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Aggregate Resources Inventory of the District Municipality of Muskoka

Ontario Geological Survey
Aggregate Resources Inventory
Paper 182

2010



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Aggregate Resources Inventory
Paper 182

By C. Gao

2010

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*** 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

This report contains an inventory and evaluation of the sand and gravel resources in the District Municipality of Muskoka, Ontario. The report is based on a detailed field assessment of potential aggregate deposits undertaken in the summer of 2004 and on previous studies completed for the area. The investigation was conducted to delineate and determine the quality and quantity of aggregate within the area to help ensure that sufficient aggregate resources are available for future use.

In the District Municipality of Muskoka, the easily accessible sand and gravel resources are largely depleted and there are few remaining undeveloped resource areas available that are capable of supplying large volumes of crushable granular materials because of previous extraction activity and cultural constraints. In the future, aggregate is likely to be supplied from bedrock sources or imported from the adjacent municipalities.

In the District Municipality of Muskoka, the sand and gravels were deposited primarily by glacial, glaciolacustrine and glaciofluvial processes. They consist predominantly of sandy materials and are mostly found in the towns of Huntsville, Bracebridge and Gravenhurst along the Highway 11 corridor, and in the Township of Lake of Bays. At the primary level of significance, 3 sand and gravel resource areas have been selected in the towns of Bracebridge and Huntsville and the Township of Lake of Bays. These deposits contain aggregate resources considered suitable for the production of a variety of granular aggregate including crushed gravels. In addition, several deposits have been selected as areas of secondary significance. The selected sand and gravel resource areas of primary significance occupy an estimated total area of 554 ha. Cultural constraints and previous extraction reduce the area currently available to 352 ha. The selected areas contain possible sand and gravel resources of approximately 37.4 million tonnes.

The report area is underlain by Precambrian gneissic rock that exhibits wide variations in lithology and aggregate quality. For this reason, no bedrock resource areas have been selected. Instead, the report provides a description of rock lithology and aggregate quality test data for selected bedrock samples.

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.

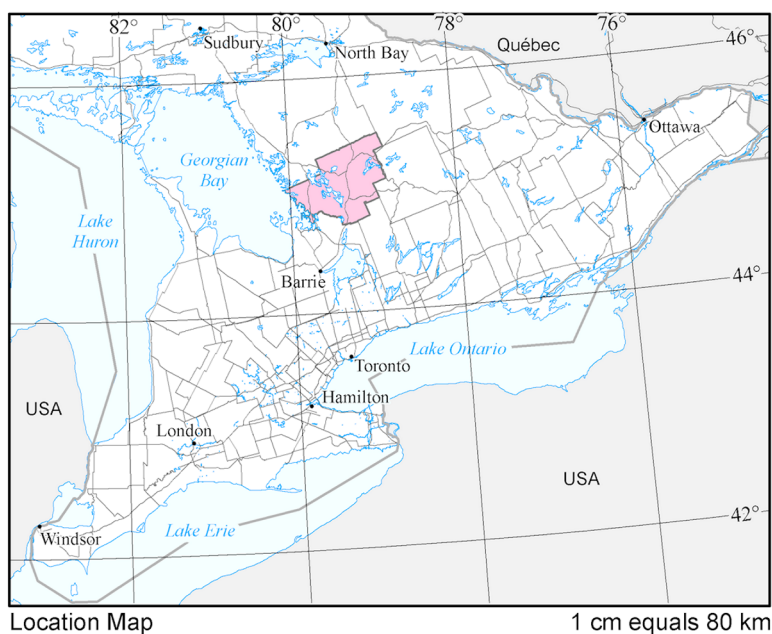


Figure 1. Key map showing the location of the study area.

Aggregate Resources Inventory of the District Municipality of Muskoka

By C. Gao¹

Field work by C. Gao and assistants, map compilation and report by C. Gao.

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 hectareage 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 gravel-

sized 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,

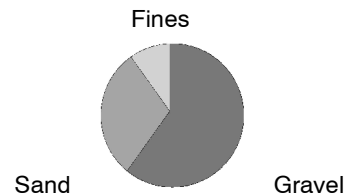
“G / 1 / OW / C”,

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/m³.

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

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, unlicensed 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 licensed 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, licensed hectareage and an estimate of face height. Unlicensed 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 “x”. 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/m³; sandstone resources are calculated using a density estimate of 2344 kg/m³; and shale resources are calculated with a factor of 2408 kg/m³ (Telford et al. 1980).

Assessment of Aggregate Resources in the District Municipality of Muskoka

LOCATION AND POPULATION

The District Municipality of Muskoka is located east of Georgian Bay and consists of the townships of Georgian Bay, Muskoka Lakes and Lake of Bays, and the towns of Huntsville, Bracebridge and Gravenhurst. The District Municipality of Muskoka is bordered by the District of Parry Sound and District of Nipissing to the north and northeast, the County of Haliburton to the east, and the County of Simcoe and the City of Kawartha Lakes (formerly Victoria County) to the south and southeast. Major highways traversing this area include highways 400, 11, 35, 60, 118, 117, 141 and 169. The scenic landscape, the presence of more than 1000 lakes and Muskoka's proximity

to Toronto have combined to make the region one of the most popular recreational areas in Ontario.

The District Municipality of Muskoka, with an areal extent of approximately 3827 km², is covered by all or part of these 1:50 000 scale map sheets of the National Topographic System: Penetanguishene (31 D/13), Gravenhurst (31 D/14), Minden (31 D/15), Haliburton (31 E/2), Bracebridge (31 E/3), Lake Joseph (31 E/4), Orrville (31 E/5), Huntsville (31 E/6), Kawagama Lake (31 E/7), Tom Thomson Lake (31 E/10, formerly Algonquin), Christian Island (41 A/16) and Sans Souci (41 H/1).

In 2006, the population of the District Municipality of Muskoka was 57 355, an increase of 8.4% over the 2001 population (Table A; Statistics Canada 2006).

Table A – Area and Population, District Municipality of Muskoka

Municipality	Area (km ²)	2001 Population	2006 Population
Town of Bracebridge	617.42	13 751	15 652
Township of Georgian Bay	535.48	1991	2340
Town of Gravenhurst	517.99	10 899	11 046
Town of Huntsville	703.23	17 338	18 280
Township of Lake of Bays	671.46	2900	3570
Township of Muskoka Lakes	781.55	6042	6467
TOTAL	3827.13	52 921	57 355

PHYSIOGRAPHY AND SURFICIAL GEOLOGY

Several physiographic regions are present within the District Municipality of Muskoka, these include the Algonquin highlands in the north and northeast; the Georgian Bay fringe in the west and south; and the north-trending "Number 11 strip" (a physiographic region so named as it closely follows Highway 11) (Chapman and Putnam 1984). More than two-thirds of the study area is within the Algonquin highlands, the western boundary of which roughly follows Highway 169. Both the Algonquin highlands and the Georgian Bay fringe are bisected by the Number 11 strip. The former 2 regions are dominated by bedrock terrains consisting of bare or thin-drift covered knobs and ridges of Precambrian bedrock. The Algonquin highlands, however, has higher surface relief and less exposed bedrock. In contrast to these regions, the Number 11 strip, which is only a few kilometres wide, has a subdued landscape with relatively thick surficial deposits.

Low bedrock knobs and ridges with a thin veneer of soil, as seen along Highway 400 within the study area, are characteristic of the Georgian Bay fringe. The Algonquin

highlands is a region where bedrock ridges and hills are interspersed with areas of varying thickness of till or other glacial deposits. Within the 2 physiographical units, glaciolacustrine and glaciofluvial deposits exist in limited extent, often in low-lying bedrock depressions. Extensive glaciolacustrine and glaciofluvial deposits, consisting of sand and, in places, gravel, occur in the Number 11 strip (Bajc and Henry 1991; Bajc and Paterson 1992a; Ontario Geological Survey 2003). These are the major sources of sand and gravel resources for Muskoka (Staff of the Algonquin Region 1983; Ontario Geological Survey 1990).

The surficial sediments and landscape of the study area were strongly affected by the Late Wisconsinan glaciation. Glacial till was deposited during the advance and retreat of the ice sheet that flowed to the south and southwest. In front of the receding ice, glaciofluvial and glaciolacustrine sediments were deposited in meltwater channels and lakes. As the ice sheet withdrew to the north, much of the study area was progressively inundated by glacial Lake Algonquin approximately 11 500 years BP (Eschman and Karrow 1985). With the shifting of the lake's outlets, the lake declined in elevation leaving a sequence of low-level beaches. Re-submergence of part of the area took place during the Nipissing stage approximately 5000 years BP.

Present levels of the Great Lakes were achieved sometime after 3000 years BP. In the study area, various deposits associated with the glacial lakes were formed, including deep-water silt-rich deposits, beach and nearshore sandy materials, and deltaic and subaqueous fan sands and gravels (Geddes and McClenaghan 1984a, 1984b; Kor and Miller 1987; Kor and Delorme 1989; Bajc and Henry 1991; Bajc and Paterson 1992a, 1992b; Kaszycki 2001a, 2001b; Ontario Geological Survey 2003).

Till, often occurring as a thin veneer over bedrock, consists of a silty, stony, sandy diamicton. Because of the excess fines and abundant oversized clasts, till is usually not well suited for aggregate use. It may, however, be used as a source of fill. Ice-contact stratified drift deposits occur as isolated patches throughout the study area, containing stratified sands and gravels deposited adjacent to the northward melting ice sheet. Although limited in lateral extent, they are important local sources of aggregate.

The outwash deposits, formed by meltwater streams from the retreating ice, are often located in bedrock valleys or depressions along the present large rivers and Highway 11. The deposits occur as sheets or as terraced valley trains, containing well-sorted sand and gravel deposits. Outwash deposits have a wide occurrence in the area and many of these deposits have been the traditional aggregate sources for the District Municipality of Muskoka.

Glaciolacustrine sand and, locally, gravel are common in lowland areas. Where sediment-laden meltwaters discharged into a standing body of water from tunnels at or near the base of the retreating ice, subaqueous fans developed. The extensive subaqueous fan deposits along the Number 11 strip are the major sand and gravel sources for the District Municipality of Muskoka (Staff of the Algonquin Region 1983; Ontario Geological Survey 1990). The deposits are normally fan or lobe shaped. Several fans may cascade to form large, near continuous, flat-topped ridges. The deposits consist predominantly of stratified sand that may exhibit wide variations in grain size distribution. Gravel units may occur in places in the lower part, or as the central cores, of the fans. Silt and clay are sometimes associated in varying amounts with these deposits.

At the edges of the glacial lakes that covered the area, nearshore deposits, including beach sands, were deposited. Where meltwater streams flowed into the glacial lakes, deltas developed. The deltaic deposits contain predominantly stratified sand and, in distal parts, silty sand and silt. If developed at localities proximal to the retreating ice, the deltas may contain gravel in the upper part of the successions. In shallow parts of the glacial lakes, foreshore/basinal glaciolacustrine plains were formed, consisting of fine sand to silty fine sand. In deep waters, silt and clay were deposited. Although they have little value as aggregate and are excluded from the sand and gravel resources in this report, the clay may be used in the drain tile and brick industry (Guillet 1967).

PREVIOUS WORK

This area was inventoried previously for aggregate resources on a smaller scale. The earlier publications (ARIP 147: Ontario Geological Survey 1990; Open File Report 5457: Staff of the Algonquin Region 1983) 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

The sand and gravel deposits within the District Municipality of Muskoka are shown on Map 1 that accompanies this report. Sand and gravel deposits occupy a total area of approximately 46 013 ha and contain an estimated original resource of 2556.6 million tonnes (Table 1)

At the time this report was prepared, the District Municipality of Muskoka had not been designated under the *Aggregate Resources Act* (1990) and, consequently, the extraction areas are marked as points on Map 1 (i.e., licenced properties are not outlined). Most of the pits are located in subaqueous fan, glaciofluvial outwash and ice-contact deposits. Among the 256 sand and gravel pits recorded, only a few were active at the time of the site visits. In general, many of the pits are small operations capable of meeting local demands for low-specification aggregates.

