ISSN 1917-330X [online]
ISBN 978-1-4435-1532-0 [PDF]

ISSN 0708-2061 [print]
ISBN 978-1-4435-1531-3 [print]

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Ontario

Aggregate Resources Inventory of the

Regional Municipality of Durham

Southern Ontario

Ontario Geological Survey
Aggregate Resources Inventory
Paper 185

2010

Aggregate Resources Inventory of the

Regional Municipality of Durham

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Aggregate Resources Inventory
Paper 185

By D.J. Rowell

2010

Users of OGS products are encouraged to contact those Aboriginal communities whose traditional territories may be located in the mineral exploration area to discuss their project.

ISSN 0708-2061 [print] ISSN 1917-330X [online]
ISBN 978-1-4435-1531-3 [print] ISBN 978-1-4435-1532-0 [PDF]

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PRINT

Library and Archives Canada Cataloguing in Publication Data

Rowell, D.J.
Aggregate resources inventory of the Regional Municipality of Durham, Southern Ontario

(Ontario Geological Survey aggregate resources inventory paper, ISSN 0708-2061 ; 185)
Includes bibliographical references.
Available also on the Internet.
ISBN 978-1-4435-1531-3

1. Aggregates (Building materials)—Ontario—Durham (Regional municipality). 2. Geology—Ontario—Durham (Regional municipality)—Maps. I. Ontario Geological Survey. II. Title. III. Series: Ontario Geological Survey aggregate resources inventory paper ; 185.

TN939 R68 2010 553.6'20971356 C2010-964004-7

ONLINE

Library and Archives Canada Cataloguing in Publication Data

Rowell, D.J.
Aggregate resources inventory of the Regional Municipality of Durham, Southern Ontario [electronic resource]

(Ontario Geological Survey aggregate resources inventory paper, ISSN 1917-330X ; 185)
Includes bibliographical references.
Electronic monograph in PDF format.
Issued also in printed form.
ISBN 978-1-4435-1532-0

1. Aggregates (Building materials)—Ontario—Durham (Regional municipality). 2. Geology—Ontario—Durham (Regional municipality)—Maps. I. Ontario Geological Survey. II. Title. III. Series: Ontario Geological Survey aggregate resources inventory paper (Online); 185.

TN939 R68 2010 553.6'20971356 C2010-964005-5

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Cette publication est disponible en anglais seulement.

Parts of this publication may be quoted if credit is given. It is recommended that reference be made in the following form:

Rowell, D.J. 2010. Aggregate resources inventory of the Regional Municipality of Durham, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 185, 55p.

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2. Bedrock Resources, Regional Municipality of Durham, Scale 1:100 000 .... back pocket

*** Map 1 and Map 2 accompanying this report are simplified to depict information critical to the majority of users. Enhanced information on the aggregate resources for this area is provided in a compressed (*.zip*) file available for download from GeologyOntario (www.ontario.ca/geology). Additional documents in the *.zip* file provide further details on the vector ESRI® ArcGIS® files for maps 1 and 2, Microsoft® Excel® versions of Tables 1 to 9, and other files that enhance this report.**

Abstract

Four areas of sand and gravel have been chosen as selected aggregate resource areas of primary significance in the Regional Municipality of Durham. These selected resource areas have a total unlicenced area of 8094 ha, with 6578 ha remaining after considering previously extracted areas, and cultural, physical and environmental constraints. Possible aggregate resources are estimated at 1246.1 million tonnes. The Oak Ridges moraine represents the largest and most important aggregate resource area in the region, although esker deposits located in the Township of Brock are also significant. There are a number of secondary level sand and gravel deposits that add valuable aggregate resource to the region's total.

The report area is underlain by limestone, dolostone and shale of the Upper Ordovician Bobcaygeon, Verulam, Lindsay and Blue Mountain formations. The bedrock in the report area is generally overlain by a thick cover of Quaternary sediments and some of the formations are not suitable for aggregate production. For these reasons, no bedrock resources have been selected for resource protection.

Selected Resource Areas are not intended to be permanent, single land use units that must be incorporated into an official planning document. They represent areas in which a major resource is known to exist. Such resource areas may be reserved wholly or partially for extractive development and/or resource protection within the context of the official plan.

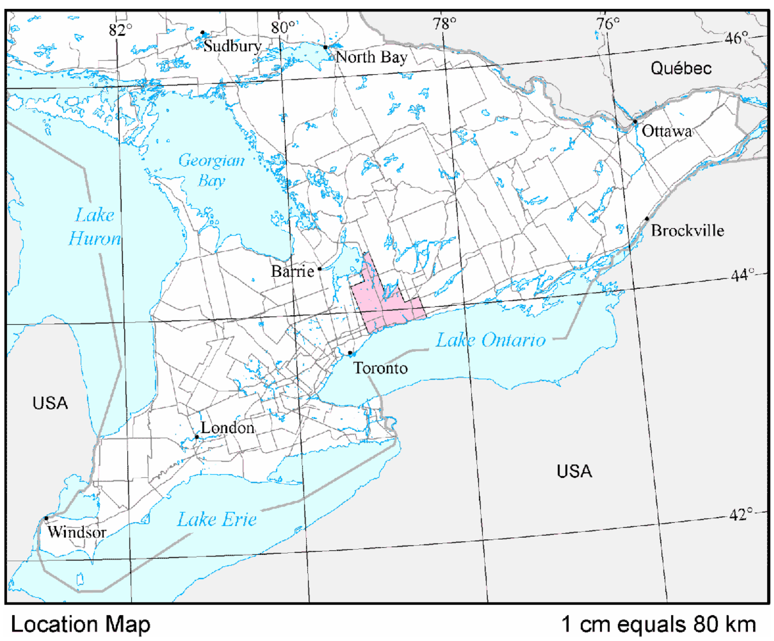


Figure 1. Key map showing the location of the study area.

Aggregate Resources Inventory of the Regional Municipality of Durham

By D.J. Rowell[1]

Field work, map production and report by D.J. Rowell.

Manuscript accepted for publication in 2009 by C.L. Baker, Senior Manager, Sedimentary Geoscience Section, Ontario Geological Survey. This report is published with the permission of the Director, Ontario Geological Survey.

[1] Sedimentary Geoscience Section, Ontario Geological Survey

Introduction

Mineral aggregates, which include bedrock-derived crushed stone as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road building and construction industries. Large quantities of these materials are used each year throughout the Province. For example, in 2006, the total tonnage of mineral aggregates extracted in Ontario was 177 million tonnes, greater than that of any other metallic or non-metallic commodity mined in the Province (The Ontario Aggregate Resources Corporation 2007).

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, non-renewable resources that can be exploited only in those areas where they occur. Mineral aggregates are characterized by their high bulk and low unit value so that the economic value of a deposit is a function of its proximity to a market area as well as its quality and size. The potential for extractive development is usually greatest in areas where land use competition is extreme. For these reasons, the availability of adequate resources for future development is now being threatened in many areas, especially urban areas where demand is the greatest.

Comprehensive planning and resource management strategies are required to make the best use of available resources, especially in those areas experiencing rapid development. Unfortunately, in some cases, the best aggregate resources are found in or near areas of environmental sensitivity, resulting in the requirement to balance the need for the different natural resources. Therefore, planning strategies must be based on a sound knowledge of the total mineral aggregate resource base at both local and regional levels. The purpose of the Aggregate Resources Inventory Program is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies. The reports should form the basis for discussion on those areas best suited for possible extraction. The aim is to assist decision-makers in protecting the public well-being by ensuring that adequate resources of mineral aggregate remain available for future use.

This report is a technical background document, based for the most part on geological information and interpretation. It has been designed as a component of the total planning process and should be used in conjunction with other planning considerations, to ensure the best use of an area's resources.

The report includes an assessment of sand and gravel resources as well as a discussion on the potential for bedrock-derived aggregate. The most recent information available has been used to prepare the report. As new information becomes available, revisions may be necessary.

Inventory Methods, Data Presentation and Interpretation

FIELD AND OFFICE METHODS

The methods used to prepare the report involved the interpretation of published geological data such as bedrock and surficial geology maps and reports, as well as field examination of possible resource areas. Field methods included the examination of natural and man-made exposures of granular material. Most observations were made at quarries and sand and gravel pits located by field surveys and from records held by the Ministry of Transportation of Ontario (MTO), the Ontario Geological Survey (OGS), and by Regional, District and Area Offices of the Ontario Ministry of Natural Resources (MNR). Observations made at pit sites included estimates of the total face height and the proportion of gravel- and sand-sized materials in the deposit. Observations regarding the shape and lithology of the particles were also made. These characteristics are important in estimating the quality and quantity of the aggregate. In areas of limited exposure, subsurface materials may be assessed by hand augering, test pitting and drilling.

Deposits with potential for extractive development, or those where existing data are scarce, were studied in greater detail. In instances, representative sites in these deposits are evaluated by taking 11 to 45 kg samples from existing pit or quarry faces, roadcuts or other exposures. The samples may be subjected to some or all of the following tests: absorption capacity, magnesium sulphate soundness test, micro-Deval abrasion test, unconfined freeze–thaw test, and accelerated mortar bar expansion test.

The field data were supplemented by pit information on file with the Soils and Aggregates Section of the Ministry of Transportation of Ontario. Data contained in these files includes field estimates of the depth, composition and "workability" of deposits, as well as laboratory analyses of the physical properties and suitability of the aggregate. Information concerning the development history of the pit and acceptable uses of the aggregate is also recorded. The locations of additional aggregate sources were obtained from records held by Regional, District and Area Offices of the Ontario Ministry of Natural Resources. In addition, testing data for type, quantity and quality of aggregates were also obtained from aggregate licence applications where these reports are on file with the MNR, and from individuals and companies.

Aerial photographs and remotely sensed imagery at various scales were used to determine the continuity of deposits, especially in areas where information is limited. Water well records, held by the Ontario Ministry of the Environment (MOE), were used in some areas to corroborate deposit thickness estimates or to indicate the presence of buried granular material. These records were used in conjunction with other evidence.

Topographic maps of the National Topographic System, at a scale of 1:50 000, were used as a compilation base for the field and office data. The information was then transferred to a base map, also at a scale of 1:50 000. These base maps were prepared using digital information taken from the Ontario Land Information Warehouse, Land Information Ontario, Ontario Ministry of Natural Resources, with modifications by staff of the Ministry of Northern Development, Mines and Forestry.

Units and Definitions

The measurements and other primary data available for resource tonnage calculations are presented in metric units in the text and on the tables that accompany the report. Data are generally rounded off in accordance with the Ontario Metric Practices Guide (Ontario Interministerial Committee on National Standards and Specifications 1975).

The tonnage estimates for aggregate deposits are termed possible resources (*see* Appendix B – Glossary) in accordance with terminology used by the Ontario Resource Classification Scheme (Robertson 1975, p.7) and the Association of Professional Engineers of Ontario (1976).

DATA PRESENTATION AND INTERPRETATION

Two maps, each portraying a different aspect of the aggregate resources in the report area, accompany the report. Map 1, "Sand and Gravel Resources", provides an inventory and evaluation of the sand and gravel resources in the report area. Map 2, "Bedrock Resources", shows the distribution of bedrock formations and the thickness of overlying unconsolidated sediments, and identifies the Selected Bedrock Resource Areas.

The hard-copy versions of Map 1 and Map 2 (back pocket of the report) are simplified to depict information critical to the majority of users.

Enhanced information on the aggregate resources for this area (e.g., complete deposit information for Map 1) is provided in vector ESRI® ArcGIS® files available for download as a compressed (*.zip*) file from GeologyOntario (www.ontario.ca/geology). A "readme" file included in the *.zip* file provides further details regarding the contents of these vector files. In addition, cross-references to data provided in the *.zip* file are provided for clients who wish to access digital data that does not require opening the vector ArcGIS® files. The tables for sand and gravel resources data are found in the folder "Sand_Gravel"; the data for bedrock resources data are in the folder "Bedrock". The tables are in database format (*.dbf* file) that can be opened using other software, for example Microsoft® Excel®. The cross-references include the folder, the table and the field name separated by a short vertical line, and the field name is indicated by bold, small capital letters (e.g., Bedrock | Drift_Thick.dbf | **AABBCC**).

Map 1: Sand and Gravel Resources

Map 1 shows the extent and quality of sand and gravel deposits within the study area and an evaluation of the aggregate resources. The map is derived from existing surficial geology maps of the area or from aerial photograph interpretation in areas where surficial mapping is incomplete.

The present level of extractive activity is also indicated on Map 1. Those areas licenced for extraction under the *Aggregate Resources Act* are shown by a solid outline and identified by a number that refers to the pit descriptions in Table 2. Each description notes the owner/operator and licenced hectarage of the pit, as well as the estimated face height and percentage gravel. A number of unlicenced pits (abandoned pits or pits operating on demand under authority of a wayside permit) are identified by a numbered dot on Map 1 and described in Table 2. Similarly, any test locations appear on Map 1 as a point symbol and the results of the test material are provided in Table 9.

SELECTED SAND AND GRAVEL RESOURCE AREAS

All the sand and gravel deposits are first delineated by geological boundaries and then classified into one of 3 levels of significance: primary, secondary or tertiary. The deposit's significance is also recorded in Sand_Gravel | Sand_Gravel.dbf | **SIGN**.

Areas of primary significance are coloured red on Map 1 and identified by a deposit number that corresponds to numbers in Table 3. The deposit number is also recorded in Sand_Gravel | Sand_Gravel.dbf | **SELECT_AREA**.

Selected Sand and Gravel Resource Areas of primary significance are not permanent, single land use units. They represent areas in which a major resource is known to exist, and may be reserved wholly or partially for extractive development and/or resource protection. In many of the recently approved municipal Official Plans, all or portions of resources of primary significance, and in some cases resources of secondary significance, are identified and protected.

Deposits of secondary significance are coloured orange on Map 1. Such deposits are believed to contain significant amounts of sand and gravel. Although deposits of secondary significance are not considered to be the best resources in the report area, they may contain large quantities of sand and gravel and should be considered as part of the overall aggregate supply of the area.

Deposits of tertiary significance are coloured yellow on Map 1. They are not considered to be important resource areas because of their low available resources or because of possible difficulties in extraction. Such areas may be useful for local needs or extraction under a wayside permit, but are unlikely to support large-scale development.

SELECTION CRITERIA

The process by which deposits are evaluated and selected involves the consideration of 2 sets of criteria. The main selection criteria are site specific, related to the characteristics of individual deposits. Factors such as deposit size, aggregate quality, and deposit location and setting are considered in the selection of those deposits best suited for extractive development. A second set of criteria involves the assessment of local aggregate resources in relation to the quality, quantity and distribution of resources in the region in which the report area is located. The intent of such a process of evaluation is to ensure the continuing availability of sufficient resources to meet possible future demands.

Site Specific Criteria

DEPOSIT SIZE AND THICKNESS

Ideally, selected deposits should contain available sand and gravel resources large enough to support a commercial pit operation using a stationary or portable processing plant. In practice, much smaller deposits may be of significant value depending on the overall resources in the rest of the project area.

The "thickness class" indicates a depth range, which is related to the potential resource tonnage for each deposit (*see* Table 1, Column 1: "Class Number"). Four thickness class divisions have been established: Class 1 deposits are greater than 6 m thick; Class 2 sand and gravel deposits are from 3 to 6 m thick; Class 3 represents a deposit that is from 1.5 to 3 m thick; and Class 4 represents a sand and gravel deposit that is less than 1.5 m thick. The thickness class for each deposit is also recorded in Sand_Gravel | Sand_Gravel.dbf | **DEP_THICK**.

Generally, deposits in Class 1 and containing more than 35% gravel are considered to be most favourable for commercial development. Thinner deposits may be valuable in areas with low total resources.

AGGREGATE QUALITY

The limitations of natural aggregates for various uses result from variations in the lithology of the particles comprising the deposit and from variations in the size distribution of these particles.

Four indicators of the quality of aggregate may be included in the deposit information: gravel content (G or S), fines (C), oversize (O) and lithology (L). Three of the quality indicators deal with grain size distribution.

The gravel content ("G" or "S") indicates the suitability of aggregate for various uses. Deposits containing at least 35% gravel ("G") in addition to a minimum of 20% material greater than the 26.5 mm sieve are considered to be the most favourable extractive sites, since this content is the minimum from which crushed products can be economically produced. In "sandy" deposits ("S"), the gravelsized aggregate (greater than 4.75 mm) makes up less than 35% of the whole deposit making it difficult to produce coarse aggregate products. The gravel content is also recorded in Sand_Gravel | Sand_Gravel.dbf | MATERIAL.

Excess fines (high silt and clay content) ("C") may severely limit the potential use of a deposit. Fines content in excess of 10% may impede drainage in road subbase aggregate and render it more susceptible to the effects of frost action. In asphalt aggregate, excess fines hinder the bonding of particles.

Deposits containing more than 20% oversize material (greater than 10 cm in diameter) ("O") may also have use limitations. The oversize component is unacceptable for uncrushed road base, so it must be either crushed or removed during processing.

Another indicator of the quality of an aggregate is lithology ("L"). Just as the unique physical and chemical properties of bedrock types determine their value for use as crushed rock, so do various lithologies of particles in a sand and gravel deposit determine its suitability for various uses. The presence of objectionable lithologies such as chert, siltstone and shale, even in relatively small amounts, can result in a reduction in the quality of an aggregate, especially for high-quality uses such as concrete and asphalt. Similarly, highly weathered, very porous and friable rock can restrict the quality of an aggregate.

If the deposit information shows either "C", "O" or "L", or any combination of these indicators, the quality of the deposit is considered to be reduced for some aggregate uses. The deposit quality, if applicable, is recorded in Sand_Gravel | Sand_Gravel.dbf | LIMITATION. No attempt is made to quantify the degree of limitation imposed. Assessment of the 4 indicators is made from published data, from data contained in files of both the Ontario Ministry of Transportation (MTO) and the Sedimentary Geoscience Section of the Ontario Geological Survey, and from field observations.

Quality data may also appear in Table 9, where the results of quality tests are listed by test type and sample location. The types of tests conducted and the test specifications are explained in Appendixes B and E, respectively.

Deposit Information

The deposit information coding is similar to that used in soil mapping and land classification systems commonly in use in North America and indicates the gravel content, thickness of material, origin (type) and quality limitations, if applicable. The "gravel content" and "thickness class", as described above, are basic criteria for distinguishing different deposits. The geologic deposit type is also reported (the types are summarized with respect to their main geologic and extractive characteristics in Appendix C of the report). The geologic deposit type is recorded in Sand_Gravel | Sand_Gravel.dbf | DEP_ORIGIN.

In the following example of a deposit information code,

"G / 1 / OW / C",

where G represents gravel content, 1 represents thickness class, OW represents geological type and C represents aggregate quality, the deposit information code is interpreted as an outwash deposit greater than 6 m thick containing more than 35% gravel with excess silt and clay.

The deposit information is recorded in Sand_Gravel | Sand_Gravel.dbf | LABEL.

Texture Symbol

The texture symbol provides a more detailed assessment of the grain size distribution of material sampled during field study. These symbols are derived from the information plotted on the aggregate grading curves that, if available, are included with the report. The relative amounts of gravel, sand, and silt and clay in the sampled material are shown graphically in the texture symbol by the subdivision of a circle into proportional segments. The following example shows a hypothetical sample consisting of 60% gravel, 30% sand and 10% silt and clay ("fines").

LOCATION AND SETTING

The location and setting of a resource area has a direct influence on its value for possible extraction. The evaluation of a deposit's setting is made on the basis of natural, environmental and man-made features that may limit or prohibit extractive development.

First, the physical context of the deposit is considered. Deposits with some physical constraint on extractive development, such as thick overburden or high water table, are less valuable resource areas because of the difficulties involved in resource recovery. Second, permanent man-made features, such as roads, railways, power lines and housing developments, which are built on a deposit, may prohibit its extraction. The constraining effect of legally required setbacks surrounding such features is included in the evaluation. A quantitative assessment of these constraints can be made by measurement of their areal extent directly from the topographic maps. The area rendered unavailable by these features is shown for each resource area in Table 3 (Column 3).

In addition to man-made and cultural features, certain natural features, such as provincially significant wetlands, may prove to be constraints. In this report, such constraints have not been outlined and the reader is advised to consult with municipal planning staff and the local office of the MNR for information on these matters. Depending on the number and type of constraint applicable, anywhere from 15 to 85% of the total resources in a municipality may be unavailable for development (Planning Initiatives Limited 1993).

The assessment of sand and gravel deposits with respect to local land use and private land ownership is an important component of the general evaluation process. Since the approval of the Provincial Policy Statement (PPS) under the authority of the *Planning Act* in 2005, recently approved Official Plans now contain detailed policies regarding the location and operation of aggregate extraction activities. These official plans should be consulted at an early stage with regard to the establishment of an aggregate extraction operation. These aspects of the evaluation process are not considered further in this report, but readers are encouraged to discuss them with personnel of the pertinent office of the MNR, Ministry of Municipal Affairs and Housing staff, and/or regional and local planning officials.

Regional Considerations

In selecting sufficient areas for resource development, it is important to assess both the local and the regional resource base, and to forecast future production and demand patterns.

Some appreciation of future aggregate requirements in an area may be gained by assessing its present production levels and by forecasting future production trends. Such an approach is based on the assumptions that production levels in an area closely reflect the demand, and that the present production or "market share" of an area will remain roughly at the same level.

The availability of aggregate resources in the region surrounding a project area should be considered in order to properly evaluate specific resource areas and to develop optimum resource management plans. For example, an area that has large resources in comparison to its surrounding region constitutes a regionally significant resource area. Areas with large resources in proximity to high-demand centres, such as metropolitan areas, are special cases as the demand for aggregate may be greater than the amount of production in the areas close to the urban boundary.

Although an appreciation of the multitude of factors affecting aggregate availability (e.g., environmental and planning constraints) is required to develop comprehensive resource management strategies, such detailed evaluation is beyond the scope of this report. The selection of resource areas made in this study is based primarily on geological data or on considerations outlined in the preceding sections.

SAND AND GRAVEL RESOURCE TONNAGE CALCULATIONS

Once the interpretative boundaries of the aggregate units have been established, quantitative estimates of the possible resources available can be made. Generally, the volume of a deposit can be calculated if its areal extent and average thickness are known or can be estimated. The computation methods used are as follows. First, the area of the deposit, as outlined on the final base map, is calculated in hectares (ha). The deposit area is also recorded in Sand_Gravel | Sand_Gravel.dbf | AREA. The thickness values used are an approximation of the deposit thickness, based on the face heights of pits developed in the deposit or on subsurface data such as test holes and water well records. Tonnage values can then be calculated by multiplying the volume of the deposit by 0.01770 (the density factor). This factor is approximately the number of tonnes in a 1 m thick layer of sand and gravel, 1 ha in extent, assuming an average density of 1770 kg/m^3.

$$\text{Tonnage} = \text{Area} \times \text{Thickness} \times \text{Density Factor}$$

Tonnage calculated in this manner must be considered only as an estimate. Furthermore, such tonnages represent amounts that existed prior to any extraction of material (i.e., original tonnage) (Table 1, Column 4).

The Selected Sand and Gravel Resource Areas in Table 3 are calculated in the following way. Two successive subtractions are made from the total area. Column 3 accounts for the number of hectares unavailable because of the presence of permanent cultural features and their associated setback requirements. Column 4 accounts for those areas that have previously been extracted (e.g., wayside, unlicenced and abandoned pits are included in this category). The remaining figure is the area of the deposit currently available for extraction (Column 5). The available area is then multiplied by the estimated deposit thickness and the density factor (Column 5 × Column 6 × 0.01770), to give an estimate of the sand and gravel tonnage (Column 7) possibly available for extractive development and/or resource protection. It should be noted, however, that studies (Planning Initiatives Limited 1993) have shown that substantial proportions of the resources in an area may be constrained due to environmental considerations (e.g., floodplains, environmentally sensitive areas). Lack of landowner interest in development, a range of planning considerations or other matters may also reduce the available resources.

Resource estimates are calculated for deposits of primary significance. Resource estimates for deposits of secondary and tertiary significance are not calculated in Table 3, however, the aggregate potential of these deposits is discussed in the report.

Map 2: Bedrock Resources

Map 2 is an interpretative map derived from bedrock geology, drift thickness and bedrock topography maps, water well data from the Ontario Ministry of the Environment (MOE), oil and gas well data from the Non-Renewable Resources Section of the MNR, and from geotechnical test hole data from various sources. Map 2 is based on concepts similar to those outlined for Map 1.

Inventory information presented on Map 2 is designed to give an indication of the present level of extractive activity in the report area. Those areas licenced for extraction under the *Aggregate Resources Act* are shown by a solid outline and identified by a number that refers to the quarry descriptions in Table 5. Each description notes the owner/operator, licenced hectarage and an estimate of face height. Unlicenced quarries (abandoned quarries or wayside quarries operating on demand under authority of a permit) are also identified and numbered on Map 2 and described in Table 5. Drill hole locations or other descriptive stratigraphic sections appear as a point symbol on Map 2. Table 7 provides these descriptions. These descriptions are also recorded in Bedrock | Add_Info.dbf.

The geological boundaries of the Paleozoic bedrock units are shown by black dashed lines. Isolated Paleozoic and Precambrian outcrops are indicated by an "×". Three sets of contour lines delineate areas of less than 1 m of drift, areas of 1 to 8 m of drift, and areas of 8 to 15 m of drift. The extent of these areas of thin drift are indicated on Map 2 and are indicated in Table 4 (Column 1). The deposit's significance is also recorded in Bedrock | Drift_Thick.dbf | CONTOUR. The darkest shade of blue indicates where bedrock crops out or is within 1 m of the ground surface. These areas constitute potential resource areas because of their easy access. The medium shade of blue indicates areas where drift cover is up to 8 m thick. Quarrying is possible in this depth of overburden and these zones also represent potential resource areas. The lightest shade of blue indicates bedrock areas overlain by 8 to 15 m of overburden.

Outside of these delineated areas, the bedrock can be assumed to be covered by more than 15 m of overburden, a depth generally considered to be too great to allow economic extraction. However, areas in which the bedrock is covered with greater than 8 m of overburden may constitute resources that have extractive value in specific circumstances. These circumstances include the resource being located adjacent to existing industrial infrastructure (e.g., a quarry operation or processing plant); speciality industrial mineral products (e.g., chemical lime and metallurgical rock) that can be produced from the resources; or part or all of the overburden being composed of an economically attractive deposit.

SELECTED BEDROCK RESOURCE AREAS

Selection of Bedrock Resource Areas has been restricted to a single level of significance. Three factors support this approach. First, quality and quantity variations within a specific geological formation are gradual. Second, the areal extent of a given quarry operation is much smaller than that of a sand and gravel pit producing an equivalent tonnage of material, and third, since crushed bedrock has a higher unit value than sand and gravel, longer haul distances can be considered. These factors allow the identification of alternative sites having similar development potential. The Selected Areas, if present, are shown on Map 2 by a line pattern and the calculated available tonnages are given in Table 6. The selected bedrock resource areas are also recorded in Bedrock | Drift_Thick.dbf | SELECT_AREA.

