown Qy	unknown	NO	17T	603500E 4782700N	Saltfleet	V	17	Cambridge	N	5.0 m	Lockport
CB-65	Tapleytown Qy	unknown	NO	17T	603100E 4781100N	Saltfleet	VII	16 or 17	Cambridge	N	1.2 m	Lockport
CB-66	Woodburn Qy	unknown	NO	17T	604250E 4778300N	Binbrook	I	1, Block 1	Cambridge	N	2.0 m	Lockport (Eramosa)
CH-01	MacGregor Qy	General Chemical Cnd.	YES	17T	333800E 4569500N	Anderdon	VI, VII	8–10, & 9–10	Chatham	Y	32.0 m	Lucas (Anderdon)
CH-02	Brunner Mond Qy	Brunner Mond Canada	NO	17T	327000E 4565000N	Anderdon	I	6–8	Chatham	N	17.0 m	Lucas (Anderdon), Dundee
CH-02a	Allied Chemicals Qy	General Chemical Cnd.	NO	17T	327200E 4564200N	Anderdon	I	2–3	Chatham	N	7.0 m	Lucas (Anderdon)
CH-03	Amherstburg Qy	Amherst Quarries Ltd.	YES	17T	327500E 4662400N	Malden	II	21–22	Chatham	Y	50.1 m	Amherstburg, Lucas
CH-04	Pelee Island Qy	670026 Ont. Ltd.	YES	17T	363350E 4630675N	Pelee Island	R.P. 35	1–2	Chatham	Y	6.0 m	Dundee
CH-05	Bastiansen Qy	John Bastiansen	YES	17T	426650E 4783150N	Bosanquet	Lake Range East	41–42	Chatham	I	1.5 m	Widder
CH-06	Thedford Qy	A. G. Cook Ltd.	NO	17T	427900E 4781800N	Bosanquet	VI	26	Chatham	I	2.5 m	Widder
CH-07	Thompson Qy	Dean Thompson	YES	17T	431000E 4781000N	Bosanquet	III	24–25	Chatham	I	3.0 m	Widder
CH-08	Sheridan Point Qy	Capt. John McCormick	NO	17T	360250E 4630500N	Pelee Island	Registered Plan 35	23	Chatham	N	3.0 m	Dundee
CH-09	Scudder W Qy	Erie Sand & Gravel	YES	17T	361000E 4629700N	Pelee Island	R.P. 35	15	Chatham	N	2.5 m	Dundee
CH-10	William McCormick Qy	William McCormick (in 1938)	NO	17T	360175E 4625450N	Pelee Island	Registered Plan 35	24	Chatham	N	5.3 m	Dundee
CH-11	Pelee Island Twp. Qy	Township of Pelee Is.	NO	17T	360000E 4623900N	Pelee Island	Registered Plan 35	25	Chatham	N	3.0 m	Dundee
CH-12	Pierce Qy	Burns Pierce	YES	17T	360600E 4623750N	Pelee Island	R.P. 35	27	Chatham	I	1.1 m	Dundee
CH-13	Landfill Qy	unknown	NO	17T	360000E 4622700N	Pelee Island	R.P. 35	29	Chatham	N	1.0 m	Dundee
CO-01	MacNammaras Qy	Nortario Limestone Ltd.	NO	17T	588450E 5288375N	Armstrong	VI	6	Cobalt	I	3.3 m	Thornloe
CO-02	Township of Harley Qy	Township of Harley	NO	17T	595525E 5278300N	Harley	VI	7	Cobalt	I	4.5 m	Thornloe
CO-03	Hanbury Qy	unknown	NO	17T	599750E 5273675N	Harley	III	9	Cobalt	N	5.5 m	Thornloe
CO-04	Dymond Clay Qy	Dymond Clay Products	NO	17T	600050E 5256675N	Bucke	IV	9	Cobalt	Y	4.6 m	Farr
CO-05	Farr Qy	unknown	NO	17T	601575E 5255550N	Bucke	III	11	Cobalt	N	6.0 m	Farr
CO-06	Earlton Airport Qy	unknown	NO	17T	584200E 5282950N	Armstrong	II	10	Cobalt	N	6.0 m	Earlton
CO-07	Middleton Qy	Roy Middleton	NO	17T	595700E 5278500N	Harley	V	5	Cobalt	N	2.5 m	Thornloe
CO-08	Dawson Point Qy	unknown	NO	17T	606700E 5261200N	Harris	I	5	Cobalt	N	1.6 m	Thornloe
CO-09	Sutton Bay Qy	unknown	NO	17T	604400E 5269900N	Harris	VII	–	Cobalt	N	4.0 m	Evanturel Creek
CO-10	Shipyards Qy	unknown	NO	17T	601400E 5258250N	Bucke	V	6	Cobalt	N	14.0 m	Bucke, Farr
CP-01	Arnprior Qy	Cavanagh Constr.	YES	18T	391000E 5026000N	Pakenham	IX	26–27	Carleton Pl.	Y	4.0 m	Bobcaygeon
CP-02	Kinburn Qy	Cavanagh Constr.	YES	18T	407300E 5022700N	Fitzroy	V	4	Carleton Pl.	Y	9.3 m	Bobcaygeon
CP-03	Almonte Qy	Robert C. Lyle (Burntland Aggregates)	YES	18T	408700E 5011500N	Ramsay	XII	16–17	Carleton Pl.	Y	5.0 m	Bobcaygeon
CP-04	W Carleton Qy	Cavanagh Constr.	YES	18T	411200E 5012550N	Huntley	XI	15	Carleton Pl.	Y	16.5 m	Bobcaygeon
CP-05	Carleton Pl. Qy	Duffy Road Oiling	YES	18T	410600E 5001650N	Ramsay	VIII	2	Carleton Pl.	I	8.8 m	March, Oxford
CP-06	Dunrobin Qy	George Kennedy	YES	18T	422800E 5031500N	Torbolton	V	1	Carleton Pl.	I	5.0 m	Oxford, Rockcliffe

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CP-07	Franktown Qy	Cavanagh Constr.	YES	18T	419250E 4989450N	Beckwith	II	16	Carleton Pl.	I	1.7 m	Oxford
CP-08	Smith's Falls Qy	Warren Paving & Mat.	YES	18T	419800E 4974800N	Montague	V	27–28	Carleton Pl.	Y	5.2 m	March
CP-09	Spratt Qy	Spratt Sand & Gravel	YES	18T	424450E 5015500N	Huntley	II	2–5	Carleton Pl.	Y	11.3 m	Bobcaygeon
CP-10	Clarke Qy	Karson Kartage & Konstr.	YES	18T	424400E 5012400N	Huntley	IV	1–2	Carleton Pl.	Y	20.0 m	Bobcaygeon
CP-11	Cavanagh (Goulbourn) Qy	Cavanagh Constr.	YES	18T	423800E 5004650N	Goulbourn	VIII	11	Carleton Pl.	Y	10.4 m	Gull River
CP-12	Rosedale Qy	Tackaberry & Sons	YES	18T	425700E 4976400N	Montague	IV	17	Carleton Pl.	Y	4.5 m	March
CP-13	Kilmarnock Qy	Tackaberry & Sons	YES	18T	428000E 4972250N	Montague	I	19	Carleton Pl.	Y	6.0 m	Oxford
CP-14	Fallowfield Qy	R. W. Tomlinson	YES	18T	436050E 5014250N	Nepean	V	24–25	Carleton Pl.	Y	10.9 m	Gull River, Bobcaygeon
CP-15	Fallowfield Qy	Geo. Wimpey Can. Ltd.	YES	18T	436100E 5013700N	Nepean	V	21–23	Carleton Pl.	Y	36.2 m	Gull River, Bobcaygeon
CP-16	Fallowfield Qy	Warren Paving & Mat.	YES	18T	437500E 5013400N	Nepean	IV	21	Carleton Pl.	Y	18.7 m	Gull River, Bobcaygeon
CP-17	S Gloucester Qy	United Aggregates Ltd.	YES	18T	455150E 5016500N	Gloucester	V	24–25	Carleton Pl.	Y	27.3 m	March, Oxford
CP-18	S Gloucester Qy	Warren Paving & Mat.	YES	18T	455600E 5016600N	Gloucester	V	25	Carleton Pl.	Y	12.2 m	March, Oxford
CP-19	S Gloucester Qy	Beaver Asphalt	YES	18T	456200E 5016050N	Gloucester	V	26–27	Carleton Pl.	Y	13.5 m	Oxford
CP-20	Hawthorne Road Qy	Permanent Concrete	YES	18T	457050E 5016250N	Gloucester	VI	28	Carleton Pl.	Y	12.3 m	March, Oxford
CP-21	Greely Qy	Cornwall Sand & Gravel	YES	18T	459800E 5010000N	Osgoode	VI	14	Carleton Pl.	Y	8.0 m	Oxford
CP-22	Francon Qy	Francon–Division of Canfarge	YES	18T	455600E 5032600N	Gloucester	II	12–14	Carleton Pl.	Y	135 m	Gull River, Bobcaygeon
CP-23	LeBlanc Qy	Permanent Concrete	YES	18T	469750E 5031500N	Cumberland	VI	7–9	Carleton Pl.	Y	21.0 m	Lindsay
CP-24	Sarsfield Qy	Bertrand et Frere Constr.	YES	18T	474300E 5031100N	Cumberland	III	12	Carleton Pl.	Y	13.0 m	Lindsay
CP-25	Arnprior Qy	unknown	NO	18T	395100E 5026300N	Pakenham	XII	22–23	Carleton Pl.	N	2.0 m	Gull River
CP-26	Pakenham Qy	unknown	NO	18T	399450E 5020700N	Pakenham	XI	11	Carleton Pl.	N	7.6 m	Bobcaygeon
CP-27	County of Lanark Qy	unknown	NO	18T	400000E 5021000N	Pakenham	XII	11	Carleton Pl.	N	1.0 m	Bobcaygeon
CP-28	Pakenham Qy	unknown	NO	18T	400100E 5020500N	Pakenham	XII	9–10	Carleton Pl.	N	2.0 m	Bobcaygeon
CP-29	Marathon Qy	unknown	NO	18T	410600E 5021900N	Fitzroy	VI	1	Carleton Pl.	N	2.0 m	Bobcaygeon
CP-30	Hodgins Qy	unknown	NO	18T	412300E 5025200N	Fitzroy	IX	3	Carleton Pl.	N	2.0 m	Gull River
CP-31	Snedden Qy	unknown	NO	18T	403400E 5013950N	Ramsay	X	24	Carleton Pl.	N	3.0 m	Gull River
CP-32	McGill Qy	B. McGill	YES	18T	406000E 5009500N	Ramsay	Town of Almonte	3–4	Carleton Pl.	N	0.5 m	Bobcaygeon
CP-33	Galbraith Qy	unknown	NO	18T	407100E 5000300N	Ramsay	VI	5	Carleton Pl.	N	3.0 m	March
CP-34	Carp Qy	Bertrand Concrete Prod.	YES	18T	412000E 5018000N	Huntley	VIII	21	Carleton Pl.	I	3.5 m	Bobcaygeon
CP-35	Stittsville Qy	unknown	NO	18T	422000E 5013000N	Huntley	V	4	Carleton Pl.	N	4.0 m	Bobcaygeon
CP-36	MacMillan Qy	Allan MacMillan	NO	18T	416750E 5005500N	Huntley	II	1	Carleton Pl.	I	1.0 m	Gull River
CP-37	Harwood Plains Qy	unknown	NO	18T	422800E 5024950N	March	II	18	Carleton Pl.	N	2.7 m	March
CP-38	Malwood Qy	unknown	NO	18T	424300E 5029650N	March	V	22	Carleton Pl.	N	3.4 m	Rockcliffe (St. Martin)
CP-39	Strathearn Qy	unknown	NO	18T	428600E 5022950N	March	V	9	Carleton Pl.	N	1.4 m	Oxford
CP-40	Drummond Centre Qy #3	unknown	NO	18T	400700E 4982000N	Drummond	VII	11	Carleton Pl.	N	1.0 m	March
CP-41	Drummond Centre Qy #2	unknown	NO	18T	402950E 4978750N	Drummond	IV	10	Carleton Pl.	N	3.0 m	March
CP-42	Drummond Centre Qy #1	unknown	NO	18T	403400E 4078900N	Drummond	IV	11	Carleton Pl.	N	2.0 m	March
CP-43	Barrie Qy	unknown	NO	18T	403200E 4977900N	Drummond	III	10	Carleton Pl.	N	3.0 m	March
CP-44	Tay Qy	unknown	NO	18T	406950E 4972900N	N Elmsley	IX	18	Carleton Pl.	N	4.0 m	March
CP-45	Highway 43 Qy	unknown	NO	18T	416500E 4973400N	N Elmsley	VI	3	Carleton Pl.	N	3.0 m	March
CP-46	Carleton Pl. Qy	unknown	NO	18T	411000E 4997400N	Beckwith	XI	14	Carleton Pl.	N	1.0 m	March
CP-47	Beckwith Qy	unknown	NO	18T	413700E 4992000N	Ramsay	VI	11	Carleton Pl.	N	3.5 m	March
CP-48	Smith's Falls Qy	Ontario Building Mat.	NO	18T	419200E 4974100N	Montague	V	29	Carleton Pl.	N	2.5 m	March
CP-49	Highway 7 Qy	unknown	NO	18T	419000E 5006700N	Goulbourn	XII	7	Carleton Pl.	N	4.0 m	Gull River
CP-50	Stittsville Qy	Warren Paving & Mat.	YES	18T	422650E 5008400N	Goulbourn	XI	13–14	Carleton Pl.	I	2.7 m	Gull River
CP-51	Ashton Qy	unknown	NO	18T	421800E 5003500N	Goulbourn	IX	7	Carleton Pl.	N	0.5 m	Gull River
CP-52	Mansfield Qy	unknown	NO	18T	424800E 5005900N	Goulbourn	IX	13	Carleton Pl.	N	1.2 m	Gull River
CP-53	Stapledon Qy	unknown	NO	18T	430300E 5001200N	Goulbourn	III	15	Carleton Pl.	N	0.5 m	Gull River
CP-54	Dwyer Hill Qy	unknown	NO	18T	428000E 4994700N	Goulbourn	I	6	Carleton Pl.	N	2.0 m	March
CP-55	Shirleys Bay Qy	unknown	NO	18T	430000E 5023000N	Nepean	A on Ottawa River	3	Carleton Pl.	N	0.8 m	Oxford
CP-56	Bruce Farm Qy	unknown	NO	18T	436700E 5020500N	Nepean	II on Ottawa River	16	Carleton Pl.	N	4.5 m	Oxford
CP-57	Fallowfield Qy	unknown	NO	18T	437000E 5014700N	Nepean	IV	24	Carleton Pl.	N	1.0 m	March
CP-58	Clyde Avenue Qy	Frazer Duntile Ltd.	NO	18T	441500E 5024300N	Gloucester	City of Ottawa	–	Carleton Pl.	N	9.8 m	Gull River, Bobcaygeon
CP-59	Brule Qy	unknown	NO	18T	445700E 5024500N	Gloucester	City of Ottawa	–	Carleton Pl.	N	4.0 m	Bobcaygeon
CP-60	McCarthy Road Qy	Dibblee Constr. Co.	NO	18T	447600E 5022100N	Gloucester	III	3–4	Carleton Pl.	N	20.8 m	Gull River, Bobcaygeon
CP-61	Orleans Qy	Frazer Duntile Ltd.	NO	18T	458750E 5036400N	Gloucester	I	3	Carleton Pl.	N	8.8 m	Bobcaygeon