Field investigation indicates that crushable granular resources are depleted in most areas because of extensive extraction and cultural constraints. Within the study area, there are few remaining sand and gravel resources available that are capable of supplying large volumes of crushable granular materials. Some gravelly deposits are located in remote areas where long haul distance and/or poor road conditions impose constraints on resource utilization. Pits in these areas are intermittently active and the sand and gravel extracted are used mainly for local road maintenance.

SELECTED SAND AND GRAVEL RESOURCE AREAS

The sand and gravel deposits within the study area normally have limited potential for extraction due to the restricted amount of aggregate they contain and, in places, the poor quality of the material. Consequently, at the primary level of significance, only 3 sand and gravel resource areas have been selected (*see* Map 1). These deposits contain aggregate resources considered suitable for the production of a variety of granular base and subbase products such as Granular A and B. The selected sand and gravel resource areas of primary significance occupy an estimated total area of 554 ha. Cultural constraints and previous extraction reduce the area currently available to 352 ha. The selected areas contain possible sand and gravel resources of approximately 37.4 million tonnes. Details regarding these resource areas can be found in Table 3.

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 is a glaciofluvial outwash deposit located east of Lake of Bays and west of Highway 35 in the Township of Lake of Bays (see Map 1). The resource area forms the bulk of a flat, fan-like outwash plain that has a width of about 2.5 km. Of the 4 pits visited during the field component of this inventory, only Pit 152 was active.

Within this resource area, pit faces reveal 3 to 8 m of well-sorted, gravel material with massive to crude horizontal bedding structures. The gravel beds are normally clast supported and the matrix consists predominantly of clean medium to coarse sand. Interbedded sand or pebbly sand lenses are common. The deposit becomes finer and sandy to the west and southwest. A water well at the western margin of the selected resource area indicates 65.5 m of sand. Precambrian bedrock crops out to the northeast of the deposit along Highway 35, suggesting a rise of bedrock subsurface to the north.

Observed gravel content in the deposit ranges from 30 to 50% with an estimated average of 35% for the selected resource area. Field observations indicate that the deposit contains hard and durable clasts, suitable for the production of various granular products, such as Granular A and B, provided that oversized clasts are removed or crushed. The quality test data from a sample collected within the deposit (Sample No. 2004CG162) exhibits favourable lithology for asphalt applications (Table 9). Previous MTO records suggest the material could be used for the production of HL 4, consistent with the past aggregate production across this area.

Selected Sand and Gravel Resource Area 1 has an areal extent of about 200 ha. Previous extraction and cultural setbacks reduce the area to 106 ha. Assuming an average thickness of 6 m, the possible aggregate resource is estimated to be 11.3 million tonnes (see Table 3).

Selected Sand and Gravel Resource Area 2

Selected Sand and Gravel Resource Area 2 consists of a glaciofluvial outwash to glaciolacustrine deltaic deposit located in the southern part of the Town of Huntsville (see Map 1). The deposit is located between Highway 11 and the Muskoka River and occurs in a flat area that dips slightly to the southwest. Because of the past intense extraction, the northeastern part of the proximal fan has been depleted. In contrast, the southwestern part of the distal fan remains largely intact and, therefore, is selected for protection.

The material exposed at Pit No. 112 consists of 8 m of cross-bedded sand and gravel containing oversized cobbles, and, in places, is overlain by 1 to 2 m of glaciolacustrine fine sand. Sand occurs below the pit floor and the deposit also likely becomes sandy to the southwest. The gravel content is estimated at 20 to 40%. The deposit is suitable for Granular B and SSM provided that oversized

clasts are removed or crushed. Granular A may be produced if sand control or selective extraction is implemented. A sample collected from this deposit (Sample No. 2004CG65) yielded quality data favourable for asphalt use (HL 4) (see Table 9). Past products from the proximal fan area (not selected) include granular base aggregate and HL 4 CA.

Selected Sand and Gravel Resource Area 2 has an areal extent of 65 ha. Previous extraction and cultural setbacks reduce the potential area to 41 ha. Assuming an average thickness of 6 m, the possible aggregate resource is estimated to be 4.4 million tonnes (see Table 3).

Selected Sand and Gravel Resource Area 3

The large glaciofluvial outwash deposit of Selected Sand and Gravel Resource Area 3 is located on the eastern bank of the Muskoka River in the Town of Bracebridge (see Map 1). The deposit is a flat feature with occasional bedrock outcrops. Sand and gravel extraction is active in the central part of the selected area.

Sections of Pit No. 173 reveal 5 m of massive, clast-supported, subrounded to rounded cobble gravel with a medium to coarse sand matrix. The pebble lithology consists entirely of gneissic rock, derived primarily from the local Precambrian bedrock terrain. Grain-size distribution becomes finer to the south due to the southward-flowing meltwater responsible for the deposition. At Pit No. 174, 5 to 9 m of horizontally bedded fine to coarse gravel with sand layers were observed. Previously drilled test holes show both sand and gravel material in the southernmost part of the selected area (Ontario Geological Survey 1990). The gravel content ranges from 30 to 70% with an overall average of 40% for the resource area.

The deposit may be suitable for a variety of granular base and subbase products. Potential use for HL 4 binder is indicated by previous quality tests completed by MTO, consistent with the documented products produced from the resource area. Although a high loss of up to 49% has been recorded in Los Angeles abrasion test, the requirement for HL 4 is 50% for the area around Huntsville (Rogers 1991).

The northern part of Selected Sand and Gravel Resource Area 3 is less favourable for extraction due to established cultural constraints fragmenting the area. The central part of the resource area is accessible through a 2.5 km gravel-surfaced road. Rock ridges of greyish gneiss are currently quarried in the northern part of Pit No. 173. Fine-grained materials in the sand and gravel deposit may be blended with the crushed stone for a variety of products.

Selected Sand and Gravel Resource Area 3 has an areal extent of 290 ha. Previous extraction and cultural setbacks reduce the area to 204 ha. An average thickness of 6 m is assumed based on the pit faces and test hole data, and the possible aggregate resource is estimated to be 21.7 million tonnes (see Table 3).

Resource Areas of Secondary Significance

A number of areas within the District Municipality of Muskoka have been selected as resource areas of secondary significance. Areas of secondary significance do not contain the highest quality aggregate in the study area; however, they may contain large quantities of sand and gravel. In some cases, resource areas of secondary significance are classed as such due to insufficient geological data. The lack of data precludes an accurate assessment of either the quality or volume 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 district's total aggregate supply. Because of the large number of secondary deposits present in the District Municipality of Muskoka, they are not labelled individually on the accompanying map and only selected descriptions are given herein.

In the Township of Muskoka Lakes, many secondary areas have been selected, including several large subaqueous and glaciolacustrine deposits between Skeleton Lake and Lake Muskoka. These deposits consist predominantly of sandy material and are used primarily for fill and winter sand. However, gravel pockets may occur particularly in the lower part of these deposits. If sand control and selective extraction measures are adopted, crushable material may be obtained. For instance, gravel material exceeding 3 m thickness is extracted beneath 6 to 7 m of sand in the northern end of Pit No. 27. In Pit No. 28, gravel material occurs in the upper 3 m of the pit face and a pinkish granite ridge has been cleared for blasting (Gao 2004). A rock sample submitted to MTO has returned favourable results for asphalt aggregate use (*see* Table 9: Sample 2004CG261). The sand in the pit can be used for blending with the crushed rock for a variety of aggregate products.

The subaqueous fan deposit located south of Lake Muskoka has been selected as a resource area of secondary significance. Pit No. 64 has been developed in this deposit. This deposit contains a gravel core, both overlain and flanked by up to 3 m of sandy material. The gravel core consists of well-sorted fine gravel ranging from 30 to 50% gravel content with an overall average of 30%.

Within the Town of Huntsville, a number of glaciofluvial and glaciolacustrine deposits have been selected as resource areas of secondary significance. In the northwest, gravel material is sometimes found in subaqueous fans, overlain by thick glaciolacustrine sand. At Pit Nos. 80 and 81, the gravel content is estimated from 20 to 50%. Extraction has been intense along a northwest-trending subaqueous fan ridge where Pit No. 84 is located.

Large resource areas of secondary significance, found near the north boundary in the Town of Huntsville, consist of thick glaciofluvial outwash and glaciolacustrine deposits. Little geological data are available due to the lack of exposures and difficult access. However, the outwash deposit likely contains crushable material as inferred from neighbouring Perry Township, District Municipality of

Parry Sound, where this deposit has been extracted. The glaciolacustrine deposit along Highway 11 may also contain gravel pockets. Across the boundary into Perry Township, coarse gravel is found in the same deposit. Ministry of the Environment water-well records indicate that the glaciolacustrine sand can be 56 m thick beside Highway 11. However, the TransCanada natural gas pipeline has been laid through these areas and may impose a serious constraint on extraction.

A large glaciofluvial outwash sand and gravel deposit of secondary significance is located northeast of the Town of Huntsville where ongoing extraction takes place at Pit Nos. 78 and 79. The deposit has a fan-like appearance with the apex located in the northeast. The grain size decreases downstream along the fan. As such, gravel material is found at Pit No. 78, whereas fine to medium sand and pebbly sand are observed in the deposit at Pit Nos. 75 and 79. The coarsening-upward sequence of pebbly sand and fine to silty fine glaciolacustrine sand at Pit No. 79 suggests a deltaic deposit that prograded into the lake basin. Ongoing extraction and cultural factors have led to substantial resource depletion. The deposit should be suitable for Granular B and SSM. Granular A may be produced if sand control or selective extraction measures are implemented.

Thick subaqueous fan deposits occur south of Lake Vernon and west of Highway 11 in the Town of Huntsville. These deposits are often draped by glaciolacustrine fine sand and have a wedge shape, with a relief slightly above the adjacent flat glaciolacustrine plain. They are dominated by fine to medium sand, sometimes containing gravel pockets, particularly at depth. The gravel content ranges from 10 to 30% at Pit Nos. 91 and 92. An overall average of 20% gravel is estimated for these deposits. Because of intense extraction, the crushable material above the water table has been, to a large extent, removed. Gravel material likely exists below the water table that is 4 to 7 m deep from the ground surface. Up to 38 m of sand and gravel are indicated by Ministry of the Environment water-well records. The deposits are suitable for Granular B and SSM. If sand control or selective extraction measures are implemented, Granular A may be produced.

A number of glaciofluvial outwash sand and gravel deposits of secondary significance occur in the Township of Lake of Bays. These areas are topographically flat, and are located along the major river valleys. The deposits along the Big East River are largely undeveloped because of their remote locations. The gravel content is estimated at 20 to 40% based on the exposure at Pit No. 115. The gravel roads and a long haul distance greater than 10 km to Highway 60 place constraints on the use of these deposits. East of Dwight, an outwash deposit with an estimate of 25% gravel content has been extensively extracted in the past. Because of its flat topography, permanent buildings and infrastructure development has occurred within the resource area reducing the availability of aggregate resources. Aggregate products produced from this area include Granular A and HL 4 CA.