Selected Bedrock Resource Areas shown on Map 2 are not permanent, single land use units. They represent areas in which a major bedrock resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection, within an Official Plan.

SELECTION CRITERIA

Criteria equivalent to those used for sand and gravel deposits are used to select bedrock areas most favourable for extractive development.

The evaluation of bedrock resources is made primarily on the basis of performance and suitability data established by laboratory testing at the Ministry of Transportation of Ontario. The main characteristics and uses of the bedrock units found in southern Ontario are summarized in Appendix D.

Deposit "size" is related directly to the areal extent of thin drift cover overlying favourable bedrock formations. The deposit size is recorded in Bedrock | Drift_Thick.dbf | AREA; the favourable bedrock formations are reported in Bedrock | Drift_Thick.dbf | FORMATION. Since vertical and lateral variations in bedrock units are much more gradual than in sand and gravel deposits, the quality and quantity of the resource are usually consistent over large areas.

Quality of the aggregate derived from specific bedrock units is established by the performance standards previously mentioned. Location and setting criteria and regional considerations are identical to those for sand and gravel deposits.

BEDROCK RESOURCE TONNAGE CALCULATIONS

The method used to calculate resources of bedrock-derived aggregate is much the same as that described above for sand and gravel resources. The areal extent of bedrock formations overlain by less than 15 m of unconsolidated overburden is determined from bedrock geology maps, drift thickness and bedrock topography maps, and from the interpretation of water well records (Table 4). The measured extent of such areas is then multiplied by the estimated quarriable thickness of the formation, based on stratigraphic analyses and on estimates of existing quarry faces in the unit. In some cases, a standardized estimate of 18 m is used for thickness. Volume estimates are then multiplied by the density factor (the estimated weight in tonnes of a 1 m thick section of rock, 1 ha in extent). The areal extent of bedrock formations is also recorded in Bedrock | Drift_Thick.dbf | AREA.

Resources of limestone and dolostone are calculated using a density factor of 2649 kg/m^3; sandstone resources are calculated using a density estimate of 2344 kg/m^3; and shale resources are calculated with a factor of 2408 kg/m^3 (Telford et al. 1980).

Assessment of Aggregate Resources in the Regional Municipality of Durham

LOCATION AND POPULATION

The Regional Municipality of Durham encompasses a land area of 252 056 ha and includes 8 municipalities: the cities of Oshawa and Pickering; the towns of Whitby and Ajax; the townships of Brock, Uxbridge and Scugog; and the Municipality of Clarington (Figure 1). The region is bordered by Metropolitan Toronto and the Regional Municipality of York to the west, by Lake Simcoe and the County of Simcoe to the north, and by Northumberland County and the former Victoria County (now part of City of Kawartha Lakes) to the east. The study area is covered by all or parts of the Markham (30 M/14), Oshawa (30 M/15), Port Hope (30 M/16), Rice Lake (31 D/1), Scugog (31 D/2), Newmarket (31 D/3), Beaverton (31 D/6) and Lindsay (31 D/7) 1:50 000 scale map sheets of the National Topographic System (NTS).

The population of the Regional Municipality of Durham was 561 186 in 2006, an increase of 10.7% from 2001 (Statistics Canada 2006) (Table A). The region is a mixture of large urban centres, such as the cities of Oshawa and Pickering and the towns of Whitby and Ajax, and rural lands consisting of agricultural areas, hamlets and countryside residential developments. Automotive, plastic, aerospace and defence industries are the major economic activities found within the region. Resource extraction areas provide significant sand and gravel resources to the eastern end of the Greater Toronto Area (GTA).

Table A – Area and Population, Regional Municipality of Durham

Municipality	Area in 2006 (hectares)	2001 Population	2006 Population
City of Oshawa	14 567	139 051	141 590
City of Pickering	23 159	87 139	87 838
Town of Ajax	6709	73 753	90 167
Town of Whitby	14 652	87 413	111 184
Municipality of Clarington	61 110	69 834	77 820
Township of Brock	42 331	12 110	11 979
Township of Scugog	47 463	20 173	21 439
Township of Uxbridge	42 065	17 377	19 169
TOTAL	**252 056**	**506 850**	**561 186**

Provincial highways 2, 7, 7A, 12, 35, 47, 48, 115, 401 and 407 provide access across the study area. Well-maintained municipal and regional roads complement these provincial highways, providing a complete road network across the region. Rail service is provided by the Canadian Pacific (CP), Canadian National (CN), VIA Rail Canada and the Greater Toronto Transit Authority ("GO Transit"). Harbour and airport facilities are also located within the region.

SURFICIAL GEOLOGY AND PHYSIOGRAPHY

The Regional Municipality of Durham encompasses portions of 6 physiographic regions as defined by Chapman and Putnam (1984). From north to south, these include the Simcoe lowlands, Schomberg clay plains, Peterborough drumlin field, Oak Ridges moraine, South slope and the Lake Iroquois plain.

These physiographic regions and the distribution of unconsolidated sediments, including sand and gravel deposits, are the result of glacial activity that took place in the Late Wisconsinan substage of the Pleistocene Epoch. This period of glacial activity began approximately 23 000 years before present (Barnett 1992a).

During the Late Wisconsinan, the Laurentide Ice Sheet was composed of a series of glacial lobes that behaved semi-independently. The area covered by the Regional Municipality of Durham was affected by both the Simcoe lobe from the north and by the Lake Ontario lobe from the southeast. Glacial ice from the Simcoe lobe moved across the region in a southwesterly direction (Deane 1950; Gravenor 1957). The ice deposited large quantities of till across the region and in areas formed large streamlined, linear hills known as drumlins.

Drumlins in the map area are part of the Peterborough drumlin field. This drumlin field extends from the County of Simcoe in the west to the County of Hastings in the east (Chapman and Putnam 1984). The drumlins are composed of dense, stony, sandy silt to silty sand diamicton referred to as the Newmarket Till (Gwyn and DiLabio 1973). This till is regionally extensive and is present both north and south of the Oak Ridges moraine (Barnett 1992b, 1993, 1994). In low-lying areas, thin deposits of glaciolacustrine sand, silt and clay often overlie the Newmarket Till, leaving the till primarily exposed along the crests of the drumlins (Barnett 1996).

Flat-floored valleys, 1 to 4 km wide and up to 50 m deep, occur between the drumlins, beneath the Oak Ridges moraine and along the South slope. These valleys often have eskers and other glaciofluvial sand and gravel deposits associated with them and have been interpreted as tunnel valleys (Barnett 1997). The Newmarket Till appears to be absent in many of the tunnel valleys, but may be buried by infills of glaciolacustrine sand, silt and clay (Barnett 1997). Beneath the Oak Ridges moraine, the valleys are completely infilled by moraine sediments (Barnett et al. 1998). South of the moraine, the valleys are infilled by a thick sequence of interbedded layers of Halton Till, flow tills and fine-grained glaciolacustrine sediments, which comprise the majority of sediments on the South slope. Together the drumlins and valleys comprise a major erosional surface upon which younger sediments rest (Barnett et al. 1998). This erosional surface is believed to have formed as a result of large subglacial, catastrophic meltwater discharge events termed jökulhlaups (Barnett 1989, 1990).

The Oak Ridges moraine, reaching elevations in excess of 350 m, forms the dominant landform in the region. The moraine varies from 10 km wide north of Chalk Lake to approximately 1 km wide just south of Lake Scugog. It stretches across the Regional Municipality of Durham in an east-west direction, from the boundary of the Regional Municipalities of York and Durham continuing eastward into the former Victoria County (now part of City of Kawartha Lakes) and Northumberland County. The moraine formed where the Simcoe and Lake Ontario lobes separated during deglaciation, several kilometres north of the present-day Lake Ontario shoreline. As the ice lobes retreated, a re-entrant in the ice was created that acted as a focal point for meltwater flow and sediment deposition.

The moraine is built on a regional erosional surface consisting of the Newmarket Till and tunnel valleys as discussed above. This pre-moraine surface partially controlled the distribution and thickness of the sediments that form the moraine (Barnett et al. 1998). The depositional history of the Oak Ridges moraine is complex and is the result of the readvance and retreat of one or both ice margins bounding the moraine. Overall, deposition occurred in 4 stages: 1) subglacial sedimentation, 2) subaqueous fan sedimentation, 3) fan to delta sedimentation, and 4) ice-marginal sedimentation (Barnett et al. 1998). The moraine sediments represent proximal (high-energy) to distal (low-energy) environments ranging from subglacial to proglacial lake environments. As a result, the granular material that makes up the Oak Ridges moraine is extremely variable, both horizontally and vertically.

Although the Oak Ridges moraine is a major source of aggregate for the Greater Toronto Area (GTA), not all of it is favourable for aggregate extraction. Sediments associated with the later stages (3 and 4) of the Oak Ridges moraine development are often too fine to satisfy the specifications for many aggregate products. These late-stage deposits cap and/or flank the core of coarse-grained sediments. Such coarse-grained sediments were deposited in glaciofluvial environments at or near the ice front, and within or under the glacier, as well as in subaqueous fan environments. These coarse-grained deposits have the greatest potential for meeting high-specification aggregate products.

Unpredictability is a characteristic of aggregate deposits in the Oak Ridges moraine. Coarse-grained deposits may be interbedded with fine sandy glaciolacustrine deposits of limited aggregate value, and may also be buried by several metres of till. Coarse-grained deposits also tend to lack continuity, and textural properties may vary markedly over short distances or vertical intervals due to the multi-phase construction of the moraine (Barnett and Rowell 2002).

The South slope is the main physiographic landform south of the Oak Ridges moraine. It formed as the Lake Ontario lobe retreated southward from the Oak Ridges moraine and left a smooth sloping till plain that dips to the south. Low-lying drumlins and incised river valleys add relief to the South slope. Underlying ice-contact and outwash deposits are exposed in some river valleys or where the till cover is thin, and have been utilized as aggregate resources. However, these deposits are of limited extent and are buried by interbedded layers of Halton Till, flow tills and fine-grained glaciolacustrine sediments. The Halton Till tends to be thicker along the west side of the South slope and thins eastward. The till is strongly calcareous and is primarily a sandy-silt to silty-clay till (Karrow 1991; Karrow and Easton 2005; Barnett 1992a). The till deposits of the South slope are of little value as an aggregate material because of their silt and clay content. The South slope reaches an elevation of up to 150 m and covers the area from Pickering through Whitby, Oshawa and Clarington.

As the ice retreated from southern Ontario, large volumes of meltwater were dammed in front of the ice margin in the Lake Ontario basin. This resulted in elevated water levels and the formation of glacial Lake Iroquois. Meltwater from the glacial ice and runoff from deglaciated areas emptied into Lake Iroquois carrying large quantities of sand and gravel. Much of this sand and gravel was deposited as deltas and fans at the margin of Lake Iroquois and was later re-worked by wave action into bars, spits and beach deposits. These deposits became dissected as the water level in the Lake Ontario basin fell to the present level of Lake Ontario (Gravenor 1957). The beach, bar and spit deposits have been exploited as aggregate sources for many years around Whitby, Oshawa and Clarington and many deposits are now depleted. In addition, significant areas of aggregate around the City of Oshawa and the Town of Whitby have been sterilized by the rapid expansion and development of these communities.

Within Lake Iroquois, glaciolacustrine sand, silt and clay was deposited in low-lying areas and gave rise to the physiographic region known as the Iroquois plain (Chapman and Putnam 1984). These sediments are generally too fine for aggregate use.

Along the northern slope of the Oak Ridges moraine are a series of stratified silt and clay deposits, collectively called the Schomberg clay plains (Chapman and Putnam 1984). These deposits are the result of a multi-phase series of high-level lakes (Schomberg ponds) trapped between the Simcoe lobe to the north and the Oak Ridges moraine to the south. Some of these sediments were overridden by a readvance of the Simcoe lobe and were partially incorporated into the clay-rich Kettleby Till. A series of late Schomberg ponds developed as the Simcoe lobe made its final retreat from the area. Well-developed shoreline features associated with the Schomberg ponds have been mapped at elevations up to 320 m (asl). The Schomberg clay plain sediments are generally too fine to be of value as an aggregate resource.

As the Simcoe lobe continued to retreat northward, glacial Lake Algonquin formed in the Simcoe lowlands between the Peterborough drumlin field and the retreating ice margin. Extensive wave-cut platforms occur south and west of Lake Simcoe as a result of glacial Lake Algonquin. Sand and gravel beach ridges and spits commonly extend from the margin of wave-cut platforms and the base of shore bluffs (Barnett 1997). Such nearshore deposits are typically between 1.5 to 5 m thick and consist of well-sorted, coarse gravel. These deposits have been extracted extensively in the past and continue to supply minor amounts of aggregate in the northern part of the Regional Municipality of Durham. A glaciolacustrine plain, composed of silt and fine sand, developed offshore in glacial Lake Algonquin. These sediments are generally located in the lower lying areas around Lake Simcoe.

Gravenor (1957) proposed that much of the deglaciation of the northern part of the Regional Municipality of Durham was accomplished by ice stagnation and melting-in-place. Numerous deposits of ice-contact and outwash material are found throughout the northern part of the Regional Municipality of Durham. These are represented by eskers, subaqueous fans, ice-contact stratified drift deposits and outwash plains. The eskers and ice-contact deposits were deposited by meltwater within, beneath or adjacent to the melting ice. They consist primarily of stratified sand and gravel deposits. Some of the largest esker deposits include the Cannington and Sunderland eskers.

Postglacial erosional and depositional processes have been of relatively minor importance in modifying the physiography of the Regional Municipality of Durham. Some downcutting through sediments has occurred as well as the deposition of modern alluvium along some rivers. Extensive eolian deposits occurring as windblown dunes can be found on Scugog Island and between Lake Scugog and the Nonquon River valley.

PREVIOUS WORK

This area was inventoried previously for aggregate resources on a township scale. The earlier publications (ARIPs 6, 13, 40, 41, 94 and 95: Ontario Geological Survey 1980a, 1980b, 1981a, 1981b, 1984, 1986, respectively) may be of historical interest, but this report should be the principal source for the basic geological information required to include potential mineral aggregate resource areas in planning strategies.

SAND AND GRAVEL EXTRACTIVE ACTIVITY

There are currently 73 licenced sand and gravel operations (Table 2) and 1 licenced quarry (Table 5) in the Regional Municipality of Durham. The licence information was provided by the Ministry of Natural Resources in the fall of 2007. The Ministry of Northern Development, Mines and Forestry (MNDMF) would like to gratefully acknowledge the co-operation of MNR staff in providing this information. The total licenced area (pits and quarries) is approximately 3934.26 ha. Table B provides statistics on the aggregate production for the Regional Municipality of Durham for 2000 and 2006 (The Ontario Aggregate Resources Corporation 2001, 2007).

Table B – Extractive Activity, Regional Municipality of Durham

Municipality	2000 Production (tonnes)*	2006 Production (tonnes)**
Municipality of Clarington	4 350 267	5 030 295
Township of Brock	1 324 980	1 596 422
Township of Uxbridge	4 078 237	5 365 631
Township of Scugog	453 181	246 668
TOTAL	**10 206 665**	**12 239 016**

* The Ontario Aggregate Resources Corporation (2001); ** The Ontario Aggregate Resources Corporation (2007).

The majority of licenced operations in the region are located along the Oak Ridges moraine, which occurs primarily within the townships of Uxbridge and Scugog and the Municipality of Clarington. There are over 2000 ha of licenced property in the Township of Uxbridge, which represents over half of the region's total. The majority of these licences are located in the glaciofluvial deposits in the Uxbridge wedge of the Oak Ridges moraine, near the hamlet of Goodwood (Barnett et al. 1998).

The Oak Ridges moraine is the most important source of aggregate in the Regional Municipality of Durham and contributes almost 50% of the Greater Toronto Area's (GTA) total sand and gravel production (Planning Initiatives Ltd. 1993). The resources of the Oak Ridges moraine are considered to be essential to provincial, regional and municipal public infrastructure, construction and maintenance programs.

In 2001, the Ontario government enacted the *Oak Ridges Moraine Conservation Act* to provide land use and resource management direction for the approximately 190 000 ha of land and water within this geological feature. As a result, aggregate extraction and development opportunities have been reduced and/or constrained along the moraine.

The single quarry in the region is located south of Bowmanville in the Municipality of Clarington. The quarry produces stone that is used in the production of cement at an adjacent plant and also makes a substantial contribution to the region's aggregate production.

Aggregate Quality

Significant changes have occurred in the testing and specifications applied to aggregates since the original Aggregate Resource Inventory Papers were completed. The Los Angeles abrasion test (LS-603) is no longer used in the Ontario Provincial Standard Specifications (OPSS) and the magnesium sulphate soundness test (LS-606) has been reduced to an alternate test. Two new tests, the micro-Deval abrasion test (LS-618 and LS-619) and the unconfined freeze–thaw test (LS-614) have been introduced. The accelerated mortar bar expansion test (LS-620) has also become a standard test for the determination of potential alkali–silica reactivity in concrete aggregate.

Test data from MTO files have been used in the assessment of the resources of the region. The MTO files commonly contain test results for the Los Angeles abrasion test. These data are extensive and they are still useful in assessing the general quality of the material, so they have been included in the current assessment. A Los Angeles abrasion test loss of 35% or less generally indicates good physical quality in an aggregate.

Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating quality test data from individual samples to the entire deposit, particularly where the deposits are large. Where possible, a range of test results have been provided, which represents a number of sample locations distributed throughout the deposit over a long period of time.

SELECTED SAND AND GRAVEL RESOURCES AREAS

Map 1 shows all of the surficial deposits that contain sand and gravel in the Regional Municipality of Durham. The total area covered by these deposits is approximately 103 539 ha, with a possible aggregate resource of 9711 million tonnes (Table 1). **These figures represent a comprehensive inventory of all granular material in the Regional Municipality of Durham, although much of the material included in the estimate has no potential for use in aggregate products.** Many of the deposits that have not been selected for possible protection have limited value because of small deposit size, thickness and/or quality. Only the most significant deposits are suggested for possible resource protection.

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 consists of 2 esker segments situated approximately 1.5 km north and west of Cannington. The esker segments consist of a single ridge 3 to 8 m high that continues eastward into the former Victoria County (now part of City of Kawartha Lakes) where there is currently a licenced operation.

The esker consists of massive, poorly sorted sand with minor gravel, which in places is too "dirty" for many aggregate uses without processing, blending and sand control. It is mainly suited to the production of crushed granular base course aggregate (Granular A and B), Selected Subbase Material (SSM) and fill. MTO test results indicate an average gravel content of 30 to 45%, with a gravel content of 64.1% having been reported for 1 test sample. Petrographic Number (PN) values range from 104.5 to 122.6 for granular and 16 mm crushed and from 108.1 to 136.7 for hot mix and concrete. Magnesium sulphate test results for coarse aggregate vary from 3.2 to 10.7 and 9.4 to 16.4 for fine aggregate. Los Angeles abrasion results range from 23.7 to 25.2.

Selected Sand and Gravel Resource Area 1 covers a total of 341 ha. Cultural, physical and environmental constraints, and previously extracted areas reduce the possible resource area to 311 ha. Assuming an average deposit thickness of 5 m, possible aggregate resources are estimated to be 27.5 million tonnes (Table 3).

Selected Sand and Gravel Resource Area 2

The Sunderland esker has been designated as Selected Sand and Gravel Resource Area 2. The esker trends southwest from the former Victoria County (now part of the City of Kawartha Lakes), through the community of Blackwater to the southwestern boundary of the Township of Brock and southwesterly into the Township of Scugog. The esker continues eastward into the former Victoria County where there is a licenced operation. Several individual esker segments make up Selected Sand and Gravel Resource Area 2. North of Blackwater, the main esker ridge is sharply defined, whereas the southern end of the esker broadens out and is flanked by sand.

The Sunderland esker has long been a traditional source of aggregate and is now depleted in several areas. Licenced pits in the deposit have extracted material from below the water table, predominantly along the core of the esker. The east face of licenced Pit No. 7 exposes poorly sorted, massive sand and gravel consisting of approximately 50% gravel. An average of 30% of this gravel exceeds 2.5 cm in diameter and less than 10% is greater than

10 cm in diameter. Pit data from the MTO indicate that aggregate in Selected Sand and Gravel Resource Area 2 is suitable for most crushed granular base course products and SSM (Deike 1977). Some areas of the esker have produced HL(CA) and HL(FA) material. The presence of shaly limestone fragments may limit the use of the stone for high-quality crushable products; however, MTO records also indicate that some of the material can meet fine and coarse aggregate specifications for use in concrete.

Test results from the MTO indicate a coarse aggregate content that ranges from 37.2 to 78%. Petrographic Number values range from 117.4 to 186.6 for granular and 16 mm crushed and from 122.8 to 198.8 for hot mix and concrete. Los Angeles abrasion test results vary from 15.8 to 25.7. Magnesium sulphate soundness test results range from 9.2 to 14.1 for fine aggregate and 2.7 to 19.5 for coarse aggregate.

Extractive activities continue in the middle section of the deposit (Pit Nos. 6 to 10) and there are both licenced and unlicenced pits in the northernmost segments (Pit Nos. 5, 12,13,14,16 and 17). Sample DR-SS-2, collected from the northern part of the deposit, was found to contain more than 50% gravel with coarse and medium sand and less than 2% oversize material (Figures 2A and 2B). Petrographic Numbers for this sample were 119 for granular and 16 mm crushed and 138 for hot mix and concrete (Table 9).

Selected Sand and Gravel Resource Area 2 covers an area of 1552 ha exclusive of licenced areas. Cultural, physical and environmental constraints, as well as some previous extractive activity, reduces the possible resource extraction area to 1475 ha. Assuming a conservative average deposit thickness of 9 m possible aggregate resources are estimated to be 235 million tonnes (*see* Table 3).

Selected Sand and Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 extends eastward from approximately the hamlet of Goodwood to the eastern boundary of the Township of Uxbridge and into the southwestern part of the Township of Scugog. This deposit constitutes the largest and best quality sand and gravel deposit in the area. The resource area has long been a traditional source of aggregate and remains a regionally important source of road building and construction materials, particularly for the eastern Greater Toronto Area market. Selected Sand and Gravel Resource Area 3 is a combination of depositional environments, including outwash, ice-contact, glaciolacustrine and eolian. Consequently, aggregate material will vary greatly over the selected area.

At the time of writing, there were 29 licenced pits, mainly large commercial operations, in Selected Sand and Gravel Resource Area 3. Working pit faces generally range in height from 3 to 15 m, and expose stratified fine to coarse sand to fine and medium gravel. Coarse aggregate content is highly variable ranging from 15 to 60% (*see* Table 2).

Sample DR-SS-8, from the eastern edge of the selected resource area, indicates a coarse aggregate content of 35% with a low percentage of fines (Figures 5A and 5B). This seems to be consistent with other selected sample results (DR-SS-3, DR-SS-4, DR-SS-5, DR-SS-6 and DR-SS-7). Gradation results are presented in Figures 3A to 5B. A sample from just east of licenced Pit No. 49 indicates a gravel content in excess of 50%.

Petrographic Number values vary and range from 112 for granular and 16 mm crushed to 158 for hot mix and concrete (*see* Table 9). Selected Sand and Gravel Resource Area 3 contains aggregate of high quality, although there may be quality limitations imposed by a small percentage of soft shale fragments. These can be removed by leaving the aggregate in shallow stockpiles until the soft particles are broken down by natural weathering followed by mechanical processing. Los Angeles abrasion test results from the MTO indicate values ranging from 23.0 to 29.4. Magnesium sulphate soundness test results vary from 2.0 to 5.1 for coarse aggregate and 7.8 to 15.0 for fine aggregate.

In general, the selected area contains aggregate suitable for a wide range of road building and construction products given suitable processing and quality control. These products include Granular A, Granular B and SSM. Blending is required for hot mix and concrete sand. Other locations in Selected Sand and Gravel Resource Area 3 may also be capable of supplying limited quantities of stone (coarse aggregate) for higher quality HL use.

A considerable and increasing amount of Selected Sand and Gravel Resource Area 3 is now sterilized by residential development (especially around Goodwood) and additional areas have been depleted by previous extractive activity. Selected Sand and Gravel Resource Area 3 occupies a total of 3918 ha exclusive of currently licenced areas. After allowing for cultural, physical and environmental setbacks, the possible resource area is reduced to 2861 ha (*see* Table 3). Selected Sand and Gravel Resource Area 3 lies within the Oak Ridges Moraine Conservation Area and, therefore, is subject to land use planning restrictions and constraints.

The average thickness of usable granular material in Selected Sand and Gravel Resource Area 3 is estimated to be 12 m based on a conservative average of pit face heights and selected water-well data. Possible aggregate resources are estimated to be 607.6 million tonnes (*see* Table 3). Water-well data and recent drill results indicate that additional coarse granular material may be interlayered with sand at greater depths. Some of this material may lie below the water table.

Selected Sand and Gravel Resource Area 4

Selected Sand and Gravel Resource Area 4 consists of an area of the Oak Ridges moraine located along the northern boundary of the Municipality of Clarington. The ice-contact and outwash deposit is characterized by variability in percentage crushable and oversized material. Gravel content may vary from less than 10% to more than 50% over quite short distances both laterally and vertically. Therefore, extensive site investigation may be required prior to aggregate resource development and extraction. Selected Sand and Gravel Resource Area 4 represents the Pontypool wedge of the Oak Ridges moraine (Barnett et al. 1998).

Face heights in working pits vary from 3 m to more than 30 m. At Pit No. 82, glaciofluvial material is being worked to a depth of more than 30 m. Two samples from this licenced pit, DR-SS-9 and DR-SS-10, indicate up to 53% coarse aggregate with a low percentage of fines (Figures 6A and 6B). Petrographic Number values on the same samples range from 105 for granular and 16 mm crushed to 110 for hot mix and concrete (*see* Table 9). In other areas of the same pit, there are 20 m of interbedded fine sand and silt. A wide variety of road building and construction aggregate products can be produced from the material in Selected Sand and Gravel Resource Area 4 with proper blending, sand control and beneficiation.

Test results from the MTO for this selected area indicate PN values that range from 101.6 to 116.5 for granular and 16 mm crushed and 107.0 to 122.8 for hot mix and concrete. Los Angeles abrasion test values vary from 22.8 to 25.4. Magnesium sulphate soundness test results have been reported from 5.3 to 15.7 for fine aggregate and 2.8 to 8.5 for coarse aggregate.