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Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick- ness	Geological Formation(s) (Members)
CP-62	Queenswood Village Qy	unknown	NO	18T	460300E 5036500N	Cumberland	I from Ottawa River	36	Carleton Pl.	N	8.5 m	Bobcaygeon
CP-63	Cumberland Qy	unknown	NO	18T	464000E 5039700N	Cumberland	I from Ottawa River	25	Carleton Pl.	N	20.0 m	Oxford, Rockcliffe
CP-64	Navan Qy	unknown	NO	18T	465000E 5031500N	Cumberland	IX	8	Carleton Pl.	N	1.7 m	Lindsay
CP-65	Herbert Corners Qy	unknown	NO	18T	454200E 5009800N	Osgoode	IV	7	Carleton Pl.	N	0.0 m	Oxford
CP-66	Metcalfe Qy	unknown	NO	18T	460500E 5010300N	Osgoode	VII	15	Carleton Pl.	N	2.5 m	Oxford
CP-67	Tomlinson (Metcalfe) Qu.	unknown	NO	18T	467000E 5011800N	Osgoode	X	20	Carleton Pl.	N	2.9 m	Oxford
CP-68	Marrionville Qy	unknown	NO	18T	471800E 5002950N	Osgoode	XI	44	Carleton Pl.	N	0.7 m	Oxford
CW-01	Forbes Qy	Barry Forbes	YES	18T	460400E 4989450N	Mountain	VIII	8	Cornwall	Y	8.0 m	Oxford
CW-02	Iroquois Qy	Fetterley/Cornwall Gravel	YES	18T	473200E 4963400N	Matilda	Range I	30-31	Cornwall	Y	27.6 m	Oxford
CW-03	Williamsburgh Qy	Cruickshank Constr.	YES	18T	478700E 4983150N	Williamsburgh	VII	31	Cornwall	Y	14.2 m	Gull River
CW-04	St. Albert Sta Qy	A. L. Blair Constr.	YES	18T	483900E 5008850N	Finch	XII	7-8	Cornwall	Y	14.9 m	Bobcaygeon
CW-05	Embrum Qy	A. L. Blair Constr.	YES	18T	479100E 5012600N	Russell	VIII	6-7	Cornwall	Y	12.0 m	Bobcaygeon
CW-06	Limoges Qy	Dibblee Constr.	YES	18T	481300E 5015800N	Russell	X	9	Cornwall	N	6.0 m	Lindsay
CW-07	Canaan Qy	Clarence Township	YES	18T	477550E 5033200N	Clarence	XI	11	Cornwall	Y	17.0 m	Lindsay
CW-08	Rockland (Stewart) Qy	unknown	NO	18T	477000E 5041500N	Clarence	IX	B & C	Cornwall	N	29.8 m	Bobcaygeon, Gull River
CW-09	Richier Qy	Cornwall Gravel	YES	18T	494875E 5012780N	Cambridge	X	10	Cornwall	Y	12.7 m	Lindsay
CW-10	Finch Qy	A. L. Blair Constr.	YES	18T	492500E 4997350N	Finch	II	11	Cornwall	Y	4.5 m	Verulam
CW-11	Plumadore Qy	A. L. Blair Constr.	YES	18T	495600E 4986750N	Osnabruck	V	27	Cornwall	I	3.0 m	Verulam
CW-11a	Osnabruck Centre Qy	Township of Osnabruck	YES	18T	495400E 4986800N	Osnabruck	V	26	Cornwall	I	4.5 m	Verulam
CW-12	Cornwall Qy	Permanent Concrete	YES	18T	512700E 4987800N	Cornwall	IV	25-29	Cornwall	Y	19.1 m	Gull River, Bobcaygeon
CW-13	Cornwall Qy	Warren Paving & Mat.	YES	18T	513450E 4988050N	Cornwall	IV	23	Cornwall	Y	9.7 m	Gull River, Bobcaygeon
CW-14	MacLeod Qy	Cornwall Gravel Co.	YES	18T	521800E 4992800N	Cornwall	IV	3-5	Cornwall	Y	33.4 m	Gull River, Bobcaygeon
CW-15	Apple Hill Qy	A. L. Blair Constr.	YES	18T	517760E 5002400N	Charlottenburgh	IX	11-14	Cornwall	Y	4.5 m	Lindsay
CW-16	Gravel Hill Qy	A. L. Blair Constr..	YES	18T	509150E 5007150N	Roxborough	IV	9	Cornwall	Y	4.2 m	Lindsay
CW-17	Moose Creek Qy	A. L. Blair Constr.	YES	18T	501700E 5008600N	Roxborough	VI	24	Cornwall	Y	5.6 m	Lindsay
CW-18	Tayside Qy	A. L. Blair Constr.	YES	18T	502500E 5018000N	Roxborough	X	10	Cornwall	Y	6.6 m	Lindsay
CW-19	St. Isodore Qy	Bertrand et Frere Constr.	YES	18T	508000E 5022150N	S Plantagenet	XX	7	Cornwall	Y	10.9 m	Lindsay
CW-20	Alfred Qy	Raymond Tierney	YES	18T	507000E 5047580N	Alfred	III	28	Cornwall	I	3.0 m	Rockcliffe
CW-21	L'Orignal Qy	Bertrand et Frere Constr.	YES	18T	518550E 5049050N	Longueuil	--	213-215	Cornwall	Y	15.2 m	Bobcaygeon
CW-22	Ross Qy	Sintra Inc.	YES	18T	536850E 5046350N	E Hawkesbury	I	28	Cornwall	Y	9.5 m	Rockcliffe
CW-23	McAlpine Qy	Cliftondale Aggregates	YES	18T	522900E 5042800N	Caledonia	I	1-2	Cornwall	Y	10.2 m	Bobcaygeon
CW-24	Skye Qy	Sintra Inc.	YES	18T	514180E 5028675N	Caledonia	VIII	12	Cornwall	Y	9.3 m	Bobcaygeon
CW-25	Gauthier Qy	Cruickshank Constr.	YES	18T	513350E 5026250N	Caledonia	IX	12	Cornwall	I	5.5 m	Bobcaygeon
CW-26	Fiskes Corners Qy	A. L. Blair Constr.	YES	18T	519750E 5023350N	Kenyon	VIII	12	Cornwall	Y	7.0 m	Bobcaygeon
CW-27	Green Valley	Cruickshank Constr.	YES	18T	536450E 5010300N	Lancaster	VI	29	Cornwall	Y	13.8 m	Bobcaygeon, Gull River
CW-30	Rockland Qy	unknown	NO	18T	377250E 5044400N	Clarence	Village of Rockland	--	Cornwall	N	8.0 m	Oxford
CW-31	Orient Qy	unknown	NO	18T	486000E 5045300N	Clarence	on Ottawa River	5	Cornwall	N	2.1 m	Bobcaygeon
CW-32	Beauchamp Qy	unknown	NO	18T	483000E 5039800N	Clarence	V	4	Cornwall	N	0.5 m	Lindsay
CW-33	St. Pascal Qy	unknown	NO	18T	484650E 5037900N	Clarence	V	8	Cornwall	N	2.0 m	Lindsay
CW-34	Bourget Qy	unknown	NO	18T	484000E 5029850N	Clarence	VII	20	Cornwall	N	1.0 m	Lindsay
CW-35	Rollway Qy	unknown	NO	18T	494000E 5043600N	N Plantagenet	II	24	Cornwall	N	8.0 m	Lindsay
CW-36	S Nation Prov. Qy	unknown	NO	18T	496300E 5044600N	N Plantagenet	II	19	Cornwall	N	1.0 m	Lindsay
CW-37	Centrefield Qy	unknown	NO	18T	498500E 5043200N	N Plantagenet	III	10	Cornwall	N	5.0 m	Lindsay
CW-38	Treadwell Qy	unknown	NO	18T	499800E 5047300N	N Plantagenet	I	7	Cornwall	N	2.9 m	Lindsay
CW-39	Alfred Qy # 1	unknown	NO	18T	505000E 5043200N	Alfred	VI	3	Cornwall	N	0 m	Lindsay
CW-40	Lett Qy	unknown	NO	18T	506700E 5046300N	Alfred	IV	6	Cornwall	N	unknown	Bobcaygeon
CW-41	Alfred Qy # 2	unknown	NO	18T	509850E 5044000N	Alfred	VI	9	Cornwall	N	3.0 m	Lindsay
CW-42	Alfred Qy # 3	unknown	NO	18T	509700E 5046950N	Alfred	IV	11	Cornwall	N	7.7 m	Bobcaygeon
CW-43	Alfred Qy # 4	unknown	NO	18T	512200E 5047300N	Alfred	V	15	Cornwall	N	1.0 m	Bobcaygeon
CW-44	Alfred Qy # 5	unknown	NO	18T	512600E 5047100N	Alfred	V	15	Cornwall	N	0 m	Bobcaygeon
CW-45	Howes Qy	unknown	NO	18T	525300E 5051150N	Longueuil	--	--	Cornwall	N	2.0 m	Bobcaygeon
CW-47	Dunvegan Qy	unknown	NO	18T	513500E 5024500N	Kenyon	IX	24	Cornwall	N	0.5 m	Lindsay
CW-48	Menard Qy	unknown	NO	18T	478200E 5012300N	Russell	VII	7	Cornwall	N	6.3 m	Gull River
CW-49	Embrun Qy	unknown	NO	18T	479250E 5013000N	Russell	VIII	7	Cornwall	N	4.0 m	Bobcaygeon

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CW-50	Limoges Qy	unknown	NO	18T	481850E 5016600N	Cambridge	V	30	Cornwall	N	3.9 m	Lindsay
CW-51	Crysler Qy	unknown	NO	18T	487150E 5009750N	Cambridge	X	25	Cornwall	N	1.0 m	Verulam
CW-52	Patterson Qy	Edward Robinson	NO	18T	468000E 4991000N	Mountain	VII	20	Cornwall	N	2.9 m	Oxford
CW-53	S Mountain Qy	Cruickshank Constr.	YES	18T	466550E 4982350N	Mountain	II	11	Cornwall	Y	0.3 m	Oxford
CW-54	S Mountain Qy	Forbes Building Mat.	YES	18T	468200E 4981700N	Mountain	I	13	Cornwall	Y	1.5 m	Rockcliffe
CW-55	Baker Qy	unknown	NO	18T	472500E 4991800N	Winchester	VI	3	Cornwall	N	0.0 m	Gull River
CW-56	Chesterville Qy	Cornwall Gravel.	YES	18T	483350E 4991100N	Winchester	I	17-18	Cornwall	I	1.4 m	Gull River
CW-57	Crysler Qy	unknown	NO	18T	489600E 5004600N	Finch	VIII	13	Cornwall	N	1.7 m	Verulam
CW-58	Finch Qy	unknown	NO	18T	491000E 4997500N	Finch	III	9	Cornwall	N	1.0 m	Verulam
CW-59	Finch Qy	A. L. Blair Constr.	YES	18T	498100E 5001800N	Finch	III	23	Cornwall	I	1.0 m	Lindsay
CW-60	Iroquois Qy	unknown	NO	18T	473000E 4963700N	Matilda	Range I	31	Cornwall	N	1.0 m	Oxford
CW-61	Fisher Qy	unknown	NO	18T	473750E 4963650N	Matilda	Range I	28-29	Cornwall	N	2.0 m	Oxford
CW-62	Williamsburgh Qy	Warren Paving & Mat.	YES	18T	478100E 4982850N	Williamsburgh	VII	33	Cornwall	I	4.3 m	Gull River
CW-63	Whittaker Qy	unknown	NO	18T	477950E 4980150N	Williamsburgh	VI	35	Cornwall	N	1.0 m	Gull River
CW-64	Dunbar Qy	unknown	NO	18T	482000E 4987950N	Williamsburgh	VIII	18	Cornwall	N	1.0 m	Gull River
CW-65	Boucks Hill Qy	Cruickshank Constr.	NO	18T	483900E 4981950N	Williamsburgh	V	21	Cornwall	N	0.9 m	Gull River
CW-66	Durham Wells Qy	Dibblee Constr. Co. Ltd.	NO	18T	490900E 4983800N	Williamsburgh	IV	4	Cornwall	N	0.5 m	Gull River
CW-67	Cornwall Centre Qy	Ontario Hydro	NO	18T	514300E 4988700N	Cornwall	IV	20	Cornwall	N	18.3 m	Gull River, Bobcaygeon
CW-68	Apple Hill Qy	Roads Resurfacing Co.	NO	18T	519400E 5002750N	Charlottenburgh	IX	11	Cornwall	N	4.7 m	Lindsay
CW-69	McGillivary's Bridge Qu.	unknown	NO	18T	526300E 4998150N	Charlottenburgh	S of Raisin River	34	Cornwall	N	0.9 m	Verulam
CW-70	Summerstown Sta Qu.	unknown	NO	18T	533500E 4992300N	Charlottenburgh	II	11	Cornwall	N	1.0 m	Bobcaygeon
ES-01	Manitoulin Qy	Standard Aggregates	NO	17T	327600E 5086400N	Dawson	IX	45	Espanola	Y	25.0 m	Fossil Hill, Amabel
ES-02	Foxey Qy	Hercules Ornamental St.	NO	17T	382500E 5079850N	Gordon	V	17	Espanola	Y	0.5 m	Manitoulin
ES-03	Cup & Saucer Qy	Harnden & King	NO	17T	414330E 5078750N	Bidwell	VIII	29	Espanola	Y	11.0 m	St. Edmund, Fossil Hill
ES-04	Cockburn Island Qy	unknown	NO	17T	321100E 5091200N	Cockburn Island	XI	8	Espanola	N	6.7 m	St. Edmund, Fossil Hill
ES-05	Kagawong W Qy	unknown	NO	17T	400200E 5085250N	Allan	IX	4	Espanola	N	10.2 m	Georgian Bay, Manitoulin
ES-06	Qy Bay Qy	unknown	NO	17T	338750E 5080800N	Dawson	IV	17	Espanola	N	2.0 m	Amabel
ES-07	Leason Qy	unknown	NO	17T	423500E 5050000N	Tehkummah	VIII	12	Espanola	N	10.0 m	Amabel
H-01	Duntroon Qy	McKean Quarries Ltd.	YES	17T	560250E 4914520N	Nottawasaga	XII	24	Huronia	Y	12.0 m	Amabel
H-02	Duntroon Qy	Angelstone Ltd.	NO	17T	561450E 4915200N	Nottawasaga	XI	24	Huronia	N	10.3 m	Queenston, Whirlpool, Manitoulin
H-03	Coldwater (Waubaushene) Qy	Allan G. Cook Ltd.	YES	17T	606300E 4958200N	Tay	XIV	8-11	Huronia	Y	11.0 m	Gull River
H-04	Medonte (Coldwater) Qy.	Ministry of Transportation	NO	17T	609600E 4950700N	Medonte	XIII	19-20	Huronia	N	14.2 m	Gull River, Bobcaygeon
H-05	Uhthoff Qy	Nelson Aggregate Co.	YES	17T	619200E 4949500N	Orillia	III-V N Div.	7-10	Huronia	Y	24.6 m	Gull River, Bobcaygeon
H-06	Woods (Longford) Qy	Fowler Constr. Co. Ltd.	YES	17T	631800E 4950400N	Rama	BF	26-29	Huronia	Y	5.4 m	Gull River
H-07	Rama Township Qy	Rama Township	NO	17T	637400E 4950300N	Rama	E	3	Huronia	I	5.0 m	Shadow Lake, Gull River
H-08	Gamebridge Qy	Mara Limestone Aggr.	YES	17T	646175E 4928900N	Mara	A	11-12	Huronia	Y	10.5 m	Verulam
H-09	Brechin Qy	Standard Aggregates	YES	17T	646500E 4932000N	Mara	I-II	7-10	Huronia	Y	24.8 m	Bobcaygeon, Verulam
H-10	Speiran Qy	Carson S. Speiran	YES	17T	638800E 4948050N	Rama	B	3-4	Huronia	Y	<1.0 m	Gull River
H-11	Pigeon Point Qy	Cramp Steel Mills Co.	NO	17T	558500E 4929000N	Nottawasaga	XI	46	Huronia	N	0.0 m	Lindsay
H-12	Town of Collingwood Qu.	Town of Collingwood	NO	17T	560400E 4928700N	Nottawasaga	X	46	Huronia	N	unknown	Lindsay
H-13	Merchants Qy	Law Constr. Co.	NO	17T	563350E 4927850N	Nottawasaga	Town of Collingwood	-	Huronia	N	0.0 m	Lindsay
H-14	Batteaux River Qy	unknown	NO	17T	565800E 4926550N	Nottawasaga	VI	40-41	Huronia	N	4.0 m	Lindsay
H-15	Corbetton Qy	unknown	NO	17T	551550E 4889900N	Melancthon	I	244	Huronia	N	unknown	Guelph
H-16	Shelburne Qy	Ritchie Cut Stone Ltd.	NO	17T	565500E 4880975N	Amaranth	I	32	Huronia	N	5.0 m	Amabel
H-17	Waldemar Qy	unknown	NO	17T	557550E 4859600N	Amaranth	IX	2	Huronia	N	?2.0 m	Guelph
H-18	Purple Hill Qy	unknown	NO	17T	574900E 4864100N	Mono	I EHS	1	Huronia	N	unknown	Amabel
H-19	Port McNicoll Qy	Canada Iron Furnace Co.	NO	17T	593150E 4957300N	Tay	V	19-20	Huronia	N	9.9 m	Gull River
H-20	Medonte Qy	unknown	NO	17T	610050E 4951850N	Medonte	XIV	20	Huronia	N	4.0 m	Gull River
H-21	Foxmead Qy	unknown	NO	17T	614800E 4950850N	Orillia	II N Div.	15-16	Huronia	N	1.0 m	Gull River
H-22	Hampshire Mills Qy	unknown	NO	17T	621600E 4952000N	Orillia	VII	11	Huronia	N	7.6 m	Gull River, Bobcaygeon
H-23	Grass Lake Qy	unknown	NO	17T	626050E 4958100N	Orillia	XII	17	Huronia	N	unknown	Gull River
H-24	Lake St. George Qy	unknown	NO	17T	629050E 4954600N	Orillia	XII	9	Huronia	N	2.5 m	Gull River
H-25	Lake St. George S Qu.	unknown	NO	17T	628900E 4953900N	Orillia	XII	9	Huronia	N	2.6 m	Gull River
H-26	Longford Quarries	Longford Quarries Ltd.	NO	17T	631750E 4949500N	Rama	B.F.	24-26	Huronia	N	9.0 m	Gull River, Bobcaygeon
H-27	Burton Qy	T. Burton	YES	17T	643400E 4950350N	Rama	B	17	Huronia	I	<1.0 m	Gull River