In the Town of Bracebridge, the areas of secondary significance largely coincide with the previously designated primary resources (Ontario Geological Survey 1990). Continued extraction and cultural constraints have led to resource depletion to a large extent. However, crushable material likely exists in places below the water table. The quarrying operations at Q25 (*see* Table 5), adjacent to the resource area north of the Town of Bracebridge, may increase the demand for blending sand. The subaqueous deposit along the South Branch of the Muskoka River, in the northeast part of the Town of Bracebridge, consists of coarse gravel, overlain by 2 to 3 m of sandy material. The deposit is estimated to contain 30% gravel, and the observed water table is 2 to 3 m below the surface. Pit faces range from 2 to 3 m at Pit Nos. 179 and 180 and increase to 6 to 7 m at Pit No. 181. The deposit should be suitable for the production of a variety of aggregate products.

Many previously designated primary subaqueous fan deposits along Highway 11 in the Town of Gravenhurst (Ontario Geological Survey 1990) have been lowered to secondary significance due to the extensive removal of crushable material and cultural constraints. Among the numerous pits in these areas, only a few are active. These deposits are characterized by thick sand, sometimes underlain by gravel material. For instance, Pit No. 245 reveals over 4.5 m of gravel material overlain by up to 5 m of silty fine sand. The underlying gravel material, containing 20 to 60% gravel, is suitable for Granular B provided that oversized clasts are removed or crushed. If sand control or selective extraction measures are implemented, Granular A may be produced.

A large glaciofluvial outwash deposit occurs east of Highway 11 in the northeastern part of the Town of Gravenhurst. This deposit, containing 30 to 50% gravel, is suitable for the production of a variety of aggregate. However, the location of the Muskoka Airport renders this resource largely unavailable for extraction.

BEDROCK GEOLOGY AND RESOURCE POTENTIAL

The study area, located in the Central Gneiss Belt of the Grenville Province, is dominated by polycyclic, quartzofeldspathic gneisses chiefly of igneous origin, with a metamorphic grade of amphibolite or granulite facies. Lithotectonic terranes have been identified on the basis of rock types, internal structure, metamorphic grade, geological history and, where available, geophysical signature (Easton 1992). Recent geological mapping at a 1:50 000 scale provides the basic geological information for this area (Lumbers and Vertolli 2000a-d, 2003; Lumbers, Vertolli and Schwerdtner 2000a, 2000b; Easton 2001a, 2001b).

The Central Gneiss Belt is divided into several terranes; of these, the southern parts of the Algonquin Terrane and Parry Sound Terrane occur in the study area. The Al-

gonquin Terrane, formed 1800 to 1600 Ma, is characterized by felsic to intermediate gneisses and migmatites (Easton 1992). Late-stage plutonic activity occurred between 1500 to 1400 Ma. The Parry Sound Terrane consists primarily of intermediate to mafic gneisses with a north- to northwest-trending fabric and has an age of 1450 to 1350 Ma. These terranes are intruded locally by felsic to mafic plutons that show less deformed textures than the host rocks. The terranes are, in turn, subdivided into domains. Within the study area, 9 lithotectonic subunits are recognized, namely: Go Home, Rosseau, Fishog, Huntsville, Novar, McClintock, McCraney, Moon River and Seguin domains (Map 2). The first 7 domains belong to the Algonquin Terrane and the last 2 to the Parry Sound Terrane.

The bedrock geology of the study area is, in terms of lithology and potential aggregate usage, extremely varied. This is a result of the polycyclic metamorphism that took place during the long geological history of the Meso- to Neoproterozoic. The gneissic and migmatitic rocks exposed in outcrops often show well-developed foliation and strong banding structures. Platy minerals such as mica are sometimes enriched along the banding planes, in particular, in gneisses that have distinct platy and schistose structures. Because of these factors, many of the gneissic rocks are prone to weathering and tend to split along banding planes. Inconsistency in lithology between neighbouring exposures is commonly observed in the field. Rocks suitable for producing high-quality crushed stone products are often limited in extent and are difficult to outline at a regional-mapping scale.

In spite of the lithologic variability and complexity, field observations and other data available indicate that the gneissic bedrock in the District Municipality of Muskoka is capable of producing large quantities of low-specification mineral aggregate for granular base and subbase uses (Jagger Hims Limited 1998 a-d; Gao 2004). Many of the operational quarries in the area produce low-quality crushed stone products mainly for non-commercial customers. High-quality aggregate products can also be produced locally, in particular, from less-deformed felsic or mafic plutons that are more consistent in composition than the surrounding rocks. The plutons often have limited extent and may not be delineated on regional-scale geological maps. They can be identified through detailed field investigations. Some quarries extracting mafic gneisses, however, have been approved for asphalt aggregates such as HL 1 and HL 4 (Gao 2004). These observations suggest that site-specific investigations and laboratory testing are key factors in locating rocks suitable for asphalt aggregates and for ensuring consistent high quality.

Bedrock descriptions have been provided for the quarries identified in this survey (Table 5). A number of rock samples were collected as part of this project and tested by the MTO. These quality test data are provided in Table 9. There is no areal delineation for bedrock resources due to the lithologic variability and complexity in the study area.

SUMMARY

In the study area, the easily accessible sand and gravel deposits are largely depleted and there are few remaining undeveloped resources that are capable of supplying large volumes of crushable granular material due to previous extraction activity and cultural constraints. In the future, the aggregate supplies are likely to come from bedrock sources or be imported from adjacent regions.

The sand and gravel deposits in the District Municipality of Muskoka were formed by glacial, glaciofluvial and glaciolacustrine activities. They consist of primarily sand material and occur frequently in subaqueous fans and deltas along the Highway 11 corridor. At the primary level of significance, 3 sand and gravel resource areas have been selected in the towns of Bracebridge and Huntsville, and the Township of Lake of Bays. These deposits contain aggregate resources considered suitable for the production of a variety of granular aggregate products. The Selected Sand and Gravel Resource Areas of primary significance occupy a total area of 554 ha. Cultural constraints and previous extraction reduce the area currently available to 352 ha. The selected areas contain possible sand and gravel resources of approximately 37.4 million tonnes. In addition, a number of deposits have been selected as areas of secondary significance.

The Precambrian bedrock in the District Municipality of Muskoka consists of gneissic rocks that exhibit wide

variations in lithology and aggregate quality over short distances. For this reason, no bedrock resource areas have been selected. Instead, included in this report are geological descriptions of the bedrock of currently existing quarries and quality test data for rock samples collected throughout the study area. Low-quality aggregate for granular base and subbase course uses are likely to be produced in large quantity from various gneissic rocks. Less-deformed intrusive rocks or plutons that occur locally throughout the report area have the potential for asphalt and other high-specification aggregate products. These plutons often have limited lateral extent and are difficult to outline in regional-scale geological mapping. High-specification aggregate products also may derive locally from the gneissic rocks. Site-specific investigations and laboratory testing on the bedrock are imperative to determine the suitability for high-end applications. For asphalt use, some of the crushed bedrock products require application of anti-stripping chemical agents to overcome bonding problems caused by glassy cleavages and fracture surfaces inherent in minerals such as feldspar and quartz.

Enquiries regarding the Aggregate Resources Inventory of the District Municipality of Muskoka 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			
District Municipality of Muskoka			
1	2	3	4
Class Number	Deposit Type	Areal Extent (Hectares)	Original Tonnage (Million Tonnes)
Township of Georgian Bay			
2	S-LD	232	16.4
3	S-IC	121	4.3
	S-LD	452	16.0
	S-LP	649	23.0
	S-OW	266	9.4
<i>Subtotal</i>		1720	69.1
Township of Muskoka Lakes			
1	S-SF	212	22.5
2	S-IC	151	10.7
	S-LD	32	2.3
	S-LP	264	18.7
	S-SF	611	43.3
3	S-IC	420	14.9
	S-LD	1455	51.5
	S-LP	705	25.0
	S-OW	75	2.7
	S-SF	126	4.5
4	S-AL	88	1.6
	S-SF	91	1.6
<i>Subtotal</i>		4230	199.0
Town of Huntsville			
1	G-OW	35	3.7
	S-IC	97	10.3
	S-LP	2368	251.5
	S-OW	185	19.6
	S-SF	304	32.3
2	G-IC	6	0.4
	G-SF	41	2.9
	S-AL	194	13.7
	S-IC	55	3.9
	S-LP	4551	322.2
	S-OW	547	38.7
3	S-AL	696	24.7
	S-IC	557	19.7
	S-LP	4243	150.2
	S-OW	1664	58.9
<i>Subtotal</i>		15543	952.8
Township of Lake of Bays			
1	G-OW	200	21.2
	S-OW	15	1.6
2	G-IC	100	7.1
	G-OW	96	6.8
	S-IC	355	25.1
	S-LP	674	47.7
	S-OW	1027	72.7
3	G-IC	34	1.2
	G-OW	185	6.6
	S-AL	247	8.8
	S-IC	1317	46.6
	S-LD	14	0.5
	S-LP	461	16.3
	S-OW	5008	177.3
<i>Subtotal</i>		9734	439.5

Table 1 - Total Sand and Gravel Resources District Municipality of Muskoka			
1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
Town of Bracebridge			
1	G-OW	290	30.8
	S-IC	24	2.6
	S-LP	170	18.1
	S-OW	63	6.7
	S-SF	339	36.0
2	G-SF	86	6.1
	S-IC	18	1.3
	S-LP	4582	324.4
	S-OW	485	34.3
3	S-SF	4	0.3
	G-OW	56	2.0
	S-AL	606	21.4
	S-IC	185	6.6
	S-LD	2264	80.1
	S-LP	931	33.0
	S-OW	165	5.9
<i>Subtotal</i>		10268	609.4
Town of Gravenhurst			
1	S-IC	166	17.6
	S-LP	82	8.7
	S-OW	219	23.2
	S-SF	51	5.4
2	G-SF	161	17.1
	S-AL	1192	84.4
	S-LP	696	49.3
3	S-OW	68	4.8
	G-IC	268	19.0
	S-IC	1617	57.2
<i>Subtotal</i>		4519	286.8
TOTAL		46013	2556.6
<p>Minor variations in all tables are caused by the rounding of data.</p> <p>* 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.</p> <p>Explanation of Deposit Type</p> <p>First letter denotes gravel content: G = >35% gravel; S = generally "sandy", gravel-size (>4.75 mm) aggregate <35% gravel</p> <p>Letters after hyphen denote the geologic deposit type (<i>see also</i> Appendix C): AL = alluvium; IC = ice-contact stratified drift; LD = glaciolacustrine delta; LP = glaciolacustrine plain; OW = outwash; SF=subaqueous fan.</p>			

Table 2 - Sand and Gravel Pits District Municipality of Muskoka				
Pit No.	Owner/Operator	Face Height (Metres)	% Gravel	Remarks
Township of Georgian Bay				
Unlicenced				
1	-	4	Sand	Depleted
2	-	2 - 3	Sand	Inactive during field investigation
3	-	2 - 3	Sand	Inactive during field investigation
4	-	3	Sand	Overgrown
5	-	2 - 3	Sand	Inactive during field investigation
6	-	2 - 4	<20	Depleted
7	-	2 - 4	<10	Inactive during field investigation
8	-	2 - 3	Sand	Overgrown
9	-	2	Sand	Overgrown
10	-	1 - 2	Sand	Intermittently active
11	-	2 - 3	Sand	Intermittently active. Flat sandy plain. Gravel may exist in pockets. High water table.
12	-	2 - 2.5	Sand	Intermittently active
13	-	1 - 3	Sand	Inactive during field investigation
14	-	2 - 10	<10	Inactive during field investigation
15	-	n/a	Sand	Inactive during field investigation
Township of Muskoka Lakes				
Unlicenced				
16	-	2	20 - 30	Inactive during field investigation. Partially overgrown.
17	-	3	20 - 30	Inactive during field investigation. Interbedded sand, pebbly sand or fine gravel in a small ridge.
18	-	1 - 2	<10	Inactive during field investigation
19	-	3 - 4	<30	Inactive during field investigation
20	-	1 - 1.5	Sand	Inactive during field investigation. Flat topography.
21	-	1 - 1.5	Sand	Inactive during field investigation. Flat topography.
22	-	4	Sand	Overgrown
23	-	1 - 1.5	Sand	Overgrown
24	-	3 - 4	Sand	Inactive during field investigation. Partially overgrown.
25	-	5 - 9	60	Inactive during field investigation
26	-	3 - 7	Variable	Inactive during field investigation. Gravel core has been removed. Sandy flanks are left.
27	-	6 - 7	5 - 15	Active during field investigation. Small gravel deposit overlain by sand.
28	-	5 - 6	10 - 30	Active during field investigation. Sand and pebbly sand overlain by massive gravel. Preparing for a quarry operation along the northeastern side.
29	-	n/a	Sand	Rehabilitated
30	-	2 - 4	30	Inactive during field investigation. Oversized clasts were present, including limestone cobbles/boulders.
31	-	3 - 5	5 - 15	Active during field investigation
32	-	10 - 12	Sand	Active during field investigation
33	-	2	Sand	Inactive during field investigation
34	-	2 - 3	40 - 60	Intermittently active. Grey gneiss quarried in southeastern part of the pit.
35	-	2 - 4	<15	Inactive during field investigation
36	-	3 - 4	Sand	Inactive during field investigation
37	-	6	Sand	Intermittently active. Predominantly a fine sand.
38	-	8	Sand	Overgrown. Predominantly a fine sand with silt.