In this selected area, the total unlicenced area of 2283 ha has been reduced to 1931 ha by cultural, physical and environmental constraints and previous extraction. Assuming a conservative deposit thickness of 11 m, estimated possible resources in Selected Sand and Gravel Resource Area 4 are 375.9 million tonnes. Selected Sand and Gravel Resource Area 4 lies within the Oak Ridges Moraine Conservation Area and, therefore, is subject to land use planning restrictions and constraints.

Resource Areas of Secondary Significance

A number of areas within the Regional Municipality of Durham have been selected as resource areas of secondary significance. Areas of secondary significance do not have the best aggregate, specifically a blend of crushable gravel and sand-sized material; however, they may contain large quantities of material. In some cases, resource areas of secondary significance are classed as secondary due to the lack of reliable geological data. This lack of data may not allow an accurate assessment of either the quality or quantity of sand and gravel within a deposit. Resource areas of secondary significance serve as important alternative extraction sites and should be considered as part of a region's total aggregate supply. Secondary aggregate resources can also be used for wayside pit operations, which are generally related to specific, time-restricted projects. The secondary deposits are not labelled individually on the accompanying maps and only selected descriptions are provided herein. Many of the secondary deposits, particularly along the moraine have been selected because of the large volume of aggregate material they contain.

TOWNSHIP OF BROCK

Several thin beach deposits are found along the glacial Lake Algonquin shore bluff, which trends parallel to, and several kilometres inland from, the present Lake Simcoe shoreline. Small quantities of crushable gravel may be available in these beach ridges. One such deposit, located just southeast of Beaverton, has been selected at the secondary significance level. Licenced Pit No. 1 has been developed in this deposit. Pit faces expose well-sorted sand and fine gravel suitable for base course aggregate.

There is a small ice-contact deposit along the eastern boundary of Township of Brock that has also been selected as a resource of secondary importance. This deposit extends eastward into the former Victoria County (now part of City of Kawartha Lakes) where there is an abandoned pit.

An ice-contact deposit, northeast of Wilfrid, has been extensively extracted in the past. There are currently 3 licenced pits (Pit Nos. 2, 3 and 4) operating in this deposit. Pit faces expose 3 to 8 m of stratified fine to coarse sand, silty fine sand and some fine gravel. The gravel often occurs in pockets or seams. The deposit has little crushable material and production of granular material is limited by the presence of excess fines. These pits are mainly suited to supplying subbase material and fill for local use (Deike 1977; Ontario Geological Survey 1980a; Gwyn 1976). During the course of this investigation, a sample, DR-SS-1, was collected and tested. Test results for this sample indicates 27% coarse material, 68% sand and 5% fines (*see* Figures 2A and 2B).

TOWNSHIPS OF UXBRIDGE AND SCUGOG

Separate areas to the north, west and south of the Oak Ridges moraine, which lie outside Selected Sand and Gravel Resource Area 3, have been selected as a resource area of secondary significance. The deposits cover a large area and have characteristic rolling to hummocky topography. Water-well data indicate that the uppermost portions of the deposits are predominantly sand, but there may be considerable amounts of crushable gravel at depth. Detailed field investigation, including drilling, is required to identify areas suited for extractive development. The aggregate contained in these secondary resource areas contains a higher percentage of sand than that described for Selected Sand and Gravel Resource Area 3. Representative pit face heights range from 6 to 15 m. Some of the material is suitable for producing crushed products including road-surfacing aggregate. The deposits continue westward into the Regional Municipality of York and have been selected as a secondary resource area in that municipality.

An area of buried aggregate, shown on Map 1 by hatching, along the southern boundary of the Oak Ridges moraine in Township of Uxbridge has been selected as a resource area of secondary significance. This area is an eastward extension of a buried deposit identified in the Regional Municipality of York. Water-well and drill-hole data indicate an overburden cover as little as 1 m along the eastern boundary of York Region. Barnett et al. (1998)

speculate that the aggregate material on the west side of the boundary with the Regional Municipality of York should be coarser since it represents the proximal end of a subaqueous fan deposit (the buried Bloomington fan).

An extensive area of the Oak Ridges moraine lying east of Selected Sand and Gravel Resource Area 3 in Township of Scugog has been selected at the secondary level of significance. Detailed subsurface investigation is required to confirm the location of pockets of crushable gravel and determine the aggregate potential of individual areas. The near-surface materials found in the moraine are undifferentiated silts, sands and gravels generally associated with an ice-contact environment (Duckworth 1975). Poor sorting, slumping and discontinuous stratification are common ice-contact features seen throughout the moraine. Water-well data indicate that the uppermost sediments of the moraine may overlie deposits of crushable gravel at varying depths. Currently, there are several licenced and unlicenced pits in this section of the moraine, although selective extraction procedures are widely employed to avoid interbedded layers of silt and till (Ontario Geological Survey 1986). These 3 areas of secondary significance in the townships of Uxbridge and Scugog described above lie within the Oak Ridges Moraine Conservation Area and, therefore, are subject to land use planning restrictions and constraints.

One glaciolacustrine beach and 2 small ice-contact deposits, located between Marsh Hill and Epsom, have been selected at the secondary level. One licenced property (Pit No. 54) has been developed in the beach deposit. The 6 to 8 m working face exposes cross-bedded, stratified coarse sand and 15 to 35% medium gravel. Up to 65% gravel has been recorded. The aggregate is acceptable for most products including asphaltic aggregate, subject to processing. Oversize material must be removed or crushed and blending is necessary for sand which grades too fine and dirty for hot mix products. There are no pits currently operating within the 2 small ice-contact deposits. The resource area has been identified primarily on the basis of topography and water-well data. Water-well data indicate 1 to 3 m of sand over 4 to 12 m of gravelly sand to sandy gravel with some clay interbeds. MTO test results for these deposits indicate a content of 67.0% gravel, 32.1% sand and 0.9% fines. The PN values range from 113.5 for granular and 16 mm crushed to 120.5 for hot mix and concrete. Magnesium sulphate soundness test result for coarse aggregate was 3.0; Los Angeles abrasion test result was 25.8; and micro-Deval abrasion text result for fine aggregate was 12.1% (Deike 1978; Ontario Geological Survey 1980b).

CITIES OF OSHAWA AND PICKERING, TOWNS OF WHITBY AND AJAX

A number of small glaciolacustrine beach deposits, representing the former shoreline of glacial Lake Iroquois, have been selected at the secondary significance level. These beach deposits have provided significant aggregate material in the past as the deposits were located close to high-demand areas (Pickering, Ajax, Whitby and Oshawa). Currently, there is only 1 licenced pit (Pit No. 73) located within these deposits.

These beach deposits are generally thin and the granular material is sometimes quite variable. Water-well data have indicated that, in some areas, there is 6.7 m of sand, whereas, in other areas of these deposits, there may be up to 9.8 m of sand and gravel. The deposits generally consist of well-stratified coarse sand and gravel. The sand may require blending and excess fines may have to be removed. Crushable material may occur only in localized pockets or may be layered or interbedded with sand. Material from these deposits has been used for the production of Granular A, Granular B, SSM and fill. The deposits are often flanked by glaciolacustrine fine sand and silt, which have little potential to supply aggregate material.

Test results from the MTO for these beach deposits indicate a coarse aggregate content from 20.2 to 62.1%. Sand varies from 36.6 to 84.1%. The PN values range from 109.0 to 127.5 for granular and 16 mm crushed and from 112.0 to 144.5 for hot mix and concrete. Magnesium sulphate soundness test results range from 3.0 to 10.0 for coarse aggregate and 4.5 to 11 for fine aggregate. Los Angeles abrasion test results vary from 22.3 to 24.5 (Ontario Geological Survey 1981a, 1981b).

Many of these smaller granular deposits have been sterilized by the growth of the major urban centres. As a result, only the segments that appear to be outside the current urban boundaries have been shown as resource areas of secondary significance.

MUNICIPALITY OF CLARINGTON

A considerable area of the Oak Ridges moraine, surrounding Selected Sand and Gravel Resource Area 4, in the northern part of the Municipality of Clarington has been selected as a sand and gravel resource area of secondary significance. The resources in this part of the moraine are relatively unexploited. There are, however, several licenced pits with faces exposing up to 24 m of generally sandy aggregate suitable for use as Granular B as well as SSM. The sand fraction of the aggregate from pits in this deposit requires blending for concrete sand use and a small number of the pits contain pockets of crushable material. A sample taken from Pit No. 95 revealed 14% gravel. This selected area continues eastward into Northumberland County and northward into the former Victoria County (now part of City of Kawartha Lakes). This area is also subject to the land use planning restrictions and constraints as outlined in the *Oak Ridges Moraine Conservation Act.*

Similar to the secondary beach deposits within the cities of Oshawa and Pickering, and the towns of Whitby and Ajax, the glacial Lake Iroquois beach deposits continue eastward into the Municipality of Clarington. The physical characteristics and the aggregate potential of the deposits are similar to what is described above (Ontario Geological Survey 1984). Because the urban development has not been as extensive in the Municipality of Clarington, there are larger areas of these deposits left for extractive development.

BEDROCK GEOLOGY

Map 2 shows the Paleozoic geology of the Regional Municipality of Durham. The Regional Municipality of Durham is underlain by rocks of Ordovician age, deposited over 450 million years ago. The bedrock consists of 4 units, the oldest of which is the Bobcaygeon Formation, overlain in succession by the Verulam, Lindsay and Blue Mountain formations. This succession of rocks dip gently towards the southwest.

The Verulam Formation underlies the extreme northern part of the Regional Municipality of Durham, south of the Talbot River and north of Beaverton, where it subcrops under thin drift. The formation is subdivided into a lower member consisting of over 50 m of thin- to medium-bedded, limestone and interbedded shales, and an upper member, 3 to 8 m thick, of more resistant, fossiliferous limestone. The Verulam Formation is quarried at Gamebridge, just north of the Regional Municipality of Durham. Agricultural lime, as well as Granular A and B have been produced from the Verulam elsewhere, but its shale content presents quality limitations for use of the formation as aggregate. The material tends to be relatively soft, subject to rapid weathering and to have poor freeze–thaw resistance.

The Lindsay Formation is over 65 m thick and underlies most of the study area. It subcrops near Beaverton beneath 3 to 8 m of drift. Drift thickness over this formation reaches more than 30 m near the Township of Scugog boundary. The lower member of the formation is over 55 m thick and consists of grey, fine- to coarse-grained, argillaceous, nodular limestone with thin shale interbeds. The Collingwood Member (upper member) consists of up to 10 m of black calcareous shale and organic-rich limestone with shaly partings (Russell and Telford 1983).

St. Marys Cement Inc. operates a 241.91 ha licenced quarry southwest of Bowmanville that produces cement from the Lindsay Formation (Derry, Michener, Booth and Wahl and the Ontario Geological Survey 1989). The quarry exposes a total of 50.3 m of the Lindsay Formation. The uppermost lift reveals 4.3 m of the Collingwood Member (upper member). The remaining 46.0 m of the quarry face exposes the lower member.

The blue-grey shales of the Blue Mountain Formation crop out only rarely in the western part of central Ontario. The Blue Mountain Formation and Collingwood Member of the Lindsay Formation were previously grouped by Liberty (1969) into the Whitby Formation. Russell and Telford (1983) reassigned Liberty's lower member of the Whitby Formation, the Collingwood Member, to the upper member of the Lindsay Formation. They also reassigned the remaining middle and upper members of the Whitby Formation to the Blue Mountain Formation. The Blue Mountain Formation is not suitable for aggregate or construction use.

SUMMARY

Four areas of sand and gravel have been chosen as selected aggregate resource areas of primary significance in the Regional Municipality of Durham. These selected resource areas have a total unlicensed area of 8094 ha, with 6578 ha remaining after considering previously extracted areas, and cultural, physical and environmental constraints. Possible aggregate resources are estimated at 1246.1 million tonnes. The Oak Ridges moraine represents the largest and most important aggregate resource area in the region, although esker deposits located in the Township of Brock are also significant. There are a number of secondary level sand and gravel deposits that add valuable aggregate resource to the region's total.

The report area is underlain by limestone, dolostone and shale of the Upper Ordovician Bobcaygeon, Verulam, Lindsay and Blue Mountain formations. The bedrock in the report area is generally overlain by a thick cover of Quaternary sediments and some of the formations noted are not suitable for aggregate production. For these reasons, no bedrock resources have been selected for resource protection.

Enquiries regarding the Aggregate Resources Inventory of the Regional Municipality of Durham may be directed to the Sedimentary Geoscience Section, Ontario Geological Survey, Mines and Minerals Division, Ministry of Northern Development, Mines and Forestry, 933 Ramsey Lake Road, Sudbury, Ontario P3E 6B5 [Tel: (705) 670-5758].

Table 1 - Total Sand and Gravel Resources Regional Municipality of Durham			
1 **Class Number**	**2** **Deposit Type**	**3** **Areal Extent** **(Hectares)**	**4** **Original Tonnage** **(Million Tonnes)**
Township of Brock			
1	G-IC	2029.4	215.5
2	G-IC	1241.6	98.9
3	G-IC	276.3	9.8
	G-LB	788.7	27.9
	S-AL	546.3	19.3
	S-LP	6604.5	233.8
	S-IC	70.2	2.5
	S-WD	27.1	1.0
Subtotal		**11584.2**	**608.7**
Townships of Uxbridge and Scugog			
1	G-IC	5312.9	564.2
	G-LD	1068.0	113.4
	G-OW	3953.6	419.9
	S-AL	2706.8	287.5
	S-LP	14186.3	1506.6
	S-IC	1358.1	144.2
	S-LD	969.8	103.0
	S-WD	480.3	51.0
2	G-IC	1342.8	107.0
	G-LB	325.0	25.9
	G-LD	66.2	5.3
	G-OW	14.0	1.1
	S-AL	2492.0	198.5
	S-LP	5660.2	450.8
	S-LD	493.8	39.3
	S-WD	711.1	56.6
3	G-IC	215.5	7.6
	G-LB	196.9	7.0
	G-OW	2.2	0.1
	S-AL	149.5	5.3
	S-LP	275.1	9.7
	S-LD	49.9	1.8
	S-WD	39.2	1.4
4	G-IC	0.1	0.0
	G-LB	3.3	0.1
	S-AL	10.6	0.2
	S-LP	26.3	0.5
	S-LD	2.8	0.0
	S-WD	23.9	0.4
Subtotal		**42136.1**	**4108.4**

Table 1 - Total Sand and Gravel Resources
Regional Municipality of Durham

1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
Cities of Oshawa and Pickering, Towns of Whitby and Ajax			
1	G-IC	7076.9	751.6
	S-AL	2145.1	227.8
	S-LP	7410.6	787.0
2	G-IC	88.3	7.0
	G-LB	1458.3	116.2
	S-AL	817.6	65.1
	S-LP	1437.9	114.5
3	G-LB	134.1	4.7
	S-AL	24.0	0.8
	S-LP	36.5	1.3
Subtotal		**20629.3**	**2076.1**
Municipality of Clarington			
1	G-IC	2413.2	256.3
	G-OW	2731.4	290.1
	S-AL	4106.3	436.1
	S-LP	15231.7	1617.6
2	G-IC	15.5	1.2
	G-LB	2110.4	168.1
	S-AL	655.3	52.2
	S-LP	640.0	51.0
3	G-IC	6.0	0.2
	G-LB	648.6	23.0
	S-AL	297.9	10.5
	S-LP	284.1	10.1
	S-WD	49.1	1.7
Subtotal		**29189.5**	**2918.1**
TOTAL		**103539.0**	**9711.2**

Minor variations in all tables are caused by the rounding of data.

* The above figures represent a comprehensive inventory of all granular materials in the map area. Some of the material included in the estimate has no aggregate potential and some is unavailable for extraction due to land use restrictions.

Explanation of Deposit Type

First letter denotes gravel content:

G = >35% gravel; S = generally "sandy", gravel-size (>4.75 mm) aggregate <35% gravel

Letters after hyphen denote the geologic deposit type (see also Appendix C):

AL = alluvium; IC = ice-contact stratified drift; LB = glaciolacustrine beach deposit; LD = glaciolacustrine delta; LP = glaciolacustrine plain; OW = outwash; WD = windblown deposit

Table 2 - Sand and Gravel Pits
Regional Municipality of Durham

Pit No.	Owner/Operator	Licenced Area (Hect-ares)	Face Height (Metres)	% Gravel	Remarks
Township of Brock					
Licenced					
1	Marion Speedie	66.37	2 - 4	Variable	Glaciolacustrine beach deposit
2	Edward C. Lamb	15.70	Variable	10 - 20	Ice-contact deposit
3	M. Lloyd & Sons Limited	5.40	2 - 5	Variable	Ice-contact deposit
4	M. Lloyd & Sons Limited	6.45	2 - 5	Variable	Ice-contact deposit
5	St. Marys Cement Inc. (Canada)	37.60	2 - 6	Variable	Ice-contact deposit (Sunderland Esker)
6	Vicdom Sand and Gravel (Ontario) Ltd.	61.00	Variable	Variable	Ice-contact deposit (Sunderland Esker)
7	Brock Aggregates Inc.	238.17	7 - 13	Variable	Ice-contact deposit (Sunderland Esker)
8	St. Marys Cement Inc. (Canada)	203.00	7 - 13	Variable	Ice-contact deposit (Sunderland Esker)
9	St. Marys Cement Inc. (Canada)	100.00	7 - 13	Variable	Ice-contact deposit (Sunderland Esker)
10	St. Marys Cement Inc. (Canada)	40.34	-	Variable	Ice-contact deposit (Sunderland Esker)
Unlicenced					
11	-	-	2 - 3	30 - 40	Old, badly overgrown pit. Another pit on the east side of the road is now used for agricultural purposes (rehabilitated)
12	-	-	2 - 3	25 - 35	Ice-contact deposit (Sunderland Esker). Licenced pit to the east has now been rehabilitated
13	-	-	2 - 3	25 - 35	Old, badly overgrown pit
14	-	-	3 - 5	-	Old, badly overgrown pit located just north of Hwy 7
15	-	-	3 - 4	30 - 45	Small ice contact deposit
16	-	-	1 - 2	25 - 40	Small pit located along the north side of the road. Pit has been developed in the Sunderland Esker
17	-	-	3 - 7	20 - 35	Pit is located on the south side of the road. Pit is also located in the Sunderland Esker
Townships of Uxbridge and Scugog					
Licenced					
18	Cedarhurst Quarries & Crushing Limited	13.46	-	Variable	
19	LaRue, Linda	6.47	-	Variable	
20	Chefero, Fred	20.00	3 - 4	20	
21	Lafarge Canada Inc.	155.00	10 - 14	Variable	
22	1302824 Ontario Limited	28.30	-	Variable	
23	1159644 Ontario Limited	81.40	10 - 14	Variable	
24	Lafarge Canada Inc.	57.00	-	Variable	
25	614002 Ontario Limited	24.30	10 - 14	Variable	
26	1713238 Ontario Limited	28.50	-	<10	
27	2083293 Ontario Ltd.	66.90	10 - 14	Variable	
28	Lafarge Canada Inc.	40.50	-	Variable	
29	Lafarge Canada Inc.	40.50	8 - 12	Variable	
30	Cedarhurst Quarries & Crushing Limited	34.00	-	Variable	
31	Lafarge Canada Inc.	35.00	-	Variable	
32	Lafarge Canada Inc.	125.00	8 - 12	Variable	
33	Lok Home Holdings Inc.	24.20	-	Variable	
34	Cedarhurst Quarries & Crushing Limited	27.10	10	Variable	
35	Pedersen Aggregates Limited	23.90	10 - 12	Variable	
36	Lafarge Canada Inc.	82.00	9 - 11	Variable	

Table 2 - Sand and Gravel Pits
Regional Municipality of Durham

Pit No.	Owner/Operator	Licenced Area (Hect-ares)	Face Height (Metres)	% Gravel	Remarks
37	Miller Paving Limited	49.00	7 - 9	20 - 30	
38	1209646 Ontario Limited	13.00	4 - 5	Variable	
39	Lafarge Canada Inc.	72.00	-	Variable	
40	Lafarge Canada Inc.	40.50	-	Variable	
41	Abbruzi Transport Limited	16.00	6	Variable	
42	Vicdom Sand and Gravel (Ontario) Limited	117.00	10 - 12	30 - 40	
43	978970 Ontario Inc.	63.17	-	Variable	
44	Giordano Sand and Gravel Property Limited	65.30	7 - 11	Variable	
45	Lafarge Canada Inc.	186.00	-	Variable	
46	The Corporation of the Township of Uxbridge	18.23	-	Variable	
47	Miller Paving Limited	202.00	7 - 9	Variable	
48	Miller Paving Limited	51.00	-	Variable	
49	Lafarge Canada Inc.	39.00	3 - 5	Variable	
50	The Corporation of the Town of Whitby	48.50	-	Variable	
51	Vicdom Sand & Gravel (Ontario) Limited	21.87	6 - 10	30 - 50	
52	VanCamp Contracting Limited	16.20	6 - 8	15 - 35	
53	Mason, Donald	4.05	-	Variable	
54	1198257 Ontario Limited	32.36	5 - 7	35 - 45	
55	The Warren Paving & Materials Group Limited	23.00	-	Variable	
56	K.J. Beamish Construction Co. Limited	7.95	3 - 5	<20	
57	Holtby, Margaret Jean	36.73	5 - 7	<10	
58	The Warren Paving & Materials Group Limited	75.53	-	Variable	
59	Chow, James T.	102.63	-	Variable	
60	VanCamp Contracting Limited	9.90	3 - 7	<20	
61	Martyn, James	30.30	-	Variable	
Unlicenced					
62	-	-	3 - 7	Variable	Old, badly overgrown pit located in a small ice-contact deposit
63	-	-	1 - 2	Variable	Old, badly overgrown pit located in an ice-contact deposit. Pit looks like there has been some rehab work completed
64	-	-	-	Variable	Pit is located in an outwash deposit
65	-	-	-	Variable	Pit is located just north of Goodwood. Looks like there has been an attempt to rehabilitate pit, but it is still noticeable
66	-	-	1 - 2	Variable	Pit is located just west of licenced Pit No. 36
67	-	-	3 - 4	Variable	Old, badly overgrown pit located in a delta deposit
68	-	-	2 - 4	Variable	Old, badly overgrown pit located west of Conc Rd 8. There is also a small pit on the west side of the Rd, closer to Reg. Rd 23
69	-	-	-	Variable	Small, badly overgrown pit located on the west side of Reg. Rd 23 in an outwash deposit
70	-	-	2	Variable	Old small pit located in a farm field. Deposit has been developed in a small beach deposit
71	-	-	1 - 2	Variable	Small, overgrown pit located in an ice-contact deposit
72	-	-	1 - 3	Variable	Small pit located just east of Hwy 12. Pit is located in a small beach deposit

Table 2 - Sand and Gravel Pits
Regional Municipality of Durham

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Cities of Oshawa and Pickering, Towns of Whitby and Ajax					
Licenced					
73	Brock Aggregates Inc.	19.89	-	Variable	
74	Hard-Co Construction Ltd.	21.36	-	Variable	
Unlicenced					
Municipality of Clarington					
Licenced					
75	Ambrose, Harvey	59.50	-	Variable	
76	1463295 Ontario Inc.	140.54	3 - 8	<20	
77	VanCamp Contracting Limited	22.83	-	Variable	
78	715636 Ontario Ltd.	20.25	-	Variable	
79	1559300 Ontario Limited	21.06	-	Variable	
80	Keystone Sand and Gravel Inc.	11.06	3 - 5	30 - 40	
81	St. Lawrence Cement Inc.	24.48	-	Variable	
82	St. Lawrence Cement Inc.	83.34	-	Variable	
83	St. Lawrence Cement Inc.	86.79	7 - 10	Variable	
84	Lafarge Canada Inc.	28.45	-	Variable	
85	C.D.R. Young's Aggregates Inc.	30.83	-	Variable	
86	Reid, Elva Eleanor Ann	10.59	-	Variable	
87	The Warren Paving & Materials Group Limited	6.71	-	Variable	
88	Coombes, G.A.	7.96	-	Variable	
89	761368 Ontario Inc.	1.83	-	Variable	
90	St. Marys Cement Inc. (Canada)	41.63	-	Variable	
91	Ron Robinson Jr.	24.48	-	Variable	
Unlicenced					
92	-	-	-	Variable	Old abandoned pit in ice-contact deposit
93	-	-	2	Variable	Small, badly overgrown pit located near Mosport
94	-	-	-	Variable	Old pit area now has rural residential home
95	-	-	-	Variable	Old pit located near Hwy 35-115
96	-	-	2-3	Variable	Old, badly overgrown pit with reasonably mature trees
97	-	-	1 - 3	Variable	Old, badly overgrown pit
98	-	-	2 - 3	Variable	Old, badly overgrown pit located along the west side of road in a glaciolacustrine beach deposit
99	-	-	2 - 3	Variable	Old, badly overgrown pit located along the east side of road in a glaciolacustrine beach deposit

Table 3 - Selected Sand and Gravel Resource Areas
Regional Municipality of Durham

1 Deposit No.	2 Unlicenced Area* (Hectares)	3 Cultural Setbacks** (Hectares)	4 Extracted Area*** (Hectares)	5 Possible Resource Area**** (Hectares)	6 Estimated Deposit Thickness (Metres)	7 Possible Aggregate Resources (Million Tonnes)
Township of Brock						
1	341.2	24	6.0	311.2	5	27.5
2	1349.3	44	26.0	1279.3	9	203.8
Subtotal	**1690.5**	**68.0**	**32.0**	**1590.5**		**231.3**
Townships of Uxbridge and Scugog						
2	202.9	4.0	3.0	195.9	9	31.2
3	3917.8	942.0	115.0	2860.8	12	607.6
Subtotal	**4120.7**	**946.0**	**118.0**	**3056.7**		**638.8**
Cities of Oshawa and Pickering, Towns of Whitby and Ajax						
Subtotal	**0.0**	**0.0**	**0.0**	**0.0**		**0.0**
Municipality of Clarington						
4	2282.6	320.0	32.0	1930.6	11	375.9
Subtotal	**2282.6**	**320.0**	**32.0**	**1930.6**		**375.9**
TOTAL	**8093.8**	**1334.0**	**182.0**	**6577.8**		**1246.1**

Minor variations in the tables are caused by the rounding of the data.

* Excludes areas licenced under the *Aggregate Resources Act*.

** Cultural setbacks include heavily populated urban areas, roads (including a 100 m wide strip centred on each road), water features (e.g., lakes, streams), 1 ha for individual houses. NOTE: This provides a preliminary and generalized constraint application only. Additional environmental and social constraints will further reduce the deposit area.

*** Extracted area is a rough estimate of areas that are not licenced, but, due to previous extractive activity, are largely depleted.

**** Further environmental, resource, social and economic constraints will greatly reduce the selected resource quantity realistically available for potential extraction.