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H-28	Sebright Qy	M. Campbell	NO	17T	643800E 4949100N	Rama	A	16	Huronia	N	4.4 m	Gull River, Bobcaygeon
H-29	Uptergrove Qy	unknown	NO	17T	637800E 4941700N	Mara	X	19	Huronia		0.0 m	Bobcaygeon
H-30	Millington Qy	unknown	NO	17T	640800E 4939300N	Mara	VIII	14	Huronia	N	0.5 m	Bobcaygeon
H-31	MTC Qy	Ministry of Transportation	NO	17T	642100E 4838400N	Mara	VII	12	Huronia	N	unknown	Bobcaygeon
H-32	Harrington (Udney) Qy	unknown	NO	17T	645250E 4941750N	Mara	IX	6	Huronia	N	1.0 m	Gull River
H-33	E Brechin Qy	unknown	NO	17T	648550E 4935500N	Mara	IV	4	Huronia	N	0.5 m	Bobcaygeon
L-01	Bowmanville Qy	St. Mary's Cement Co.	YES	17T	685350E 4868550N	Darlington	Broken Front	12-17	Lindsay	Y	50.3 m	Lindsay (lower, Collingwood)
L-02	Dalrymple Qy	Miller Paving Ltd.	YES	17T	650600E 4940850N	Carden	II-III	8-12	Minden	Y	6.7 m	Bobcaygeon
L-03	Carden Qy	Gormley Aggregates Ltd.	YES	17T	651000E 4936600N	Carden	I	1-4	Minden	Y	20.0 m	Bobcaygeon, Verulam
L-04	Coboconk E Qy	Cedarhurst Crush. & Qys	NO	17T	675000E 4947100N	Somerville	Front	37	Minden	Y	9.5 m	Bobcaygeon
L-05	Britnell Qy	unknown	NO	17T	682100E 4948200N	Somerville	VI	13	Minden	N	7.3 m	Gull River
L-06	Flynns Turn Qy	Nelson H. Windover	YES	17T	702900E 4941100N	Harvey	XIII	21	Minden	Y	1.0 m	Gull River
L-07	Harvey Qy	Ormell Sand & Gravel	YES	17T	708500E 4941300N	Harvey	IX	17	Lindsay	Y	8.3 m	Gull River
L-08	Buckhorn Qy	Nelson H. Windover	YES	17T	708800E 4938100N	Harvey	IX	12	Minden	Y	2.0 m	Gull River
L-09	Warsaw Qy	E. W. Payne	YES	17T	729850E 4930000N	Dummer	IV	21	Lindsay	Y	0.5 m	Gull River
L-10	Havelock Qy	Harnden & King Constr.	YES	18T	267250E 4924300N	Belmont	XI	8-9	Lindsay	I	2.0 m	Bobcaygeon
L-11	Old Bowmanville Qy	unknown	NO	17T	687000E 4863300N	Darlington	BF	10	Lindsay	N	unknown	Lindsay
L-12	Cameron (Oakwood) Qy	Cameron	NO	17T	669500E 4915800N	Mariposa	XII	19	Lindsay	N	3.1 m	Lindsay
L-13	Kirkfield Qy	Kirkfield Crushed Stone	NO	17T	661200E 4938800N	Eldon	NPR	50-52	Lindsay	N	3.0 m	Bobcaygeon, Verulam
L-14	Kirkfield Qy # 2	unknown	NO	17T	659100E 4939100N	Carden	VII	2	Minden	N	unknown	Bobcaygeon
L-15	Corsons Qy	unknown	NO	17T	666950E 4943450N	Bexley	IV	4	Lindsay	N	3.3 m	Bobcaygeon
L-16	Norland Qy	unknown	NO	17T	673900E 4952000N	Laxton	XI	1	Minden	N	unknown	Gull River
L-17	Coboconk W Qy	Toronto Lime Co.	NO	17T	674600E 4946800N	Somerville	Front	36	Minden	N	6.0 m	Bobcaygeon
L-18	Fell Qy	unknown	NO	17T	681200E 4943600N	Somerville	III	17	Minden	N	5.0 m	Gull River
L-19	Burnt River Qy	unknown	NO	17T	683100E 4946900N	Somerville	IV	13	Minden	N	unknown	Gull River
L-20	Dongola Qy	unknown	NO	17T	678900E 4957000N	Somerville	XII	13	Minden	N	unknown	Gull River
L-21	Dunsford (English) Qy	unknown	NO	17T	688300E 4923400N	Verulam	III	2	Lindsay	N	unknown	Verulam
L-22	Little Bob Qy	unknown	NO	17T	695950E 4933700N	Verulam	XIX	12	Lindsay	N	6.0 m	Bobcaygeon
L-23	Windover Qy	H. Windover	NO	17T	707900E 4952900N	Cavendish	I	unknown	Minden	Y	19.5 m	Gull River
L-24	Rocky Point Qy	unknown	NO	17T	697000E 4936600N	Harvey	XVIII	17	Minden	N	unknown	Gull River
L-25	Big Island Qy	unknown	NO	17T	698100E 4935950N	Harvey	XVII	15	Minden	N	unknown	Gull River
L-26	Volturno Lake Qy	unknown	NO	17T	700100E 4946000N	Harvey	XIII	30	Minden	N	2.9 m	Gull River
L-27	Nogies Creek Quarries	Black River Limestone Products	NO	17T	700500E 4942000N	Harvey	XIV	23	Minden	N	1.5 m	Gull River
L-28	Lakehurst Qy	James Hutchinson	NO	17T	702200E 4931200N	Harvey	XVI	5	Minden	N	8.1 m	Verulam, Bobcaygeon
L-29	Buckhorn Quarries	unknown	NO	17T	709300E 4937750N	Harvey	IX	12	Minden	N	2.0 m	Gull River
L-30	Rockcroft Qy	Evan C. Traynor	YES	17T	708500E 4945900N	Harvey	VII	25-26	Minden	N	unknown	Gull River
L-31	Reeves Qy	Elizabeth Reeves	NO	17T	715000E 4939900N	Harvey	V	12	Minden	N	3.0 m	Gull River
L-32	Burleigh Falls Qy	unknown	NO	17T	718850E 4939950N	Harvey	II	11	Minden	N	unknown	Gull River
L-33	Telford Bay Qy	unknown	NO	17T	706400E 4917500N	Ennismore	III	8	Lindsay	N	4.8 m	Verulam
L-34	Peterborough Qy	City of Peterborough	NO	17T	715800E 4917200N	Smith	V	23	Lindsay	N	12.0 m	Verulam
L-35	Burleigh Falls Quarries	unknown	NO	17T	721900E 4936800N	Smith	XVI	44	Lindsay	N	unknown	Bobcaygeon
L-36	Lakefield Qy	Canada Cement Co. Ltd.	NO	17T	718600E 4922400N	Douro	VII	16	Lindsay	N	13.4 m	Verulam
L-37	Brysons Bay Qy	unknown	NO	17T	723900E 4932950N	Dummer	I	30	Lindsay	N	unknown	Gull River
L-38	Warsaw Qy #3	unknown	NO	17T	728800E 4924400N	Dummer	II	14	Lindsay	N	2.0 m	Gull River
L-39	Warsaw Qy #2	unknown	NO	17T	729200E 4929500N	Dummer	IV	21	Lindsay	N	1.5 m	Gull River
L-40	Warsaw Qy #1	unknown	NO	17T	729050E 4930100N	Dummer	IV	22	Lindsay	N	1.0 m	Gull River
L-41	Warsaw Qy	K.J. Kostiuk	YES	17T	729450E 4930400N	Dummer	IV	22	Lindsay	I	1.5 m	Gull River
L-42	McCrakens Landing Qy	unknown	NO	17T	727100E 4935200N	Dummer	IV	31	Lindsay	N	unknown	Gull River
L-43	Armstrong Qy	P. Armstrong	NO	17T	737200E 4938700N	Dummer	XII	29	Lindsay	N	5.1 m	Gull River
L-44	Bullied Qy	Larry Bullied	NO	17T	269800E 4939700N	Belmont	VI	31	Lindsay	N	1.0 m	Gull River
L-45	Havelock Qy	3M Canada Ltd.	NO	18T	275100E 4924800N	Belmont	VI	7	Lindsay	N	6.0 m	Gull River, Bobcaygeon
L-46	Woodview Qy	unknown	NO	17T	725000E 4940500N	Burleigh	III	7	Bancroft	N	5.0 m	Gull River
L-47	Booth Qy	unknown	NO	17T	726100E 4941200N	Burleigh	IV	7	Bancroft	N	unknown	Gull River
MA-01	Melville Hill Qy	unknown	NO	17T	574000E 4861800N	Caledon	I W	29	Maple	N	12.0 m	Amabel
MA-02	Wells Qy	S. Wells	NO	17T	575100E 4860850N	Caledon	I W	27	Maple	N	11.0 m	Amabel
MA-03	Saferi Qy	Mr. Saferi	NO	17T	575950E 4858000N	Caledon	II	23	Maple	N	13.0 m	Amabel

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Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick-ness	Geological Formation(s) (Members)
MA-04	Alton Qy	unknown	NO	17T	575350E 4855700N	Caledon	IV	21	Maple	N	6.3 m	Amabel
MA-05	Sleswick Qy	unknown	NO	17T	585300E 4864300N	Albion	I	34	Maple	N	unknown	Amabel
MA-06	Cation (Speers) Qy	Cation, J.F.	NO	17T	584100E 4859500N	Caledon	IV EHS	14	Maple	N	6.5 m	Amabel
MA-07	Credit Forks Qy	unknown	NO	17T	580300E 4850550N	Caledon	IV	9	Maple	N	6.7 m	Manitoulin
MA-08	Deforest Qy	Deforest Brothers	YES	17T	– –	Caledon	III W	4–5	Maple	Y	3.0 m	Whirlpool, Manitoulin
MA-09	Credit Valley Qy	H.M. Norrie	YES	17T	– –	Caledon	III W	1	Maple	Y	10.0 m	Whirlpool, Manitoulin
MO-01	Labelle Qy	M.J. Labelle Co. Ltd.	NO	17U	520500E 5675000N	Horden	VIII	7	Moosonee	N	12.2 m	Kwataboahegan
NI-01	Lincoln Qy	Nelson Aggregate Co.	YES	17T	622800E 4773900N	Clinton	IX	20	Niagara	Y	19.2 m	Lockport (Goat Island, Eramosa)
NI-02	Vineland Qy #1	Vineland Quarries & Crushed Stone	YES	17T	629000E 4777700N	Clinton	VI, VII	1–4	Niagara	Y	9.0 m	Rochester, Decew, Lockport
NI-03	Thorold Qy	Walker Brothers Quarries	YES	17T	648800E 4776500N	Stamford	X	11, 30–31, 49–50, 66	Niagara	Y	9.8 m	Rochester, Decew, Lockport (Gasport)
NI-04	Queenston Qy	Steetley Industries Ltd.	YES	17T	655300E 4779200N	Niagara	X	44–45, 47–49	Niagara	Y	9.7 m	Rochester, Decew, Lockport(G.& G.Is)
NI-05	Hagersville Quarries	Standard Aggregates	YES	17T	578400E 4757300N	Oneida	I Rge E. of Plank Rd	28–29	Niagara	Y	16.4 m	Bertie(Akron),Bois Blanc(Springvale)
NI-06	Abandoned Oneida Qy	Cayuga Mat. & Constr.	NO	17T	585450E 4756200N	Oneida	1 N of Cayuga	49	Niagara	N	4.1 m	Bertie, Oriskany
NI-07	Oneida Qy	Nelson Aggregate Co.	YES	17T	586000E 4756250N	Oneida	I N of Cayuga	48	Niagara	N	18.8 m	Bertie, Oriskany, Bois Blanc
NI-08	Cayuga (Decewsville) Qy	Cayuga Mat. & Constr.	YES	17T	587400E 4754800N	N Cayuga	I N	44–47	Niagara	Y	19.8 m	Bertie, Oriskany, Bois Blanc
NI-09	Sweets Corners Quarries	unknown	NO	17T	595800E 4748400N	S Cayuga	IV	31	Niagara	N	6.9 m	Bois Blanc, Onondaga
NI-10	Dunnville Rock Products	Dunnville Rock Products	YES	17T	612900E 4748700N	Dunn	Earl Tract	3, 6–8	Niagara	Y	11.7 m	Bertie(Akron),Bois Blanc(Springvale)
NI-11	Port Colborne (Law) Qy	Hard Rock Paving	YES	17T	638700E 4750500N	Wainfleet	II	3–5	Niagara	Y	17.9 m	Bertie, Bois Blanc
NI-12	Port Colborne Qy	Port Colborne Quarries	YES	17T	644500E 4751700N	Humberstone	II	19–22 new; 23–24 old	Niagara	Y	15.3 m	Bertie (several members), Bois Blanc
NI-13	Bertie Bay Qy	unknown	NO	17T	663500E 4750200N	Bertie	II Lake Erie Front	12	Niagara	N	4.2 m	Onondaga (Clarence)
NI-14	Ridgemount Qy #1	Ridgemount Quarries	YES	17T	662700E 4752900N	Bertie	VIII	3–4	Niagara	N	10.6 m	Bertie, Bois Blanc, Onondaga
NI-15	Ridgemount Qy #2	Ridgemount Quarries	YES	17T	662600E 4754300N	Bertie	VIII	5–8	Niagara	Y	14.3 m	Bertie, Bois Blanc
NI-16	Clinton Qy	Clinton Quarry Ltd.	YES	17T	– –	Clinton	V, VI	5–6	Niagara	Y	8.9 m	Rochester, Decew Lockport (G. & G. Is.)
NI-17	E Clanbrassil Qy	Leonard	NO	17T	586050E 4758250N	Oneida	III	25	Niagara	N	6.5 m	Bertie (Williamsville)
NI-18	Nelles Corners Quarries	unknown-abandoned	NO	17T	586600E 4753300N	N Cayuga	XV	48 & 49	Niagara	N	2.0 m	Bois Blanc
NI-19	Decewsville NE Qy	unknown-abandoned	NO	17T	589500E 4754750N	N Cayuga	I N	40	Niagara	N	5.0 m	Bertie
NI-20	Kohler Road Qy	unknown-abandoned	NO	17T	591100E 4755200N	N Cayuga	I N	36	Niagara	N	3.0 m	Bertie (Akron)
NI-21	S Cayuga Qy	unknown	NO	17T	601700E 4747000N	S Cayuga	VI	19	Niagara	N	2.2 m	Onondaga
NI-22	Upper Qy	unknown	NO	17T	602700E 4750200N	S Cayuga	V	14	Niagara	N	4.3 m	Bois Blanc
NI-23	Onondaga (Byng) Qy	unknown	NO	17T	607600E 4748500N	Dunn	I N	5	Niagara	N	4.1 m	Bois Blanc, Onondaga (Edgecliff)
NI-24	Byng Qy	unknown	NO	17T	610000E 4749000N	Dunn	1S	11	Niagara	N	1.5 m	Bertie
NI-25	Weber (Byng) Qy	unknown	NO	17T	612000E 4749100N	Dunn	Haldimand Tract	19	Niagara	N	7.7 m	Bertie (Scajaquanda, Williamsville)
NI-26	Byng Airport Qy	K.W. Ricker (owner)	NO	17T	614700E 4748600N	Dunn	II Sheehan Tract	9–10	Niagara	N	1.5 m	Bois Blanc
NI-27	Smively (Stromness) Qu.	Haldimand County	NO	17T	618200E 4747300N	Sherbrooke	III	3	Niagara	N	4.0 m	Bertie, Bois Blanc
NI-28	Metcalfe (Grimsby) Qy	unknown	NO	17T	616200E 4782700N	N Grimsby	II	11–12	Niagara	N	4.4 m	Decew, Lockport (Gasport)
NI-29	Grimsby Qy #1	unknown	NO	17T	616000E 4782000N	N Grimsby	II	10	Niagara	N	unknown	Lockport
NI-30	Grimsby Qy #2	unknown	NO	17T	617100E 4781800N	N Grimsby	II	8	Niagara	N	6.0 m	Lockport (Gasport)
NI-31	Smithville Qy	unknown	NO	17T	618500E 4772500N	S Grimsby	IX	8	Niagara	N	2.0 m	Lockport
NI-32	Vineland Qy # 2	Vineland Qys & Cr. St.	YES	17T	623200E 4773500N	Clinton	IX	19	Niagara	N	6.0 m	Lockport (Eramosa)
NI-33	Beamsville Qy #1	unknown	NO	17T	625050E 4777500N	Clinton	VI	14	Niagara	N	0 m	Lockport
NI-34	Beamsville Qy #2	unknown	NO	17T	624600E 4777600N	Clinton	VI	15	Niagara	N	unknown	Lockport
NI-35	Beamsville Qy #3	unknown	NO	17T	624800E 4777800N	Clinton	V	15	Niagara	N	unknown	Lockport
NI-36	Beamsville Qy #4	unknown	NO	17T	624400E 4778000N	Clinton	V	16	Niagara	N	2.0 m	Lockport
NI-37	Beamsville Qy #5	unknown	NO	17T	623900E 4777900N	Clinton	V	17	Niagara	N	unknown	Lockport
NI-38	Gibson (Beamsville) Qu.	County of Lincoln	NO	17T	625700E 4777600N	Clinton	VI	12–13	Niagara	N	8.5 m	Decew, Lockport (Gasport)
NI-40	Jordan Qy	unknown	NO	17T	630200E 4775900N	Clinton	VIII	2	Niagara	N	7.0 m	Lockport
NI-41	Balls Falls Quarries	unknown	NO	17T	632400E 4777300N	Louth	VI	21	Niagara	N	3.3 m	Lockport (Gasport)