Table 2 - Sand and Gravel Pits District Municipality of Muskoka				
Pit No.	Owner/Operator	Face Height (Metres)	% Gravel	Remarks
39	-	7	10	Inactive during field investigation. Gravel core has been removed, sandy flanks left. Part of this operation is a 3-4 m felsic gneiss quarry.
40	-	1 - 4	Sand	Overgrown
41	-	3 - 4	Variable	Inactive during field investigation. Mainly sand. Felsic gneiss quarried in the southeastern end of the pit.
42	-	2.5	Sand	Overgrown
43	-	3 - 4	Sand	Intermittently active. Gravel core has been removed, sandy flanks left. Felsic gneiss is being quarried.
44	-	4	Sand	Intermittently active. Gravel core has been removed, sandy flanks left.
45	-	1.5 - 4	Sand	Overgrown
46	-	2 - 5	10	Overgrown
47	-	6	Sand	Inactive during field investigation. Predominantly fine to very fine sand.
48	-	6	Sand	Active during field investigation. Predominantly fine sand.
49	-	3 - 4	Sand	Inactive during field investigation. Gravel core has been removed, sandy flanks left.
50	-	3	<5	Overgrown
51	-	n/a	n/a	Now a landfill site
52	-	6	Sand	Inactive during field investigation. Oversized clasts are frequent.
53	-	1.5 - 3	Sand	Depleted
54	-	3 - 5	5 - 15	Inactive during field investigation
55	-	3 - 6	5 - 15	Intermittently active. Grey gneiss being quarried.
56	-	2 - 4	5 - 20	Inactive during field investigation. Partially overgrown.
57	-	3 - 5	Sand	Overgrown
58	-	2 - 10	Variable	Overgrown
59	-	6 - 10	<5	Inactive during field investigation. Partially overgrown.
60	-	4	Sand	Overgrown
61	-	1.5	10 - 30	Overgrown
62	-	2 - 3	20	Inactive during field investigation. Gravel core has been removed, sandy flanks left.
63	-	2	10 - 30	Inactive during field investigation. Partially overgrown. Pond in pit.
64	-	2 - 3	20 - 40	Active during field investigation. Gravel deposit overlain by sand.
65	-	2	<10	Inactive during field investigation. Pit in a sand ridge.
66	-	3 - 6	20 - 40	Inactive during field investigation. Pit in a large sand and gravel ridge.
67	-	1.5 - 3	10 - 30	Inactive during field investigation
68	-	5 - 10	Sand	Intermittently active
69	-	4	40 - 60	Poorly sorted hill slope deposit, frequently containing oversized clasts

Table 2 - Sand and Gravel Pits District Municipality of Muskoka				
Pit No.	Owner/Operator	Face Height (Metres)	% Gravel	Remarks
Town of Huntsville				
Unlicensed				
70	-	1 - 2.5	10 - 40	Overgrown
71	-	2	30 - 40	Inactive during field investigation. Partially overgrown. Oversized clasts to be removed or crushed.
72	-	1 - 4	10 - 30	Inactive during field investigation
73	-	3 - 4	20 - 40	Inactive during field investigation. Large pond in pit.
74	-	4 - 10	Variable	Inactive during field investigation. Nearing depletion.
75	-	5 - 8	<15	Depleted
76	-	1	Sand	Overgrown
77	-	0.5 to 1	Sand	Inactive during investigation. Predominantly silty sand.
78	-	3 - 4	30 - 40	Intermittently active
79	-	3 - 5	<15	Active. Mainly sand and pebbly sand in the northeastern end. 3 to 4 m fine sand below water table.
80	-	2	20 - 50	Inactive during field investigation. Partially overgrown. Gravel material overlain by sand.
81	-	2 - 3	30 - 50	Inactive during field investigation. Gravel material likely available below sand.
82	-	6 - 20	35	Depleted
83	-	4 - 7	Sand	Overgrown
84	-	3 - 5	50 - 60	Intermittently active. Cobble gravel core removed, sandy flanks left.
85	-	3 - 4	10 - 20	Active. Sandy ridge contains gravel material in upper part of deposit.
86	-	3 - 4	20 - 30	Inactive during field investigation
87	-	4 - 5	Sand	Inactive during field investigation. Partially overgrown.
88	-	2 - 3	Sand	Overgrown
89	-	5 - 7	15	Inactive during field investigation. Partially overgrown.
90	-	n/a	Sand	Overgrown, reforested
91	-	4 - 7	10 - 30	Active during field investigation. Gravel core has been removed, sandy flanks left. About 30 m of sand and gravel below pit floor/water table.
92	-	4 - 9	10 - 30	Intermittently active. Oversized clasts are frequent.
93	-	4 - 7	<5	Overgrown
94	-	3	Sand	Inactive during field investigation. Flat-lying topography.
95	-	4 - 5	30 - 60	Inactive during field investigation. Cobble gravel deposit. Coarsening upward. Oversized clasts are frequent.
96	-	2 - 3	Sand	Inactive during field investigation. Flat-lying topography.
97	-	2 - 6	10 - 30	Inactive during field investigation. Gravel deposit overlain by sand.
98	-	n/a	<20	Overgrown
99	-	3 - 7	20 - 30	Inactive during field investigation. Gravel deposit overlain by sand.
100	-	7 - 8	10 - 40	Inactive during field investigation
101	-	2.5	30 - 50	Inactive during field investigation
102	-	2 - 7	25	Intermittently active. Oversized clasts to be removed or crushed.
103	-	2 - 6	30 - 40	Overgrown. Pit in a gravel-cored ridge with sandy flanks. Oversized clasts to be removed or crushed.
104	-	3 - 6	10 - 30	Inactive during field investigation

Table 2 - Sand and Gravel Pits District Municipality of Muskoka				
Pit No.	Owner/Operator	Face Height (Metres)	% Gravel	Remarks
105	-	5 - 12	20 - 40	Active during field investigation. Gravel deposit flanked/overlain by up to 6 m of sand. Grey gneiss quarried in northern part of the pit.
106	-	3 - 4	10 - 30	Inactive during field investigation
107	-	3 - 7	<30	Inactive during field investigation. Gravel core has been removed, sandy flanks left.
108	-	2 - 15	5 - 15	Depleted
109	-	5 - 8	<20	Inactive during field investigation. Gravel core has been removed, sandy flanks left.
110	-	3 - 8	20 - 50	Inactive during field investigation. Partially overgrown.
111	-	3 - 7	30 - 40	Inactive during field investigation. Partially overgrown.
112	-	3 - 8	20 - 40	Active
113	-	5	Sand	Inactive during field investigation. Predominantly fine to medium sand.
Township of Lake of Bays				
Unlicenced				
114	-	2	Sand	Inactive during field investigation
115	-	2 - 3	20 - 40	Inactive during field investigation. Flat-lying topography.
116	-	1 - 1.5	30 - 60	Inactive during field investigation
117	-	2 - 2.5	30 - 40	Active. Predominantly sand below pit floor.
118	-	1 - 2	50 - 60	Active. Predominantly sand below pit floor.
119	-	2	30 - 50	Inactive during field investigation.
120	-	1 - 2	30 - 50	Inactive during field investigation.
121	-	1	20 - 30	Intermittently active. Silty.
122	-	8 - 10	<30	Inactive during field investigation. Gravel deposit underlain by sand. Partially overgrown.
123	-	5 - 6	40 - 60	Inactive during field investigation. Cobble gravel. Oversized clasts to be removed or crushed.
124	-	1 - 2	40 - 60	Inactive during field investigation. Oversized clasts to be removed or crushed.
125	-	n/a	Sand	Inactive during field investigation
126	-	3 - 4	10 - 30	Inactive during field investigation. Gravel core has been removed, sandy flanks left.
127	-	4 - 9	20 - 70	Inactive during field investigation
128	-	3 - 4	<10	Inactive during field investigation
129	-	3	<10	Inactive during field investigation
130	-	2	Sand	Inactive during field investigation. Flat-lying topography. Pond in pit.
131	-	2 - 2.5	10 - 20	Inactive during field investigation
132	-	1 - 5	Variable	
133	-	3 - 4	10 - 20	Inactive during field investigation. Fine gravel underlain by fine to very fine sand.
134	-	2 - 3	<20	Overgrown
135	-	1 - 3	20 - 60	Overgrown. Cobble gravel underlain by sand.
136	-	1 - 4	<20	Overgrown
137	-	3 - 4	20	Inactive during field investigation
138	-	4 - 6	Sand	Active. 10 m of sand above water table.
139	-	3 - 6	<10	
140	-	2 - 4	Sand	Inactive during field investigation. Flat-lying topography.
141	-	3 - 4	40 - 60	Inactive during field investigation
142	-	2 - 4	10 - 20	Inactive during field investigation. Partially overgrown.