Table 4 - Total Identified Bedrock Resources
Regional Municipality of Durham

1 **Drift Thickness (Metres)**	2 **Formation**	3 **Estimated Deposit Thickness (Metres)**	4 **Areal Extent (Hectares)**	5 **Original Tonnage (Million Tonnes)**
Township of Brock				
8 to 15	Bobcaygeon	18	140.8	67.1
0 to 1	Verulam	18	791.1	377.2
1 to 8	Verulam	18	2574.8	1227.7
8 to 15	Verulam	18	2825.0	1347.0
0 to 1	Lindsay	18	852.2	406.3
1 to 8	Lindsay	18	3908.1	1863.5
8 to 15	Lindsay	18	7536.8	3593.7
Subtotal			**18628.8**	**8882.6**
Cities of Oshawa and Pickering, Towns of Whitby and Ajax				
0 to 1	Blue Mountain	18	0.2	0.1
1 to 8	Blue Mountain	18	27.0	12.9
8 to 15	Blue Mountain	18	5820.9	2775.5
Subtotal			**5848.1**	**2788.5**
Municipality of Clarington				
8 to 15	Lindsay	18	2109.7	1005.9
Subtotal			**2109.7**	**1005.9**
TOTAL			**26586.6**	**12677.0**

Minor variations in the tables are caused by the rounding of data.

The above figures represent a comprehensive inventory of all bedrock resources in the map area. Some of the material included in the estimate has no aggregate potential and some is unavailable for extraction due to land use restrictions.

Table 5 - Quarries
Regional Municipality of Durham

No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	Remarks
Municipality of Clarington				
Q1	St. Marys Cement Inc. (Canada)	241.9	50.3	Quarry face exposes the Lindsay Formation - approximately 4.3 m of the Collingwood Member over 46 m of the unnamed lower member

Table 6 - Selected Bedrock Resource Areas
Regional Municipality of Durham

1 Formation and Area Number	2 Depth of Overburden (Metres)	3 Area (Hectares)	4 Cultural Setbacks (Hectares)	5 Extracted Area (Hectares)	6 Possible Resource Area (Hectares)	7 Estimated Workable Thickness (Metres)	8 Possible Bedrock Resources (Million Tonnes)
– NONE –							

Table 7 - Summary of Test Hole Data Regional Municipality of Durham					
Test Hole Number	Location: General Location and Other Information	Location: UTM Co-ordinates (NAD83, Zone 17) Easting (m)	Location: UTM Co-ordinates (NAD83, Zone 17) Northing (m)	Depth (m)	Description
LSRCA-01	Conc. III, Lot 31 – Conc. IV road allowance	639772	4898362	0 - 4.3	Peat
	Township of Uxbridge			4.3 - 5.2	Silty sand
				5.2 - 7.9	Silt and clay
	NTS Sheet: 31 D/3			7.9 - 16.7	Coarse gravel
	Date Drilled: 2008			16.7 - 17.4	Sand
	Drilled by Lake Simcoe Region Conservation Authority			17.4 - 25.0	Interbedded sand and gravel
				25.0 - 27.1	Peastone gravel
				27.1 - 28.9	Stones, cemented gravel
				28.9 - 30.2	Interbedded stone and clay (till)
					END OF HOLE
LSRCA-02	Sandford Rd. and Conc. II	639317	4887199	0 - 0.73	Silty sand
	Township of Uxbridge			0.73 - 3.84	Fine to medium sand
				3.84 - 10.28	Fine to medium sand
	NTS Sheet: 31 D/3			10.28 - 24.59	Fine sand
	Date Drilled: 2008			24.59 - 32.59	Silty fine to medium sand
	Drilled by Lake Simcoe Region Conservation Authority			32.59 - 37.59	Coarse to very coarse pebbly gravel
				37.59 - 39.09	Cobble gravel
				39.09 - 61.58	Silty sand, stone rich
					END OF HOLE
LSRCA-03	Meyers Road - road allowance	639444	4893753	0 - 1.0	Peat
	Township of Uxbridge			1.0 - 7.3	Silt, sand and clay
				7.3 - 13.4	Clay
	NTS Sheet: 31 D/3			13.4 - 17.7	Silty clay
	Date Drilled: 2008			17.7 - 26.8	Silt
	Drilled by Lake Simcoe Region Conservation Authority			26.8 - 31.7	Sand
				31.7 - 34.4	Sand and gravel
				34.4 - 35.4	Gravel
				35.4 - 27.5	Clay, stone (till)
					END OF HOLE
LSRCA-04	Meyers Road - road allowance	639465	4893765	0 - 1.0	Peat
	Township of Uxbridge			1.0 - 8.2	Clayey silt
				8.2 - 18.3	Clayey silt
	NTS Sheet: 31 D/3			18.3 - 28.9	Clayey silt
	Date Drilled: 2008			28.9 - 38.4	Layered sand and gravel
	Drilled by Lake Simcoe Region Conservation Authority			38.4 - 41.7	Sand with some stones
				41.7 - 45.1	Gravel with some stones
				45.1 - 45.9	Stones and clay (till)
					END OF HOLE
LSRCA-05	Meyers Road - road allowance	639491	4893774	0 - 1.0	Peat
	Township of Uxbridge			1.0 - 4.3	Clayey silt
				4.3 - 6.2	Clay
	NTS Sheet: 31 D/3			6.2 - 17.4	Clay
	Date Drilled: 2008			17.4 - 21.6	Peastone gravel
	Drilled by Lake Simcoe Region Conservation Authority				END OF HOLE

Table 7 - Summary of Test Hole Data
Regional Municipality of Durham

Test Hole Number	Location: General Location and Other Information	Location: UTM Co-ordinates (NAD83, Zone 17) Easting (m)	Location: UTM Co-ordinates (NAD83, Zone 17) Northing (m)	Depth (m)	Description
LSRCA-06	Meyers Road - road allowance	639516	4893782	0 - 1.0	Peat
	Township of Uxbridge			1.0 - 5.8	Silt, sand and clay
				5.8 - 11.9	Clay
	NTS Sheet: 31 D/3			11.9 - 14.6	Silty sand
	Date Drilled: 2008			14.6 - 16.5	Clayey silt
	Drilled by Lake Simcoe Region Conservation Authority			16.5 - 23.8	Clayey silt with gravel layers
				23.8 - 34.5	Layers of sand and gravel
				34.5 - 35.7	Peastone gravel
				35.7 - 36.6	Stones and clay (till)
					END OF HOLE
OGS-93-18	Along the southern flank of the Oak Ridges moraine			0 - 1.52	Gravel
	Township of Uxbridge			1.52 - 18.59	Sand
				18.59 - 27.43	Silt and clay
	NTS Sheet: 31 D/3			27.43 - 35.66	Sand
	Date Drilled: 1993			35.66 - 35.96	Gravel
	Drilled by Ontario Geological Survey (P.J. Barnett)			35.96 - 39.62	Sand
				39.62 - 39.92	Silt and clay
				39.92 - 46.63	Sand
				46.63 - 46.93	Silt and clay
				46.93 - 49.37	Sand
				49.37 - 50.59	Gravel
				50.59 - 58.51	Till
				58.51 - 59.42	Sand
				59.42 - 62.47	Till
					END OF HOLE
OGS-93-19	Along the southern flank of the Oak Ridges moraine			0 - 3.05	Till
	Township of Uxbridge			3.05 - 3.66	Silt and clay
				3.66 - 6.71	Till
	NTS Sheet: 31 D/3			6.71 - 21.95	Sand
	Date Drilled: 1993			21.95 - 22.25	Gravel
	Drilled by Ontario Geological Survey (P.J. Barnett)			22.25 - 22.55	Sand
				22.55 - 22.86	Gravel
				22.86 - 28.04	Sand
				28.04 - 30.48	Till
				30.48 - 31.39	Gravel
				31.39 - 83.21	Till
					END OF HOLE

Table 8 - Summary of Geophysical Data
Regional Municipality of Durham

- NONE -

Table 9 - Results of Aggregate Quality Tests
Regional Municipality of Durham

Sample No.	Petrographic Number	
	Granular and 16 mm	Hot Mix and Concrete
DR-SS-1	122	132
DR-SS-2	119	138
DR-SS-3	134	150
DR-SS-4	131	146
DR-SS-5	112	130
DR-SS-6	141	151
DR-SS-7	125	141
DR-SS-8	149	158
DR-SS-9	105	110
DR-SS-10	105	110

NOTE: The quality test data refer strictly to a specific sample. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit, particularly where some of the deposits may be quite large.

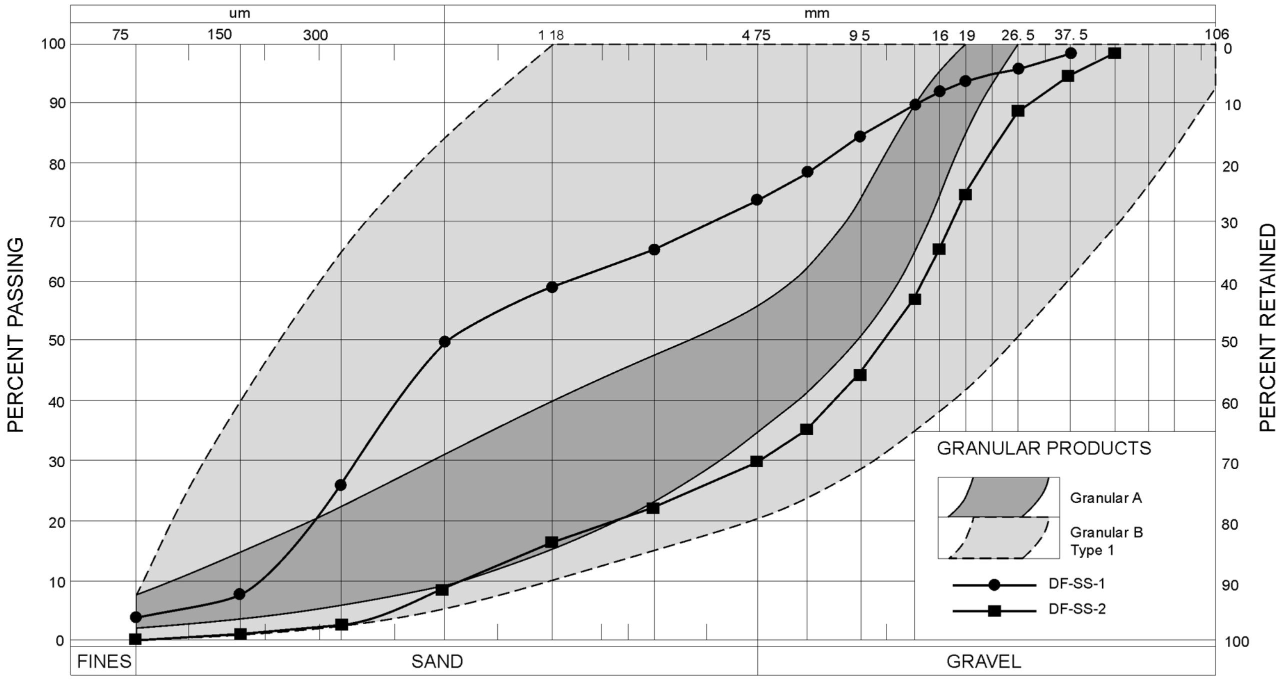


Figure 2A. Aggregate Grading Curves, Regional Municipality of Durham – Total Aggregate.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1010 (1988)).

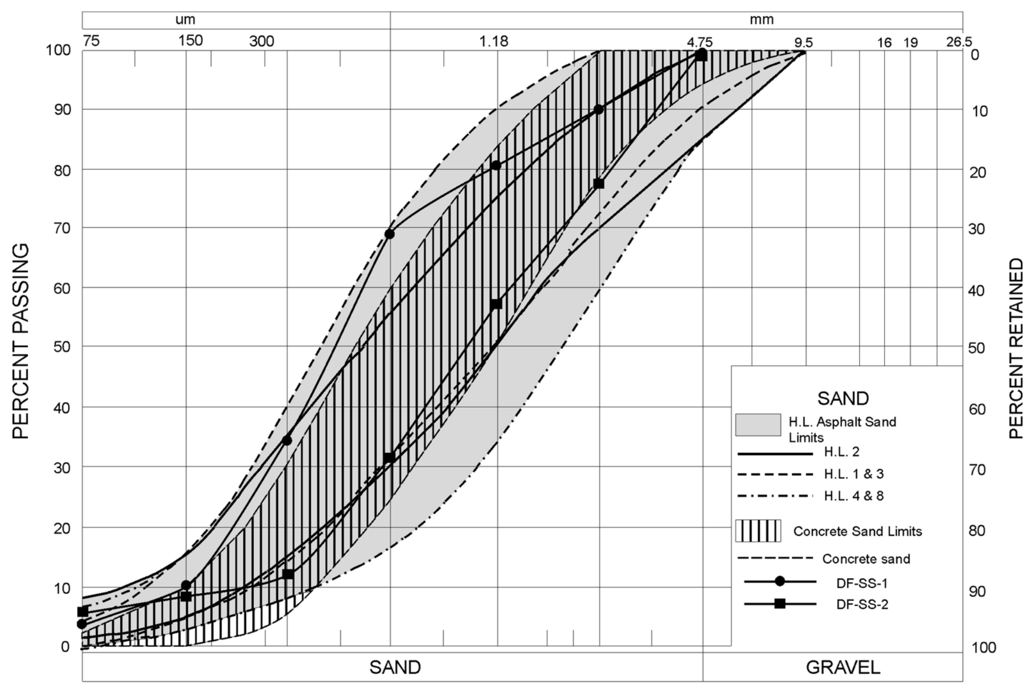


Figure 2B. Aggregate Grading Curves, Regional Municipality of Durham – Sand Fraction.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1002 (1988) and 1003 (1988)).

Note: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit.

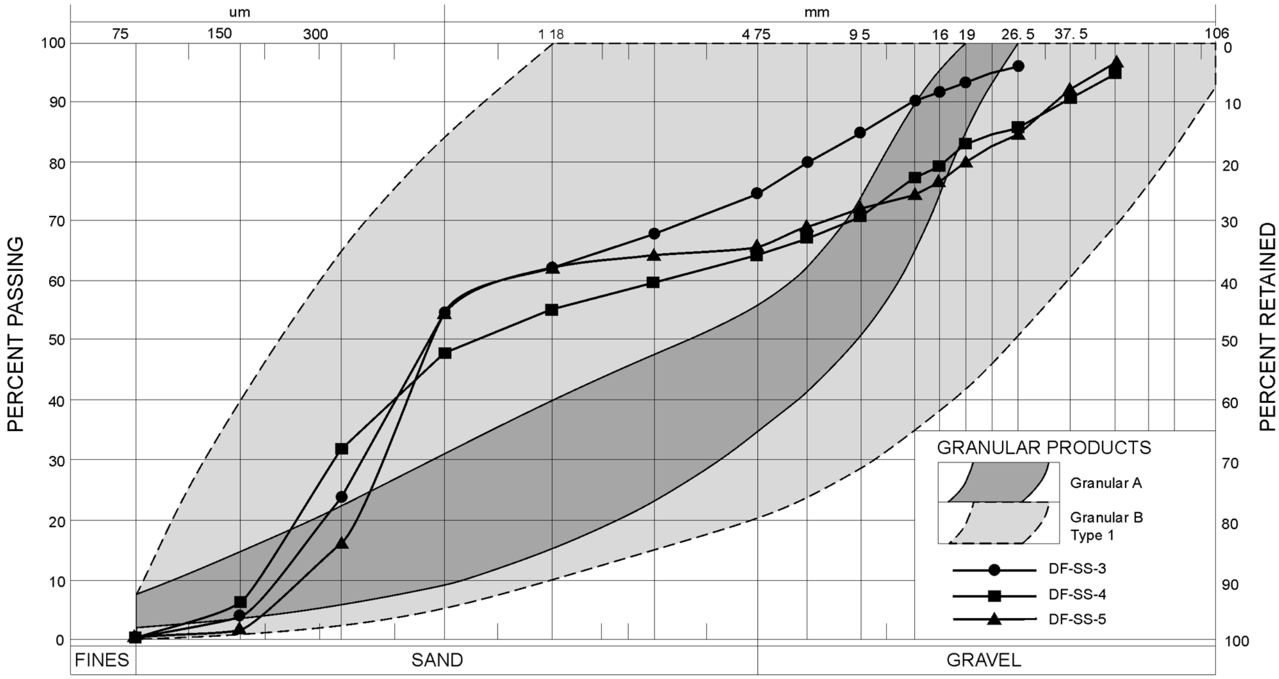


Figure 3A. Aggregate Grading Curves, Regional Municipality of Durham – Total Aggregate.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1010, 1988).

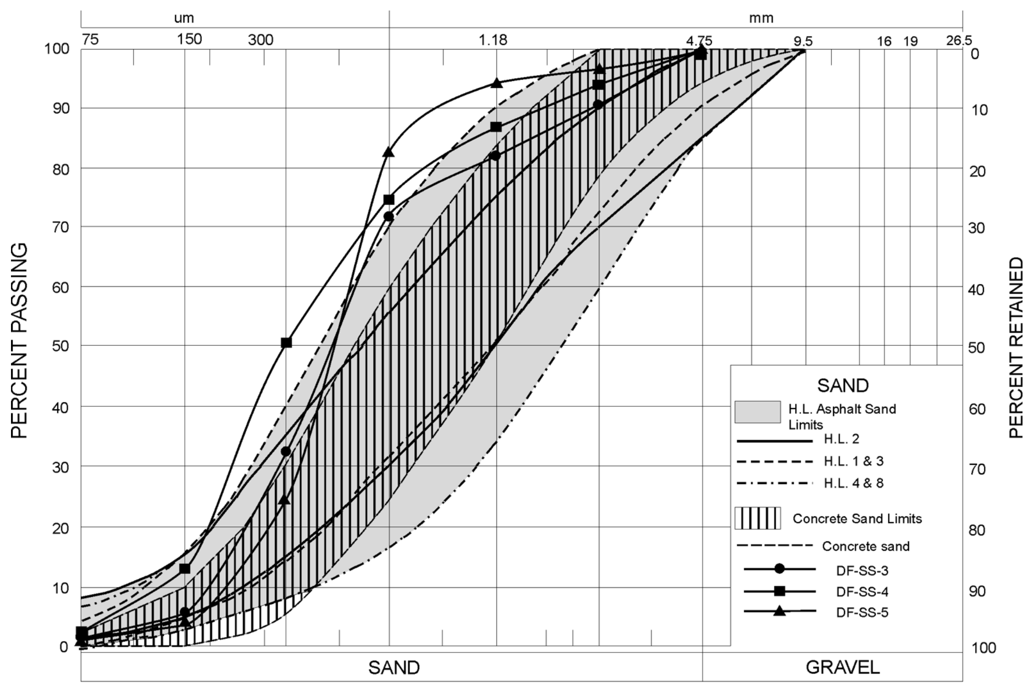


Figure 3B. Aggregate Grading Curves, Regional Municipality of Durham – Sand Fraction.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1002 (1988) and 1003 (1988)).

Note: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit.

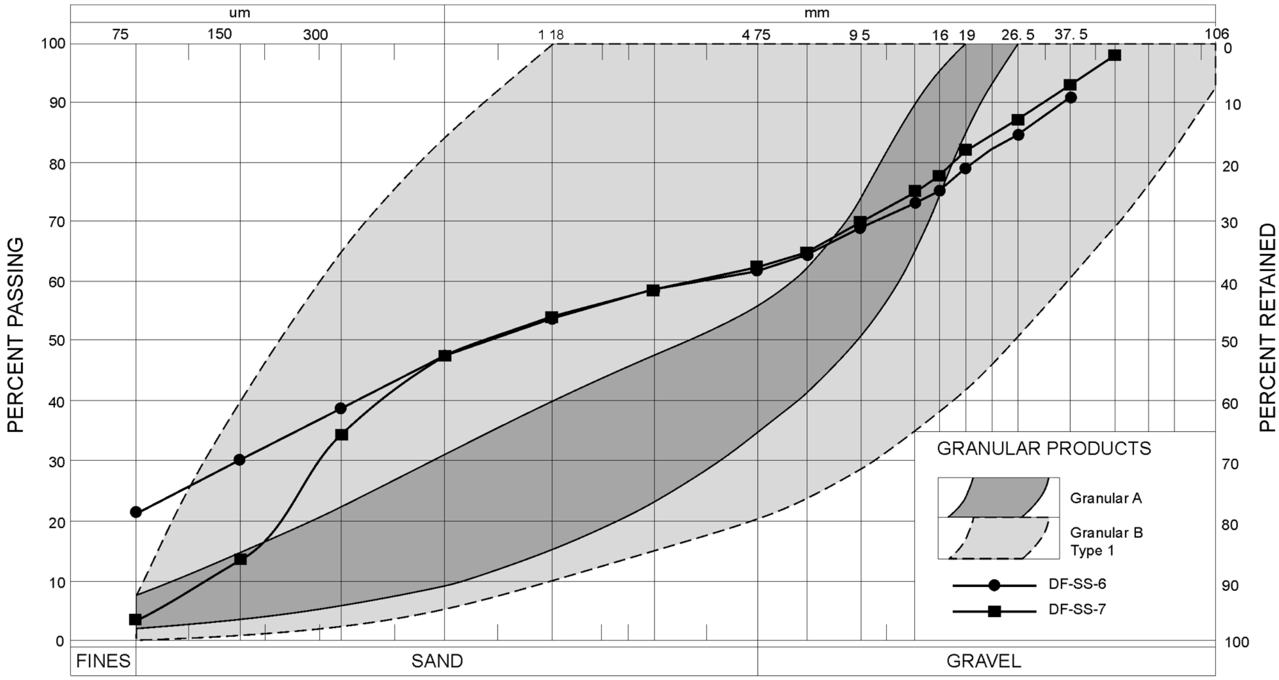


Figure 4A. Aggregate Grading Curves, Regional Municipality of Durham – Total Aggregate.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1010, 1988).

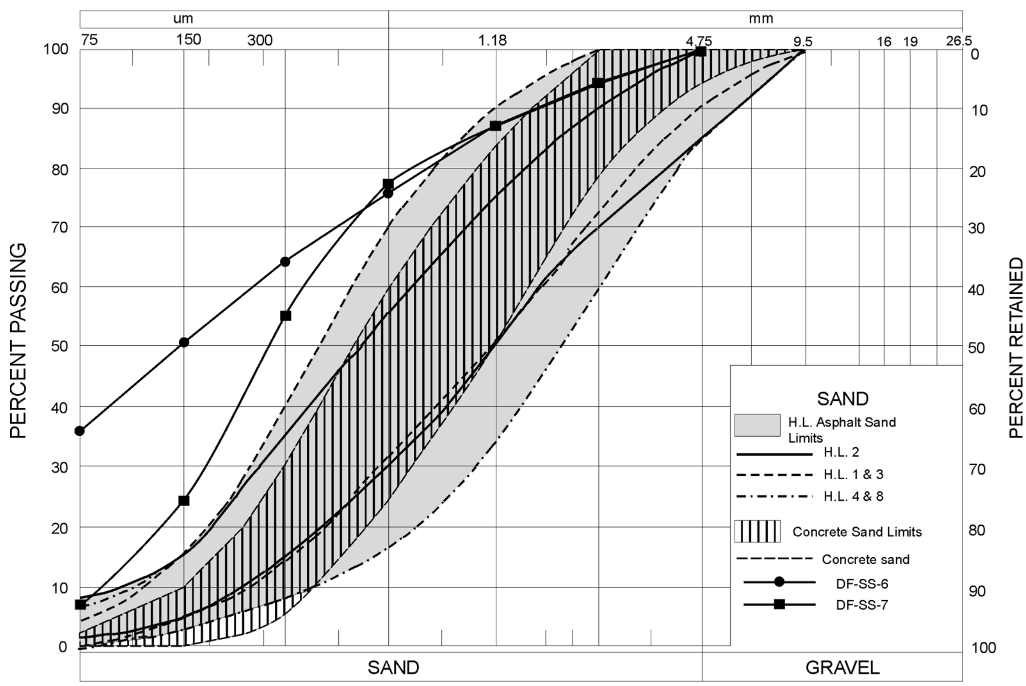


Figure 4B. Aggregate Grading Curves, Regional Municipality of Durham – Sand Fraction.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1002 (1988) and 1003 (1988)).

Note: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit.

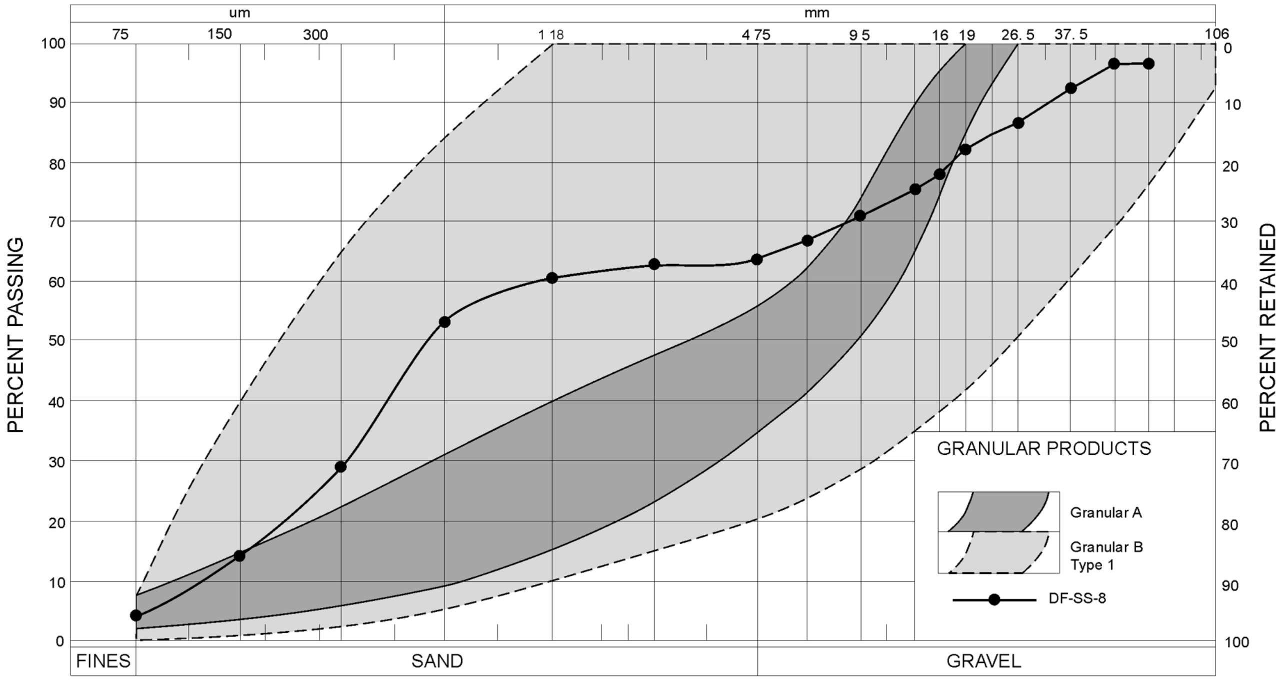


Figure 5A. Aggregate Grading Curves, Regional Municipality of Durham – Total Aggregate.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1010, 1988).