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Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick-ness	Geological Formation(s) (Members)
NI-42	Rockway Qy #1	unknown	NO	17T	635200E 4775300N	Louth	VII	12	Niagara	N	2.0 m	Lockport
NI-43	Rockway Falls Qy	Maple Leaf Gun Club	NO	17T	636000E 4774600N	Louth	VIII	11	Niagara	N	4.3 m	Lockport (Gasport)
NI-44	Rockway Qy #2	owned by John Cairns	NO	17T	638800E 4773800N	Pelham	I	4	Niagara	N	1.3 m	Lockport (Gasport)
NI-45	Rathton Point Qy	unknown	NO	17T	637700E 4749700N	Wainfleet	I	7	Niagara	N	unknown	Onondaga
NI-46	W Qy,Port Colborne	Canada Cement Co.	NO	17T	638000E 4749100N	Wainfleet	I	5–6	Niagara	N	6.8 m	Onondaga (Edgecliff)
NI-47	Reebs Bay Qy	unknown	NO	17T	639800E 4749250N	Wainfleet	I	3	Niagara	N	unknown	Onondaga
NI-48	Sugar Loaf Qy	unknown	NO	17T	640300E 4749300N	Wainfleet	I	1	Niagara	N	unknown	Onondaga
NI-49	Brock University Qy 1	Brock University	NO	17T	641500E 4775300N	Grantham	X	20	Niagara	N	3.7 m	Lockport (Gasport)
NI-50	Brock Univ – Pub Qy	unknown	NO	17T	642200E 4775500N	Grantham	X	18	Niagara	N	3.5 m	Decew, Lockport (Gasport)
NI-51	Brock University Qy 2	Brock University	NO	17T	642700E 4775700N	Grantham	X	18	Niagara	N	7.0 m	Lockport (Gasport, Goat Island)
NI-52	St. Catharines Qy	St. Catharines Crushed Stone	NO	17T	643500E 4775800N	Grantham	X	16–17	Niagara	N	13.0 m	Rochester,Lockport (Gasport Goat Is)
NI-53	St. David's Rd Qy # 1	unknown	NO	17T	644400E 4775850N	Thorold	–	21	Niagara	N	3.5 m	Goat Island
NI-54	St. David's Rd Qy # 2	unknown	NO	17T	644800E 4776000N	Thorold	–	21	Niagara	N	2.0 m	Lockport (Goat Island)
NI-55	Grantham Qy	unknown	NO	17T	649400E 4778500N	Grantham	X	2	Niagara	N	4.3 m	Lockport (Gasport)
NI-56	Thorold Tunnel Qy	unknown	NO	17T	647150E 4774600N	Thorold	–	28	Niagara	N	unknown	unknown
NI-57	Thorold (Battle) Qy	Walker Brothers Quarries	NO	17T	648000E 4776500N	Thorold	–	43–45	Niagara	N	0.0 m	Decew, Lockport (Gasport)
NI-58	Mountain Road Qy	unknown	NO	17 T	650500E 4777900N	Stamford	–	8	Niagara	N	2.0 m	Irodequoit
NI-59	St. Davids Qy	unknown	NO	17T	652100E 477888N	Niagara	–	138	Niagara	N	0.0 m	Lockport
NI-60	Town of Queenston Qy #2	unknown	NO	17T	654900E 4779400N	Niagara	–	91	Niagara	N	4.0 m	Lockport (Gasport)
NI-61	Town of Queenston Qy #1	unknown	NO	17T	657700E 4780200N	Niagara	–	43	Niagara	N	4.2 m	Lockport (Gasport)
NI-62	E Qy,Port Colborne	Canada Cement Co.	NO	17T	640600E 4749500N	Humberstone	I	33	Niagara	N	4.8 m	Onondaga (Edgecliff)
NI-63	Port Colborne Qy # 2	unknown	NO	17T	642400E 4750000N	Humberstone	I	29	Niagara	N	unknown	Onondaga
NI-64	Hogan's Qy	unknown	NO	17T	642300E 4749300N	Humberstone	I	29	Niagara	N	5.0 m	Onondaga
NI-65	Port Colborne Qy # 3	unknown	NO	17T	644000E 4748600N	Humberstone	I	25	Niagara	N	unknown	Onondaga
NI-66	Port Colborne Qy # 4	unknown	NO	17T	644700E 4750600N	Humberstone	II	20	Niagara	N	0.5 m	Onondaga
NI-67	Humberstone County Qy	Welland County	NO	17T	646250E 4753400N	Humberstone	III	19	Niagara	N	8.0 m	Bertie, Bois Blanc
NI-68	Bethel Qy	unknown	NO	17T	646800E 4754150N	Humberstone	III	18	Niagara	N	0.0 m	Bois Blanc
NI-69	Shisler Point Qy	Sherkston Beach Ltd.	NO	17T	652600E 4748100N	Humberstone	I	4–5	Niagara	N	5.7 m	Onondaga (Edgecliff)
NI-70	Sherkston N Qy	unknown	NO	17T	652600E 4749300N	Humberstone	I	4	Niagara	N	2.8 m	Onondaga (Clarence)
NI-71	Ridgewood Qy	Township of Bertie (ex)	NO	17T	659700E 4751700N	Bertie	III Lake Erie Front	21	Niagara	N	1.8 m	Bertie
NI-72	Ridgewood Qy #2	unknown	NO	17T	659850E 4752150N	Bertie	X	1	Niagara	N	8.0 m	Bertie
NI-73	Windmill Point Qy	Coast & Lake Constr.	NO	17T	662800E 4749500N	Bertie	I Lake Erie Front	14	Niagara	N	3.0 m	Onondaga (Clarence)
NI-74	Windmill Point Qy #2	Windmill Point Crushed Stone	NO	17T	663200E 4749600N	Bertie	I Lake Erie Front	13	Niagara	N	1.7 m	Onondaga (Edgecliff)
NI-75	Buel Quarries	unknown	NO	17T	663500E 4750000N	Bertie	II Lake Erie Front	12	Niagara	N	2.0 m	Onondaga (Edgecliff)
NI-76	Ridgemount Qy # 3	Ridgemount Quarries	YES	17T	663200E 4754800N	Bertie	VII	8	Niagara	N	4.2 m	Bertie (Will., Akron), Bois Blanc
NI-77	Woehl Qy	George Woehl	NO	17T	665500E 4754200N	Bertie	V	6	Niagara	N	2.0 m	Bois Blanc
NI-78	W Clanbrassil Qy	Christensen (Lewis)	NO	17T	585900E 4758250N	Oneida	III	24	Niagara	N	6.9 m	Bertie (Falk., Scaj., Williamsville)
NP-01	Ogden Point Qy	St. Lawrence Cement	YES	18T	268900E 4873700N	Cramahe	BF I	29–35	Napanee	Y	40.0 m	Verulam, Lindsay
NP-02	Consecon Qy	Trenton Gravel Products	YES	18T	298900E 4872250N	Hillier	V Bayside	107	Napanee	I	11.2 m	Lindsay
NP-03	Mountain View Qy	H.J. McFarland Constr.	YES	18T	311500E 4883000N	Ameliasburgh	IV	64–65	Napanee	I	8.4 m	Lindsay
NP-04	Cannifton Qy	Harvey Putnam/ Cannifton Quarries	YES	18T	310300E 4897400N	Thurlow	III	10	Napanee	Y	6.2 m	Verulam
NP-05	Point Anne Qy	Lafarge Canada/ McFarland-operator	YES	18T	317000E 4892750N	Thurlow	Broken Front & I	16–27	Napanee	I	30.0 m	Gull River, Bobcaygeon
NP-06	Long Qy	H.J. McFarland Constr.	YES	18T	320000E 4901650N	Tyendinaga	III	6	Napanee	Y	6.7 m	Verulam
NP-07	Picton Qy	Lake Ontario Cement	YES	18T	329750E 4879250N	Sophiasburgh	I SW of Green Point	13–18	Napanee	Y	54.0 m	Verulam, Lindsay
NP-08	Picton Qy	Miller Paving Ltd.	YES	18T	331000E 4881500N	Sophiasburgh	I	19–20	Napanee	Y	6.4 m	Lindsay
NP-09	Napanee Qy	Trenton Gravel Products	NO	18T	340900E 4898300N	Richmond	I	12	Napanee	Y	7.0 m	Verulam
NP-10	Roblindale Qy	H. J. McFarland Constr.	NO	18T	339900E 4915250N	Camden East	VI	1	Napanee	N	18.3 m	Gull River, Bobcaygeon
NP-11	Selby Qy	Custom Mobile Concrete	NO	18T	341800E 4905800N	Richmond	III	21	Napanee	Y	6.0 m	Verulam
NP-12	Napanee Qy	J.R. Storey Constr.	NO	18T	345200E 4002500N	N Fredericks-burgh	VII	19	Napanee	Y	16.0 m	Gull River
NP-13	Napanee Qy	J.C. Denison	NO	18T	345500E 4901600N	N Fredericks-burgh	VII	21	Napanee	Y	7.5 m	Gull River