Table 2 - Sand and Gravel Pits District Municipality of Muskoka				
Pit No.	Owner/Operator	Face Height (Metres)	% Gravel	Remarks
143	-	4	Sand	Inactive during field investigation. Fine to medium beach sand.
144	-	4 - 5	30 - 50	Inactive during field investigation. Partially overgrown.
145	-	3 - 5	20	Active during field investigation
146	-	3	40 - 70	Inactive during field investigation
147	-	3 - 4	50 - 70	Overgrown. Cobble gravel. Oversized clasts are frequent.
148	-	3	30 - 60	Inactive during field investigation. Oversized clasts are frequent.
149	-	1 - 2	n/a	Rehabilitated
150	-	1 - 2.5	Sand	Inactive during field investigation
151	-	3 - 4	30	Inactive during field investigation. Partially overgrown.
152	-	3 - 8	30 - 60	Active. Well-sorted outwash gravel deposit. 4-5 m of gravel material available below pit floor.
153	-	4 - 8	30 - 60	Pit located along a ridge. Ridge is 100-200 m wide on top, with sandy flanks and a cobble gravel core that becomes fine and sandy to the south.
154	-	3 - 6	40	
155	-	1 - 2	10 - 20	Inactive during field investigation. Silty sand with cobbles. Mafic rock quarried at the northern end of the pit.
156	-	3 - 4	Sand	Depleted
157	-	1 - 3	Sand	Overgrown
158	-	n/a	n/a	Rehabilitated
159	-	1.5 - 4.5	Sand	Inactive during field investigation
160	-	3 - 6	15	Depleted
161	-	2 - 5	10 - 20	Inactive during field investigation. Gravel material occurs more commonly in upper face.
162	-	1.5 - 4	Sand	Inactive during field investigation
163	-	3	40	Overgrown
164	-	4 - 5	40 - 60	Inactive during field investigation. Cobble gravel. Oversized clasts are frequent.
165	-	1 - 8	60	Depleted
166	-	2 - 3	20	
167	-	1 - 2	Sand	Inactive during field investigation
168	-	2 - 3.5	30 - 40	Active. Oversized clasts to be removed or crushed.
169	-	2	<10	Inactive during field investigation. Partially overgrown.
170	-	2 - 3	30 - 40	Inactive during field investigation. Partially overgrown.
Town of Bracebridge				
Unlicensed				
171	-	3 - 4	Sand	Inactive during field investigation. Pit in a sand ridge.
172	-	4	40 - 70	Inactive during field investigation
173	-	3 - 5	60 - 70	Active. Cobble gravel. Grey gneiss quarried at the northeastern end of the pit.
174	-	5 - 9	30 - 60	
175	-	4 - 10	<20	Gravel core has been removed, sandy flanks left.
176	-	4	Variable	Inactive during field investigation
177	-	6 - 7	<10	
178	-	2 - 3	40 - 60	Inactive during field investigation
179	-	2 - 3	30 - 50	Inactive during field investigation. Gravel deposit overlain by sand. Shallow pond in pit.
180	-	2 - 3	10 - 20	Active. Sand flanks are left.
181	-	6 - 7	30 - 40	Inactive during field investigation. Partially overgrown.

Table 2 - Sand and Gravel Pits District Municipality of Muskoka				
Pit No.	Owner/Operator	Face Height (Metres)	% Gravel	Remarks
182	-	4	<10	Now a landfill site
183	-	2 - 4	20 - 50	Overgrown
184	-	2 - 5	20	Inactive during field investigation
185	-	5 - 6	50 - 60	Inactive during field investigation
186	-	5	20 - 60	Active. Dragline being used. Gravel material present below pit floor/water table.
187	-	1 - 2	Sand	Overgrown
188	-	2 - 4	Variable	Overgrown
189	-	2 - 3.5	45	Inactive during field investigation. Partially overgrown.
190	-	2 - 6	10 - 20	Gravel core has been removed, sandy flanks left. Gravel material probably present below water table.
191	-	7 - 8	<10	Inactive during field investigation. Gravel core has been removed, sandy flanks left.
192	-	2	Sand	Inactive during field investigation. Pit in a flat-topped sand and gravel ridge.
193	-	5 - 8	10 - 20	Active during field investigation
194	-	10	Sand	Overgrown. Fine sand.
195	-	6 - 10	20 - 40	Inactive during field investigation. Gravel core flanked/ overlain by sand. Oversized clasts are frequent.
196	-	2 - 3	Sand	Overgrown. Fine to very fine sand.
197	-	1 - 2.5	<10	Inactive during field investigation. Partially overgrown.
198	-	2 - 5	Variable	Depleted
199	-	1 - 3	10 - 40	Inactive during field investigation
200	-	1 - 3	<10	Inactive during field investigation. Gravel core has been removed, sandy flanks left. Gravel material present below water table/pit floor.
201	-	5 - 6	20 - 30	Inactive during field investigation
202	-	3 - 5	10 - 30	Inactive during field investigation
203	-	1.5 - 2	<10	Inactive during field investigation. Flat-lying topography.
Town of Gravenhurst				
Unlicensed				
204	-	3 - 4	30 - 60	Depleted
205	-	2	30 - 40	Depleted
206	-	3	30 - 40	Depleted
207	-	3 - 4	5	Intermittently active
208	-	2 - 3	50 - 80	Overgrown. Deposit becomes sandy to the south.
209	-	2.5	50 - 60	Inactive during field investigation
210	-	2 - 3	10 - 30	Depleted
211	-	5	20 - 50	Depleted. Pond in pit.
212	-	3 - 6	Sand	Largely depleted. Pond in pit.
213	-	2 - 3	10 - 30	Overgrown. Oversized clasts to be removed or crushed.
214	-	2 - 3	10 - 30	Overgrown
215	-	2 - 4	Sand	Active during field investigation. Dragline is being used for extracting sand in water. Grey gneiss quarried on the northeastern side of the pit.
216	-	1 - 1.5	10 - 20	Inactive during field investigation
217	-	2 - 4	5 - 15	Depleted
218	-	3 - 6	20 - 60	Overgrown
219	-	4 - 8	Sand	Depleted
220	-	2 - 3	30 - 60	Inactive during field investigation. Pond in southern part of the pit.

Table 2 - Sand and Gravel Pits District Municipality of Muskoka				
Pit No.	Owner/Operator	Face Height (Metres)	% Gravel	Remarks
221	-	3	10 - 70	Active during field investigation. 3 m+ of gravel material below water table/pit floor.
222	-	4 - 5	Sand	Active during field investigation
223	-	2 - 3	Variable	Inactive during field investigation. Partially overgrown.
224	-	2 - 4	Sand	Overgrown. Gravel material probably present below pit floor.
225	-	4 - 5	Sand	Active during field investigation. Predominantly a fine sand.
226	-	1 - 2	n/a	Depleted
227	-	4 - 5	Sand	Depleted. Pond in pit.
228	-	4 - 5	Sand	Depleted. Pond in pit.
229	-	4 - 5	Sand	Depleted. Pond in pit.
230	-	4 - 8	10 - 20	Inactive during field investigation. Gravel core has been removed, sandy flanks left.
231	-	1.5	20 - 50	Inactive during field investigation. Flat-lying topography.
232	-	5 - 6	<10	Inactive during field investigation
233	-	3 - 5	Sand	Inactive during field investigation. Partially overgrown.
234	-	4 - 8	Sand	Inactive during field investigation
235	-	4 - 9	10 - 30	Inactive during field investigation
236	-	3 - 4	Sand	Intermittently active. Gravel material below water table.
237	-	1 - 2	Sand	
238	-	2	20 - 30	Depleted
239	-	2	Sand	Inactive during field investigation
240	-	1.5	Sand	Overgrown
241	-	1 - 2	Sand	Depleted. Pond in pit.
242	-	2	Sand	Depleted. Pond in pit.
243	-	3 - 5	Sand	Inactive during field investigation. Partially overgrown. Pond in pit.
244	-	4 - 5	10 - 20	Depleted
245	-	3 - 9	10 - 40	Active during field investigation. Gravel deposit flanked by up to 5 m of sand.
246	-	2 - 6	Sand	Inactive during field investigation
247	-	2 - 4	10 - 40	Gravel core has been removed, sandy flanks left. Gravel material may be available below pit floor.
248	-	3 - 4	<10	Partially overgrown. Fine to medium sand with rare gravel lenses/pockets.
249	-	3	30 - 50	Overgrown. Pond in pit.
250	-	2 - 2.5	Variable	Inactive during field investigation. Gravel available below pit floor.
251	-	2	Sand	Inactive during field investigation. Partially overgrown.
252	-	2 - 3	Sand	Inactive during field investigation. Partially overgrown. Pond in pit.
253	-	4 - 7	Sand	Depleted
254	-	4 - 7	10 - 30	Active during field investigation. Gravel deposit overlain by 3-4 m of sand.
255	-	2	Sand	Depleted
256	-	1.5 - 4	Sand	Overgrown

Table 3 - Selected Sand and Gravel Resource Areas District Municipality of Muskoka						
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 Lake of Bays						
1	199.7	36.6	56.8	106.3	6	11.3
Town of Huntsville						
2	65.0	20.1	3.5	41.4	6	4.4
Town of Bracebridge						
3	289.6	55.5	30.0	204.1	6	21.7
TOTAL	554.2	112.2	90.3	351.8		37.4
<p>Minor variations in the tables are caused by the rounding of the data.</p> <p>* Excludes areas licenced under the <i>Aggregate Resources Act</i>.</p> <p>** 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.</p> <p>*** Extracted area is a rough estimate of areas that are not licenced, but, due to previous extractive activity, are largely depleted.</p> <p>**** Further environmental, resource, social and economic constraints will greatly reduce the selected resource quantity realistically available for potential extraction.</p>						

Table 4 - Total Identified Bedrock Resources District Municipality of Muskoka				
1 Drift Thickness (Metres)	2 Formation	3 Estimated Deposit Thickness (Metres)	4 Areal Extent (Hectares)	5 Original Tonnage (Million Tonnes)
– NONE –				

Table 5 - Quarries District Municipality of Muskoka			
Quarry No.	Owner/Operator	Quarry Face (Metres)	Geological Description
Township of Georgian Bay			
Q1	-	4 - 6	Intermediate to mafic gneiss; grey to pinkish grey; medium grained; 20-30% pink wispy leucosome streaks and planar bands; strong foliation; amphibolitic pods; fairly uniform
Q2	-	15 - 20	Migmatitic gneiss; light to medium grey; medium grained
Q3	-	4 - 8	Intermediate gneiss; light grey; medium grained; 20-30% pink-white wispy streaks; moderate to strong foliation; massive; albite-quartz-microcline-biotite-hornblende-calcite mineralogy; fairly uniform
Township of Muskoka Lakes			
Q4	-	5 - 6	Granite; pink; medium grained; slightly deformed; weak foliation; hard and durable; some mafic inclusions; dominated by feldspars and quartz with minor hornblende and biotite; fairly uniform
Q5	-	4 - 6	Felsic gneiss; pink; fine to medium grained; weak foliation; hard and durable; some friable amphibolitic pods; dominated by quartz, potassium feldspar (orthoclase and/or microcline) and plagioclase; fairly uniform
Q6	-	6	Gneiss
Q7	-	8 - 10	Intermediate gneiss; grey; medium grained; 10-30% pink planar leucosome; planar foliation and banding; occasional potassium feldspar veins; fairly uniform
Q8	-	3 - 4	Felsic gneiss; pink to light pink; medium grained; some mafic layers
Q9	-	8 - 10	Felsic to intermediate gneiss; light grey to light pink; medium grained; some mafic layers that define moderate to strong banding
Q10	-	4 - 7	Intermediate gneiss; grey to pink; medium grained; 30-40% pink-white wispy streaks that define strong foliation; fairly uniform
Q11	-	6 - 8	Intermediate gneiss; light grey to pinkish grey; medium grained; 20-30% pink planar to locally swirly leucosome; strong foliation and banding; rare potassium feldspar veins, fairly uniform
Q12	-	8 - 10	Intermediate to mafic gneiss; grey to pinkish grey; medium grained; 20-30% pink planar leucosome; strong foliation and banding; rare potassium feldspar veins; some small amphibolitic pods; fairly uniform
Q13	-	8 - 15	Intermediate gneiss; pink to grey; medium grained; 30-40% pink planar to locally swirly leucosome; strong foliation and banding; frequent amphibolitic pods up to 2 m high and 5 m long
Q14	-	6	Intermediate gneiss; grey to pinkish grey; medium grained; 10-30% pink planar leucosome; strong foliation and banding; occasional potassium feldspar veins present; becoming migmatitic in the northern end of the quarry
Town of Huntsville			
Q15	-	8 - 9	Intermediate gneiss; grey; fine to medium grained; 10-20% pink-white leucosome; weak to strong foliation and banding; fairly uniform
Q16	-	6 - 10	Intermediate to mafic gneiss; grey; medium grained; weak to moderate foliation in central part; flanks change to intermediate gneiss; fairly uniform
Q17	-	8	Intermediate gneiss; grey; medium grained; 10-20% white-pink planar leucosome bands; sugary fresh surfaces; occasionally containing friable amphibolitic pods; fairly uniform
Q18	-	4 - 10	Intermediate to mafic gneiss; grey; medium grained; northern flank becoming strongly banding
Q19	-	5 - 7	Intermediate gneiss; grey; medium grained; 10-20% pink-white planar leucosome; moderate to strong foliation and banding