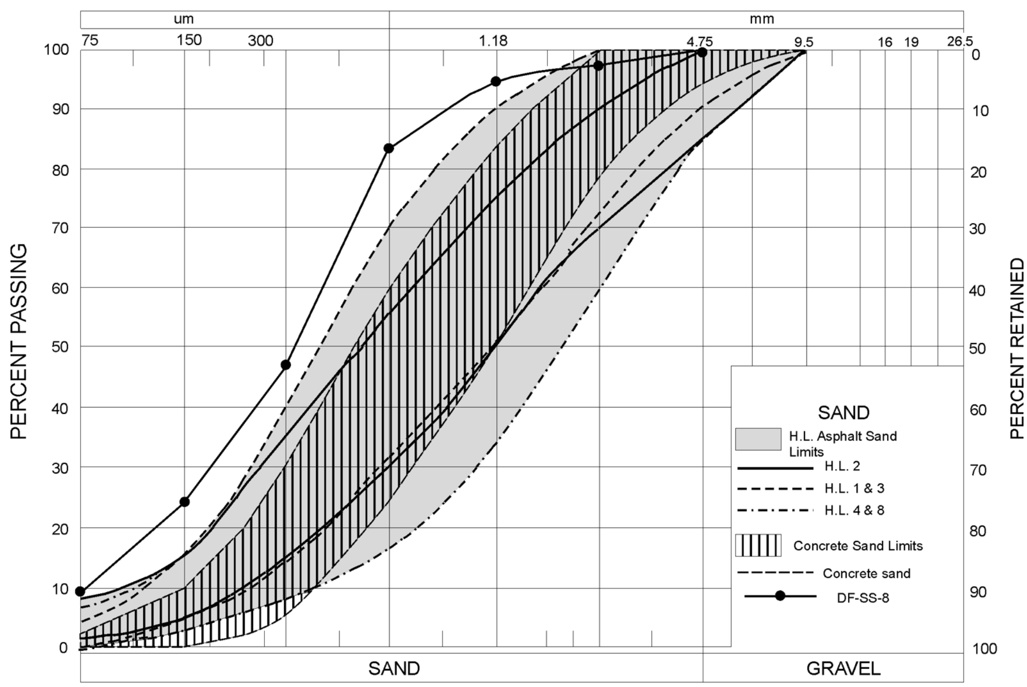


Figure 5B. Aggregate Grading Curves, Regional Municipality of Durham – Sand Fraction.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1002 (1988) and 1003 (1988)).

Note: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit.

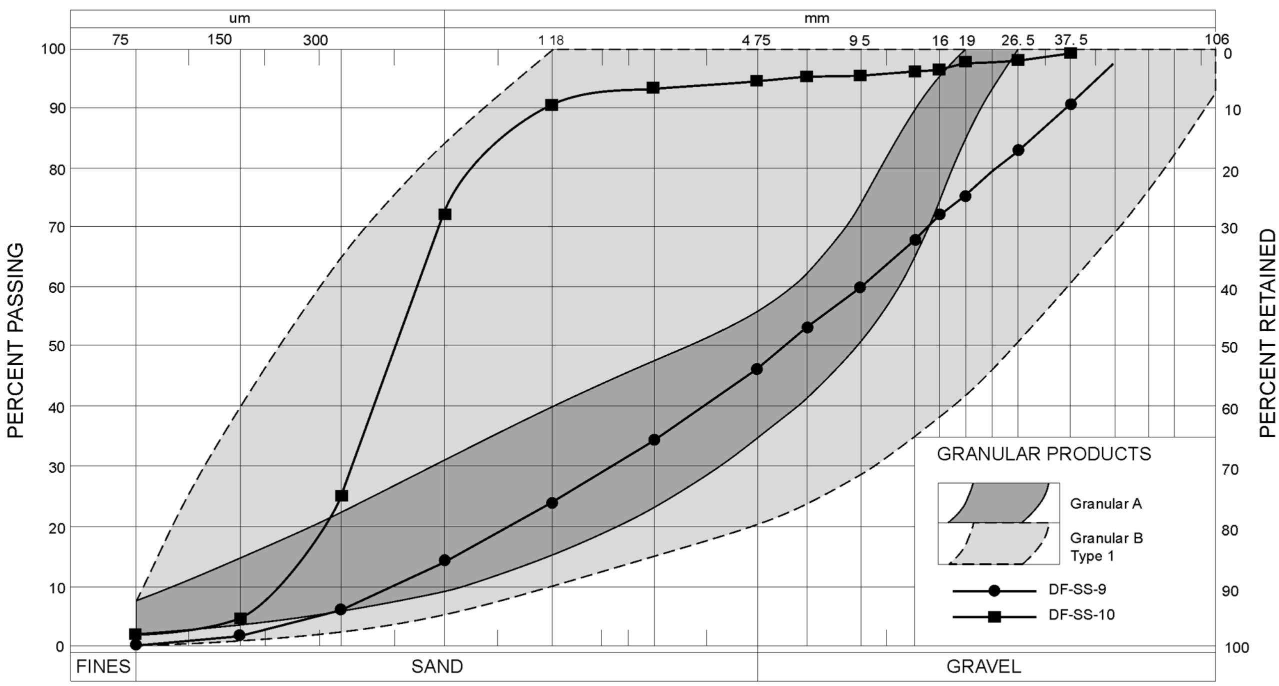


Figure 6A. Aggregate Grading Curves, Regional Municipality of Durham – Total Aggregate.
Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1010, 1988).

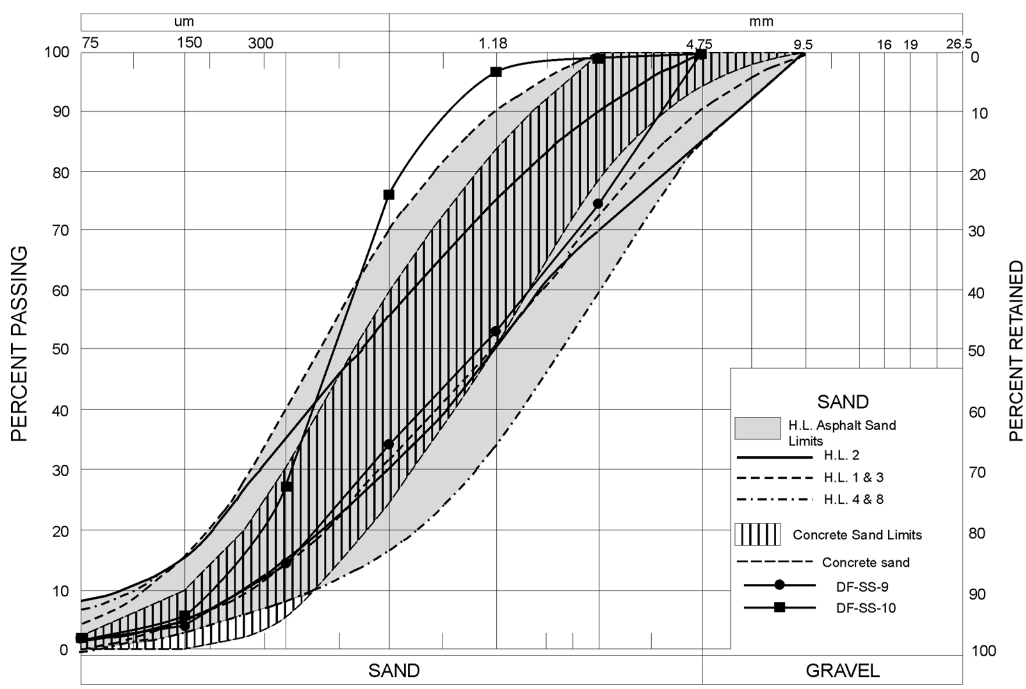


Figure 6B. Aggregate Grading Curves, Regional Municipality of Durham – Sand Fraction.
Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1002 (1988) and 1003 (1988)).

Note: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit.

References

Armstrong, D.K. and Carter, T.R. 2006. An updated guide to the subsurface Paleozoic stratigraphy of southern Ontario; Ontario Geological Survey, Open File Report 6191, 214p.

Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 219.

Association of Professional Engineers of Ontario 1976. Performance standards for professional engineers advising on and reporting on oil, gas and mineral properties; Association of Professional Engineers of Ontario, 11p.

Barnett, P.J. 1989. Tunnel valleys in the Georgian Bay area, Ontario; Geological Association of Canada–Mineralogical Association of Canada, Program with Abstracts, v.14, p.A89.

——— 1990. Tunnel valleys: evidence of catastrophic release of subglacial meltwater, central–southern Ontario, Canada; Geological Society of America, Northeastern Section, Abstracts with Programs, v.22, no.2, p.3.

——— 1992a. Quaternary geology of Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.1011-1088.

——— 1992b. Geological investigations within the Oak Ridges moraine area, Whitchurch–Stouffville and Uxbridge township municipalities, Ontario; *in* Summary of Field Work and Other Activities 1992, Ontario Geological Survey, Miscellaneous Paper 160, p.144-146.

——— 1993. Geological investigations in the Oak Ridges moraine area, parts of Scugog, Manvers and Newcastle township municipalities and Oshawa City municipality, Ontario; *in* Summary of Field Work and Other Activities 1993; Ontario Geological Survey, Miscellaneous Paper 162, p.158-159.

——— 1994. Geology of the Oak Ridges moraine area, parts of Peterborough and Victoria counties and part of the Regional Municipality of Durham, Ontario; *in* Summary of Field Work and Other Activities 1994, Ontario Geological Survey, Miscellaneous Paper 163, p.155-156.

——— 1996. Field investigations in the Newmarket and Beaverton map areas, Durham and York regional municipalities, Ontario; *in* Summary of Field Work and Other Activities 1996, Ontario Geological Survey, Miscellaneous Paper 166, p.78-80.

——— 1997. Geology of the Beaverton map area, Durham and York regional municipalities and Victoria County municipality, Ontario; *in* Summary of Field Work and Other Activities 1997, Ontario Geological Survey, Miscellaneous Paper 168, p.110-112.

Barnett, P.J., Dodge, J.E.P., McCrae, M.K. and Stuart, A. 1999. Quaternary geology, Newmarket area, Ontario; Ontario Geological Survey, Map 2562, scale 1:50 000.

Barnett, P.J. and Mate, D.J. 1998. Quaternary geology, Beaverton area; Ontario Geological Survey, Map 2560, scale 1:50 000.

Barnett, P.J. and McCrae, M.K. 1996a. Quaternary geology, Mount Albert area, Ontario; Ontario Geological Survey, Map 2631, scale 1:20 000.

——— 1996b. Quaternary geology, Stouffville area, Ontario; Ontario Geological Survey, Map 2632, scale 1:20 000.

Barnett, P.J. and Rowell, D.J. 2002. The geology and mineral aggregate potential of the Oak Ridges moraine, Ontario, Canada; *in* Industrial minerals in Canada, Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 53, p.151-157.

Barnett, P.J., Sharpe, D.R., Russell, H.A.J., Brennand, T.A., Gorrell, G., Kenny, F. and Pugin, A. 1998. On the origin of the Oak Ridges moraine; Canadian Journal of Earth Sciences, v.35, p.1152-1167.

Bezys, R.K. and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario; The Canadian Mining and Metallurgical Bulletin, v.81, no.912, p.49-58

Chapman, L.J. and Putnam, D.F. 1984. The physiography of southern Ontario; Ontario Geological Survey, Special Volume 2, 270p., accompanied by Preliminary Map P.2715, scale 1:600 000.

Deane, R.E. 1950. Pleistocene geology of the Lake Simcoe district, Ontario; Geological Survey of Canada, Memoir 256, 108p.

Deike, W. 1977. Aggregate suitability evaluation, Brock Township; unpublished report, Ministry of Transportation and Communications, Engineering Materials Office, Aggregate Unit, Pavement Design and Management Sections, Toronto, Ontario, 4p.

——— 1978. Aggregate suitability evaluation, Cartwright and Scugog and the east half of Reach Township; unpublished report, Ministry of Transportation and Communications, Engineering Materials Office, Aggregate Unit, Pavement Design and Management Sections, Toronto, Ontario, 12p.

Derry Michener Booth and Wahl and Ontario Geological Survey 1989. Limestone industries of Ontario, Volume 3—Limestone industries and resources of central and southwestern Ontario; Ministry of Natural Resources, Land Management Branch, Toronto, Ontario, 175p.

Duckworth, P.B. 1975. Paleocurrent trends in the latest outwash at the western end of the Oak Ridges moraine, Ontario; unpublished PhD thesis, University of Toronto, Toronto, Ontario, 274p.

Gravenor, C.P. 1957. Surficial geology of the Lindsay–Peterborough area, Ontario, Victoria, Peterborough, Durham and Northumberland counties, Ontario; Geological Survey of Canada, Memoir 288, 60p.

Gwyn, Q.H.J. 1976. Recommendations for sand and gravel extractive areas, Brock Township, Ontario Division of Mines, Open File Report 5164, 4p.

Gwyn, Q.H.J and DiLabio, R.N.W. 1973. Quaternary geology, Newmarket area, southern Ontario; Ontario Division of Mines, Preliminary Map P.836, scale 1:50 000.

Hewitt, D.F. and Liberty, B.A. 1972. Paleozoic geology of southern Ontario showing bedrock industrial mineral producers; Ontario Division of Mines, Map 2254, scale 1:1 013 760.

Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G., and Rutka, M.A. 1992. Paleozoic and Mesozoic geology of Ontario; *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 2, p.907-1011.

Karrow, P.F. 1991. Quaternary geology of the Brampton area; Ontario Geological Survey, Open File Report 5819, 136p.

Karrow, P.F. and Easton, J. 2005. Quaternary geology of the Brampton area; Ontario Geological Survey, Map 2223, scale 1:50 000.

Liberty, B.A. 1969. Paleozoic geology of the Lake Simcoe area, Ontario; Geological Survey of Canada, Memoir 355, 201p.

Ontario Geological Survey 1980a. Aggregate resources inventory of Brock Township, Regional Municipality of Durham, southern Ontario; Ontario Geological Survey, Aggregate Resource Inventory Paper 6, 33p.

——— 1980b. Aggregate resources inventory of Uxbridge Township, Regional Municipality of Durham, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 13, 32p.

——— 1981a. Aggregate resources inventory of the City of Oshawa, Regional Municipality of Durham, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 40, 31p.

——— 1981b. Aggregate resources inventory of the Town of Whitby, Regional Municipality of Durham, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 41, 31p.

——— 1984. Aggregate resources inventory of the Town of Newcastle, Regional Municipality of Durham, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 94, 38p.

——— 1986. Aggregate resources inventory of Scugog Township, Regional Municipality of Durham, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 95, 39p.

Ontario Interministerial Committee on National Standards and Specifications (Metric Committee) 1975. Metric Practice Guide; 67p.

Planning Initiatives Limited 1993. Aggregate resources of southern Ontario — A state of the resources study; Ministry of Natural Resources, Toronto, Ontario, 201p.

Robertson, J.A. 1975. Mineral deposit studies, mineral potential evaluation and regional planning in Ontario; Ontario Division of Mines, Miscellaneous Paper 61, 42p.

Russell, D.J. and Telford, P.G. 1983. Revisions to the stratigraphy of the Upper Ordovician Collingwood beds of Ontario – a potential oil shale; Canadian Journal of Earth Sciences, v.20, p.1780-1790.

Statistics Canada 2006. Population and dwelling counts for Canada, province and territories; Government of Canada, 2006 Census of Population.

Telford, P.G. 1976. Paleozoic geology, Guelph, southern Ontario; Ontario Division of Mines, Map 2342, scale 1:50 000.

Telford, W.M., Geldart, L.P., Sherriff, R.E. and Keys, D.A. 1980. Applied geophysics; Cambridge University Press, London, United Kingdom, 860p.

The Ontario Aggregate Resources Corporation 2001. Mineral aggregates in Ontario, statistical update 2000; The Ontario Aggregate Resources Corporation, unpublished report, 20p.

——— 2007. Mineral aggregates in Ontario, statistical update 2006; The Ontario Aggregate Resources Corporation, unpublished report, 20p.

Appendix A – Suggested Additional Reading and References

Antevs, E. 1928. The last glaciation, with special reference to the ice retreat in northeastern North America; American Geography Society, Research Series No. 17, 292p.

Banerjee, I. and McDonald, B.C. 1975. Nature of esker sedimentation; *in* Glaciofluvial and glaciolacustrine sedimentation, Society of Economic Paleontologists and Mineralogists, Special Paper No. 23, p.132-154.

Bauer, A.M. 1970. A guide to site development and rehabilitation of pits and quarries; Ontario Department of Mines, Industrial Mineral Report 33, 62p.

Bezys, R.K. and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario; The Canadian Mining and Metallurgical Bulletin, v.81, no.912, p.49-58.

Carson, D.M. 1980. Paleozoic geology of the Rice Lake–Port Hope area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2338, scale 1:50 000.

Chapman, L.J. and Putnam, D.F. 2007. Physiography of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 228.

Cowan, W.R. 1977. Toward the inventory of Ontario's mineral aggregates; Ontario Geological Survey, Miscellaneous Paper 73, 19p.

Deane, R.E. 1950. Pleistocene geology of the Lake Simcoe district, Ontario; Geological Survey of Canada, Memoir 256, 108p.

Derry Michener Booth and Wahl and Ontario Geological Survey 1989a. Limestone industries of Ontario, Volume 1—Geology, properties and economics; Ministry of Natural Resources, Land Management Branch, Toronto, Ontario, 158p.

——— 1989b. Limestone industries of Ontario, Volume 2—Limestone industries and resources of eastern and northern Ontario; Ministry of Natural Resources, Land Management Branch, Toronto, Ontario, 196p.

——— 1989c. Limestone industries of Ontario, Volume 3—Limestone industries and resources of central and southwestern Ontario; Ministry of Natural Resources, Land Management Branch, Toronto, Ontario, 175p.

Fairbridge, R.W. ed. 1968. The encyclopedia of geomorphology; Encyclopedia of Earth Sciences, v.3, Reinhold Book Corp., New York, 1295p.

Flint, R.F. 1971. Glacial and Quaternary geology; John Wiley and Sons Inc., New York, 892p.

Gwyn, Q.H.J. 1976. Quaternary geology and granular resources of the western part of the Regional Municipality of Durham, parts of Uxbridge, Pickering, Reach and Whitby townships, southern Ontario; Ontario Division of Mines, Open File Report 5161, 7p.

Gwyn, Q.H.J and DiLabio, R.N.W. 1973. Quaternary geology, Newmarket area, southern Ontario; Ontario Division of Mines, Preliminary Map P.836, scale 1:50 000.

Hewitt, D.F. 1969. Industrial mineral resources sheet of the Markham–Newmarket area: York and Ontario counties; Ontario Department of Mines, Map 2124, scale 1:63 360.

Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G., and Rutka, M.A. 1992. Paleozoic and Mesozoic geology of Ontario; *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 2, p.907-1011.

Karrow, P.F. 2005. Quaternary geology of the Brampton area; Ontario Geological Survey, Report 257, 59p.

Karrow, P.F. and Easton, J. 2005. Quaternary geology of the Brampton area; Ontario Geological Survey, Map 2223, scale 1:50 000.

Lowe, S.B. 1980. Trees and shrubs for the improvement and rehabilitation of pits and quarries in Ontario; Ministry of Natural Resources, Toronto, Ontario, 71p.

McLellan, A.G., Yundt, S.E. and Dorfman, M.L. 1979. Abandoned pits and quarries in Ontario; Ontario Geological Survey, Miscellaneous Paper 79, 36p.

Michalski, M.F.P., Gregory, D.R. and Usher, A.J. 1987. Rehabilitation of pits and quarries for fish and wildlife; Ministry of Natural Resources, Land Management Branch, Toronto, Ontario, 59p.

Ministry of Natural Resources 1975. Vegetation for the rehabilitation of pits and quarries; Ministry of Natural Resources, Division of Forests, Forest Management Branch, Toronto, Ontario, 38p.

Neuendorf, K.K.E., Mehl, J.P., Jr. and Jackson, J.A. 2005. Glossary of geology, 5th ed.; American Geological Institute, Alexandria, Virginia, 779p.

Ontario 2007. *The Mining Act*; Revised Statutes of Ontario, 1990, Chapter M.14.

Ontario Mineral Aggregate Working Party 1977. A policy for mineral aggregate resource management in Ontario; Ministry of Natural Resources, Toronto, Ontario, 232p.

Rogers, C.A. 1985. Alkali aggregate reactions, concrete and aggregate testing and problem aggregates in Ontario – A review, 5th ed.; Ministry of Transportation and Communications, Engineering Materials Office, Toronto, Ontario, Paper EM-31, 44p.

——— 1986. Evaluation of the potential for expansion and cracking of concrete caused by the alkali–carbonate reaction; CCAGDP, Journal of Cement, Concrete and Aggregates, v.8, no.1, p.13-23.

Singer, S.N. 1974. A hydrological study along the north shore of Lake Ontario in the Bowmanville–Newcastle area; Ministry of the Environment, Toronto, Ontario, Water Resources Report 5d, 72p.

Wolf, R.R. 1993. An inventory of inactive quarries in the Paleozoic limestone and dolostone strata of Ontario; Ontario Geological Survey, Open File Report 5863, 272p.

Appendix B – Glossary

Abrasion Resistance: Tests such as the Los Angeles abrasion test (*see* Appendix E) are used to measure the ability of aggregate to resist crushing and pulverizing under conditions similar to those encountered in processing and use. Measuring resistance is an important component in the evaluation of the quality and prospective uses of aggregate. Hard, durable material is preferred for road building.

Acid–Soluble Chloride Ion Content: This test measures total chloride ion content in concrete and is used to judge the likelihood of re-bar corrosion and susceptibility to deterioration by freeze–thaw in concrete structures. There is a strong positive correlation between chloride ion content and depassivation of reinforcing steel in concrete. Depassivation permits corrosion of the steel in the presence of oxygen and moisture. Chloride ions are contributed mainly by the application of de-icing salts.

Aggregate: Any hard, inert, construction material (sand, gravel, shells, slag, crushed stone or other mineral material) used for mixing in various-sized fragments with a cement or bituminous material to form concrete, mortar, etc., or used alone for road building or other construction. Synonyms include mineral aggregate and granular material.

Alkali–Aggregate Reaction: A chemical reaction between the alkalis of Portland cement and certain minerals found in rocks used for aggregate. Alkali–aggregate reactions are undesirable because they can cause expansion and cracking of concrete. Although perfectly suitable for building stone and asphalt applications, alkali-reactive aggregates should be avoided for structural concrete uses.

Beneficiation: Beneficiation of aggregates is a process or combination of processes that improves the quality (physical properties) of a mineral aggregate and is not part of the normal processing for a particular use, such as routine crushing, screening, washing, or classification. Heavy media separation, jigging, or application of special crushers (e.g., "cage mill") are usually considered processes of beneficiation.

Blending: Required in cases of extreme coarseness, fineness, or other irregularities in the gradation of unprocessed aggregate. Blending is done with approved sand-sized aggregate in order to satisfy the gradation requirements of the material.

Cambrian: The first period of the Paleozoic Era, thought to have covered the time between 540 and 500 million years age. The Cambrian precedes the Ordovician Period.

Chert: Amorphous silica, generally associated with limestone. Often occur as irregular masses or lenses, but can also occur finely disseminated through limestones. It may be very hard in unleached form. In leached form, it is white and "chalky" and is very absorptive. It has deleterious effect for aggregates to be used in Portland cement concrete due to reactivity with alkalis in Portland cement.

Clast: An individual constituent, grain or fragment of a sediment or rock, produced by the mechanical weathering of larger rock mass. Synonyms include particle and fragment.

Crushable Aggregate: Unprocessed gravel containing a minimum of 35% coarse aggregate larger than the No. 4 sieve (4.75 mm) as well as a minimum of 20% greater than the 26.5 mm sieve.

Deleterious Lithology: A general term used to designate those rock types that are chemically or physically unsuited for use as construction or road-building aggregates. Such lithologies as chert, shale, siltstone and sandstone may deteriorate rapidly when exposed to traffic and other environmental conditions.

Devonian: A period of the Paleozoic Era thought to have covered the span of time between 410 and 355 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest Paleozoic rocks in Ontario.

Dolostone: A carbonate sedimentary rock consisting chiefly of the mineral dolomite and containing relatively little calcite (dolostone is also known as dolomite).

Drift: A general term for all unconsolidated rock debris, transported from one place and deposited in another, distinguished from underlying bedrock. In North America, glacial activity has been the dominant mode of transport and deposition of drift. Synonyms include overburden and surficial deposit.

Drumlin: A low, smoothly rounded, elongated hill, mound or ridge composed of glacial materials. These landforms were formed beneath an advancing ice sheet and were shaped by its flow.

Eolian: Pertaining to the wind, especially with respect to landforms the constituents of which were transported and deposited by wind activity. Sand dunes are an example of an eolian landform.

Fines: A general term used to describe the size fraction of an aggregate which passes (is finer than) the No. 200 mesh screen (0.075 mm). Also described informally as "dirt", these particles are in the silt and clay size range.

Glacial Lobe: A tongue-like projection from the margin of the main mass of an ice cap or ice sheet. During the Pleistocene Epoch, several lobes of the Laurentide continental ice sheet occupied the Great Lakes basins. These lobes advanced then melted back numerous times during the Pleistocene, producing the complex arrangement of glacial material and landforms found in Ontario.

Gneiss: A coarse-textured metamorphic rock with the minerals arranged in parallel streaks or bands. Gneiss is relatively rich in feldspar. Other common minerals found in this rock include quartz, mica, amphibole and garnet.

Gradation: The proportion of material of each particle size, or the frequency distribution of the various sizes, which constitute a sediment. The strength, durability, permeability and stability of an aggregate depend to a great extent on its gradation. The size limits for different particles are as follows:

Boulder	more than 200 mm
Cobbles	75–200 mm
Coarse Gravel	26.5–75 mm
Fine Gravel	4.75–26.5 mm
Coarse Sand	2–4.75 mm
Medium Sand	0.425–2 mm
Fine Sand	0.075–0.425 mm
Silt, Clay	less than 0.075 mm

Granite: A coarse-grained, light-coloured rock that ordinarily has an even texture and is composed of quartz and feldspar with either mica, hornblende or both.