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Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick- ness	Geological Formation(s) (Members)
NP-14	Dillon Qy	Griffin Bros. Gananoque	NO	18T	353300E 4928800N	Camden East	N:IX, S:VIII	N:49, S:49	Napanee	Y	6.6 m	Gull River
NP-15	Camden E (Aylesworth)	Township of Camden E.	NO	18T	352600E 4912700N	Camden East	II	26	Napanee	I	7.0 m	Gull River
NP-16	Morven Qy	J.R. Storey Constr.	NO	18T	353400E 4902300N	Ernestown	V	9	Napanee	Y	4.2 m	Gull River
NP-17	Storms Corners	J.C. Denison	NO	18T	355400E 4901100N	Ernestown	IV	12–13	Napanee	Y	10.0 m	Gull River
NP-18	Bath Qy	Lafarge Canada Inc	NO	18T	355600E 4892100N	Ernestown	I	3–4	Napanee	Y	17.7 m	Verulam
NP-19	Wilton Qy	F.G. Bezanson & Son	NO	18T	362800E 4908200N	Ernestown	VI	36	Napanee	Y	11.0 m	Gull River
NP-20	Caughey – Amherst Is	Township of Amherst Is.	NO	18T	366000E 4892800N	Amherst Island	N Shore	9	Napanee	I	9.3 m	Verulam
NP-21	Hartington Qy	Portland Twp.	NO	18T	369200E 4922000N	Portland	VII	3	Napanee	Y	10.0 m	Gull River
NP-22	Westbrook Qy	W.J. McKendry & Sons	YES	18T	368875E 4901450N	Kingston	Miles Square Block		Napanee	I	6.0 m	Gull River
NP-23	Collins Bay Qy	Woods Sand & Gravel	YES	18T	371500E 4902000N	Kingston	III	2–3	Napanee	Y	36.0 m	Gull River
NP-24	Kingston Qy	H. J. McFarland Constr.	YES	18T	374000E 4904000N	Kingston	IV	9	Napanee	I	10.4 m	Bobcaygeon
NP-25	Kingston Qy	Township of Kingston	YES	18T	375000E 4904100N	Kingston	IV	11–12	Napanee	I	9.0 m	Bobcaygeon
NP-26	Kepler (Cranston) Qy	W.J. McKendry & Sons	NO	18T	374500E 4913400N	Loughborough	I	6	Napanee	I	9.0 m	Gull River
NP-27	Elginburg Qy	Frontenac Aggregates	YES	18T	375900E 4907750N	Kingston	V	14–15	Napanee	Y	10.0 m	Gull River
NP-28	Spaffordton Qy	Loughborough Township	NO	18T	379300E 4918300N	Loughborough	V	14	Napanee	I	8.3 m	Gull River
NP-29	Kingston Qy	W.J. McKendry & Sons	YES	18T	379000E 4906800N	Kingston	V	24	Napanee	Y	15.9 m	Gull River
NP-30	Macadoos Lane Qy	Woods Sand & Gravel	YES	18T	380200E 4904400N	Kingston	IV	26	Napanee	Y	17.0 m	Gull River
NP-31	Macadoos Lane (Bilow) Qy	H. J. McFarland Constr.	YES	18T	380900E 4904900N	Kingston	IV	28–29	Napanee	I	9.4 m	Gull River
NP-32	Pittsburg Qy	Frontenac Aggr.& Constr.	YES	18T	383600E 4902200N	Pittsburgh	E of Catarqui R.	7–8	Napanee	Y	20.6 m	Gull River
NP-33	Mill Point	unknown	NO	18T	383250E 4993400N	Wolfe Island	Registered Plan 73	10–11	Napanee	I	8.0 m	Gull River
NP-34	Battersea Qy	Griffin Bros./Twp. of Storrington	YES	18T	388000E 4918000N	Storrington	VIII	5	Napanee	Y	5.5 m	Gull River
NP-35	Joyceville Qy	Griffin Bros. Gananoque	YES	18T	393150E 4912050N	Pittsburgh	V	17–18	Napanee	I	13.5 m	Gull River
NP-36	Howe Island Qy # 1	unknown	NO	18T	394500E 4901800N	Howe Island	N Range	5	Napanee	I	3.0 m	Gull River
NP-37	Westbrook Qy	Warren Paving & Mat.	YES	18T	370050E 4905500N	Kingston	IV W Division	1–3	Napanee	Y	5.0 m	Gull River
NP-39	Campbellford Qy	unknown	NO	18T	275600E 4905800N	Seymour	IV	7	Napanee	N	1.0 m	Verulam
NP-40	Springbrook Qy	unknown	NO	18T	292800E 4917250N	Rawdon	VIII	12	Napanee	N	8.5 m	Bobcaygeon, Verulam
NP-41	Wellman Qy # 1	unknown	NO	18T	290400E 4911800N	Rawdon	IV	18	Napanee	N	2.0 m	Verulam
NP-42	Wellman Qy # 2	unknown	NO	18T	292000E 4910800N	Rawdon	IV	17	Napanee	N	0.0 m	Verulam
NP-43	Stirling Qy	unknown	NO	18T	295300E 4907300N	Rawdon	I	16	Napanee	N	2.0 m	Verulam
NP-44	Gosport Qy	unknown	NO	18T	282200E 4877700N	Brighton	B	33	Napanee	N	0.0 m	Lindsay
NP-45	Miron Qy	L. Miron	NO	18T	289550E 4889300N	Murray	III	9	Napanee	N	0.5 m	Verulam
NP-46	McCauley Qy	unknown	NO	18T	292400E 4890900N	Murray	III	2	Napanee	N	unknown	Verulam
NP-47	Chatterton Qy	unknown	NO	18T	303150E 4902350N	Sidney	VI	34	Napanee	N	unknown	Verulam
NP-48	Bayside Qy	Hastings Board of Ed.	NO	18T	301450E 4889400N	Sidney	I	19	Napanee	N	6.0 m	Verulam
NP-49	Foxboro Qy	Township of Thurlow	NO	18T	305250E 4903300N	Thurlow	VI	2	Napanee	N	4.6 m	Bobcaygeon
NP-50	Honeywell Corners Qy	unknown	NO	18T	310500E 4902000N	Thurlow	V	13	Napanee	N	<0.5 m	Verulam
NP-51	Cannifton Qy # 2	unknown	NO	18T	308200E 4896500N	Thurlow	III	4	Napanee	N	5.0 m	Verulam
NP-52	Belleville Qy # 1	unknown	NO	18T	308500E 4894750N	Thurlow	II	3	Napanee	N	0.0 m	Verulam
NP-53	Cannifton Qy	unknown	NO	18T	308750E 4895800N	Thurlow	II	5	Napanee	N	6.0 m	Verulam
NP-54	Belleville Qy # 2	unknown	NO	18T	310300E 4895100N	Thurlow	II	8	Napanee	N	0.0 m	Verulam
NP-55	Thurlow Qy	unknown	NO	18T	316050E 4898050N	Thurlow	II	25	Napanee	N	unknown	Verulam
NP-56	Honeywell Corners Qy	Gerald O'Neill Ltd.	YES	18T	318000E 4900000N	Thurlow	III	31	Napanee	N	4.0 m	Verulam
NP-57	Ox Point Qy # 1	unknown	NO	18T	315300E 4891600N	Thurlow	Broken Front	18	Napanee	N	6.0 m	Bobcaygeon
NP-58	Ox Point Qy # 2	unknown	NO	18T	315250E 4891650N	Thurlow	Broken Front	18	Napanee	N	4.0 m	Bobcaygeon
NP-59	Point Anne Qy # 2	unknown	NO	18T	316100E 4892100N	Thurlow	Broken Front	20	Napanee	N	5.0 m	Bobcaygeon
NP-60	Point Anne Qy # 1	unknown	NO	18T	316000E 4891750N	Thurlow	Broken Front	20	Napanee	N	4.0 m	Bobcaygeon
NP-61	Read Qy	unknown	NO	18T	324625E 4908600N	Tyendinaga	VI	21	Napanee	N	4.6 m	Bobcaygeon
NP-62	Melrose Qy # 2	unknown	NO	18T	322650E 4904000N	Tyendinaga	IV	12	Napanee	N	unknown	Bobcaygeon
NP-63	Melrose Qy # 1	unknown	NO	18T	323050E 4905050N	Tyendinaga	IV	16	Napanee	N	unknown	Bobcaygeon
NP-64	Lonsdale Qy	unknown	NO	18T	330050E 4904050N	Tyendinaga	III	31	Napanee	N	unknown	Gull River
NP-65	McGrogan Qy	W. McGrogan	NO	18T	319350E 4898150N	Tyendinaga	I	1	Napanee	N	0.0 m	Bobcaygeon
NP-66	Milltown Qy	H.J. McFarland Constr.	NO	18T	323000E 4898700N	Tyendinaga	I	11	Napanee	N	2.7 m	Verulam
NP-67	Marysville Qy # 2	H.J. McFarland Constr.	YES	18T	326800E 4898500N	Tyendinaga	I	19	Napanee	I	7.0 m	Bobcaygeon
NP-68	Shannonville Qy	Ontario Limestone & Clay	NO	18T	320300E 4894700N	Tyendinaga	III IR 18	1–2	Napanee	N	unknown	Gull River

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Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick-ness	Geological Formation(s) (Members)
NP-69	Shannonville Qy	unknown	NO	18T	322100E 4894900N	Tyendinaga	II	6	Napanee	N	1.0 m	Bobcaygeon
NP-70	Deseronto Airport Qy	unknown	NO	18T	332500E 4893800N	Tyendinaga	III IR 18	29	Napanee	N	unknown	Verulam
NP-71	Deseronto Qy # 2	unknown	NO	18T	335250E 4994950N	Tyendinaga	I	36	Napanee	N	0.0 m	Verulam
NP-72	Deseronto Qy # 1	unknown	NO	18T	336000E 4897450N	Tyendinaga	I	40	Napanee	N	unknown	Verulam
NP-73	Gardenville Qy	unknown	NO	18T	292300E 4879050N	Ameliasburgh	SW of Carrying Pl Rd	2	Napanee	N	0.0 m	Verulam
NP-74	Carrying Place Qy	unknown	NO	18T	293995E 4880600N	Ameliasburgh	SW of Carrying Pl Rd	13	Napanee	N	2.0 m	Lindsay
NP-75	Albury Qy	unknown	NO	18T	296700E 4881600N	Ameliasburgh	I	99	Napanee	N	1.0 m	Lindsay
NP-76	Rossmore Qy # 1	unknown	NO	18T	307900E 4889000N	Ameliasburgh	I	65	Napanee	N	0.0 m	Verulam
NP-77	Bates Qy	W. Bates	NO	18T	309000E 4888300N	Ameliasburgh	I	63	Napanee	N	unknown	Verulam
NP-78	Rossmore Qy # 2	unknown	NO	18T	309500E 4889800N	Ameliasburgh	I	60	Napanee	N	0.0 m	Verulam
NP-79	Massasauga Point Qy	unknown	NO	18T	315200E 4890500N	Ameliasburgh	II	-	Napanee	N	16.5 m	Bobcaygeon, Verulam
NP-80	Consecon Qy # 2	unknown	NO	18T	298750E 4872150N	Hillier	V Bayside	108	Napanee	N	7.0 m	Lindsay
NP-81	Niles Corners Qy # 1	unknown	NO	18T	306200E 4871600N	Hillier	II	13	Napanee	N	1.0 m	Lindsay
NP-82	Niles Corners Qy # 2	unknown	NO	18T	309000E 4871800N	Hillier	II	6	Napanee	N	0.0 m	Lindsay
NP-83	Wellington Qy # 1	unknown	NO	18T	310400E 4871300N	Hillier	I	4	Napanee	N	0.0 m	Lindsay
NP-84	Wellington Qy # 2	unknown	NO	18T	311200E 4872200N	Hillier	II	1	Napanee	N	0.5 m	Lindsay
NP-85	Melville Qy	unknown	NO	18T	306700E 4877600N	Hillier	V	83	Napanee	N	2.0 m	Lindsay
NP-86	Burr Qy	unknown	NO	18T	309200E 4879400N	Hillier	V	75	Napanee	N	1.0 m	Lindsay
NP-87	Crofton Qy	unknown	NO	18T	313050E 4882900N	Sophiasburgh	I Broken Front	62	Napanee	N	4.0 m	Lindsay
NP-88	Redner Qy	J. Redner	NO	18T	315000E 4881100N	Sophiasburgh	II Broken Front	60	Napanee	N	0.5 m	Lindsay
NP-90	Gilbert Mills Qy # 1	unknown	NO	18T	319100E 4880650N	Sophiasburgh	II W of Green Point	52	Napanee	N	0.0 m	Lindsay
NP-91	Desmorestville Qy	Twp. of Sophiasburgh	YES	18T	323100E 4883800N	Sophiasburgh	I	39	Napanee	I	3.8 m	Lindsay
NP-92	Desmorestville Qy # 2	unknown	NO	18T	324350E 4882950N	Sophiasburgh	II W of Green Point	38	Napanee	N	0.5 m	Lindsay
NP-93	N Port Qy	unknown	NO	18T	325500E 4888400N	Sophiasburgh	I W of Green Point	27	Napanee	N	2.5 m	Verulam
NP-94	Desmorestville Qy # 3	unknown	NO	18T	326500E 4883600N	Sophiasburgh	II W of Green Point	32	Napanee	N	0.0 m	Lindsay
NP-95	Bethesda Qy # 2	unknown	NO	18T	327950E 4883500N	Sophiasburgh	II SW of Green Point	21	Napanee	N	1.0 m	Lindsay
NP-96	Bethesda Qy # 1	unknown	NO	18T	329500E 4884300N	Sophiasburgh	Gore B	-	Napanee	N	0.5 m	Lindsay
NP-97	Bethesda Qy # 3	unknown	NO	18T	330950E 4885500N	Sophiasburgh	I SW of Green Point	29	Napanee	N	unknown	Lindsay
NP-98	Woodville Qy	unknown	NO	18T	332400E 4883000N	Sophiasburgh	I SW of Green Point	25	Napanee	N	1.0 m	Lindsay
NP-99	Solmesville Qy	unknown	NO	18T	331500E 4891150N	Sophiasburgh	I W of Green Point	10	Napanee	N	unknown	Verulam
NP-100	Green Point Qy	unknown	NO	18T	332800E 4892150N	Sophiasburgh	VIII Gore	1	Napanee	N	unknown	Verulam
NP-101	Mount Carmel Qy	H.J. McFarland Constr.	NO	18T	333300E 4888300N	Sophiasburgh	I SW of Green Point	38	Napanee	N	6.0 m	Lindsay
NP-102	Huff's Corners Qy # 1	unknown	NO	18T	316500E 4876100N	Hallowell	Irvine Gore	65	Napanee	N	2.0 m	Lindsay
NP-103	Huff's Corners Qy # 2	unknown	NO	18T	316900E 4875400N	Hallowell	Irvine Gore	65	Napanee	N	1.0 m	Lindsay
NP-104	Gilbert Mills Qy # 2	unknown	NO	18T	321200E 4877200N	Hallowell	Gerow Gore	53	Napanee	N	0.5 m	Lindsay
NP-105	Bloomfield Qy # 1	unknown	NO	18T	320300E 4874800N	Hallowell	II Military Tract	5	Napanee	N	0.5 m	Lindsay
NP-106	Bloomfield Qy # 2	unknown	NO	18T	320000E 4872650N	Hallowell	I Military Tract	1	Napanee	N	0.0 m	Lindsay
NP-107	Yerexville Qy # 1	unknown	NO	18T	324000E 4876000N	Hallowell	III Military Tract	13	Napanee	N	0.0 m	Lindsay
NP-108	Yerexville Qy # 2	unknown	NO	18T	323950E 4875800N	Hallowell	III Military Tract	13	Napanee	N	0.0 m	Lindsay
NP-109	Picton Qy # 3	unknown	NO	18T	327600E 4878600N	Hallowell	II NW of Carrying Pl	9	Napanee	N	0.9 m	Lindsay
NP-110	Picton Qy # 4	unknown	NO	18T	327900E 4878800N	Hallowell	I NW of Carrying Pl.	10	Napanee	N	1.5 m	Lindsay
NP-111	Yerexville Qy # 3	unknown	NO	18T	327300E 4877700N	Hallowell	I NW of Carrying Pl	7	Napanee	N	0.0 m	Lindsay
NP-112	Bedborough Qy	unknown	NO	18T	327050E 4872800N	Hallowell	II Military Tract	23	Napanee	N	3.0 m	Lindsay
NP-113	Picton Landfill	unknown	NO	18T	329000E 4874300N	Hallowell	I SE of Carrying Pl.	22	Napanee	N	20.0 m	Verulam, Lindsay
NP-114	Picton Qy # 5	unknown	NO	18T	329600E 4874600N	Hallowell	SE of Carrying Place	20	Napanee	N	1.0 m	Verulam

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Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick-ness	Geological Formation(s) (Members)
NP-115	Picton Qy # 6	unknown	NO	18T	331500E 4875300N	Hallowell	Gore K	–	Napanee	N	0.5 m	Lindsay
NP-116	Picton Qy # 7	unknown	NO	18T	331800E 4875200N	Hallowell	Gore K	–	Napanee	N	unknown	Lindsay
NP-117	Picton Qy # 8	unknown	NO	18T	330550E 4874400N	Hallowell	SE of Carrying Place	21	Napanee	N	1.0 m	Lindsay
NP-118	Picton Qy # 9	unknown	NO	18T	330900E 4874250N	Hallowell	Gore K	–	Napanee	N	0.0 m	Lindsay
NP-119	Cherry Valley Qy # 4	unknown	NO	18T	324900E 4868200N	Athol	N of E Lake	15	Napanee	N	0.0 m	Lindsay
NP-120	Cherry Valley Qy # 3	unknown	NO	18T	327000E 4868500N	Athol	E of E Lake	3	Napanee	N	0.0 m	Lindsay
NP-121	Cherry Valley Qy # 2	unknown	NO	18T	327650E 4867300N	Athol	E of E Lake	6	Napanee	N	unknown	Lindsay
NP-122	Cherry Valley Qy # 1	unknown	NO	18T	327500E 4864800N	Athol	II	4	Napanee	N	unknown	Lindsay
NP-123	Milford Qy # 4	unknown	NO	18T	328500E 4864500N	Athol	II	3	Napanee	N	<1.0 m	Lindsay
NP-124	Milford Qy # 1	unknown	NO	18T	330000E 4865500N	S Marysburgh	I N of Black River	31	Napanee	N	0.5 m	Lindsay
NP-125	Milford Qy # 2	unknown	NO	18T	332750E 4869000N	S Marysburgh	I N of Black River	20	Napanee	N	0.0 m	Lindsay
NP-126	Black River Bridge Qy	unknown	NO	18T	335700E 4869900N	S Marysburgh	I N of Black River	12	Napanee	N	0.0 m	Lindsay
NP-127	Port Milford Qy	unknown	NO	18T	335750E 4867250N	S Marysburgh	Round Pr Edward Bay	25	Napanee	N	2.2 m	Lindsay
NP-128	Milford Qy # 3	unknown	NO	18T	333800E 4864250N	S Marysburgh	I S of Black River	24	Napanee	N	1.0 m	Lindsay
NP-129	Waupoos Qy # 2	unknown	NO	18T	337700E 4874100N	N Marysburgh	N of S Bay	2	Napanee	N	2.0 m	Lindsay
NP-130	Waupoos Qy	Harold Wilkinson	YES	18T	338000E 4873750N	N Marysburgh	Lakeside N. of Smith	2	Napanee	N	3.5 m	Verulam, Lindsay
NP-131	Bongard Corners Qy	unknown	NO	18T	346500E 4881400N	N Marysburgh	Bayside	41	Napanee	N	unknown	Lindsay
NP-132	Marys Cove Qy	unknown	NO	18T	347400E 4877850N	N Marysburgh	Ordance Reserve	6	Napanee	N	2.0 m	Lindsay
NP-133	Roblin Qy	unknown	NO	18T	338400E 4916600N	Richmond	IX	21	Napanee	N	3.0 m	Bobcaygeon
NP-134	Richmond Township Qy	unknown	NO	18T	340100E 4911400N	Richmond	VII	21	Napanee	N	6.8 m	Gull River, Bobcaygeon
NP-135	Selby Qy # 1	unknown	NO	18T	341500E 4907450N	Richmond	IV	21	Napanee	N	unknown	Bobcaygeon
NP-136	Selby Qy # 4	unknown	NO	18T	340400E 4906400N	Richmond	IV	17	Napanee	N	unknown	Bobcaygeon
NP-137	Selby Qy # 3	unknown	NO	18T	340500E 4906500N	Richmond	IV	18	Napanee	N	unknown	Bobcaygeon
NP-138	Selby Qy # 2	unknown	NO	18T	340750E 4906350N	Richmond	III	18	Napanee	N	unknown	Bobcaygeon
NP-139	Marysville Qy # 1	H.J. McFarland Constr.	NO	18T	336000E 4901300N	Richmond	III	3	Napanee	N	7.0 m	Verulam
NP-140	Napanee Qy # 4	H.J. McFarland Constr.	NO	18T	344100E 4903300N	Richmond	III	24	Napanee	N	2.3 m	Bobcaygeon
NP-141	Pybus Qy	unknown	NO	18T	344150E 4903200N	Richmond	I Gore	30	Napanee	N	3.5 m	Gull River
NP-142	Gretna Qy # 1	unknown	NO	18T	340700E 4893700N	N Fredericksburgh	V Additional	1	Napanee	N	unknown	Verulam
NP-143	Gretna Qy # 2	unknown	NO	18T	340900E 4894800N	N Fredericksburgh	IV	1	Napanee	N	unknown	Bobcaygeon
NP-144	Napanee Qy # 5	unknown	NO	18T	342750E 4896900N	N Fredericksburgh	IV	9	Napanee	N	2.0 m	Bobcaygeon
NP-145	Bergin Qy	unknown	NO	18T	345000E 4900400N	N Fredericksburgh	VII	18	Napanee	N	unknown	Gull River
NP-146	Kinkley Qy	H. Kinkley	NO	18T	345150E 4901200N	N Fredericksburgh	VII	19	Napanee	N	8.8 m	Gull River
NP-147	Napanee Qy # 6	unknown	NO	18T	348300E 4902100N	N Fredericksburgh	VII	27	Napanee	N	unknown	Gull River
NP-148	Napanee Qy	unknown	NO	18T	347100E 4898900N	N Fredericksburgh	VI	19	Napanee	N	6.0 m	Gull River
NP-149	Napanee Qy # 8	unknown	NO	18T	350000E 4897250N	N Fredericksburgh	IV	23	Napanee	N	1.0 m	Verulam
NP-150	Napanee Qy # 9	unknown	NO	18T	347500E 4904200N	N Fredericksburgh	VII	28	Napanee	N	unknown	Gull River
NP-151	Napanee Qy # 10	unknown	NO	18T	348000E 4903990N	N Fredericksburgh	VII	29	Napanee	N	unknown	Gull River
NP-152	Adulphostown Qy	unknown	NO	18T	339800E 4886700N	S Fredericksburgh	III Additional	13	Napanee	N	4.0 m	Verulam
NP-153	Sandhurst Qy # 1	unknown	NO	18T	344600E 4888500N	S Fredericksburgh	II	1	Napanee	N	2.0 m	Verulam
NP-154	Sandhurst Qy # 2	unknown	NO	18T	345900E 4889400N	S Fredericksburgh	II	5	Napanee	N	2.0 m	Verulam
NP-155	Sandhurst Qy # 3	unknown	NO	18T	347500E 4887000N	S Fredericksburgh	I	5	Napanee	N	0.0 m	Verulam