Table 5 - Quarries District Municipality of Muskoka			
Quarry No.	Owner/Operator	Quarry Face (Metres)	Geological Description
Township of Lake of Bays			
Q20	-	3 - 5	Felsic gneiss; pink; medium grained; weak to moderate foliation; some amphibolitic pods; hard and durable, fairly uniform
Q21	-	10 - 15	Intermediate gneiss; pinkish grey; fine to medium grained; 20-40% pink planar leucosome; strong foliation, fairly uniform
Q22	-	10 - 15	Intermediate gneiss; light grey to pinkish grey; fine to medium grained; 10-40% pink planar leucosome; strong foliation; some friable amphibolitic layers present; fairly uniform
Q23	-	3 - 4	Peridotite and minor olivine gabbro with primary igneous mineralogy and textures; dark; fine-grained; friable to brittle; fairly uniform; disseminated sulphide minerals (pyrrhotite); upper 1-2 m deeply weathered
Town of Bracebridge			
Q24	-	4 - 5	Intermediate gneiss; grey; medium grained; 20-40% pink planar leucosome bands; sugary fresh surfaces; fairly uniform
Town of Gravenhurst			
Q25	-	5 - 10	Intermediate to mafic gneiss; grey; medium grained; 10-20% pink planar leucosome; moderate foliation; sugary fresh surfaces; fairly uniform
Q26	-	4 - 8	Intermediate gneiss; grey; medium to coarse grained; 10-30% pink planar leucosome; strong foliation and banding; sugary fresh surfaces; fairly uniform

Table 6 - Selected Bedrock Resource Areas District Municipality of Muskoka							
1 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 District Municipality of Muskoka				
Test Hole ID	Depth (Metres)	Description	Elevation (Metres above sea level)	Location*
Town of Bracebridge				
MU-TH-1	0-3.6	Fine to coarse gravel with minor iron staining	300	Conc. X, Lot 14
MU-TH-2	0-3.3	Fine to coarse gravel with clean coarse sand	300	Conc. IX, Lot 13
	3.3-4.3	Silty fine sand		
MU-TH-3	0-4	Fine to coarse gravel with clean medium to coarse sand	305	Conc. IX, Lot 13
MU-TH-4	0-0.9	Fine sand	315	Conc. IX, Lot 14
	0.9-1.5	Fine to coarse gravel with clean medium to coarse sand		
	1.5-3	Fine sand		
* All test holes drilled October 6, 1988, in the former Macaulay Geographic Township (now part of the Town of Bracebridge).				

Table 8 - Summary of Geophysical Data District Municipality of Muskoka
- NONE -

Table 9 - Aggregate Quality Test Data									
District Municipality of Muskoka									
		COARSE AGGREGATE							FINE AGGREGATE
Sample No.	Type of Sample	Petrographic Number		Absorption (%)	Bulk Relative Density	Freeze-Thaw (% Loss)	Micro-Deval Abrasion (% Loss)	Polished Stone Value	Micro-Deval Abrasion (% Loss)
		Granular & 16 mm Crushed	Hot Mix & Concrete						
Township of Georgian Bay									
2004CG218	Rock		135	0.26	2.75	1	13.5	52	8.6
Township of Muskoka Lakes									
2004CG261	Rock	100	143	0.48	2.62	0	9.3		10
Town of Huntsville									
2004CG65	S&G*	104	133	0.43	2.68		11.5		8.1
2004CG69	Rock	100	103	0.24	2.69	1	7.4		10.9
2004CG90	Rock	100	110	0.29	2.86	1	13		13.5
2004CG310	Rock	100	104	0.41	2.67	1	8		
Township of Lake of Bays									
2004CG162	S&G*	100	111	0.43	2.67	2	8.3		10.8
2004CG197	Rock	100	104	0.29	2.65	1	6		12.2
2004CG302	Rock		302	0.92	2.8	2	14	46	
Town of Bracebridge									
2004CG62	S&G*	100	138	0.41	2.67	2	15.8		7
Town of Gravenhurst									
2004CG26	S&G*	112	167	0.52	2.75		15.8		7.8
2004CG31	Rock	100	113	0.22	2.78	1	10.1		10.1
<p>* S&G = sand and gravel sample; locations are shown on Map 1. Rock sample locations are shown on Map 2.</p> <p>Note - The quality test data refer strictly to a specific sample. Because of the inherent variability of rock outcrops as well as sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit.</p>									

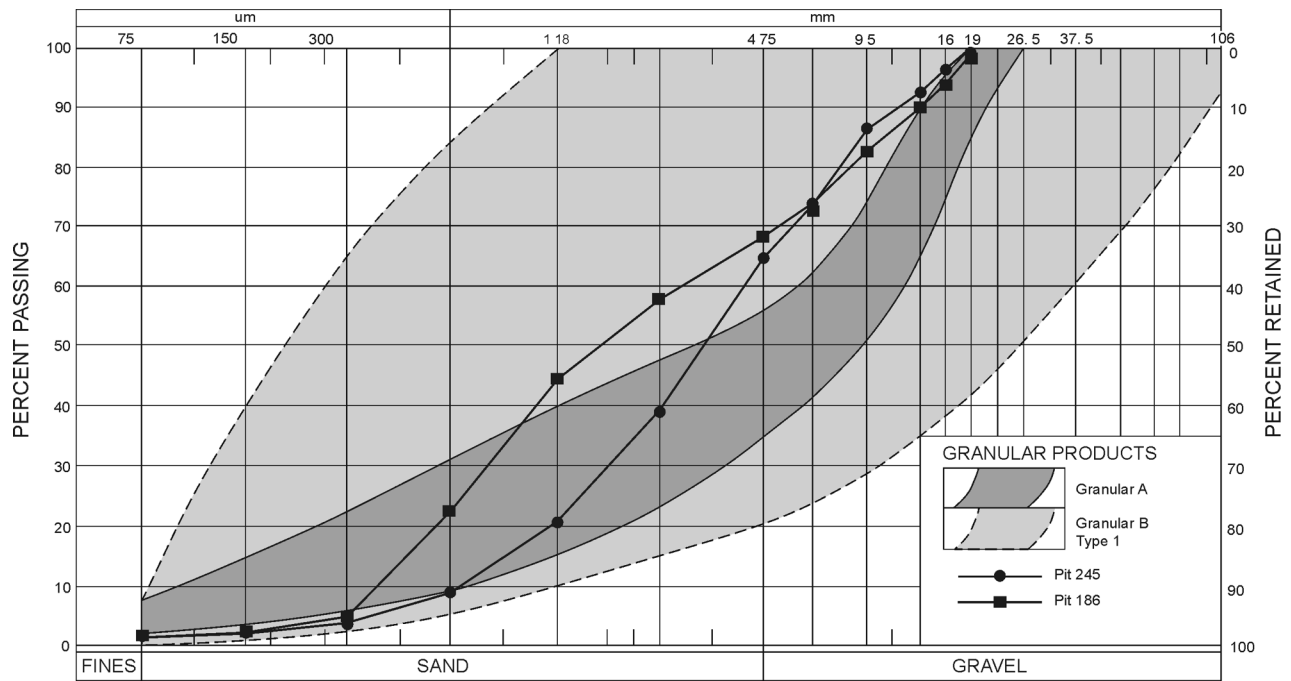


Figure 2A. Aggregate Grading Curves, District Municipality of Muskoka – Total Aggregate.

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

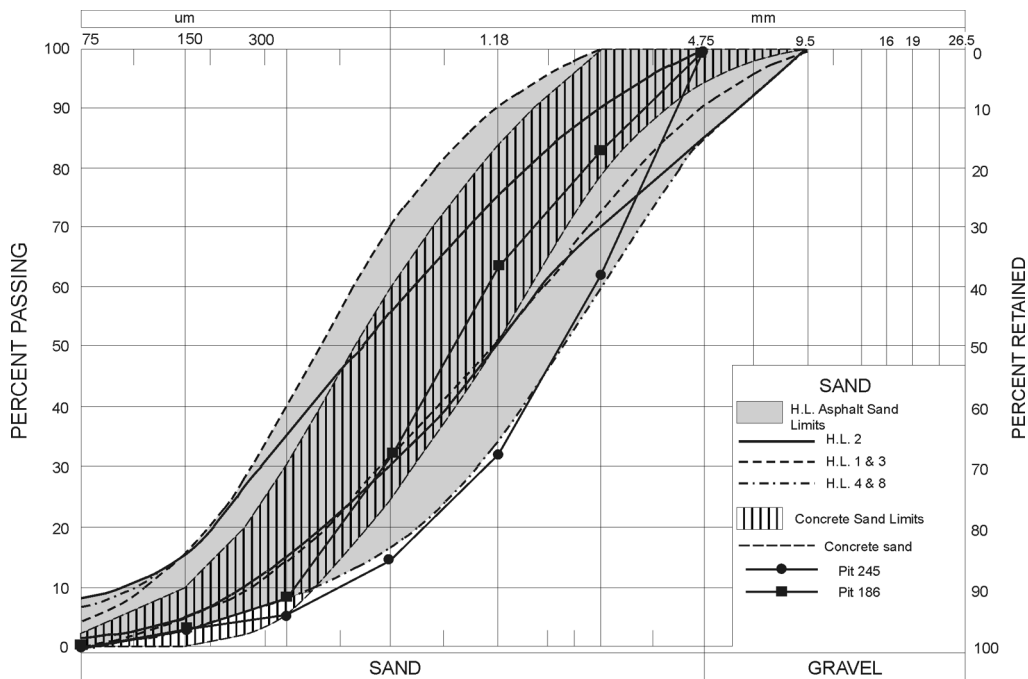


Figure 2B. Aggregate Grading Curves, District Municipality of Muskoka – Sand Fraction.

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.

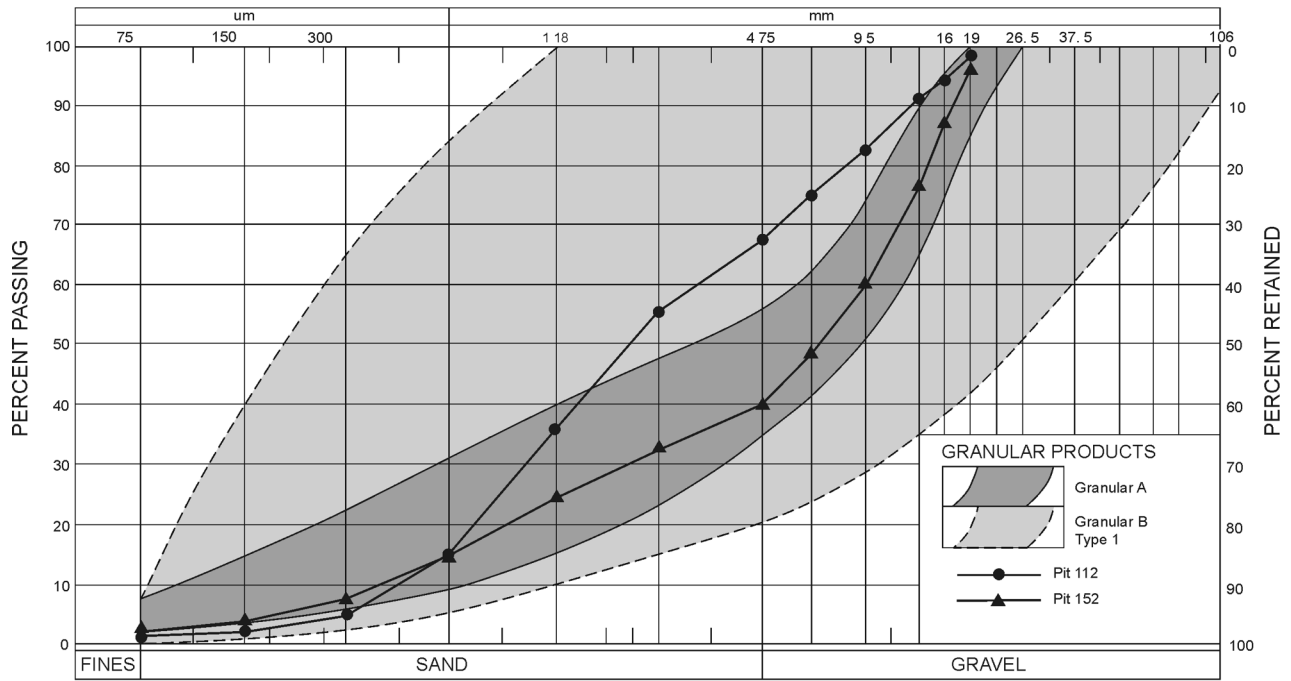


Figure 3A. Aggregate Grading Curves, District Municipality of Muskoka – Total Aggregate. Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1010, 1988).