Granular Base and Subbase: Components of a pavement structure of a road, which are placed on the subgrade and are designed to provide strength, stability and drainage, as well as support for surfacing materials. Granular A consists of crushed and processed aggregate and has relatively stringent quality standards in comparison to Granular B, which is usually pit-run or other unprocessed aggregate. Granular M is a shouldering and surface dressing material with quality requirements similar to Granular A. Select Subgrade Material (SSM) has similar quality requirements to Granular B and it provides a stable platform for the overlying pavement structure. (For more specific information, the reader is referred to Ontario Provincial Standard Specification (OPSS) 1010 and Appendix E).

Heavy Duty Binder: Second layer from the top of hot mix asphalt pavements used on heavily travelled (especially by trucks) expressways, such as Highway 401. Coarse and fine aggregates are to be produced from high-quality bedrock quarries, except when gravel is permitted by special provisions.

Hot–Laid (or Asphaltic) Paving Aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course or as binder course used to bind the surface course to the underlying granular base.

Limestone: A carbonate sedimentary rock consisting chiefly of the mineral calcite. It may contain the mineral dolomite up to about 40%.

Lithology: The description of rocks on the basis of such characteristics as colour, structure, mineralogic composition and grain size. Generally, the description of the physical character of a rock.

Medium Duty Binder: Second layer from the top of hot mix asphalt pavements used on heavily travelled, usually four-lane, highways and municipal arterial roads. It may be constructed with high-quality quarried rock or high-quality gravel with a high percentage of fractured faces or polymer modified asphalt cements.

Meltwater Channel: A drainage way, often terraced, produced by water flowing away from a melting glacier margin.

Ordovician: An early period of the Paleozoic Era thought to have covered the span of time between 500 and 435 million years ago.

Paleozoic: One of the major divisions of the geologic time scale thought to have covered the time period between 540 and 250 million years ago, the Paleozoic Era (or Ancient Life Era) is subdivided into 6 geologic periods, of which only 4 (Cambrian, Ordovician, Silurian and Devonian) can be recognized in southern Ontario.

Pleistocene: An epoch of the recent geological past including the time from approximately 1.75 million years ago to 7000 years ago. Much of the Pleistocene was characterized by extensive glacial activity and is popularly referred to as the “Great Ice Age”.

Possible Resource: Reserve estimates based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on assumed continuity or repetition for which there are reasonable geological indications, but do not take into account many site-specific natural and environmental constraints that could render the resource inaccessible.

Precambrian: The earliest geological period extending from the consolidation of the Earth’s crust to the beginning of the Cambrian Period.

Sandstone: A clastic sedimentary rock consisting chiefly of sand-sized particles of quartz and minor feldspar, cemented together by calcareous minerals (calcite or dolomite) or by silica.

Shale: A fine-grained, sedimentary rock formed by the consolidation of clay, silt or mud and characterized by well-developed bedding planes, along which the rock breaks readily into thin layers. The term shale is also commonly used for fissile claystone, siltstone and mudstone.

Siltstone: A clastic sedimentary rock consisting chiefly of silt-sized particles, cemented together by calcareous minerals (calcite and dolomite) or by silica.

Silurian: An early period of the Paleozoic Era thought to have covered the time between 435 and 410 million years ago. The Silurian follows the Ordovician Period and precedes the Devonian Period.

Soundness: The ability of the components of an aggregate to withstand the effects of various weathering processes and agents. Unsound lithologies are subject to disintegration caused by the expansion of absorbed solutions. This may seriously impair the performance of road-building and construction aggregates.

Till: Unsorted and unstratified rock debris, deposited directly by glaciers, and ranging in size from clay to large boulders.

Wisconsinan: Pertaining to the last glacial period of the Pleistocene Epoch in North America. The Wisconsinan began approximately 100 000 years ago and ended approximately 7000 years ago. The glacial deposits and landforms of Ontario are predominantly the result of glacial activity during the Wisconsinan Stage.

Appendix C – Geology of Sand and Gravel Deposits

The type, distribution and extent of sand and gravel deposits in Ontario are the result of extensive glacial and glacially influenced activity in Wisconsinan time during the Pleistocene Epoch, approximately 100 000 to 7000 years ago. The deposit types reflect the different depositional environments that existed during the melting and retreat of the continental ice masses, and can readily be differentiated on the basis of their morphology, structure and texture. The deposit types are described below.

GLACIOFLUVIAL DEPOSITS

These deposits can be divided into 2 broad categories: those that were formed in contact with (or in close proximity to) glacial ice, and those that were deposited by meltwaters carrying materials beyond the ice margin.

Ice–Contact Terraces (ICT): These are glaciofluvial features deposited between the glacial margin and a confining topographic high, such as the side of a valley. The structure of the deposits may be similar to that of outwash deposits, but, in most cases, the sorting and grading of the material is more variable and the bedding is discontinuous because of extensive slumping. The probability of locating large amounts of crushable aggregate is moderate, and extraction may be expensive because of the variability of the deposits both in terms of quality and grain size distribution.

Kames (K): Kames are defined as mounds of poorly sorted sand and gravel deposited by meltwater in depressions or fissures on the ice surface or at its margin. During glacial retreat, the melting of supporting ice causes collapse of the deposits, producing internal structures characterized by bedding discontinuities. The deposits consist mainly of irregularly bedded and cross-bedded, poorly sorted sand and gravel. The present forms of the deposits include single mounds, linear ridges (crevasse fillings) or complex groups of landforms. The latter are occasionally described as "undifferentiated ice-contact stratified drift" (IC) when detailed subsurface information is unavailable. Since kames commonly contain large amounts of fine-grained material and are characterized by considerable variability, there is generally a low to moderate probability of discovering large amounts of good quality, crushable aggregate. Extractive problems encountered in these deposits are mainly the excessive variability of the aggregate and the rare presence of excess fines (silt- and clay-sized particles).

Eskers (E): Eskers are narrow, sinuous ridges of sand and gravel deposited by meltwaters flowing in tunnels within or at the base of glaciers, or in channels on the ice surface. Eskers vary greatly in size. Many, though not all, eskers consist of a central core of poorly sorted and stratified gravel characterized by a wide range in grain size. The core material is often draped on its flanks by better sorted and stratified sand and gravel. The deposits have a high probability of containing a large proportion of crushable aggregate and, since they are generally built above the surrounding ground surface, are convenient extraction sites. For these reasons, esker deposits have been traditional aggregate sources throughout Ontario, and are significant components of the total resources of many areas.

Some planning constraints and opportunities are inherent in the nature of the deposits. Because of their linear nature, the deposits commonly extend across several property boundaries leading to unorganized extractive development at numerous small pits. On the other hand, because of their form, eskers can be easily and inexpensively extracted and are amenable to rehabilitation and sequential land use.

Undifferentiated Ice-Contact Stratified Drift (IC): This designation may include deposits from several ice-contact, depositional environments which usually form extensive, complex landforms. It is not feasible to identify individual areas of coarse-grained material within such deposits because of their lack of continuity and grain size variability. They are given a qualitative rating based on existing pit and other subsurface data.

Outwash (OW): Outwash deposits consist of sand and gravel laid down by meltwaters beyond the margin of the ice lobes. The deposits occur as sheets or as terraced valley fills (valley trains) and may be very large in extent and thickness. Well-developed outwash deposits have good horizontal bedding and are uniform in grain size distribution. Outwash deposited near the glacier's margin is much more variable in texture and structure. The probability of locating useful crushable aggregates in outwash deposits is moderate to high depending on how much information on size, distribution and thickness is available.

Subaqueous Fans (SF): Subaqueous fans are formed within or near the mouths of meltwater conduits when sediment-laden meltwaters are discharged into a standing body of water. The geometry of the resulting deposit is fan or lobe shaped. Several of these lobes may be joined together to form a larger, continuous sedimentary body. Internally, subaqueous fans consist of stratified sands and gravels that may exhibit wide variations in grain size distribution. As these features were deposited under glacial lake waters, silt and clay that settled out of these lakes may be associated in varying amounts with these deposits. The variability of the sediments and presence of fines are the main extractive problems associated with these deposits.

Alluvium (AL): Alluvium is a general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during postglacial time by a stream as sorted or semi-sorted sediment, on its bed or on its floodplain. The probability of locating large amounts of crushable aggregate in alluvial deposits is low, and they have generally low value because of the presence of excess silt- and clay-sized material. There are few large postglacial alluvium deposits in Ontario.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine Beach Deposits (LB): These are relatively narrow, linear features formed by wave action at the shores of glacial lakes that existed at various times during the deglaciation of Ontario. Well-developed lacustrine beaches are usually less than 6 m thick. The aggregate is well sorted and stratified and sand-sized material commonly predominates. The composition and size distribution of the deposit depends on the nature of the source material. The probability of obtaining crushable aggregate is high when the material is developed from coarse-grained materials such as a stony till, and low when developed from fine-grained materials. Beaches are relatively narrow, linear deposits, so that extractive operations are often numerous and extensive.

Glaciolacustrine Deltas (LD): These features were formed where streams or rivers of glacial meltwater flowed into lakes and deposited their suspended sediment. In Ontario, such deposits tend to consist mainly of sand and abundant silt. However, in near-ice and ice-contact positions, coarse material may be present. Although deltaic deposits may be large, the probability of obtaining coarse material is generally low.

Glaciolacustrine Plains (LP): The nearly level surface marking the floor of an extinct glacial lake is called a glaciolacustrine plain. The sediments that form the plain are predominantly fine to medium sand, silt and clay, and were deposited in relatively deep water. Lacustrine deposits are generally of low value as aggregate sources because of their fine grain size and lack of crushable material. In some aggregate-poor areas, lacustrine deposits may constitute valuable sources of fill and some granular subbase aggregate.

GLACIOMARINE DEPOSITS

Glaciomarine Beach Deposits (MB): Similar to glaciolacustrine beach deposits, glaciomarine beach deposits are formed in a glaciomarine environment (i.e., ocean rather than lake environment).

Glaciomarine Plains (MP): Similar to glaciolacustrine plains, glaciomarine plains are the result of a glaciomarine environment.

GLACIAL DEPOSITS

End Moraines (EM): These are belts of glacial drift deposited at, and parallel to, glacier margins. End moraines commonly consist of ice-contact stratified drift and, in such instances, are usually called kame moraines. Kame moraines commonly result from deposition between 2 glacial lobes (interlobate moraines). The probability of locating aggregates within such features is moderate to low. Exploration and development costs are high. Moraines may be very large and contain vast aggregate resources, but the location of the best areas within the moraine is usually poorly defined.

EOLIAN DEPOSITS

Windblown Deposits (WD): Windblown deposits are those formed by the transport and deposition of sand by winds. The form of the deposits ranges from extensive, thin layers to well-developed linear and crescentic ridges known as dunes. Most windblown deposits in Ontario are derived from, and deposited on, pre-existing lacustrine sand plain deposits. Windblown sediments almost always consist of fine to coarse sand and are usually well sorted. The probability of locating crushable aggregate in windblown deposits is very low.

Appendix D – Geology of Bedrock Deposits

The purpose of this appendix is to familiarize the reader with the general bedrock geology of southern Ontario (Figure D1) and, where known, the potential uses of the various bedrock formations. The reader is cautioned against using this information for more specific purposes. The stratigraphic chart (Figure D2) is intended only to illustrate the stratigraphic sequences in particular geographic areas and should not be used as a regional correlation table.

The following description is arranged in ascending stratigraphic order, on a group and formation basis. Precambrian rocks are not discussed. Additional stratigraphic information is included for some formations where necessary. The publications and maps of the Ontario Geological Survey (e.g., Johnson et al. 1992 and Armstrong and Carter 2006) and the Geological Survey of Canada should be referred to for more detailed information. The lithology, thickness and general use of rocks from these formations are noted. If a formation may be suitable for use as aggregate and aggregate suitability test data are available, the data have been included in the form of ranges. The following short forms have been used in presenting these data:

AAV = aggregate abrasion value,
Absn = absorption (percent),
BRD = bulk relative density,
LA = Los Angeles abrasion and impact test (loss in percent),
$MgSO_4$ = magnesium sulphate soundness test (loss in percent),
PN (A-C) = PN (Asphalt & Concrete) = petrographic number for asphalt ("A") and concrete ("C") use,
PSV = polished stone value.

The ranges are intended as a guide only and care should be exercised in extrapolating the information to specific situations. Aggregate suitability test data have been provided by the Ministry of Transportation of Ontario. Aggregate suitability tests are defined in Appendix E. Aggregate product specifications are also provided in Appendix E.

Covey Hill Formation (Cambrian)

STRATIGRAPHY and/or OCCURRENCE: Lower formation of the Potsdam Group.
LITHOLOGY: Interbedded noncalcareous feldspathic conglomerate and sandstone.
THICKNESS: 0 to 14 m.
USES: Has been quarried for aggregate in the United Counties of Leeds–Grenville.

Nepean Formation (Cambrian)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Potsdam Group.
LITHOLOGY: Thin- to massive-bedded quartz sandstone with some conglomerate interbeds and rare shaly partings.
THICKNESS: 0 to 30 m.
USES: Suitable as dimension stone; quarried at Philipsville and Forfar for silica sand; alkali–silica reactive in Portland cement concrete.
AGGREGATE SUITABILITY TESTING: PSV = 54-68, AAV = 4-15, $MgSO_4$ = 9-32, LA = 44-90, Absn = 1.6-2.6, BRD = 2.38-2.50, PN (A-C) = 130-140.

March Formation (Lower Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Lower formation of the Beekmantown Group.
LITHOLOGY: Interbedded quartz sandstone, dolomitic quartz sandstone, sandy dolostone and dolostone.
THICKNESS: 6 to 64 m.
USES: Quarried extensively for aggregate in areas of outcrop and subcrop; alkali–silica reactive in Portland cement concrete; lower part of formation is an excellent source of skid-resistant aggregate. The formation is suitable for use as facing stone and paving stone.
AGGREGATE SUITABILITY TESTING: PSV = 55-60, AAV = 4-6, $MgSO_4$ = 1-17, LA = 15-38, Absn = 0.5-0.9, BRD = 2.61-2.65, PN (A-C) = 110-150.

Oxford Formation (Lower Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Beekmantown Group.
LITHOLOGY: Thin- to thick-bedded, microcrystalline to medium-crystalline, grey dolostone with thin shaly inter-beds.
THICKNESS: 61 to 102 m.
USES: Quarried in the Brockville and Smith Falls areas and south of Ottawa for use as aggregate.
AGGREGATE SUITABILITY TESTING: PSV = 47-48, AAV = 7-8, $MgSO_4$ = 1-4, LA = 18-23, Absn = 0.7-0.9, BRD = 2.74-2.78, PN (A-C) = 105-120.

Rockcliffe Formation (Lower Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Divided into a lower member and an upper (St. Martin) member.
LITHOLOGY: Interbedded quartz sandstone and shale; interbedded shaly bioclastic limestone and shale predominate in the upper member.
THICKNESS: 0 to 125 m.
USES: Upper member has been quarried east of Ottawa for aggregate; lower member has been used as crushed stone; some high-purity limestone beds in upper member may be suitable for use as fluxing stone and in lime production.
AGGREGATE SUITABILITY TESTING: PSV = 58-63, AAV = 10-11, $MgSO_4$ = 12-40, LA = 25-28, Absn = 1.8-1.9, BRD = 2.55-2.62, PN (A-C) = 122-440.

Shadow Lake Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The basal unit of the Black River Group. Informally, the formation is known as the basal unit of the Ottawa Group in eastern Ontario and the basal unit of the Simcoe Group in central Ontario.
LITHOLOGY: Poorly sorted, red and green sandy shales; argillaceous and arkosic sandstones; minor sandy argillaceous dolostones and rare basal arkosic conglomerate.
THICKNESS: 0 to 15 m.

USES: Potential source of decorative stone; very limited value as aggregate source.

Gull River Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Part of the Black River Group. Informally, the formation is part of the Simcoe Group in central Ontario and the Ottawa Group in eastern Ontario. In eastern Ontario, the formation is subdivided into upper and lower members; in central Ontario, it is presently subdivided into upper, middle and lower members.
LITHOLOGY: In central and eastern Ontario, the lower member consists of alternating units of limestone, dolomitic limestone and dolostone. West of Lake Simcoe, the lower member is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone. The upper and middle members are dense microcrystalline limestones with argillaceous dolostone interbeds. The upper member also consists of thin-bedded limestones with thin shale partings.
THICKNESS: 7.5 to 135 m.
USES: Quarried in the Lake Simcoe, Kingston, Ottawa and Cornwall areas for crushed stone. Rock from certain layers has proven to be alkali reactive when used in Portland cement concrete (alkali–carbonate reaction).
AGGREGATE SUITABILITY TESTING: PSV = 41-49, AAV = 8-12, MgSO4 = 3-17, LA = 18-28, Absn = 0.3-0.9, BRD = 2.68-2.73, PN (A-C) = 100-153, micro-Deval (C) = 8.8-18.7, mortar bar (14 days) = 0.004-0.030.

Bobcaygeon Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Informally, the formation is part of the Simcoe Group in central Ontario and the Ottawa Group in eastern Ontario. The formation is subdivided into upper, middle and lower members. Formally, some researchers refer to the lower member as the Coboconk Formation of the Black River Group. The upper and middle members are sometimes referred to as the Kirkfield Formation, a part of the Trenton Group.
LITHOLOGY: The lower member is light grey-tan to brown-grey, medium- to very thick-bedded, fine- to medium-grained, bioturbated to current-laminated, bioclastic limestones, wackestones, packstones and grainstones. The middle member is thin- to medium-bedded, tabular-bedded, bioclastic, very fine- to fine-grained limestones with green shale interbeds and partings. The upper member is similar to the middle member, but also includes fine- to medium-grained, dark grey to light brown, thin- to medium-bedded, irregular to tabular bedded, bioturbated, horizontal to low-angle cross-laminated, bioclastic, fossiliferous limestones, wackestones, packstones and grainstones.
THICKNESS: 7 to 87 m.
USES: Quarried at Brechin, Marysville and in the Ottawa area for crushed stone. Generally suitable for use as granular base course aggregate. Rock from certain layers has been found to be alkali reactive when used in Portland cement concrete (alkali–silica reaction).
AGGREGATE SUITABILITY TESTING: PSV = 47-51, AAV = 14-23, $MgSO_4$ = 1-40, LA = 18-32, Absn = 0.3-2.4, BRD = 2.5-2.69, PN (A-C) = 100-320.

Verulam Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Verulam Formation is often referred to as the Sherman Fall Formation of the Trenton Group. Informally, the formation is part of the Simcoe and Ottawa groups.
LITHOLOGY: The Verulam Formation is informally subdivided into 2 members. The lower member consists of interbedded with limestone and calcareous shale. The limestone beds are very fine to coarse grained, thin to thick bedded, nodular to tabular bedded, light to dark grey-brown and fossiliferous. The upper member is thin- to thick-bedded, medium- to coarse-grained, cross-stratified, tan to light grey, fossiliferous, bioclastic limestone.
THICKNESS: 32 to 67 m.
USES: Quarried at Picton and Bath for use in cement manufacture. Quarried for aggregate in Ramara Township, Simcoe County and in the Belleville–Kingston area. The formation may be unsuitable for use as aggregate in some areas because of its high shale content.
AGGREGATE SUITABILITY TESTING: PSV = 43-44, AAV = 9-13, $MgSO_4$ = 4-45, LA = 22-29, Absn = 0.4-2.1, BRD = 2.59-2.70, PN (A-C) = 120-255.

Lindsay Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Lindsay Formation is divided into 2 members. The lower member is often referred to as the Cobourg Formation of the Trenton Group. The upper member is referred to as the Collingwood Member of the Trenton Group. In eastern Ontario, the Collingwood Member is often referred to as the Eastview Member. Informally, the Lindsay Formation is part of the Simcoe and Ottawa groups.
LITHOLOGY: The lower member is interbedded, very fine- to coarse-grained, bluish-grey to grey-brown limestone with undulating shale partings and interbeds of dark grey calcareous shale. The Collingwood Member is a black, organic-rich, petroliferous, calcareous shale with very thin, fossiliferous, bioclastic limestone interbeds.
THICKNESS: The upper member is up to 10 m thick, whereas the lower member can be up to 60 m thick.
USES: In eastern Ontario, the lower member is used extensively for aggregate production; in central Ontario, it is quarried at Picton, Ogden Point and Bowmanville for cement. The formation may be suitable or unsuitable for use as concrete and asphalt aggregate.
AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 2-47, LA = 20-28, Absn = 0.4-1.3, BRD = 2.64-2.70, PN (A-C) = 110-215.

Blue Mountain and Billings Formations (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Blue Mountain Formation includes the upper and middle members of the former Whitby Formation. In eastern Ontario, the Billings Formation is equivalent to part of the Blue Mountain Formation.

LITHOLOGY: Blue-grey to grey-brown, noncalcareous shales with thin, minor interbeds of limestone and siltstone. The Billings Formation is dark grey to black, noncalcareous to slightly calcareous, pyritiferous shale with dark grey limestone laminae and grey siltstone interbeds.
THICKNESS: Blue Mountain Formation - 43 to 60 m; Billings Formation - 0 to 62 m.
USES: The Billings Formation may be a suitable source for structural clay products and lightweight expanded aggregate. The Blue Mountain Formation may be suitable for structural clay products.

Georgian Bay and Carlsbad Formations (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Georgian Bay Formation trends in a northwest direction from Lake Ontario toward Georgian Bay. The Carlsbad Formation is the equivalent of the Georgian Bay Formation in eastern Ontario.
LITHOLOGY: The Georgian Bay Formation consists of greenish to bluish-green shale interbedded with limestone, siltstone and sandstone. The Carlsbad Formation consists of interbedded shale, siltstone and bioclastic limestone.
THICKNESS: Georgian Bay Formation - 125 to 200 m; Carlsbad Formation - 0 to 186 m.
USES: Georgian Bay Formation was previously used by several producers in the Metropolitan Toronto area to produce brick and structural tile, as well as for making Portland cement. At Streetsville, expanded shale was used in the past to produce lightweight aggregate. These operations are no longer in production. The Carlsbad Formation may be used as a source material for brick and tile manufacturing and has potential as a lightweight expanded aggregate.

Queenston Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Queenston Formation conformably overlies the Georgian Bay Formation and crops out along the base of the Niagara Escarpment.
LITHOLOGY: Red-maroon, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding.
THICKNESS: 45 to 335 m.
USES: There are several quarries developed in the Queenston Formation along the base of the Niagara Escarpment and one at Russell, near Ottawa. All extract shale for brick manufacturing. The Queenston Formation is the most important source of material for brick manufacture in Ontario.

Whirlpool Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Lower formation of the Cataract Group, generally located in the Niagara Peninsula and along the Niagara Escarpment as far north as Duntroon.
LITHOLOGY: White to grey to maroon, fine-grained, orthoquartzitic sandstone with thin grey shale partings.
THICKNESS: 0 to 9 m.
USES: Building stone, flagstone.

Manitoulin Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. The formation generally occurs north of Stoney Creek.
LITHOLOGY: Thin- to medium-bedded, moderately fossiliferous, fine- to medium-crystalline dolostone with minor grey-green shale. Chert nodules or lenses, and silicified fossils have also been reported within the formation.
THICKNESS: 0 to 25 m.
USES: Extracted for crushed stone in Grey County, and for decorative stone on Manitoulin Island.

Cabot Head Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. The formation occurs in the subsurface throughout southwestern Ontario and crops out along the length of the Niagara Escarpment.
LITHOLOGY: Grey to green to red-maroon, noncalcareous shales with subordinate sandstone and carbonate interbeds.
THICKNESS: 12 to 40 m.
USES: Potential source of lightweight aggregate. Extraction opportunities are limited by the lack of suitable exposures.

Grimsby Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Cataract Group. The formation has been identified along the Niagara Peninsula as far north as Clappison's Corners.
LITHOLOGY: Interbedded sandstone, dolomitic sandstone and red shale. The lower part of the Grimsby Formation becomes greener and shalier as it grades into the upper Cabot Head Formation.
THICKNESS: 0 to 15 m.
USES: No present uses.

Thorold Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Lower formation in the Clinton Group.
LITHOLOGY: Grey-green to white, fine- to coarse-grained, quartzose sandstone with minor thin grey to green shale or siltstone partings.
THICKNESS: 2 to 7 m.
USES: No present uses.

Neagha Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group.
LITHOLOGY: Dark to greenish grey shale, sparsely fossiliferous, fissile shale, with minor thin limestone interbeds. The base of the Neagha Formation consists of a phosphatic pebble lag that indicates an unconformable contact with the underlying Thorold Formation.
THICKNESS: 0 to 2 m.
USES: No present uses.

Dyer Bay Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. Crops out on Manitoulin Island and along the east side of the Bruce Peninsula as far south as Owen Sound. In the subsurface, it underlies the Bruce Peninsula and most of Essex and Kent counties.

LITHOLOGY: Thin- to medium-bedded, fine- to medium-grained, blue-grey to brown, argillaceous, fossiliferous dolostone with green-grey shaly partings.
THICKNESS: 0 to 8 m.
USES: No present uses.

Wingfield Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. Occurs on Manitoulin Island and the northernmost part of the Bruce Peninsula.
LITHOLOGY: Interbedded brown, fine- to medium-grained, argillaceous dolostone and olive-green, noncalcareous, sparsely fossiliferous shale.
THICKNESS: 0 to 15 m.
USES: No present uses.

St. Edmund Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. Occurs on Manitoulin Island and the northernmost part of the Bruce Peninsula. The upper portion of the formation was previously termed the Mindemoya Formation.
LITHOLOGY: Light creamy tan, microcrystalline, thin-bedded, sparsely fossiliferous dolostone with tan to brown, fine- to medium-crystalline, thick-bedded dolostone.
THICKNESS: 0 to 25 m.
USES: Quarried for fill and crushed stone on Manitoulin Island.
AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-2, LA = 19-21, Absn = 0.6-0.7, BRD = 2.78-2.79, PN (A-C) = 105.

Fossil Hill Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group. Occurs on Manitoulin Island and the northern part of the Bruce Peninsula.
LITHOLOGY: Thin- to medium-bedded, very fine- to coarse-grained, very fossiliferous dolostone. The formation also contains intervals of tan-grey, very fine-crystalline, sparsely fossiliferous dolostone.
THICKNESS: 3 to 34 m.
USES: The formation is sometimes quarried along with the overlying Amabel and Lockport formations.
AGGREGATE SUITABILITY TESTING: (Fossil Hill Formation on Manitoulin Island) $MgSO_4$ = 41, LA = 29, Absn = 4.1, BRD = 2.45, PN (A-C) = 370.

Reynales Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group. The Reynales Formation occurs on the Niagara Peninsula and along the Niagara Escarpment as far north as the Forks of the Credit.
LITHOLOGY: Light to dark grey, buff weathering, thin- to thick-bedded, very fine- to fine-grained, sparsely fossiliferous dolostone to argillaceous dolostone, with thin shaly interbeds and partings.
THICKNESS: 0 to 5 m.
USES: The formation is sometimes quarried along with overlying Amabel and Lockport formations.