* Y = yes; N = no; I = intermittent

Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick-ness	Geological Formation(s) (Members)
NP-156	Lennox G.S. Qy	Ontario Hydro	NO	18T	350900E 4890050N	S Fredericks-burgh	I	16	Napanee	N	2.0 m	Verulam
NP-157	Hawley Qy	unknown	NO	18T	350900E 4896000N	S Fredericks-burgh	III	24	Napanee	N	1.5 m	Bobcaygeon
NP-158	Lawrence Qy	unknown	NO	18T	341950E 4881050N	Adolphustown	I	17	Napanee	N	0.0 m	Verulam
NP-159	Croydon Qy # 1	unknown	NO	18T	341800E 4921500N	Camden East	VIII	14	Napanee	N	1.0 m	Gull River
NP-160	Croydon Qy # 2	unknown	NO	18T	343700E 4919200N	Camden East	VII	15-16	Napanee	N	unknown	Gull River
NP-161	Centreville Qy # 1	unknown	NO	18T	345550E 4917650N	Camden East	VI	19	Napanee	N	4.0 m	Gull River
NP-162	Enterprise Qy	unknown	NO	18T	351150E 4922800N	Camden East	V	36	Napanee	N	2.8 m	Gull River
NP-163	Moscow Qy # 1	unknown	NO	18T	353900E 4923955N	Camden East	VI	42	Napanee	N	0.0 m	Gull River
NP-164	Moscow Qy # 2	unknown	NO	18T	354800E 4922700N	Camden East	VI	42	Napanee	N	2.0 m	Gull River
NP-165	Centreville Qy # 2	unknown	NO	18T	349000E 4917250N	Camden East	V	24	Napanee	N	3.0 m	Gull River
NP-166	Centreville Qy # 3	unknown	NO	18T	349550E 4916900N	Camden East	V	25	Napanee	N	2.0 m	Gull River
NP-167	Milsap Qy	unknown	NO	18T	350950E 4915300N	Camden East	IV	25	Napanee	N	3.9 m	Gull River
NP-168	Wesley Qy	unknown	NO	18T	345700E 4911700N	Camden East	IV	9	Napanee	N	0.0 m	Gull River
NP-169	Strathcona Qy	Pearson & R. Sheltor	NO	18T	348250E 4907900N	Camden East	I	11	Napanee	N	unknown	Gull River
NP-170	Strathcona Qy	Napanee Cement Co.	NO	18T	348250E 4907900N	Camden East	I	10	Napanee		unknown	Gull River
NP-171	Strathcona Qy # 3	unknown	NO	18T	349850E 4908200N	Camden East	I	14	Napanee	N	3.0 m	Gull River
NP-172	Newburgh Qy # 1	unknown	NO	18T	349300E 4910900N	Camden East	II	16	Napanee	N	unknown	Gull River
NP-173	Newburgh Qy # 2	unknown	NO	18T	350650E 4909750N	Camden East	II	17	Napanee	N	unknown	Gull River
NP-174	Newburgh Qy	unknown	NO	18T	350800E 4908850N	Camden East	I	17	Napanee	I	4.5 m	Gull River
NP-175	Camden E Qy # 1	unknown	NO	18T	354050E 4910550N	Camden East	I	26	Napanee	N	0.0 m	Gull River
NP-176	Camden E Qy # 2	unknown	NO	18T	355800E 4910600N	Camden East	I	30	Napanee	N	2.0 m	Gull River
NP-177	Camden E Qy # 3	unknown	NO	18T	357050E 4912000N	Camden East	I	35	Napanee	N	1.0 m	Gull River
NP-178	Yarker Qy # 1	unknown	NO	18T	358650E 4915400N	Camden East	II	43	Napanee	N	0.0 m	Gull River
NP-179	Yarker Qy # 2	unknown	NO	18T	359050E 4913900N	Camden East	I	41	Napanee	N	1.0 m	Gull River
NP-180	Yarker Qy # 3	unknown	NO	18T	359700E 4914700N	Camden East	I	44	Napanee	N	1.0 m	Gull River
NP-181	Camden E Qy # 4	unknown	NO	18T	355000E 4909000N	Ernestown	VII	20	Napanee	N	2.0 m	Gull River
NP-182	Camden E Qy # 5	unknown	NO	18T	355250E 4908700N	Ernestown	VII	21	Napanee	N	0.0 m	Gull River
NP-183	Camden E Qy # 6	unknown	NO	18T	355800E 4906800N	Ernestown	VI	20	Napanee	N	1.0 m	Gull River
NP-184	Switzerville Qy	Carter Constr. Co.	NO	18T	353000E 4904400N	Ernestown	VI	10	Napanee	N	1.0 m	Gull River
NP-185	Camden E Qy # 7	unknown	NO	18T	355000E 4904250N	Ernestown	VI	15	Napanee	N	4.0 m	Gull River
NP-186	Camden E Qy # 8	unknown	NO	18T	356500E 4906250N	Ernestown	VI	21	Napanee	N	1.0 m	Gull River
NP-187	Wilton Qy # 2	unknown	NO	18T	360500E 4910500N	Ernestown	VII	35	Napanee	N	unknown	Gull River
NP-188	Wilton Qy # 3	unknown	NO	18T	362700E 4910900N	Ernestown	VII	40	Napanee	N	1.0 m	Gull River
NP-189	Wilton Qy # 4	unknown	NO	18T	362100E 4908300N	Ernestown	VI	36	Napanee	N	1.5 m	Gull River
NP-190	Violet Qy # 1	unknown	NO	18T	352100E 4902600N	Ernestown	V	7	Napanee	N	1.0 m	Gull River
NP-191	Violet Qy # 2	unknown	NO	18T	355500E 4903100N	Ernestown	V	15	Napanee	N	2.0 m	Gull River
NP-192	Hwy 133-401 interchange	unknown	NO	18T	357600E 4903900N	Ernestown	V	20	Napanee	N	2.0 m	Gull River
NP-193	Potter (Odessa) Qy	unknown	NO	18T	363000E 4903600N	Ernestown	IV	31-32	Napanee	N	2.0 m	Gull River
NP-194	Odessa Qy	unknown	NO	18T	364050E 4901900N	Ernestown	III	33	Napanee	N	2.0 m	Gull River
NP-195	Bath Qy # 1	unknown	NO	18T	354750E 4900000N	Ernestown	IV	7	Napanee	N	0.0 m	Gull River
NP-196	Napanee Qy # 11	unknown	NO	18T	352250E 4898800N	Ernestown	IV	3	Napanee	N	unknown	Gull River
NP-197	Bath Qy # 2	unknown	NO	18T	355150E 4899400N	Ernestown	IV	10	Napanee	N	1.0 m	Bobcaygeon
NP-198	Millhaven Qy # 1	unknown	NO	18T	358900E 4900450N	Ernestown	III	20	Napanee	N	2.5 m	Bobcaygeon
NP-199	Asseltine Qy	unknown	NO	18T	361800E 4900500N	Ernestown	III	26	Napanee	N	2.0 m	Gull River
NP-200	Amherstview Qy # 3	unknown	NO	18T	365600E 4899000N	Ernestown	I	34	Napanee	N	unknown	Gull River
NP-201	Bath Qy # 3	unknown	NO	18T	356400E 4895450N	Ernestown	II	9	Napanee	N	7.8 m	Bobcaygeon
NP-202	Bath Qy # 4	unknown	NO	18T	356700E 4895800N	Ernestown	II	10	Napanee	N	3.0 m	Bobcaygeon
NP-203	Bath Qy # 5	unknown	NO	18T	356950E 4892500N	Ernestown	I	7	Napanee	N	5.0 m	Verulam
NP-204	Millhaven Qy # 2	unknown	NO	18T	360800E 4894650N	Ernestown	I	18	Napanee	N	6.0 m	Gull River
NP-205	Amherstview Qy # 1	unknown	NO	18T	362000E 4898000N	Ernestown	I	22	Napanee	N	1.0 m	Gull River
NP-206	Amherstview Qy # 2	unknown	NO	18T	365000E 4897250N	Ernestown	I	30	Napanee	N	5.0 m	Gull River
NP-207	Amherstview Qy # 4	unknown	NO	18T	369800E 4897700N	Ernestown	I	42	Napanee	N	0.0 m	Gull River
NP-208	Bellrock Qy	unknown	NO	18T	359750E 4923850N	Portland	IX	19	Napanee	N	2.0 m	Gull River
NP-209	Routley Qy	unknown	NO	18T	364750E 4923000N	Portland	VIII	10-11	Napanee	N	4.5 m	Gull River
NP-210	Leonard Qy	unknown	NO	18T	366700E 4923150n	Portland	VIII	7-8	Napanee	N	5.2 m	Gull River
NP-211	Knowlton Lake Qy	unknown	NO	18T	370100E 4922300N	Portland	VIII	2	Napanee	N	unknown	Gull River