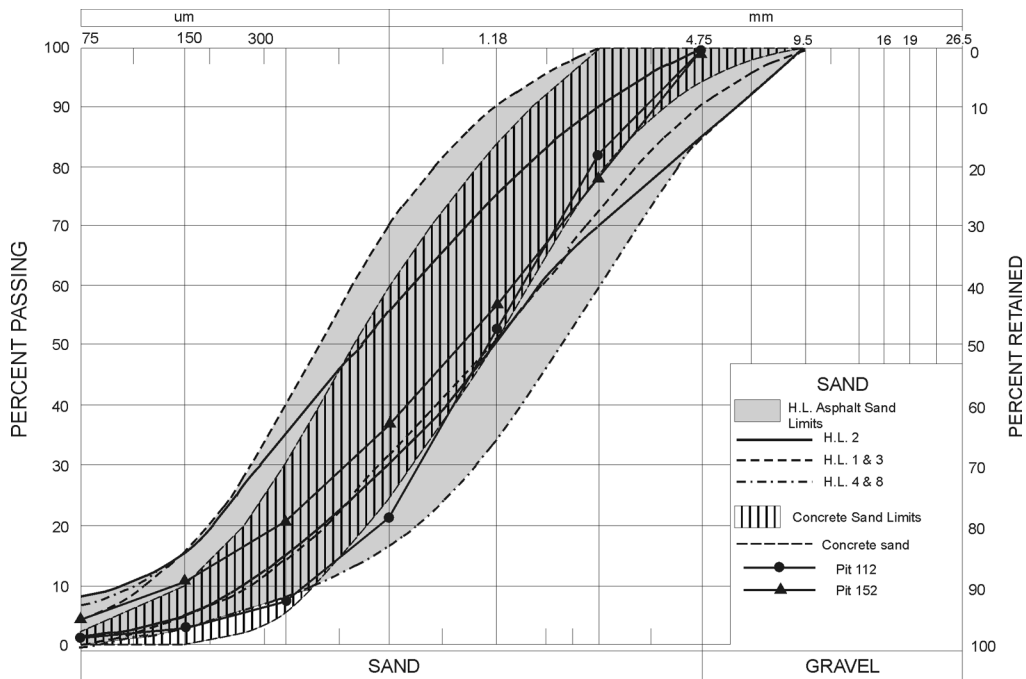


Figure 3B. Aggregate Grading Curves, District Municipality of Muskoka – Sand Fraction. Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1002 (1988) and 1003 (1988)).

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.

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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 ago. 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 bed-rock 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),
MgSO₄ = 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 Philippsville and Forfar for silica sand; alkali–silica reactive in Portland cement concrete.

AGGREGATE SUITABILITY TESTING: PSV = 54-68, AAV = 4-15, MgSO₄ = 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, MgSO₄ = 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 interbeds.

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, MgSO₄ = 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, MgSO₄ = 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 Cobocok 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, MgSO₄ = 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, MgSO₄ = 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: MgSO₄ = 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 Wiarnton 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 Warton Member consists of massive-bedded, blue-grey mottled, light grey to white, fine- to coarse-crystalline, porous crinoidal dolostone. Underlying the Warton Member in the Bruce Peninsula is the Colpo Bay Member which is browner, finer grained and less fossiliferous than the Warton 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, MgSO₄ = 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, MgSO₄ = 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, MgSO₄ = 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, MgSO₄ = 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) MgSO₄ = 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, MgSO₄ = 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, MgSO₄ = 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: MgSO₄ = 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.

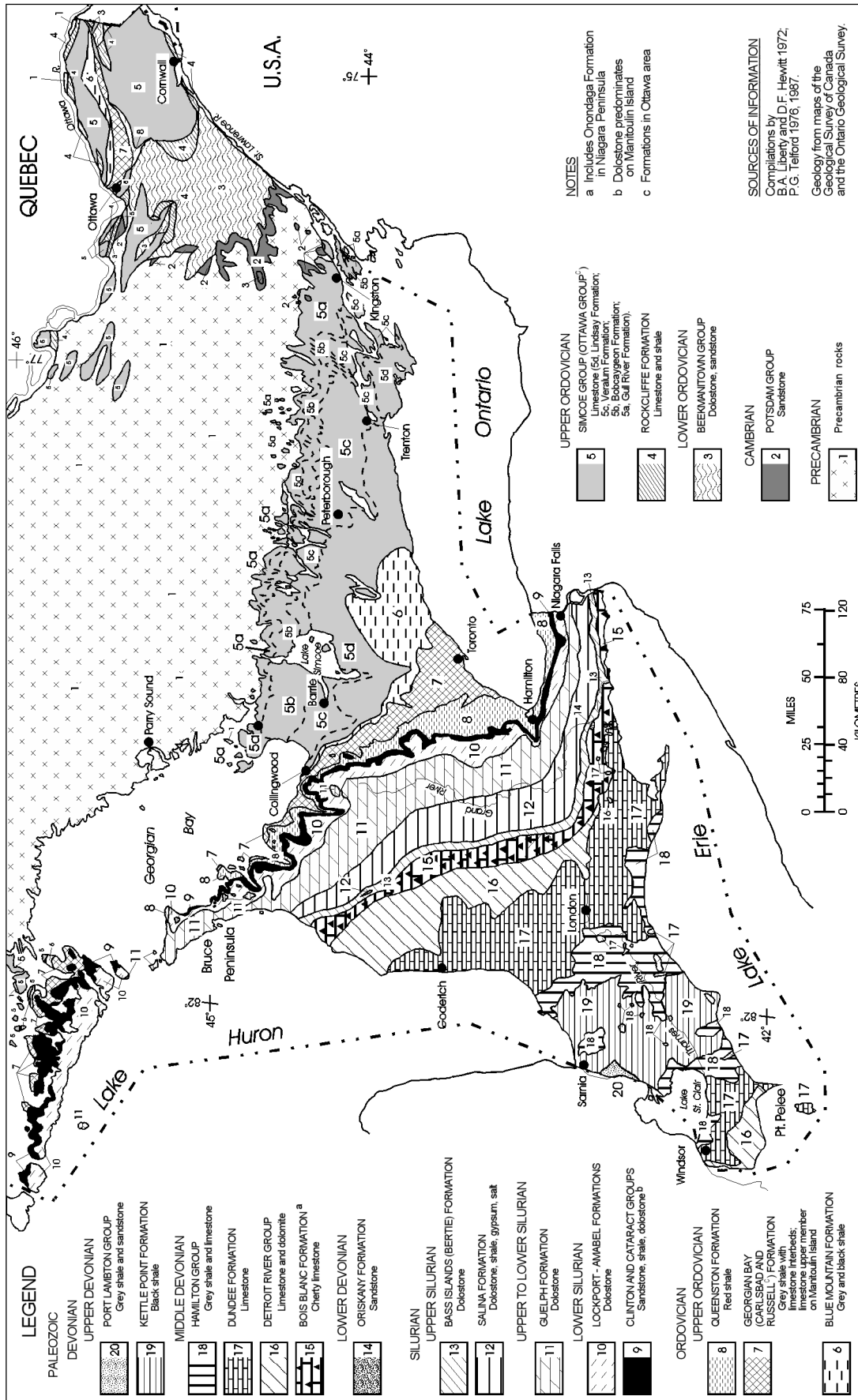


Figure D1. Bedrock geology of southern Ontario.

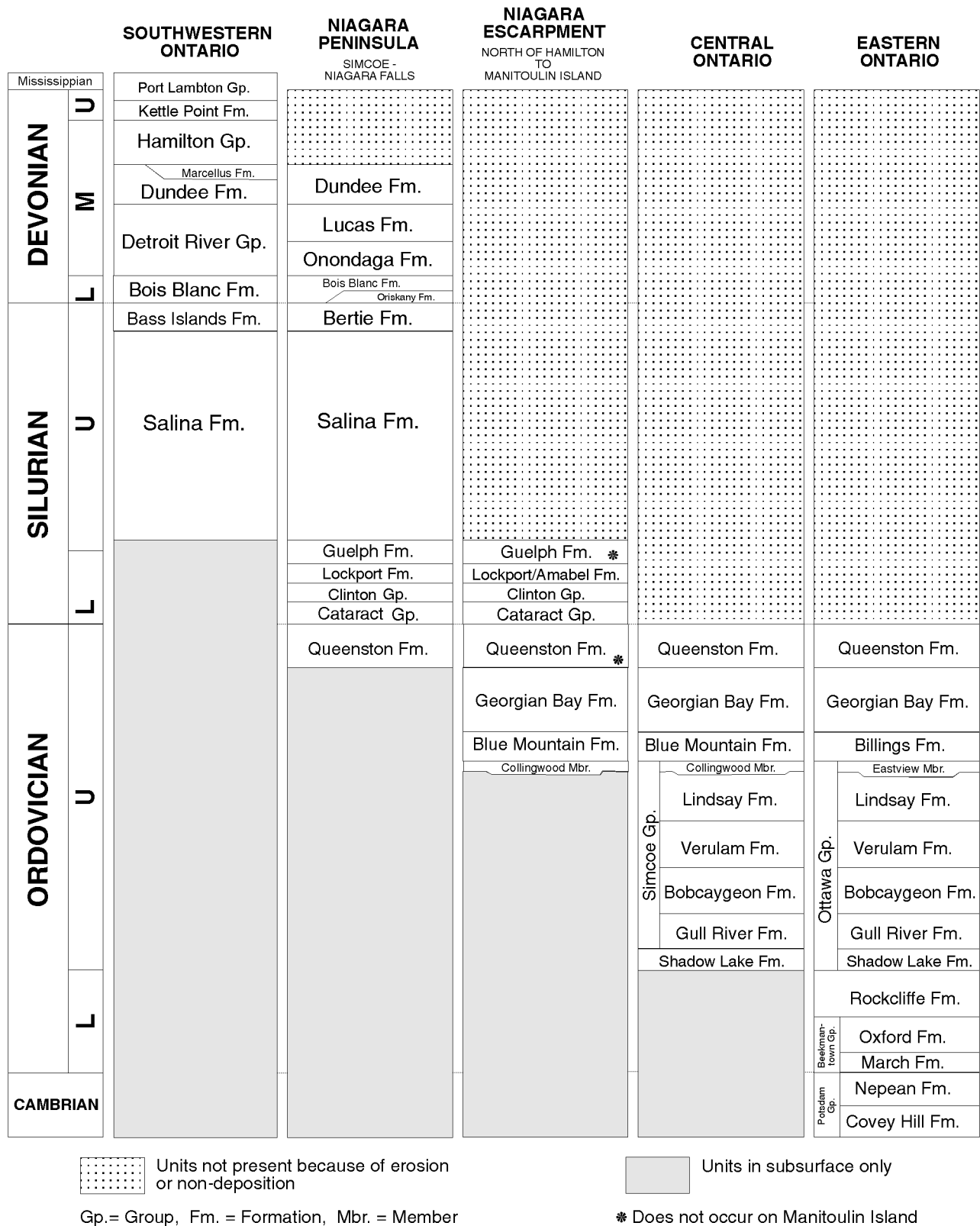


Figure D2. Exposed Paleozoic stratigraphic sequences in southern Ontario (adapted from Bezys and Johnson 1988 and Armstrong and Dodge 2007).