Irondequoit Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group generally along the Niagara Peninsula south of Waterdown.
LITHOLOGY: Thick- to massive-bedded, light to pinkish grey, medium- to coarse-grained, crinoidal- and brachiopod-rich limestone.
THICKNESS: 0 to 10 m.
USES: Not utilized extensively.

Rochester Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group generally along the Niagara Peninsula.
LITHOLOGY: Dark grey to black, calcareous shale with variably abundant, thin, fine- to medium-grained calcareous to dolomitic calcisiltite to bioclastic calcarenite interbeds.
THICKNESS: 5 to 24 m.
USES: Not utilized extensively.
AGGREGATE SUITABILITY TESTING: PSV = 69, AAV = 17, $MgSO_4$ = 95, LA = 19, Absn = 2.2, BRD = 2.67, PN (A-C) = 400.

Decew Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group south of Waterdown along the Niagara Escarpment.
LITHOLOGY: Very fine- to fine-grained, argillaceous to arenaceous dolostone, with locally abundant shale partings and interbeds.
THICKNESS: 0 to 4 m.
USES: Too shaly for high-quality uses, but it is quarried along with the Lockport Formation in places.
AGGREGATE SUITABILITY TESTING: PSV = 67, AAV = 15, $MgSO_4$ = 55, LA = 21, Absn = 2.2, BRD = 2.66, PN (A-C) = 255.

Lockport and Amabel Formations (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: The Lockport Formation occurs from Waterdown to Niagara Falls and is subdivided into 2 formal members: the Gasport and Goat Island members. The Amabel Formation is found from Waterdown to Cockburn Island and has been subdivided into the Lions Head and Wiarton members.
LITHOLOGY: The Gasport Member consists of thick- to massive-bedded, fine- to coarse-grained, blue-grey to white to pinkish grey dolostone and dolomitic limestone, with minor argillaceous dolostone. The Goat Island Member is dark to light grey to brown, very fine- to fine-crystalline, thin- to medium-bedded, irregularly bedded, variably argillaceous dolostone with locally abundant chert and vugs filled with gypsum, calcite or fluorite. Near Hamilton, abundant chert nodules and lenses in the Goat Island member have been informally named the Ancaster chert beds. A shaly interval, termed the Vinemount shale, occurs at the top of the Goat Island near and east of Hamilton.

The Wiarton Member consists of massive-bedded, blue-grey mottled, light grey to white, fine- to coarse-crystalline, porous crinoidal dolostone. Underlying the Wiarton Member in the Bruce Peninsula is the Colpoy Bay Member which is browner, finer grained and less fossiliferous than the Wiarton Member. The Lions Head Member consists of light grey to grey-brown, fine-crystalline, thin- to medium-bedded, sparsely fossiliferous dolostone with abundant chert nodules.

THICKNESS: (Lockport and Amabel) 3 to 40 m.

USES: Both formations have been used to produce lime, crushed stone, concrete aggregate and building stone throughout their area of occurrence, and are a resource of provincial significance.

AGGREGATE SUITABILITY TESTING: PSV = 36-49, AAV = 10-17, $MgSO_4$ = 2-6, LA = 25-32, Absn = 0.4-1.54, BRD = 2.61-2.81, PN (A-C) = 100-105.

Guelph Formation (Lower to Upper Silurian)

STRATIGRAPHY and/or OCCURRENCE: Exposed south and west of the Niagara Escarpment from the Niagara River to the tip of the Bruce Peninsula. The formation is also present in the subsurface of southwestern Ontario.

LITHOLOGY: The formation is tan- to brown-coloured, fine- to medium-crystalline, moderately to very fossiliferous, commonly biostromal to biohermal, sucrosic dolostones. In places, the formation is characterized by extensive vuggy, porous reefal facies of high chemical purity. The Eramosa Member consists of thin- to thick-bedded, tan to black, fine- to medium-crystalline, variably fossiliferous, bituminous dolostone. Locally, the Eramosa Member is argillaceous and cherty.

THICKNESS: 4 to 100 m.

USES: Some areas appear soft and unsuitable for use in the production of load-bearing aggregate. This unit requires additional testing to fully establish its aggregate suitability. The main use is for dolomitic lime for cement manufacture. The formation is quarried near Hamilton and Guelph.

Salina Formation (Group) (Upper Silurian)

STRATIGRAPHY and/or OCCURRENCE: Present in the subsurface of southwestern Ontario; only rarely exposed at surface. In southern Ontario, the succession of evaporates and evaporite-related sediments underlying the Bass Islands and Bertie formations, and overlying the reefal dolostones of the Guelph Formation, have been termed the Salina Formation. In other jurisdictions, this formation is often referred to as the Salina Group.

LITHOLOGY: Grey and maroon shale, brown dolostone and, in places, salt, anhydrite and gypsum; consists predominantly of evaporitic-rich material with up to 8 units identifiable. The Salina Group is dominated by evaporate lithologies in the Michigan Basin and become gradually shalier into the Appalachian Basin.

THICKNESS: 113 to 420 m.

USES: Gypsum mines at Hagersville, Caledonia and Drumbo. Salt is mined at Goderich and Windsor and is produced from brine wells at Amherstburg, Windsor and Sarnia.

Bertie and Bass Islands Formations (Upper Silurian)

STRATIGRAPHY and/or OCCURRENCE: The Bertie Formation is an Appalachian Basin unit found in the Niagara Peninsula. The Bertie Formation is equivalent to the Bertie Group of New York and, therefore, consists of the Oatka, Falkirk, Scajaquada, Williamsville and Akron members in Ontario. The Bass Islands Formation is a Michigan Basin equivalent of the Bertie Formation, which rarely crops out in Ontario, but is present in the subsurface in southwestern Ontario.

LITHOLOGY: The Bertie Formation consists of a succession of dark brown to light grey-tan, very fine- to fine-grained, variably laminated and bituminous, sparsely fossiliferous dolostones with argillaceous dolostones and minor shales. The Bass Islands Formation consists of dark brown to light grey-tan, variably laminated, mottled, argillaceous and bituminous, very fine- to fine-crystalline and sucrosic dolostones with minor anhydritic and sandstone beds.

THICKNESS: 10 to 90 m.

USES: Quarried for crushed stone on the Niagara Peninsula; shaly intervals are unsuitable for use as high specification aggregate because of low freeze–thaw durability. These formations have also been extracted for the production of lime.

AGGREGATE SUITABILITY TESTING: PSV = 46-49, AAV = 8-11, $MgSO_4$ = 4-19, LA = 14-23, Absn = 0.8-2.8, BRD = 2.61-2.78, PN (A-C) = 102-120.

Oriskany Formation (Lower Devonian)

STRATIGRAPHY and/or OCCURRENCE: Lower Devonian clastic unit, found in the Niagara Peninsula. The formation is equivalent to the Oriskany Formation in New York and Ohio and the Garden Island Formation of Michigan.

LITHOLOGY: Grey to yellowish white, coarse-grained, thick- to massive-bedded, calcareous quartzose sandstone.

THICKNESS: 0 to 5 m.

USES: The formation has been quarried for silica sand, building stone and armour stone. The formation may be acceptable for use as rip rap and well-cemented varieties may be acceptable for some asphaltic products.

AGGREGATE SUITABILITY TESTING: (of a well-cemented variety of the formation) PSV = 64, AAV = 6, $MgSO_4$ = 2, LA = 29, Absn = 1.2-1.3, BRD = 2.55, PN (A-C) = 107.

Bois Blanc Formation (Lower Devonian)

STRATIGRAPHY and/or OCCURRENCE: The formation disconformably overlies Silurian strata or, where present, the Lower Devonian Oriskany Formation. The Springvale Member forms the lower portion of formation.

LITHOLOGY: Greenish grey to grey-brown, thin- to medium-bedded, fine- to medium-grained, fossiliferous, bioturbated, cherty limestone and dolostone. The Springvale Member is a white to green-brown, commonly glauconitic, rarely argillaceous, quartzitic sandstone with minor sandy carbonates.

THICKNESS: 3 to 50 m. The Springvale Member is generally from 3 to 10 m thick; however, 30 m thickness has been reported.

USES: Quarried at Hagersville, Cayuga and Port Colborne for crushed stone. Material is generally unsuitable for concrete aggregate because of a high chert content.

AGGREGATE SUITABILITY TESTING: PSV = 48-53, AAV = 3-7, $MgSO_4$ = 3-18, LA = 15-22, Absn = 1.3-2.8, BRD = 2.50-2.70, PN (A-C) = 102-290.

Onondaga Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Correlated to part of the Detroit River Group. Outcrops occur on the Niagara Peninsula from Simcoe to Niagara Falls. The formation includes the Edgecliffe, Clarence and Moorehouse members.
LITHOLOGY: Medium-bedded, fine- to coarse-grained, dark grey-brown or purplish-brown, variably cherty limestone.
THICKNESS: 8 to 25 m.
USES: Quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne. The high chert content makes much of the material unsuitable for use as concrete and asphaltic aggregate. The formation has been used as a raw material in cement manufacture.
AGGREGATE SUITABILITY TESTING: (Clarence and Edgecliffe members) $MgSO_4$ = 1-6, LA = 16.8-22.4, Absn = 0.5-1.1, PN (A-C) = 190-276.

Amherstburg Formation (Lower to Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Detroit River Group. The formation correlates to the Amherstburg Formation of Michigan and the lower part of the Onondaga Formation in western New York. The Onondaga Formation terminology has been used in the outcrop belt of southern Ontario east of Norfolk County.
LITHOLOGY: Tan to grey-brown to dark brown, fine- to coarse-grained, bituminous, bioclastic, fossiliferous limestones and dolostone. Stromatoporoid-dominated bioherms are locally significant in Bruce and Huron counties and have been termed the Formosa Reef Limestone or Formosa reef facies.
THICKNESS: 0 to 60 m. The Formosa Reef Limestone is up to 26 m.
USES: Cement manufacture, agricultural lime, aggregate.
AGGREGATE SUITABILITY TESTING: PSV = 57, AAV = 19, $MgSO_4$ = 9-35, LA = 26-52, Absn = 1.1-6.4, BRD = 2.35-2.62, PN (A-C) = 105-300.

Lucas Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Detroit River Group in southwestern Ontario. The formation is subdivided into 3 lithological units: the Lucas Formation undifferentiated, the Anderdon Member limestone and the Anderdon Member sandy limestone.
LITHOLOGY: The undifferentiated Lucas Formation consists of thin- to medium-bedded, light to grey-brown, fine crystalline, poorly fossiliferous dolostone and limestone. Anhydrite and gypsum beds are present near Amherstburg and Goderich. The Anderdon Member consists of light to dark grey-brown, thin- to medium-bedded, fine-grained, sparsely fossiliferous limestone, alternating with coarse-grained, bioclastic limestone.
THICKNESS: 40 to 99 m.
USES: Most important source of high-purity limestone in Ontario. Used as calcium lime for metallurgical flux and for the manufacture of chemicals. Rock of lower purity is used for cement manufacture, agricultural lime and aggregate. The Anderdon Member is quarried at Amherstburg for crushed stone.
AGGREGATE SUITABILITY TESTING: PSV = 46-47, AAV = 15-16, $MgSO_4$ = 2-60, LA = 22-47, Absn = 1.1-6.5, BRD = 2.35-2.40, PN (A-C) = 110-160.

Dundee Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: The Dundee Formation occurs between the Hamilton Group or Marcellus Formation and the limestones and dolostones of the Detroit River Group. There are few outcrops and the formation is observed mostly in the subsurface of southwestern Ontario.
LITHOLOGY: Grey to tan to brown, fossiliferous, medium- to thick-bedded limestones and minor dolostones. Bituminous partings and microstylolites are common. Chert nodules are locally abundant.
THICKNESS: 35 to 45 m.
USES: Quarried near Port Dover and on Pelee Island for crushed stone. Used at St. Marys as a raw material for Portland cement.
AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-28, LA = 22-46, Absn = 0.6-6.8, PN (A-C) = 125-320.

Marcellus Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Subsurface unit, mostly found below Lake Erie and extending into the eastern USA, pinches out in the Port Stanley area. The formation occurs on the southeast side of the Algonquin Arch.
LITHOLOGY: Black, organic-rich shales with interbeds of grey shale and very fine- to medium-grained, impure carbonates.
THICKNESS: 0 to 12 m.
USES: No present uses.

Bell Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Lowest formation of the Hamilton Group, not known to crop out in Ontario.
LITHOLOGY: Blue-grey, soft, calcareous shale with thin limestone and organic-rich interbeds toward the base of the formation.
THICKNESS: 0 to 14.5 m.
USES: No present uses.

Rockport Quarry Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Hamilton Group; not known to crop out in Ontario.
LITHOLOGY: Grey to brown, fine-grained argillaceous limestone.
THICKNESS: 0 to 6 m.
USES: No present uses.

Arkona Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Hamilton Group.
LITHOLOGY: Blue-grey, plastic, soft, calcareous shale with minor thin and laterally discontinuous argillaceous limestone beds.

THICKNESS: 5 to 37 m.
USES: Has been extracted at Thedford and near Arkona for the production of drainage tile.

Hungry Hollow Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Hamilton Group.
LITHOLOGY: The upper part of the formation is a coral-rich, calcareous shale-dominated unit. The lower part of the formation is predominantly fossiliferous, bioclastic limestone.
THICKNESS: 0 to 2 m.
USES: Suitable for some crushed stone and fill with very selective quarrying methods.

Widder Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Hamilton Group.
LITHOLOGY: Calcareous, grey to brown-grey shale, bioturbated, fine-grained, argillaceous, nodular limestone and coarse-grained bioclastic limestone.
THICKNESS: 0 to 21 m.
USES: No present uses.

Ipperwash Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Hamilton Group; very limited distribution in Ontario.
LITHOLOGY: Grey-brown, fine- to coarse-grained, argillaceous and bioclastic limestone with shaly interbeds.
THICKNESS: 2 to 13 m.
USES: No present uses.

Kettle Point Formation (Upper Devonian)

STRATIGRAPHY and/or OCCURRENCE: Occurs in a northwest-trending band between Sarnia and Lake Erie; small part overlain by Port Lambton Group rocks in extreme northwest.
LITHOLOGY: Dark brown to black, highly fissile, organic-rich shale with subordinate organic-poor, grey-green silty shale and siltstone interbeds.
THICKNESS: 0 to 75 m.
USES: Possible source of lightweight aggregate or fill.

Bedford Formation (Upper Devonian)

STRATIGRAPHY and/or OCCURRENCE: Lower formation of the Port Lambton Group.
LITHOLOGY: Light grey, soft, fissile shale with silty and sandy interbeds in the upper part of the formation.
THICKNESS: 0 to 30 m.
USES: No present uses.

Berea Formation (Upper Devonian)

STRATIGRAPHY and/or OCCURRENCE: Middle formation of the Port Lambton Group; not known to crop out in Ontario.
LITHOLOGY: Grey, fine- to medium-grained sandstone with grey shale and siltstone interbeds.
THICKNESS: 0 to 60 m.
USES: No present uses.

Sunbury Formation (Lower Mississippian)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Port Lambton Group; not known to crop out in Ontario.
LITHOLOGY: Black, organic-rich shale.
THICKNESS: 0 to 20 m.
USES: No present uses.

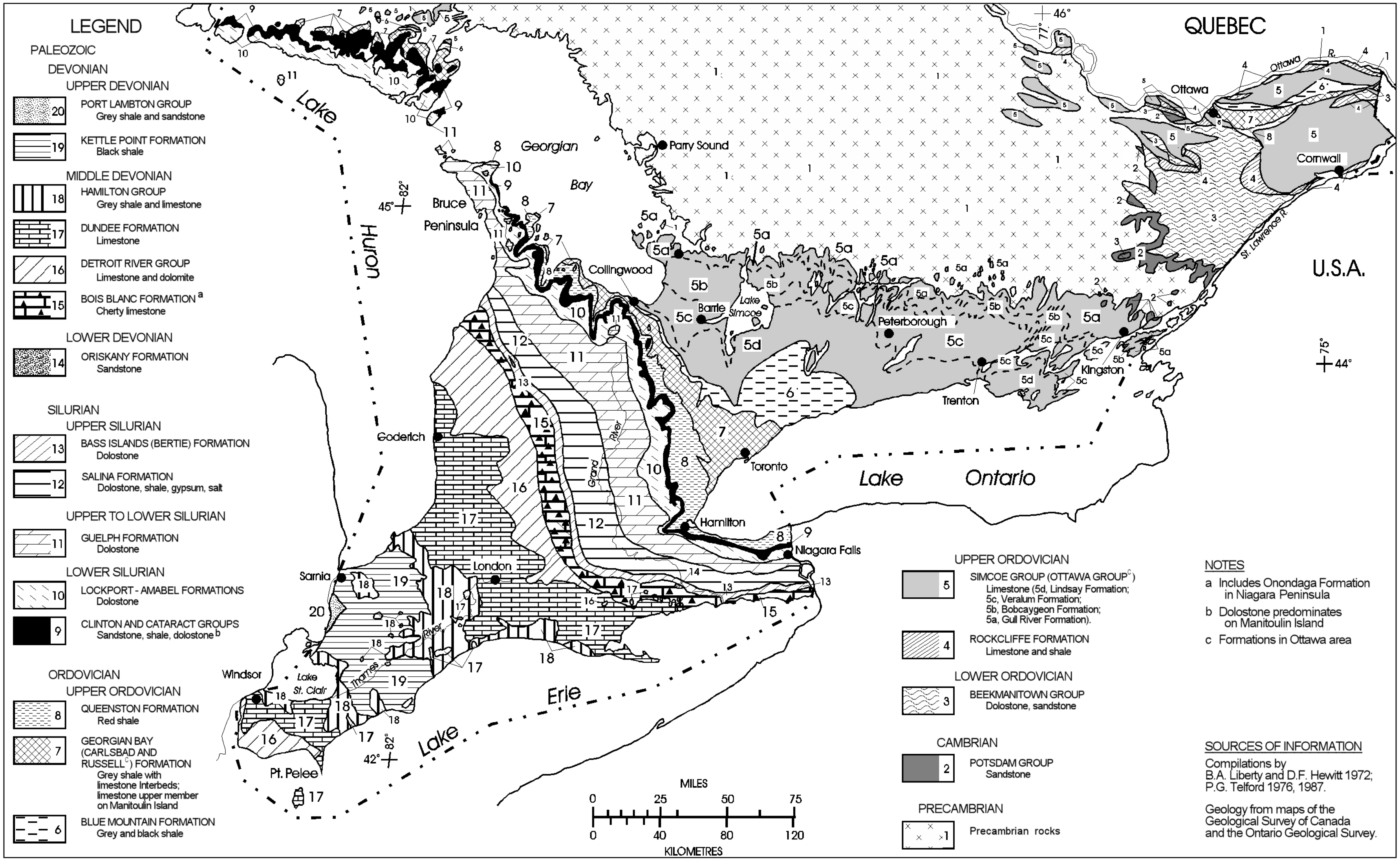


Figure D1. Bedrock geology of southern Ontario.

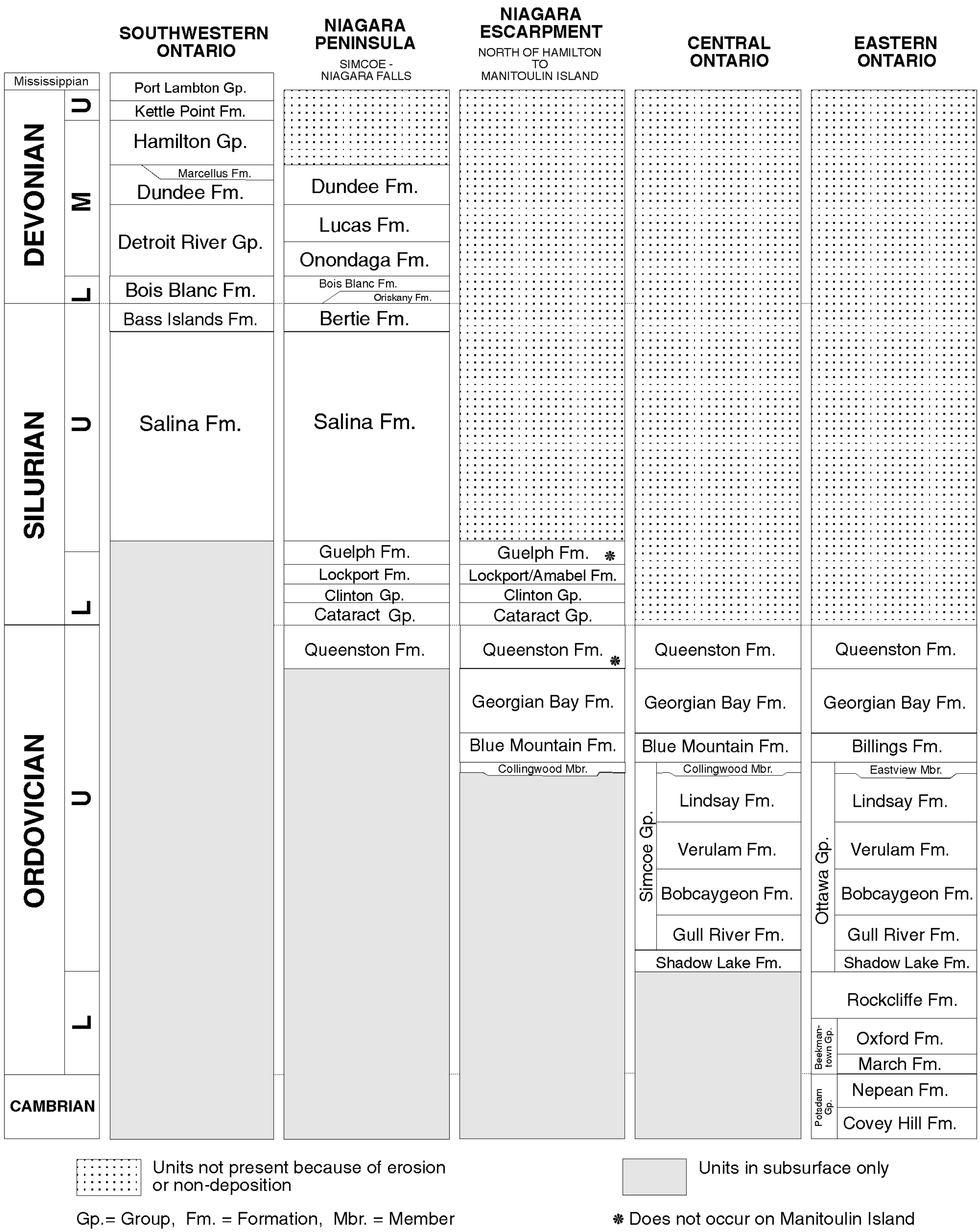


Figure D2. Exposed Paleozoic stratigraphic sequences in southern Ontario (*adapted from* Bezys and Johnson 1988 and Armstrong and Dodge 2007).

Appendix E – Aggregate Quality Test Specifications

Aggregate quality tests are performed by the Ministry of Transportation of Ontario (MTO) for the Ontario Geological Survey on sampled material. A brief description and the specification limits for each test are included in this appendix. Although a specific sample meets or does not meet the specification limits for a certain product, it may or may not be acceptable for that use based on field performance. Additional quality tests other than the tests listed in this appendix can be used to determine the suitability of an aggregate. Greater detail on the tests and aggregate specifications can be obtained from the MTO.

Absorption Capacity (LS-604): This test is related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate. This test is conducted in conjunction with the determination of the sample's relative density.

Accelerated Mortar Bar Expansion Test (LS-620): This is a rapid test for detecting alkali–silica reactive aggregates. It involves the crushing of the aggregate and the creation of standard mortar bars. For coarse and fine aggregates, suggested expansion limits of 0.10 to 0.15% are indicated for innocuous aggregates; greater than 0.10%, but less than 0.20%, indicates that it is unknown whether a potentially deleterious reaction will occur; and greater than 0.20% indicates that the aggregate is probably reactive and should not be used for Portland cement concrete. If the expansion limit exceeds 0.10% for coarse and fine aggregates, it is recommended that supplementary information be developed to confirm that the expansion is actually because of alkali reactivity. If confirmed deleteriously reactive, the material should not be used for Portland cement concrete unless corrective measures are undertaken such as the use of low- or reduced-alkali cement.

Aggregate Abrasion Value (AVV) (British Standard 812): The AAV is a measure of the resistance of aggregate to surface wear by abrasion using a standard silica sand. A low AVV (6 or less) implies good resistance to abrasion. An aggregate with good resistance to abrasion will usually give good macrotexture. This test is described in British Standard 812 (1975).

Bulk Relative Density (BRD) (ASTM C29): An aggregate with low relative density is lighter in weight than one with a high relative density. Low relative-density aggregates (less than about 2.5) are often non-durable for many aggregate uses.

Los Angeles Abrasion and Impact Test (LS-603 or ASTM C131): This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing. This test has been replaced by the micro-Deval abrasion test for coarse aggregate (see below), but, because of the large number of Los Angeles abrasion analyses that exist in historical MTO records, this test can still provide an indication of the aggregate quality.

Magnesium Sulphate Soundness Test (LS-606): This test is designed to simulate the action of freezing and thawing on aggregate. Those aggregates which are susceptible will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Micro-Deval Abrasion Test (LS-618 and LS-619): The micro-Deval abrasion test for fine aggregate is an accurate measure of the amount of hard, durable materials in sand-sized particles. This abrasion test is quick, cheap and more precise than the fine aggregate magnesium sulphate soundness test that suffers from a wide multi-laboratory variation. The magnesium sulphate soundness test is still considered an alternative test as indicated in many of the accompanying tables in this appendix. The micro-Deval abrasion test for coarse aggregate has replaced the Los Angeles abrasion and impact test.

Petrographic Examination (LS-609): Individual aggregate particles in a sample are divided into categories good, fair, poor and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

Polished Stone Value (PSV) (British Standard 812): The PSV is a measure of the resistance of aggregate to the polishing action of a pneumatic tire under conditions similar to those occurring on the road surface. The actual relationship between skidding resistance and PSV varies depending on the type of road surface, age, amount of traffic and other factors. Nevertheless, an aggregate with a high PSV will generally provide higher skid resistance than one with a low PSV. This test is described in British Standard 812 (1975). Values less than 45 indicate marginal frictional properties, whereas values greater than 55 indicate excellent frictional properties (average value no less than 50).

Unconfined Freeze–Thaw Test (LS-614): This test is designed to identify aggregate material that may be susceptible to excessive damage caused by freeze–thaw cycles. Aggregates that give losses greater than about 6% have a high probability of causing "popouts" on concrete and asphalt surfaces.