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Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick- ness	Geological Formation(s) (Members)
NP-212	Petworth Qy	unknown	NO	18T	361200E 4920050N	Portland	VI	16	Napanee	N	4.0 m	Gull River
NP-213	Shellington Qy	unknown	NO	18T	365800E 4920700N	Portland	VI-VII	8-9	Napanee	N	3.5 m	Gull River
NP-214	Wolfe's Swamp Qy	unknown	NO	18T	364700E 4917850N	Portland	V	11	Napanee	N	3.0 m	Gull River
NP-215	Sydenham Qy # 2	unknown	NO	18T	370900E 4918500N	Portland	V	1	Napanee	N	2.0 m	Gull River
NP-216	Groenewegen Qy	unknown	NO	18T	366300E 4916000N	Portland	III	8	Napanee	N	5.0 m	Gull River
NP-217	Star Corners Qy # 1	unknown	NO	18T	364350E 4914750N	Portland	II	2	Napanee	N	unknown	Gull River
NP-218	Star Corners Qy # 2	unknown	NO	18T	364600E 4913700N	Portland	II	11	Napanee	N	unknown	Gull River
NP-219	Henderson (Murvale) Qu.	unknown	NO	18T	367450E 4913300N	Portland	I	6-7	Napanee	N	13.0 m	Gull River
NP-220	Sydenham Qy # 1	unknown	NO	18T	372000E 4918600N	Loughborough	V	2	Napanee	N	unknown	Gull River
NP-221	Rosedale Qy	unknown	NO	18T	374600E 4921400N	Loughborough	VII	7	Napanee	N	9.1 m	Gull River
NP-222	Sydenham Qy # 3	unknown	NO	18T	373400E 4918150N	Loughborough	IV	5	Napanee	N	2.0 m	Gull River
NP-223	Railton Qy	unknown	NO	18T	373050E 4915300N	Loughborough	III	4	Napanee	N	unknown	Gull River
NP-224	Inverary Qy # 2	unknown	NO	18T	382600E 4918000N	Storrington	IV	20	Napanee	N	5.0 m	Gull River
NP-225	Inverary Qy # 1	unknown	NO	18T	383350E 4915400N	Storrington	II	21	Napanee	N	4.0 m	Gull River
NP-226	Latimer Qy # 1	unknown	NO	18T	379300E 4914700N	Storrington	II	14	Napanee	N	unknown	Gull River
NP-227	Latimer Qy # 2	unknown	NO	18T	338450E 4912050N	Storrington	VII W	20	Napanee	N	1.0 m	Gull River
NP-228	Shannons Corners Qy 1	unknown	NO	18T	380500E 4911900N	Storrington	VII W	26	Napanee	N	unknown	Gull River
NP-229	Collins Lake Qy	unknown	NO	18T	383000E 4912500N	Storrington	VII W	32	Napanee	N	5.0 m	Gull River
NP-230	Sunbury Qy	unknown	NO	18T	386500E 4915900N	Storrington	VII	1	Napanee	N	3.0 m	Gull River
NP-231	Sharpton Qy # 1	unknown	NO	18T	367000E 4910100N	Kingston	VI W Division	11	Napanee	N	1.0 m	Gull River
NP-232	Sharpton Qy # 2	unknown	NO	18T	366650E 4909600N	Kingston	VI W Division	12	Napanee	N	2.0 m	Gull River
NP-233	Sharpton Qy # 3	unknown	NO	18T	366550E 4909450N	Kingston	VI W Division	12	Napanee	N	0.0 m	Gull River
NP-234	Glenvale Qy # 1	unknown	NO	18T	370200E 4911000N	Kingston	VIII W Division	3	Napanee	N	1.5 m	Gull River
NP-235	Glenvale Qy # 2	unknown	NO	18T	370250E 4910600N	Kingston	VIII W Division	3	Napanee	N	1.5 m	Gull River
NP-236	Glenvale Qy # 3	unknown	NO	18T	370050E 4908000N	Kingston	V	2	Napanee	N	2.0 m	Gull River
NP-237	Westbrook Qy # 4	unknown	NO	18T	368100E 4905500N	Kingston	IV W Division	8	Napanee	N	3.0 m	Gull River
NP-238	Westbrook Qy	Kingston Aggregates	NO	18T	369900E 4905250N	Kingston	IV W Division	4-5	Napanee	N	1.0 m	Gull River
NP-239	Elginburg Qy # 2	unknown	NO	18T	377250E 4909500N	Kingston	VI	17	Napanee	N	2.0 m	Gull River
NP-240	Shannons Corners Qy 2	unknown	NO	18T	380000E 4909500N	Kingston	VI	24	Napanee	N	0.0 m	Gull River
NP-241	Elginburg Qy # 3	unknown	NO	18T	375500E 4907200N	Kingston	V	13	Napanee	N	unknown	Gull River
NP-242	Shannons Corners Qy 3	unknown	NO	18T	379250E 4907500N	Kingston	V	22	Napanee	N	2.0 m	Gull River
NP-243	Silvers Corners Qy	unknown	NO	18T	377850E 4906000N	Kingston	IV	20	Napanee	N	0.0 m	Gull River
NP-244	Glenburnie Qy	unknown	NO	18T	382500E 4908750N	Kingston	VI	30	Napanee	N	unknown	Gull River
NP-245	Fairmount Qy # 1	unknown	NO	18T	383600E 4909050N	Kingston	VI	34	Napanee	N	unknown	Gull River
NP-246	Fairmount Qy # 2	unknown	NO	18T	383400E 4908750N	Kingston	VI	33	Napanee	N	2.0 m	Gull River
NP-247	Fairmount Qy # 3	unknown	NO	18T	383600E 4908500N	Kingston	VI	33	Napanee	N	0.0 m	Gull River
NP-248	Fairmount Qy # 4	unknown	NO	18T	382400E 4907300N	Kingston	V	32	Napanee	N	unknown	Gull River
NP-249	Maple Lawn Qy	unknown	NO	18T	383750E 4905900N	Kingston	IV	32	Napanee	N	2.0 m	Gull River
NP-250	Aylesworth Qy # 1	unknown	NO	18T	375500E 4904550N	Kingston	IV	19	Napanee	N	2.0 m	Gull River
NP-251	Aylesworth Qy # 2	unknown	NO	18T	375800E 4904200N	Kingston	IV	14	Napanee	N	1.0 m	Gull River
NP-252	Aylesworth Qy # 3	unknown	NO	18T	377200E 4904700N	Kingston	IV	18	Napanee	N	0.0 m	Gull River
NP-253	Aylesworth Qy # 4	unknown	NO	18T	378100E 4904100N	Kingston	IV	20	Napanee	N	4.0 m	Gull River
NP-254	Kingston Mills Qy	unknown	NO	18T	282950E 4904300N	Kingston	IV	33	Napanee	N	9.3 m	Gull River
NP-256	Westbrook Qy # 5	unknown	NO	18T	368400E 4904500N	Kingston	IV	8	Napanee	N	1.0 m	Gull River
NP-257	Westbrook Qy # 6	unknown	NO	18T	368600E 4903750N	Kingston	IV W Division	7	Napanee	N	unknown	Gull River
NP-258	Westbrook Qy # 7	unknown	NO	18T	367750E 4903200N	Kingston	III W Division	9	Napanee	N	2.0 m	Gull River
NP-259	Collins Bay Qy # 3	unknown	NO	18T	370050E 4901600N	Kingston	III W Division	3	Napanee	N	2.0 m	Gull River
NP-260	Collins Bay Qy # 4	unknown	NO	18T	371250E 4900600N	Kingston	II	1	Napanee	N	0.0 m	Gull River
NP-261	Collins Bay Qy	W.B. Bennett Ltd.	NO	18T	372950E 4899000N	Kingston	I	5	Napanee	N	12.0 m	Gull River, Bobcaygeon
NP-262	Lemoine's Point Qy	unknown	NO	18T	372000E 4896800N	Kingston	I	3	Napanee	N	8.0 m	Gull River
NP-263	Collins Bay Pen. Qy 1	Collins Bay Pen.	NO	18T	375950E 4897200N	Kingston	I	-	Napanee	N	1.0 m	Gull River
NP-264	Collins Bay Pen. Qy 2	Collins Bay Pen.	NO	18T	375250E 4898900N	Kingston	I	10	Napanee	N	8.4 m	Gull River
NP-265	Turner Drive Qy	unknown	NO	18T	375800E 4899650N	Kingston	II	-	Napanee	N	3.5 m	Gull River
NP-266	Kirkpatrick Qy	unknown	NO	18T	377500E 4899800N	Kingston	II	16	Napanee	N	3.0 m	Gull River
NP-267	Valleyview Qy	unknown	NO	18T	377950E 4900250N	Kingston	II	18	Napanee	N	2.0 m	Gull River
NP-268	Kingston Qy # 5	unknown	NO	18T	378000E 4900600N	Kingston	II	18	Napanee	N	0.0 m	Gull River
NP-269	Kingston Qy # 6	unknown	NO	18T	378250E 4901250N	Kingston	II	18	Napanee	N	0.0 m	Gull River

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NP-270	Kingston Qy # 7	unknown	NO	18T	378600E 4901200N	Kingston	II	19	Napanee	N	0.0 m	Gull River
NP-271	Kingston Qy # 8	unknown	NO	18T	378350E 4901950N	Kingston	III	20	Napanee	N	2.0 m	Gull River
NP-272	Kingston Qy	Frontenac Quarries	NO	18T	380600E 4902100N	Kingston	W. of Cataraqui R.	1–5	Napanee	N	17.0 m	Gull River
NP-273	Rideau Heights Qy	unknown	NO	18T	381800E 4901700N	Kingston	II	28	Napanee	N	2.0 m	Gull River
NP-274	Kingston Qy # 9	unknown	NO	18T	379700E 4901500N	Kingston	III	23	Napanee	N	0.0 m	Gull River
NP-275	Kingscourt Qy	unknown	NO	18T	380100E 4901500N	Kingston	II	22	Napanee	N	4.0 m	Gull River
NP-276	Weham Qy	J. Weham	NO	18T	380400E 4900250N	Kingston	I	25	Napanee	N	10.0 m	Gull River
NP-277	Roddy Qy	J.M. Roddy	NO	18T	380600E 4900200N	Kingston	I	25	Napanee	N	5.0 m	Gull River
NP-278	Montreal Street Qy #1	unknown	NO	18T	381050E 4899950N	Kingston	I	26	Napanee	N	7.0 m	Gull River
NP-279	Montreal Street Qy #2	unknown	NO	18T	481200E 4899900N	Kingston	I	26	Napanee	N	3.0 m	Gull River
NP-280	Montreal Street Qy #3	unknown	NO	18T	381250E 4899100N	Kingston	I	26	Napanee	N	3.0 m	Gull River
NP-281	Montreal Street Qy #4	unknown	NO	18T	381250E 4898900N	Kingston	II	26	Napanee	N	3.1 m	Gull River
NP-282	Portsmouth Qy # 1	unknown	NO	18T	278950E 4898300N	Kingston	I	–	Napanee	N	0.0 m	Gull River
NP-283	Portsmouth Qy # 2	unknown	NO	18T	379200E 4897900N	Kingston	I	–	Napanee	N	0.0 m	Gull River
NP-284	Portsmouth Qy # 3	unknown	NO	18T	378950E 4898000N	Kingston	I	–	Napanee	N	0.0 m	Gull River
NP-285	Portsmouth Qy # 4	unknown	NO	18T	378200E 4897800N	Kingston	I	–	Napanee	N	0.0 m	Gull River
NP-286	Portsmouth Qy # 5	unknown	NO	18T	378600E 4897500N	Kingston	I	19	Napanee	N	5.0 m	Gull River
NP-287	Portsmouth Qy # 6	unknown	NO	18T	379000E 4897800N	Kingston	I	–	Napanee	N	0.0 m	Gull River
NP-288	Pine Hill Qy # 1	unknown	NO	18T	391100E 4910150N	Pittsburgh	IV	12	Napanee	N	2.0 m	Gull River
NP-289	Joyceville Pen. Qy	Joyceville Penitentiary	NO	18T	392500E 4911750N	Pittsburgh	V	16	Napanee	N	4.0 m	Gull River
NP-290	Pine Hill Qy # 2	unknown	NO	18T	393150E 4910400N	Pittsburgh	IV	17	Napanee	N	6.0 m	Gull River
NP-291	Rideau Sta Qy	unknown	NO	18T	386000E 4905050N	Pittsburgh	E of Cataraqui R.	D	Napanee	N	8.0 m	Gull River
NP-292	Joyceville Road Qy	unknown	NO	18T	393750E 4907000N	Pittsburgh	III	18	Napanee	N	5.0 m	Gull River
NP-293	Middle Road Qy	unknown	NO	18T	393650E 4906500N	Pittsburgh	III	18	Napanee	N	6.3 m	Gull River
NP-294	Bateau Channel Qy # 2	unknown	NO	18T	397450E 4906350N	Pittsburgh	II	28	Napanee	N	1.2 m	Gull River
NP-295	Bateau Channel Qy # 1	unknown	NO	18T	397250E 4906000N	Pittsburgh	II	27	Napanee	N	2.1 m	Gull River
NP-296	Pitts Ferry Qy	unknown	NO	18T	393750E 4904400N	Pittsburgh	I	18	Napanee	N	3.5 m	Gull River
NP-297	Abbey Dawn Qy	unknown	NO	18T	388400E 4901800N	Pittsburgh	I	4	Napanee	N	4.0 m	Gull River
NP-298	MacLean Qy	unknown	NO	18T	384650E 4901650N	Pittsburgh	E of Catarqui R.	11	Napanee	N	unknown	Gull River
NP-299	Barriefield Qy	unknown	NO	18T	383100E 4899350N	Pittsburgh	E of Cataraqui R.	–	Napanee	N	3.0 m	Gull River
NP-300	Howe Island Qy # 2	unknown	NO	18T	394200E 4902600N	Howe Island	N Range	5	Napanee	N	4.1 m	Gull River
NP-301	Howe Island Qy # 3	unknown	NO	18T	395000E 4900150N	Howe Island	S Range	5	Napanee	N	1.2 m	Gull River
NP-302	Howe Island Qy # 4	unknown	NO	18T	395600E 4900200N	Howe Island	S Range	6	Napanee	N	1.0 m	Gull River
NP-303	Howe Island Qy # 5	unknown	NO	18T	398700E 4901700N	Howe Island	S Range	13	Napanee	N	2.0 m	Gull River
NP-304	Howe Island Qy # 6	unknown	NO	18T	400700E 4903700N	Howe Island	S Range	19	Napanee	N	unknown	Gull River
NP-305	Howe Island Qy # 7	unknown	NO	18T	401900E 4903700N	Howe Island	S Range	21	Napanee	N	6.0 m	Gull River
NP-306	Ramsay Qy	unknown	NO	18T	348500E 4909000N	Camden East	II	12	Napanee	N	unknown	Gull River
NP-307	Consecon Qy # 3	unknown	NO	18T	298050E 4873600N	Hillier	IV	107	Napanee	N	3.0 m	Lindsay
NP-308	Boat Channel Qy	unknown	NO	18T	380750E 4892250N	Wolfe Island	Registered Plan 73	23	Napanee	N	0.0 m	Gull River
NP-309	Lamberts Hill Qy	unknown	NO	18T	383000E 4893700N	Wolfe Island	Registered Plan 73	11	Napanee	N	2.0 m	Gull River
NP-310	White Qy	Ken White	NO	18T	384400E 4893400N	Wolfe Island	Registered Plan 73	6–8	Napanee	N	unknown	Gull River
NP-311	Marysville Qy # 3	unknown	NO	18T	384950E 4893400N	Wolfe Island	Registered Plan 73	2	Napanee	N	1.0 m	Gull River
NP-312	Hulton Qy	E.J. Hulton	NO	18T	386500E 4892800N	Wolfe Island	VIII N	2	Napanee	N	0.5 m	Bobcaygeon
NP-313	Marysville Qy # 4	unknown	NO	18T	385550E 4894050N	Wolfe Island	VIII N	3	Napanee	N	3.0 m	Bobcaygeon
NP-314	Wolfe Island Landfill	unknown	NO	18T	386000E 4894500N	Wolfe Island	VIII N	3	Napanee	N	4.0 m	Gull River
NP-315	Fawcett Qy	R.F. Fawcett	NO	18T	389800E 4897000N	Wolfe Island	XI N	4	Napanee	N	unknown	Gull River
NP-316	Scotch Settlement Qy	unknown	NO	18T	392950E 4895600N	Wolfe Island	XIII S	2	Napanee	N	2.3 m	Gull River
NP-317	Lewis Bay Qy	unknown	NO	18T	398900E 4896450N	Wolfe Island	XVII	6	Napanee	N	2.6 m	Gull River
NP-318	The Ridge Qy	unknown	NO	18T	387400E 4888950N	Wolfe Island	VII	6	Napanee	N	2.0 m	Verulam
O-01	Adair Marble –Main Qy	Arriscraft Corp.	YES	17T	487250E 4969300N	Albemarle	VIII	7–8,	Owen Snd	Y	7.0 m	Amabel (Wiarton/ Colpoy Bay)
O-02	Moor Developments Qy	Moor Developments Inc.	YES	17T	479200E 4968300N	Albemarle	I EBR	3	Owen Snd	Y	5.0 m	Amabel (Eramosa)