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 AVV 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	<i>[Note 1]</i>					
LS-618	Micro-Deval Abrasion Loss, Coarse Aggregate (% maximum loss)	21	25	30 <i>[Note 2]</i>	30	25	30 <i>[Note 2]</i>
LS-619	Micro-Deval Abrasion Loss, Fine Aggregate (% maximum loss)	25	30	35	35	30	–
LS-630	Amount of Contamination	<i>[Note 3]</i>					
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 $>1.0 \times 10^{-4}$ 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 (Superpave 12.5 FC1 only)	Quarried Rock (SMA, Superpave 12.5 FC1 and 12.5 FC2)		
				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] <ul style="list-style-type: none"> • 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		
<i>SI Unit</i>	<i>Multiplied by</i>	<i>Gives</i>	<i>Imperial Unit</i>	<i>Multiplied by</i>	<i>Gives</i>
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

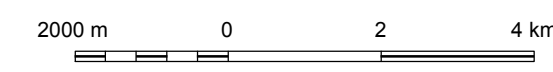
	<i>Multiplied by</i>	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in boldtype 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.

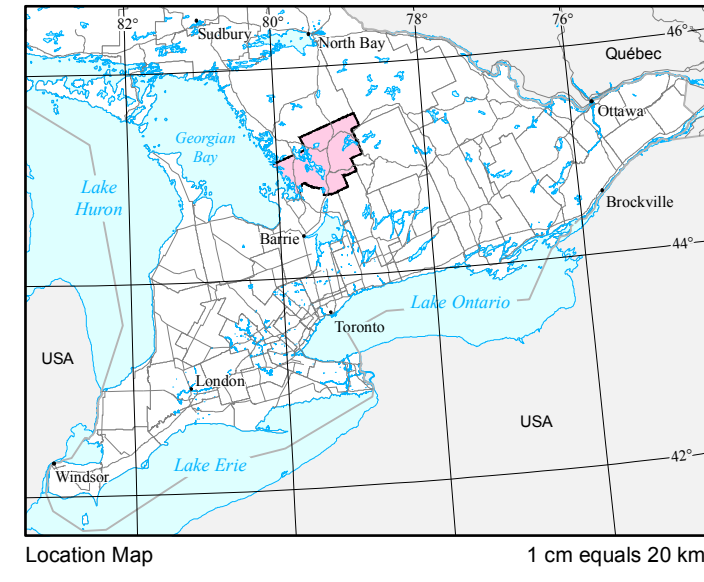
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Sand and Gravel Resources for the District Municipality of Muskoka

Scale 1:100 000



NTS References: 31 D/13, 14, 15; 31 E/2, 3, 4, 5, 6, 7, 10; 41 A/16; 41 H/1



SAND AND GRAVEL RESOURCES

- 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

- Licensed property boundary, property number (see Table 2)
- Unlicensed sand or gravel pit (i.e. abandoned pit or waste 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)
- Geological and aggregate thickness boundary of sand and gravel deposits
- Administrative boundary

SOURCES OF INFORMATION

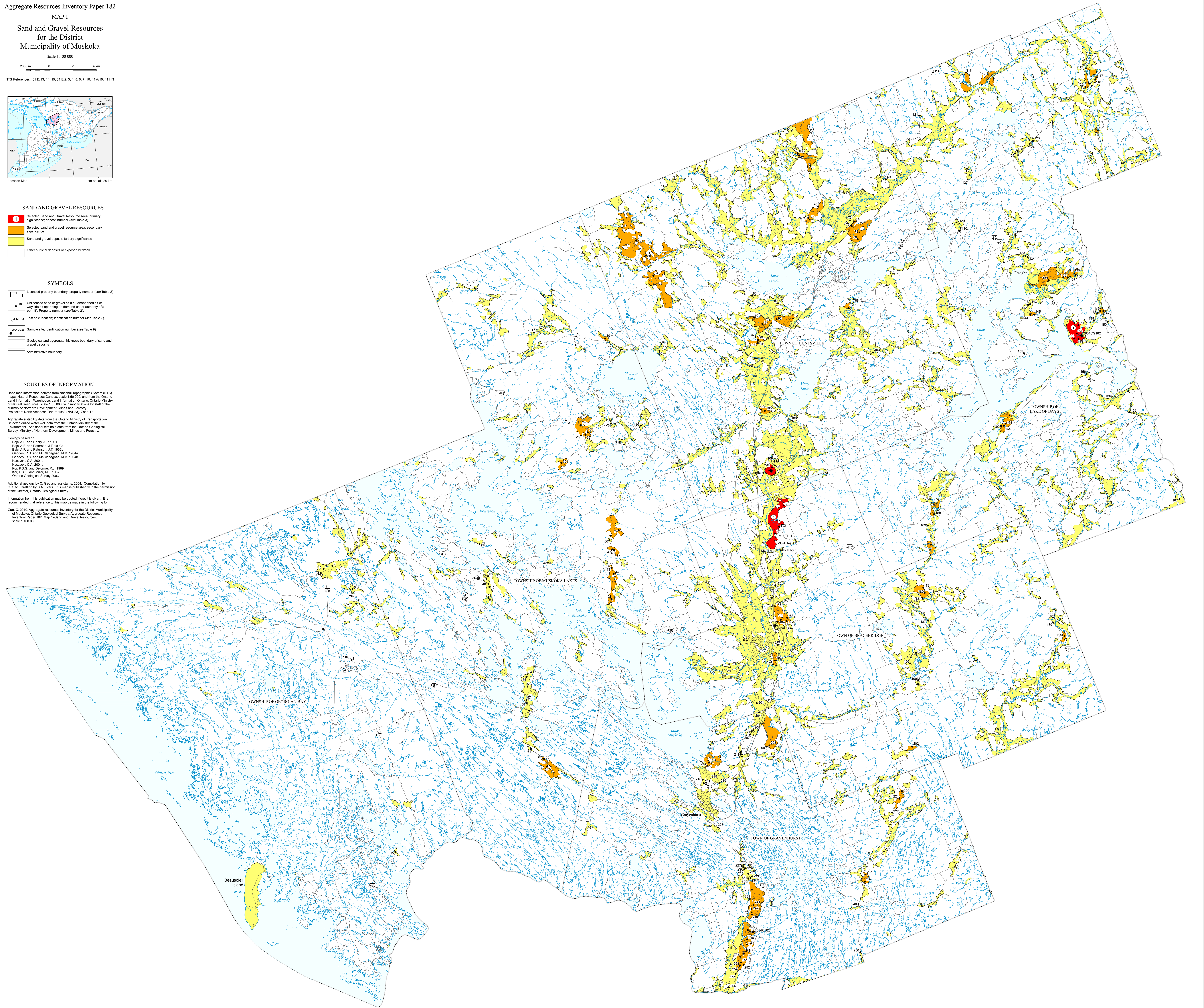
Base map information derived from National Topographic System (NTS) maps: Natural Resources Canada, scale 1:50 000, and from the Ontario Land Information Warehouse, Land Information Ontario, Ontario Ministry of Natural Resources, scale 1:50 000, with modifications by staff of the Ministry of Northern 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. Additional test hole data from the Ontario Geological Survey, Ministry of Northern Development, Mines and Forestry.

Geology based on:
 Bag, A.F. and Henry, A.P. 1951
 Bag, A.F. and Peterson, J.T. 1952a
 Bag, A.F. and Peterson, J.T. 1952b
 Gosses, R.S. and McClenaghan, M.B. 1984a
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 Koz, P.S.G. and Delorme, R.J. 1989
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 Ontario Geological Survey 2003

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Information from this publication may be quoted if credit is given. It is recommended that reference to this map be made in the following form:
 Gao, C. 2010. Aggregate resources inventory for the District Municipality of Muskoka. Ontario Geological Survey, Aggregate Resources Inventory Paper 182, Map 1—Sand and Gravel Resources, scale 1:100 000.

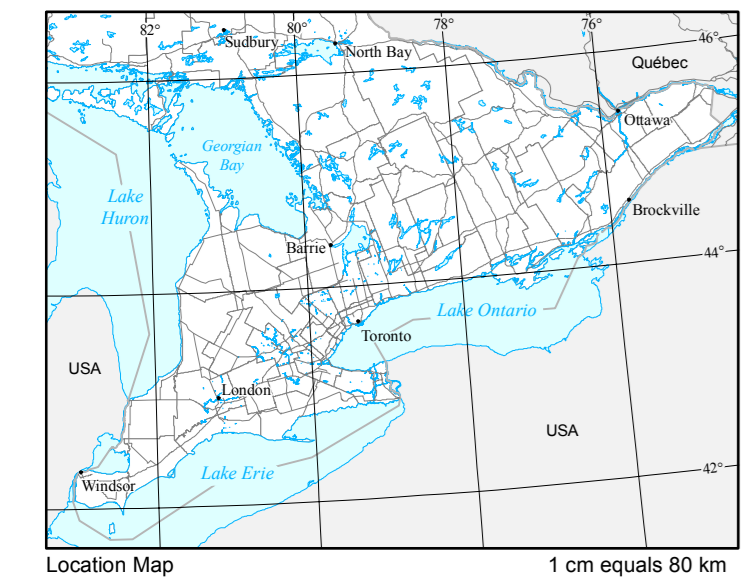


Bedrock Resources for the District Municipality of Muskoka

Scale 1:100 000



NTS References: 31 D13, 14, 15, 31 E2, 3, 4, 5, 6, 7, 10, 41 A16, 41 H1



LEGEND—LITHOTECTONIC UNITS

PRECAMBRIAN

PROTEROZOIC

Grenville Province

Central Gneiss Belt

Parry Sound Terrane

Moon River domain

Seguin domain

Algonquin Terrane

Go Home domain

Fishog domain

Rosseau domain

McClelland domain

Huntsville domain

Novar domain

McCraney domain

LEGEND—ROCK UNITS

Mafic rock

Felsic igneous rock

Anorthosite and alkalic igneous rock

Gneiss (metasedimentary origin)

Migmatitic rock and gneiss (underdetermined protolith)

SYMBOLS

Licensed quarry boundary, property number (see Table 5)

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

Bedrock outcrop (examined, sampled)

Sample site, identification number (see Table 6)

Geological contact

Geological domain boundary

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.

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

Geology based on:
Ontario Geological Survey 1992a
Ontario Geological Survey 1992b
Ontario Geological Survey 1992c
Lumbers, S.B. and Vertell, V.M. 2000a
Lumbers, S.B. and Vertell, V.M. 2000b
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Lumbers, S.B., Vertell, V.M. and Schwedner, W.M. 2000b

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Gao, C., 2010. Aggregate resources inventory for the District Municipality of Muskoka, Ontario Geological Survey, Aggregate Resources Inventory Paper 182, Map 2—Bedrock Resources, scale 1:100 000.