MATERIAL SPECIFICATIONS FOR AGGREGATES: BASE AND SUBBASE PRODUCTS

Table E1. Physical property requirements for aggregates: base, subbase, select subgrade and backfill material**.**

MTO Test Number	Laboratory Test	Granular O	Granular A	Granular B (Type I and Type III)	Granular B (Type II)	Granular M	Select Subgrade Material
LS-614	Unconfined Freeze–Thaw Loss (% maximum)	15	–	–	–	–	–
LS-616 LS-709	Fine Aggregate Petrographic Requirement	*[Note 1]*					
LS-618	Micro-Deval Abrasion Loss, Coarse Aggregate (% maximum loss)	21	25	30 *[Note 2]*	30	25	30 *[Note 2]*
LS-619	Micro-Deval Abrasion Loss, Fine Aggregate (% maximum loss)	25	30	35	35	30	–
LS-630	Amount of Contamination	*[Note 3]*					
LS-631	Plastic Fines	None Permitted					
LS-704	Plasticity Index (maximum)	0	0	0	0	0	0

Note 1. For materials north of the French River and Mattawa River only: for materials with >5.0% passing the 75 µm sieve, the amount of mica retained on the 75 µm sieve (passing the 150 µm sieve) shall not exceed 10% of the material in that sieve fraction unless testing (LS-709) determines permeability values >1.0 ×10^{-4} cm/s and/or field experience show satisfactory performance (prior data demonstrating compliance with this requirement will be acceptable provided such testing has been done within the past 5 years and field performance has been satisfactory).

Note 2. The coarse aggregate micro-Deval abrasion loss test requirement will be waived if the material has more than 80% passing the 4.75 mm sieve.

Note 3. Granular A, B Type I, B Type III, or M may contain up to 15% by mass crushed glass and/or ceramic material. Granular A, O, B Type I, B Type III and M shall not contain more than 1.0% by mass of wood, clay brick, and/or gypsum, and/or gypsum wall board or plaster. Granular B Type II and SSM shall not contain more than 0.1% by mass of wood.

Greater detail, additional specifications and other aggregate product information can be obtained from the Ministry of Transportation. Details above are derived from MTO SP-110513 (August 2007).

MATERIAL SPECIFICATIONS FOR AGGREGATES: HOT MIX ASPHALT PRODUCTS

Table E2. Physical property requirements for coarse aggregate (surface course): SMA, Superpave™ 9.5, 12.5, 12.5 FC1 and 12.5 FC2.

MTO Test Number	Laboratory Test	Superpave 9.5, 12.5	Aggregate Type			
			Gravel	Quarried Rock (SMA, Superpave 12.5 FC1 and 12.5 FC2)		
			(Superpave 12.5 FC1 only)	Dolomitic Sandstone	Traprock, Diabase, Andesite	Meta-arkose, Metagabbro, Gneiss
LS-601	Wash Pass, 75 µm sieve (% maximum loss)	1.3 *[Note 4]*	1.0 *[Note 5]*	1.0 *[Note 5]*	1.0 *[Note 5]*	1.0 *[Note 5]*
LS-604	Absorption (% maximum)	2.0	1.0	1.0	1.0	1.0
LS-608	Flat and Elongated Particles (% maximum (4:1))	20	15	15	15	15
LS-609	Petrographic Number (HL) (maximum)	*[Note 6]*	120	145	120	145
LS-613	Insoluble Residue Retained, 75 µm sieve (% minimum)	–	–	45	–	–
LS-614	Unconfined Freeze–Thaw Loss (% maximum loss)	6 *[Note 7]*	6	7	6	6
LS-618	Micro-Deval Abrasion Loss (% maximum loss)	17	10	15	10	15
Alternative Requirement for LS-614						
LS-606	Magnesium Sulphate Soundness Loss (% maximum loss)	12	–	–	–	–

Note 4. When control charts (n >20) are used for LS-601, the average value shall not exceed the specification maximum (1.3%), with no single value greater than 1.7%. When quarried rock is used as a source of coarse aggregate, a maximum of 2.0% passing the 75 µm sieve shall be permitted. When control charts (n >20) are used from LS-601 for quarried rock, the average value shall not exceed the specification maximum (2.0%) with no single value greater than 2.4%.

Note 5. When control charts (n >20) are used for LS-601, the average value shall not exceed the specification maximum (1.0%), with no single value greater than 1.4%.

Note 6. For the locations listed below, Petrographic Number (HL) is replaced by the following Petrographic Examination requirements. When the coarse aggregate for use in a surface course mix is obtained from a gravel pit or quarry containing more than 40% carbonate rock type, e.g., limestone and dolostone, then blending with aggregate of non-carbonate rock type shall be required such as to increase the non-carbonate rock type content of the coarse aggregate to 60% minimum, as determined by LS-609. The method of blending shall be uniform and shall be subject to approval by the owner. In cases of dispute, LS-613 shall be used with a minimum of acid insoluble residue of 60%. When the aggregate for a surface course mix is obtained from a non-carbonate gravel or quarry source, blending with carbonate rock types shall not be permitted. This requirement is applicable to coarse aggregates used in surface course mixes in the area to the north and west of a boundary defined as follows: the north shore of Lake Superior, the north shore of the St. Mary's River, the south shore of St. Joseph Island, the north shore of Lake Huron easterly to the north and east shore of Georgian Bay (excluding Manitoulin Island), along the Severn River to Washago and a line easterly passing through Norland, Burnt River, Burleigh Falls, Madoc, and hence easterly along Highway 7 to Perth and northerly to Calabogie and easterly to Arnprior and the Ottawa River.

Note 7. For Superpave 12.5 only, the requirements will be waived by the owner when the aggregate meets the alternative requirements for LS-606.

Table E3. Physical property requirements for coarse aggregate (binder course): Superpave™ 9.5, 12.5, 19.0, 25.0 and 37.5.

MTO Test Number	Laboratory Test	Superpave 9.5, 12.5, 19.0, 25.0 and 37.5
LS-601	Wash Pass, 75 µm sieve (% maximum loss)	1.3 *[Note 8]*
LS-604	Absorption (% maximum)	2.0
LS-608	Flat and Elongated Particles (% maximum (4:1))	*
LS-614	Unconfined Freeze–Thaw Loss (% maximum loss) *[Note 9]*	15
LS-618	Micro-Deval Abrasion Loss (% maximum loss)	21
Alternative Requirement for LS-614		
LS-606	Magnesium Sulphate Soundness Loss (% maximum loss)	15

Note 8. When control charts (n >20) are used for LS-601, the average value shall not exceed the specification maximum (1.3%), with no single value greater than 1.7%. When quarried rock is used as a source of coarse aggregate, a maximum of 2.0% passing the 75 µm sieve shall be permitted. When control charts (n>20) are used for LS-601 for quarried rock, the average value shall not exceed the specification maximum (2.0%), with no single value greater than 2.4%.

Note 9. This requirement will be waived by the owner when the aggregate meets the requirements for LS-606.

* Designer fill-in, contact the MTO.

Table E4. Physical property requirements for fine aggregate: SMA, Superpave™ 9.5, 12.5, 12.5 FC1, 12.5 FC2, 19.0, 25.0 and 37.5.

MTO Test Number	Laboratory Test	SMA, Superpave 12.5 FC2	Superpave 12.5 FC1	Superpave 9.5, 12.5, 19.0, 25.0 and 37.5
LS-619	Micro-Deval Abrasion Loss (% maximum loss) *[Note 10]*	15	20	25
LS-704	Plasticity Index (maximum)	0	0	0

Note 10. Where the blending method has been selected for QC, the micro-Deval abrasion loss of each individual fine aggregate in the stockpile, prior to blending, shall not exceed 35%.

Greater detail, additional specifications and other aggregate product information can be obtained from the Ministry of Transportation. The above specifications are from MTO SP-110F12 (2007).

MATERIAL SPECIFICATIONS FOR AGGREGATES: CONCRETE PRODUCTS

Table E5. Physical property requirements for coarse aggregate**.**

MTO or CSA Test Number	Laboratory Test	Acceptance Requirements	
		Pavement	Structures, Sidewalk, Curb and Gutter, and Concrete Base
LS-601	Material finer than 75 µm sieve, by washing (% maximum loss) *[Note 11]* • for gravel • for crushed rock	 1.0 2.0	 1.0 2.0
LS-604 or CSA A23.2-12A	Absorption (% maximum)	2.0	2.0
LS-608	Flat and Elongated Particles (% maximum (4:1))	20	20
LS-609	Petrographic Number (Concrete) (maximum)	125	140
LS-614 or CSA A23.2-24A	Unconfined Freeze–Thaw Loss (% maximum loss) *[Note 12]*	6	6
LS-618 or CSA A23.2-29A	Micro-Deval Abrasion Loss (% maximum loss)	14	17
LS-620 or CSA A23.2-25A	Accelerated Mortar Bar Expansion (% maximum at 14 days) *[Note 13, Note 14]*	0.150 *[Note 15]*	0.150 *[Note 15]*
CSA A23.2-14A	Concrete Prism Expansion (% maximum at 1 year) *[Note 13, Note 16]*	0.040	0.040
CSA A23.2-26A	Potential Alkali–Carbonate Reactivity of Quarried Carbonate Rock *[Note 17]*	Chemical composition must plot in the nonexpansive field of a specific figure used with test	
Alternative Requirement for LS-614			
LS-606	Magnesium Sulphate Soundness Loss, 5 cycles (% maximum loss) *[Note 12]*	12	12

General Notes:

- Where a concrete surface is subject to vehicular traffic, the physical requirements for "Pavement" will apply to the aggregate used.
- For air-cooled blast-furnace slag aggregate, the allowable maximum value for micro-Deval shall be 21% for structures and pavements and the allowable maximum value for absorption will conform to the owner's requirements for slag aggregate.
- A coarse aggregate may be accepted or rejected by the owner based on the results of freeze–thaw testing of concrete or field performance.

Note 11. When control charts (n >20) are used for LS-601, the average value shall not exceed the specification maximum (1.3%), with no single value greater than 1.7%. When quarried rock is used as a source of coarse aggregate, a maximum of 2.0% passing the 75 µm sieve shall be permitted. When control charts (n >20) are used for LS-601 for quarried rock, the average value shall not exceed the specification maximum (2.0%), with no single value greater than 2.4%.

Note 12. The owner will waive the requirements for freeze–thaw loss when the aggregate meets the alternative magnesium sulphate soundness requirements, LS-606.

Note 13. The need to demonstrate compliance with this requirement will be waived by the Contract Administrator if the source is on the current Ministry of Transportation regional Aggregate Source List (ASL) for Structural Concrete Fine and Coarse Aggregates or the Aggregate Source List of Concrete Base/Pavement Coarse Aggregates. If the aggregate is potentially expansive due to alkali-carbonate reaction as determined by CSA A23.2-26A, the aggregate shall meet the requirements of CSA A23.2-14A, even though it may be shown as a coarse aggregate on the ASL for Structural Concrete Fine and Coarse Aggregates or the ASL for Concrete Base/Pavement Coarse Aggregates.

Note 14. An aggregate that fails to meet these requirements will be accepted by the Contract Administrator provided the requirements of CSA A23.2-14A are met.

Note 15. If the aggregate is a quarried sandstone, siltstone, granite or gneiss, the expansion shall be less than 0.080% after 14 days. For quarried aggregates of the Gull River, Bobcaygeon, Verulam and Lindsay formations, the expansion shall be less than 0.100% after 14 days.

Note 16. An aggregate needs to meet this requirement only if it fails the requirements of either CSA A23.2-25A or CSA A23.2-26A. The test data shall have been obtained within the past 18 months from aggregate from the same location within the source as that to be used in the work. If this test is conducted to show that an average deemed potentially expansive by CSA A23.2-26A does not exceed 0.040% after one year, then chemical analysis, CSA A23.2-26A, shall be provided to show that the aggregate intended for use has the same chemical composition as the material tested in CSA A23.2-14A.

Note 17. This requirement only applies to aggregate quarried from the Gull River and Bobcaygeon formations of southern and eastern Ontario. These dolomitic limestones crop out on the southern margin of the Canadian Shield from Midland to Kingston and in the Ottawa–St. Lawrence Lowlands near Cornwall.

Table E6. Physical property requirements for fine aggregate**.**

MTO or CSA Test Number	Laboratory Test	Acceptance Limits
LS-610	Organic Impurities, (organic plate number) *[Note 18]*	3
LS-619 or CSA A23.2-23A	Micro-Deval Abrasion Loss (% maximum loss)	20
LS-620 or CSA A23.2-25A	Accelerated Mortar Bar Expansion (% maximum at 14 days) *[Note 19, Note 20]*	0.150
CSA A23.2-14A	Concrete Prism Expansion (% maximum at 1 year) *[Note 19, Note 21]*	0.040

Note 18. A fine aggregate producing a colour darker than standard colour No. 3 shall be considered to have failed this requirement. A failed fine aggregate may be used if comparative mortar specimens prepared according to ASTM C87 meet the following requirements:

- Mortar specimens prepared using unwashed fine aggregate shall have a 7 day compressive strength that is a minimum of 95% of the strength of mortar specimens prepared using the same fine aggregate washed in a 3% sodium hydroxide solution. Type GU hydraulic cement shall be used.
- Setting time of the unwashed fine aggregate mortar specimens shall not differ from washed fine aggregate mortar specimens by more than 10%.

Note 19. The need for data to demonstrate compliance with this requirement shall be waived by the Contract Administrator if the aggregate source is on the current Ministry of Transportation's regional Aggregate Source List for Structural Concrete Fine and Coarse Aggregates.

Note 20. An aggregate that fails this requirement may be accepted provided the requirements of CSA A23.2-14A are met.

Note 21. An aggregate need only meet this requirement if it fails the requirements of CSA A23.2-25A. Test data shall have been obtained with the past 18 months from aggregate that is from the same source, processed in the same manner, as the material intended for use.

Greater detail, additional specifications and other aggregate product information can be obtained from the Ministry of Transportation. The above specifications are from MTO SP-110F11 (2007).

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

ISSN 0708-2061 [print]
ISBN 978-1-4435-1531-3 [print]

ISSN 1917-330X [online]
ISBN 978-1-4435-1532-0 [PDF]

Aggregate Resources Inventory Paper 185

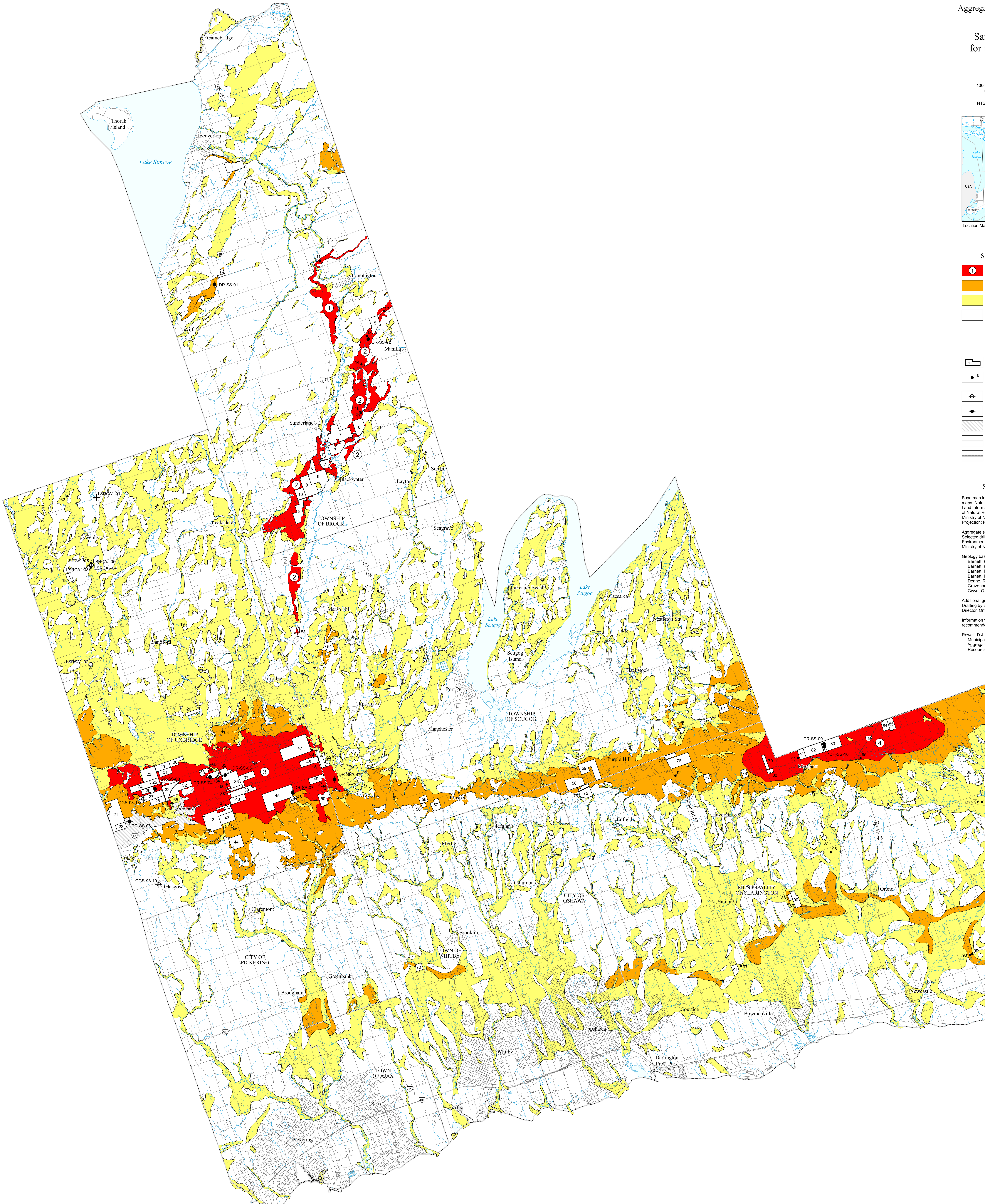
MAP 1

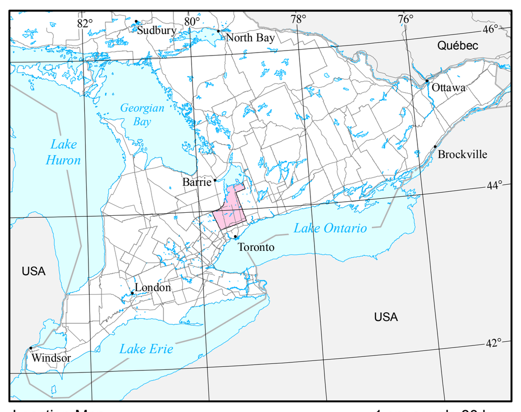
Sand and Gravel Resources for the Regional Municipality of Durham

Scale 1:100 000

1000 m 0 1 2 km

NTS References: 30 M/14, 15, 16; 31 D/1, 2, 3, 6, 7, 11





Location Map 1 cm equals 80 km

SAND AND GRAVEL RESOURCES

- (1) Selected Sand and Gravel Resource Area, primary significance; deposit number (*see* Table 3)
- Selected sand and gravel resource area, secondary significance
- Sand and gravel deposit, tertiary significance
- Other surficial deposits or exposed bedrock

SYMBOLS

- Licenced property boundary: property number (*see* Table 2)
- Unlicenced sand or gravel pit (i.e., abandoned pit or wayside pit operating on demand under authority of a permit). Property number (*see* Table 2).
- Test hole location; identification number (see Table 7)
- Sample site; identification number (*see* Table 9)
- Buried aggregate deposit
- Geological and aggregate thickness boundary of sand and gravel deposits
- Administrative boundary

SOURCES OF INFORMATION

Base map information derived from National Topographic System (NTS) maps, Natural Resources Canada, scale 1:50 000, and from the Ontario Land Information Warehouse, Land Information Ontario, Ontario Ministry of Natural Resources, scale 1:50 000, with modifications by staff of the Ministry of Northern Development, Mines and Forestry.
Projection: North American Datum 1983 (NAD83), Zone 17.

Aggregate suitability data from the Ontario Ministry of Transportation. Selected drilled water well data from the Ontario Ministry of the Environment. Test hole data from the Ontario Geological Survey, Ministry of Northern Development, Mines and Forestry.

Geology based on
- Barnett, P.J., Dodge, J.E.P., McCrae, M.K. and Stewart, A. 1999
- Barnett, P.J., Mate, D.J. 1998
- Barnett, P.J., McCrae, M.K. 1996a
- Barnett, P.J., McCrae, M.K. 1996b
- Deane, R.E. 1950
- Gravenor, C.P. 1957
- Gwyn, Q.H.J. and DiLabio, R.N.W. 1973

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Rowell, D.J. 2010. Aggregate resources inventory for the Regional Municipality of Durham, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 185, Map 1–Sand and Gravel Resources, scale 1:100 000.

Aggregate Resources Inventory Paper 185

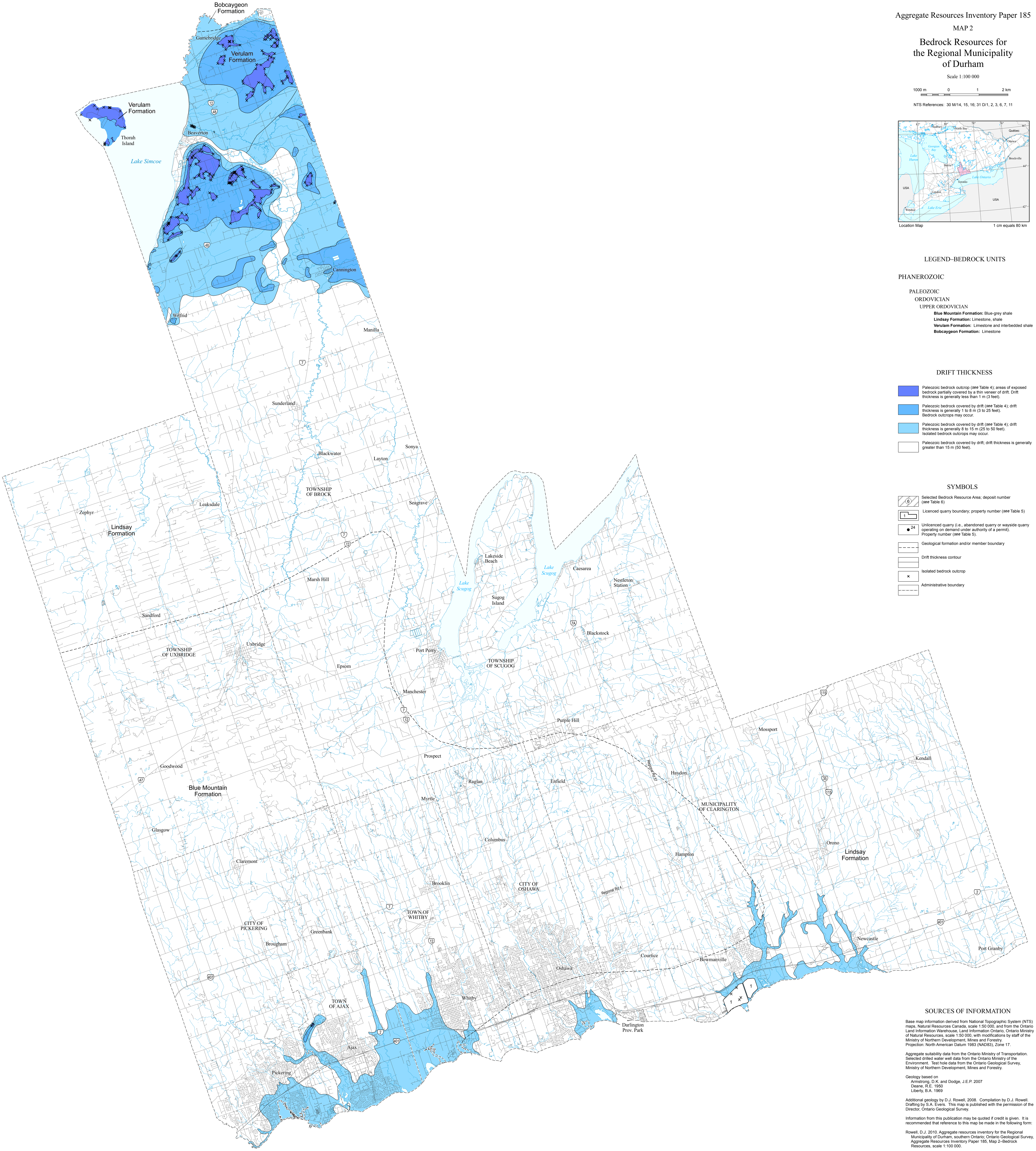
MAP 2

Bedrock Resources for the Regional Municipality of Durham

Scale 1:100 000

1000 m 0 1 2 km

NTS References: 30 M/14, 15, 16; 31 D/1, 2, 3, 6, 7, 11



Location Map 1 cm equals 80 km

LEGEND–BEDROCK UNITS

PHANEROZOIC

PALEOZOIC

ORDOVICIAN

UPPER ORDOVICIAN

Blue Mountain Formation: Blue-grey shale

Lindsay Formation: Limestone, shale

Verulam Formation: Limestone and interbedded shale

Bobcaygeon Formation: Limestone

DRIFT THICKNESS

Paleozoic bedrock outcrop (*see* Table 4); areas of exposed bedrock partially covered by a thin veneer of drift. Drift thickness is generally less than 1 m (3 feet).

Paleozoic bedrock covered by drift (*see* Table 4); drift thickness is generally 1 to 8 m (3 to 25 feet). Bedrock outcrops may occur.

Paleozoic bedrock covered by drift (*see* Table 4); drift thickness is generally 8 to 15 m (25 to 50 feet). Isolated bedrock outcrops may occur.

Paleozoic bedrock covered by drift; drift thickness is generally greater than 15 m (50 feet).

SYMBOLS

6 Selected Bedrock Resource Area; deposit number (*see* Table 6)

1 Licenced quarry boundary; property number (*see* Table 5)

24 Unlicenced quarry (i.e., abandoned quarry or wayside quarry operating on demand under authority of a permit). Property number (*see* Table 5).

Geological formation and/or member boundary

Drift thickness contour

× Isolated bedrock outcrop

Administrative boundary

SOURCES OF INFORMATION

Base map information derived from National Topographic System (NTS) maps, Natural Resources Canada, scale 1:50 000, and from the Ontario Land Information Warehouse, Land Information Ontario, Ontario Ministry of Natural Resources, scale 1:50 000, with modifications by staff of the Ministry of Northern Development, Mines and Forestry.
Projection: North American Datum 1983 (NAD83), Zone 17.

Aggregate suitability data from the Ontario Ministry of Transportation. Selected drilled water well data from the Ontario Ministry of the Environment. Test hole data from the Ontario Geological Survey, Ministry of Northern Development, Mines and Forestry.

Geology based on
Armstrong, D.K. and Dodge, J.E.P. 2007
Deane, R.E. 1950
Liberty, B.A. 1969

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Rowell, D.J. 2010. Aggregate resources inventory for the Regional Municipality of Durham, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 185, Map 2–Bedrock Resources, scale 1:100 000.