* Y = yes; N = no; I = intermittent

Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick-ness	Geological Formation(s) (Members)
O-03	Ross Qy	Donald Ross	YES	17T	484750E 4956550N	Amabel	XXV	10-11	Owen Snd	Y	4.0 m	Amabel (Eramosa)
O-04	Cook Qy	J.S. Cook	NO	17T	485900E 4955350N	Amabel	XXIV	7-8	Owen Snd	N	4.6 m	Amabel (Eramosa), Guelph
O-05	Wiarton Qy	Owen Sound Ledgerock	YES	17T	484800E 4955200N	Amabel	XXIII	10-11	Owen Snd	Y	8.3 m	Amabel (Eramosa)
O-06	Ebel Qy	Griff Ebel	YES	17T	486300E 4955250N	Amabel	XXIII	6-8	Owen Snd	Y	12.0 m	Amabel (Eramosa)
O-07	McCartney Qy	Cliff McCartney	YES	17T	492150E 4949650N	Keppel	XVIII	7-9	Owen Snd	Y	3.4 m	Amabel (Eramosa)
O-08	Cruickshank (Keppel) Qy	Owen Sound Ledgerock	YES	17T	496450E 4937200N	Keppel	IV	17	Owen Snd	Y	1.9 m	Amabel (Eramosa)
O-09	Tolhurst Qy	E.C. King Contracting	YES	17T	505500E 4949200N	Sarawak	II	37	Owen Snd	I	6.0 m	Manitoulin
O-10	Sydenham Qy	E.C. King Contracting	YES	17T	511100E 4934750N	Sydenham	I-II S.C.R.	23-25	Owen Snd	Y	15.2 m	Amabel (Wiarton/ Colpoy Bay)
O-11	Davison Farm Qy	H. Sutherland	YES	17T	533500E 4932500N	St. Vincent	V	5	Owen Snd	Y	3.0 m	Manitoulin
O-12	Lions Head Qy	unknown	NO	17T	479600E 4982000N	Eastnor	V or VI	29 or 30	Owen Snd	N	7.0 m	Amabel
O-13	Hope Bay	unknown	NO	17T	486600E 4971650N	Albemarle	VIII	2	Owen Snd	N	2.0 m	Amabel (Wiarton/ Colpoy Bay)
O-14	Arriscraft - N Qy	Arriscraft Corp.	YES	17T	486750E 4970800N	Albemarle	VIII	4	Owen Snd	N	5.0 m	Amabel (Wiarton/ Colpoy Bay)
O-15	Wiarton N Qy	Owen Sound Ledgerock .	YES	17T	485350E 4955600N	Amabel	XXIV	9	Owen Snd	I	1.0 m	Amabel (Eramosa), Guelph
O-16	Wiarton Qy	Bruce Peninsula St. Qys.	NO	17T	487200E 4955350N	Amabel	XXIV	7	Owen Snd	N	2.1 m	Amabel (Eramosa), Guelph
O-17	Boat Lake Qy	L. Ross	NO	17T	483500E 4953500N	Amabel	XXII	14	Owen Snd	N	1.0 m	Guelph
O-18	Boat Lake Qy # 2	unknown	NO	17T	484300E 4953300N	Amabel	XII	12	Owen Snd	N	unknown	Guelph
O-19	Charles Lake Qy	unknown	NO	17T	497900E 4956700N	Keppel	XXIV	23	Owen Snd	N	2.0 m	Amabel
O-20	Kemble Qy	unknown	NO	17T	507000E 4952300N	Keppel	Georgian Range	18	Owen Snd	N	unknown	Manitoulin
O-21	Shallow Lake Qy	unknown	NO	17T	492550E 4940000N	Keppel	VII	8	Owen Snd	N	5.0 m	Amabel
O-22	McDonald Qy	unknown	NO	17T	487320E 4934000N	Amabel	II	7	Owen Snd	N	1.0 m	Guelph
O-23	Alvanley Qy	unknown	NO	17T	490200E 4932000N	Derby	Indian Strip	20	Owen Snd	N	3.0 m	Guelph
O-24	Owen Sound W Quarries	various	NO	17T	501900E 4935600N	Sarawak	II	3	Owen Snd	N	1.0 m	Amabel (Wiarton/ Colpoy Bay)
O-25	Chalmers Qy	D. Chalmers	NO	17T	501500E 4934300N	Derby	Indian Strip	6 or 7	Owen Snd	N	5.0 m	Amabel
O-26	Brown's Lime Works	Brown's Lime Works	NO	17T	505800E 4932750N	Derby	I	14 or 15	Owen Snd	N	5.0 m	Amabel
O-27	Owen Sound E Quarries	various	NO	17T	506000E 4935600N	Sydenham	City of Owen Sound	-	Owen Snd	N	6.5 m	Manitoulin
O-28	Bothwell Corners Qy	unknown	NO	17T	510300E 4936000N	Sydenham	I NCR or I SCR	25 or 26	Owen Snd	N	8.0 m	Amabel
O-29	Cape Chin Qy	unknown	NO	17T	474300E 4891300N	Lindsay	V	12	Owen Snd	N	4.0 m	Guelph
O-30	Inverhuron Qy	unknown	NO	17T	452400E 4903200N	Kincardine	A	67	Owen Snd	N	unknown	Lucas
O-31	Kincardine Qy	Ministry of Transport	NO	17T	455250E 4889600N	Kincardine	I SDR	11	Owen Snd	N	1.0 m	Lucas
O-32	Penetangore Qy	A.W. Holland & J. Keys	NO	17T	455100E 4888700N	Kincardine	III S	6-9	Owen Snd	N	15.0 m	Lucas
O-33	Formosa (Hydro) Qy	Hanover Portland Cement	NO	17T	482700E 4883200N	Brant	III S of Durham Rd	B	Owen Snd	N	9.0 m	Amherstburg ("Formosa Reef")
O-34	Cargill Qy	R. Dobson	NO	17T	482900E 4892800N	Brant	VII	2	Owen Snd	N	13.0 m	Bertie
O-35	Walkerton Qy	unknown	NO	17T	489000E 4885500N	Brant	II S of Durham Road	29	Owen Snd	N	2.0 m	Bertie
O-36	Craigleith Qy	unknown	NO	17T	551100E 4931500N	Collingwood	IV	25	Owen Snd	N	4.2 m	Lindsay (Collingwood)
PE-01	Fourth Chute Qy	Township of Bromley	NO	18T	342900E 5040200N	Grattan	XV	8	Pembroke	Y	8.5 m	Bobcaygeon
PE-02	Braeside Qy	Smiths Constr. Co. Ltd.	NO	18T	387050E 5035850N	McNab	A	16	Pembroke	Y	8.1 m	Bobcaygeon
PE-03	Clay Bank Qy	H & H Aggregates	NO	18T	390400E 5026700N	McNab	IX	1	Pembroke	Y	17.4 m	Bobcaygeon
PE-07	Pembroke Qy	unknown	NO	18T	337000E 5074600N	Pembroke	I	12	Pembroke	N	3.0 m	Gull River
PE-08	Meath Qy	unknown	NO	18T	344900E 5065100N	Westmeath	I W of Muskrat Lk	19	Pembroke	N	4.0 m	Gull River
PE-09	Eganville Qy	unknown	NO	18T	341300E 5041800N	Grattan	XVII	12	Pembroke	N	16.2 m	Bobcaygeon
S-01	Pierce Qy	Chuck Mattice	NO	17T	571700E 4757350N	Walpole	XIV	7	Simcoe	N	7.1 m	Bertie, Bois Blanc (Springvale)
S-02	Port Dover Qy	Norfolk Quarries Co.	YES	17T	566600E 4739900N	Woodhouse	II	13-14	Simcoe	Y	15.0 m	Dundee
S-03	Bealton Qy	unknown	NO	17T	566000E 4758300N	Townsend	VI	21	Simcoe	N	unknown	Bois Blanc
S-04	Villa Nova Qy	McLaren	NO	17T	564500E 4754900N	Townsend	VIII	18	Simcoe	N	2.0 m	Bois Blanc
S-05	Rockford Qy	unknown	NO	17T	568100E 4751500N	Townsend	XI	22	Simcoe	N	unknown	Onondaga
S-06	Jarvis Qy	Ont. Land Corp.	NO	17T	569700E 4749000N	Townsend	XIII	24	Simcoe	N	0.0 m	Bois Blanc, Onondaga
S-07	Jarvis Qy #2	Ministry of Transportation	NO	17T	567500E 4746200N	Townsend	XIV	19	Simcoe	N	3.2 m	Dundee
S-08	Varency Qy	unknown	NO	17T	568500E 4745000N	Woodhouse	V	20	Simcoe	N	unknown	Dundee
S-09	Stelco (Nanticoke) Qy	Stelco	NO	17T	572900E 4739250N	Woodhouse	I	24	Simcoe	N	15.0 m	Dundee
S-10	Springvale Qy # 1	unknown	NO	17T	567900E 4759050N	Walpole	XVI	2	Simcoe	N	unknown	Bertie

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Site No.	Quarry Name	Operator or Owner	MNR Lic	UTM	Coords	Township	Conc	Lot	MNR District	Active (*)	Thick-ness	Geological Formation(s) (Members)
S-11	Cayuga (Teitz) Qy	Cayuga Mat. & Constr.	NO	17T	568000E 4756800N	Walpole	XIV	1	Simcoe	N	2.0 m	Onondaga
S-12	Springvale (Winger) Qy	Standard Aggregates	NO	17T	571200E 4756650N	Walpole	XIV	5-6	Simcoe	N	2.2 m	Bois Blanc (upper member)
S-13	Gray (Springvale) Qy	unknown	NO	17T	571500E 4756400N	Walpole	XIII	6	Simcoe	N	unknown	Bois Blanc
S-14	Springvale Qy # 2	unknown	NO	17T	574000E 4757050N	Walpole	XIV	10	Simcoe	N	unknown	Bois Blanc, Onondaga
S-15	Hagersville N Qy	Standard Aggregates	YES	17T	576000E 4757800N	Walpole	XIII	13-14	Simcoe	N	6.3 m	Bois Blanc, Onondaga
S-16	Hagersville Nwest Qy	Dufferin Aggregates	NO	17T	575400E 4756200N	Walpole	XIII	12	Simcoe	N	3.9 m	Onondaga
S-17	Hagersville E Qy	Dufferin Aggregates	NO	17T	576000E 4756450N	Walpole	XIII	13	Simcoe	N	9.0 m	Bois Blanc, Onondaga
S-18	Hagersville S Qy	Dufferin Aggregates	NO	17T	576000E 4755700N	Walpole	XII	13	Simcoe	N	4.2 m	Onondaga
S-19	Hagersville (SW) Qy	Dufferin Aggregates	YES	17T	575900E 4755200N	Walpole	XII	12	Simcoe	N	0.0 m	Onondaga
S-20	Sandusk Qy	unknown	NO	17T	579250E 4744400N	Walpole	IV	13	Simcoe	N	unknown	Dundee
S-21	Nanticoke Qy	unknown	NO	17T	575700E 4741400N	Walpole	II	6	Simcoe	N	3.1 m	Dundee
S-22	Nanticoke Qy #2	unknown	NO	17T	575500E 4739900N	Walpole	I	5	Simcoe	N	1.8 m	Dundee
S-23	Cheapside Qy	Haldimand-Norfolk R. M.	NO	17T	582500E 4744800N	Walpole	IV	18	Simcoe	N	3.1 m	Dundee
S-24	Cheapside Qy #2	unknown	NO	17T	583000E 4744300N	Walpole	III	19	Simcoe	N	1.5 m	Dundee
S-25	Selkirk Qy	unknown	NO	17T	587100E 4746100N	Rainham	III	2	Simcoe	N	4.4 m	Dundee
S-26	Helkies Qy	Glen Chambers	NO	17T	587700E 4744200N	Rainham	II	2	Simcoe	N	1.5 m	Onondaga (Moorehouse)
S-27	Selkirk Qy #2	unknown	NO	17T	587700E 4743500N	Rainham	II	2	Simcoe	N	unknown	Onondaga
S-28	Selkirk Qy #1	unknown	NO	17T	588000E 4743200N	Rainham	II	2	Simcoe	N	5.0 m	Dundee
S-29	Dogs Nest Qy	unknown	NO	17T	567500E 4740000N	Woodhouse	II	15	Simcoe	N	unknown	Dundee
TW-01	Marmora Pit	Marmoraton Mining Co.	NO	18T	288750E 4928200N	Marmora	V	4	Tweed	N	43.9 m	Shadow Lake, Gull River, Bobcaygeon
TW-02	Jarvis Lake Qy	Stoklosar Marble Qys.	YES	18T	295850E 4934150N	Madoc	I	11	Tweed	Y	4.5 m	Gull River
TW-03	Madoc Marble Qy	Stoklosar Marble Qys.	YES	18T	299650E 4935125N	Madoc	IV	10	Tweed	Y	5.5 m	Shadow Lake, Gull River
TW-04	Crookston Qy	H.J. McFarland Constr.	YES	18T	304850E 4922550N	Huntingdon	IX	10	Tweed	Y	7.5 m	Bobcaygeon
TW-20	Cordova Mines Qy	unknown	NO	18T	281100E 4939300N	Marmora	III	26	Tweed	N	2.5 m	Gull River
TW-21	Marmora Qy	Bonter & American Lithography	NO	18T	284300E 4928750N	Marmora	III	8	Tweed	N	1.0 m	Gull River
TW-22	Crowe Lake Qy	American Lithography	NO	18T	285200E 4929000N	Marmora	III	7	Tweed	N	unknown	Gull River
TW-23	Pearce Qy	Pearce	NO	18T	286000E 4929100N	Marmora	IV	7	Tweed	N	unknown	Gull River
TW-24	Marmora Qy # 2	unknown	NO	18T	287500E 4927000N	Marmora	IV	3	Tweed	N	1.0 m	Bobcaygeon
TW-25	Deloro Qy	abandoned	NO	18T	291400E 4932600N	Marmora	VIII	10	Tweed	N	4.8 m	Gull River
TW-26	Keller Bridge Qy	Stoklosar Marble Qys.	YES	18T	299050E 4942950N	Madoc	VI	23	Tweed	N	5.5 m	Gull River
TW-27	Eldorado Qy	unknown	NO	18T	300150E 4939050N	Madoc	V	16	Tweed	N	6.3 m	Bobcaygeon
TW-28	Madoc Qy # 1	unknown	NO	18T	300700E 4934000N	Madoc	V	8	Tweed	N	5.0 m	Gull River
TW-29	Madoc Qy # 2	unknown	NO	18T	305100E 4933950N	Madoc	VIII	5	Tweed	N	2.0 m	Gull River
TW-30	Quinmolac Qy	unknown	NO	18T	304400E 4926200N	Huntingdon	XII	11	Tweed	N	5.0 m	Bobcaygeon
TW-31	Crookston Qy # 2	unknown	NO	18T	305000E 4922200N	Huntingdon	IX	10	Tweed	N	8.1 m	Bobcaygeon
TW-32	Crookston Qy # 3	unknown	NO	18T	305300E 4921700N	Huntingdon	VIII	11	Tweed	N	3.9 m	Bobcaygeon
TW-33	Crookston Qy # 4	unknown	NO	18T	306050E 4922300N	Huntingdon	IX	12	Tweed	N	unknown	Bobcaygeon
TW-34	Tweed Qy	unknown	NO	18T	316300E 4928700N	Hungerford	XI	12	Tweed	N	7.3 m	Bobcaygeon
TW-35	Mellon Lake Qy	unknown	NO	18T	332500E 4934600N	Sheffield	III	23	Tweed	N	2.0 m	Gull River
TW-36	Eldorado Qy	Hastings Marble Products	NO	18T	299550E 4935000N	Madoc	IV	9	Tweed	N	2.0 m	Gull River
W-01	St. Marys Qy	St. Marys Cement Co.	YES	17T	487150E 4788075N	Blanshard	BFC & Thames River C	14-16 & 25-26	Wingham	Y	18.2 m	Lucas, Dundee
W-02	Formosa Qy	Town of Formosa	NO	17T	483000E 4878700N	Carrick	A	53	Wingham	N	5.0 m	Amherstburg ("Formosa Reef")
W-03	Teeswater (N) Qy	unknown	NO	17T	477000E 4871800N	Culross	VII	15	Wingham	N	12.0 m	Amherstburg
W-04	Teeswater Qy	Gypsum, Lime & Alabast.	NO	17T	477500E 4871000N	Culross	VI	14	Wingham	N	15.0 m	Amherstburg
W-05	Teeswater (S) Qy	unknown	NO	17T	479700E 4866000N	Culross	I	11-12	Wingham	N	unknown	Amherstburg
W-06	Holliday's Qy	unknown	NO	17T	456000E 4843000N	Colborne	II-III	15	Wingham	N	3.0 m	Dundee
W-07	Belgrave Qy	unknown	NO	17T	473500E 4850000N	Morris	IV	9	Wingham	N	2.0 m	Amherstburg ?
W-08	Robert Miller Qy	Robert Miller	NO	17T	480300E 4840500N	Grey	XII	5	Wingham	N	4.0 m	Amherstburg ?
W-09	V. Grahmn Qy	V. Grahmn	NO	17T	484000E 4839500N	Grey	XI	14	Wingham	N	2.5 m	Amherstburg ?
W-10	Gorrie Qy # 1	unknown	NO	17T	489800E 4857100N	Howick	VIII	2	Wingham	N	unknown	Amherstburg
W-11	Robert Ashton Qy	Robert Ashton	NO	17T	493200E 4858200N	Howick	VIII	11	Wingham	N	6.0 m	Amherstburg
W-12	Gorrie Qy # 2	unknown	NO	17T	494250E 4857100N	Howick	VII	13	Wingham	N	4.0 m	Amherstburg ?
W-13	W.G. Hamilton Qy	W.G. Hamilton	NO	17T	496000E 4856000N	Howick	VII	17	Wingham	N	6.0 m	Amherstburg ?
W-14	Fordwich Qy	unknown	NO	17T	497500E 4857050N	Howick	VI-VII	18	Wingham	N	unknown	Amherstburg ?

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W-15	Cromarty Qy	Anthony Allen	NO	17T	470000E 4808350N	Hibbert	XI	19	Wingham	N	2.0 m	Dundee
W-16	Thames Qy	Thames Qy Co.	NO	17T	488000E 4788500N	Blanshard	Thames River Conc.	35	Wingham	N	13.0 m	Dundee
W-17	St Marys Qy # 1	Standard White Lime Co.	NO	17T	489200E 4790300N	Blanshard	XVIII	15	Wingham	N	11.0 m	Lucas
W-18	St Marys Qy # 2	Standard White Lime Co.	NO	17T	492200E 4791000N	Downie	XIV	6	Wingham	N	2.0 m	Lucas
W-19	Wildwood Con. Area Qy	unknown	NO	17T	493400E 4790050N	Downie	XIV	2	Wingham	N	3.0 m	Lucas

Note: Marble quarries and processing plant are not included in this inventory. Therefore some site numbers may not be listed, or may not correspond to the map numbers in the district inventories in Volumes II and III.

- The owner/operator for unlicensed quarries may be the current or last known owner/operator.
- Determination of active, non-active or intermittent operation status was made at the time of field work.
- Township names may be geographic or municipal township names.

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