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Aggregate Resources Inventory of the

United Counties of Leeds–Grenville

Southern Ontario

Ontario Geological Survey
Aggregate Resources Inventory
Paper 183

2009

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By Jagger Hims Limited, C. Gao and D.J. Rowell

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Contents

FIGURES

TABLES*

MAPS*

*** 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 includes an inventory and evaluation of the sand and gravel, and bedrock resources for the United Counties of Leeds–Grenville. Eight selected sand and gravel resource areas have been identified at the primary significance level, occupying a total of 799 ha. Once licenced resources are removed and an allowance has been made for cultural, environmental and other land use constraints, an estimated 707 ha remain for possible resource development and extraction. This area is estimated to contain approximately 106.3 million tonnes of sand and gravel.

Bedrock resources, associated with the Oxford, March and Gull River formations are present in a large area of the county. The Oxford and March formations extend from the west-central portion of the county eastward toward the Stormont–Dundas–Glengarry County boundary. The Gull River Formation is only present in the northwest corner of Leeds–Grenville. There are a number of active quarries within the county that supply high-quality, high specification aggregate.

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.

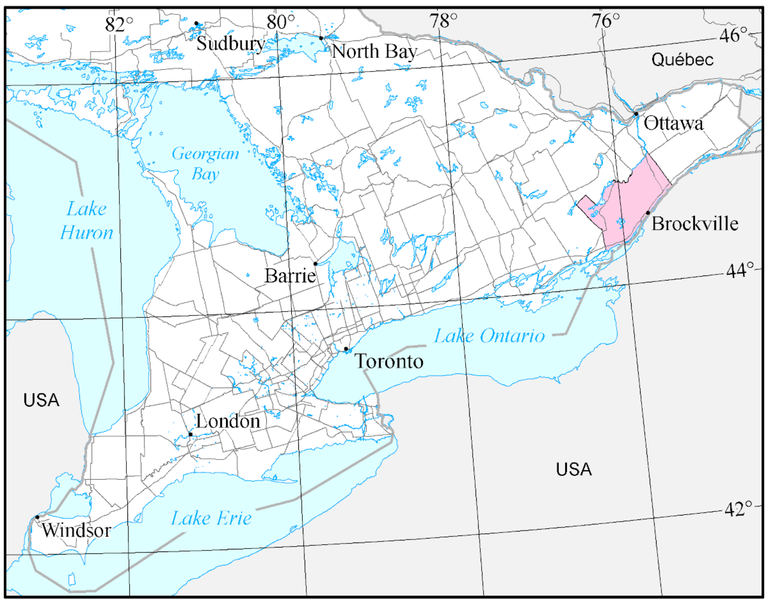

Figure 1. Key map showing the location of the study area.

Aggregate Resources Inventory of the United Counties of Leeds–Grenville

By Jagger Hims Limited[1], C. Gao[2] and D.J. Rowell[2,3]

Sand and gravel field work, map production and report by A.J. Cooper and J. McIntosh of Jagger Hims Limited.

Compilation and editing of the sand and gravel resources completed by C. Gao.

Bedrock field work, assessment and report completed by D.J. Rowell.

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

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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 2007, the total tonnage of mineral aggregates extracted in Ontario was 173 million tonnes, greater than that of any other metallic or non-metallic commodity mined in the Province (The Ontario Aggregate Resources Corporation 2008).

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; magnesium sulphate soundness test; micro-Deval abrasion test; unconfined freeze–thaw test; and some samples are selected for accelerated mortar bar testing.

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. The co-operation of the above-named groups in the compilation of inventory data is gratefully acknowledged.

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 and Mines.

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; the field name is indicated by bold, small capital letters (e.g., Bedrock | Drift_Thick.dbf | **AABBCC**).

Map 1: Sand and Gravel Resources

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

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

SELECTED SAND AND GRAVEL RESOURCE AREAS

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

Each area of primary significance is 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 | LIMITATIONS. 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 MTO 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,

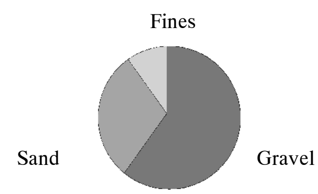
"G / 1 / OW / C",

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 "market share" of an area will remain roughly at the same level.

The aggregate resources in the region surrounding a project area should be assessed in order to properly evaluate specific resource areas and to adopt 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 high resources in proximity to large demand centres, such as metropolitan areas, are special cases. The market demand for aggregate products in urban areas is often greater than the amount of production occurring in the area close to the urban boundaries.

Although an appreciation of the regional context is required to develop comprehensive resource management techniques, 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 preceding sections.

SAND AND GRAVEL RESOURCE TONNAGE CALCULATIONS

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

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

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

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

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

Map 2: Bedrock Resources

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

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

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

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

SELECTED BEDROCK RESOURCE AREAS

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

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

SELECTION CRITERIA

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

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

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

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

BEDROCK RESOURCE TONNAGE CALCULATIONS

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

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

Assessment of Aggregate Resources in the United Counties of Leeds–Grenville

LOCATION AND POPULATION

The United Counties of Leeds–Grenville occupies an area of approximately 3350 km^2 and is located along the north shore of the St. Lawrence River between Kingston and Cornwall. The county is covered by all or parts of 10, 1:50 000 scale map sheets of the National Topographic System (NTS). These map sheets are Mallorytown (31 B/5), Johnstown (31 B/11), Brockville (31 B/12), Merrickville (31 B/13), Morrisburg (31 B/14), Gananoque (31 C/8), Westport (31 C/9), Tichborne (31 C/10), Perth (31 C/16), and Kemptville (31 G/4).

In 2006, the population of the United Counties of Leeds–Grenville was 99 206 (Table A), which represents a less than 2.7% increase from 2001 census data (Statistics Canada 2006). The United Counties of Leeds–Grenville is largely rural in character and the majority of the county is either farmed or forested. There are 2 main urban centres, Brockville and the Municipality of North Grenville (Kemptville), which comprise 22.1 and 14.3% of the overall population of the county, respectively (*see* Table A). Gananoque and Prescott are smaller urban centres with 5.3 and 4.2% of the county's population, respectively.

Major road access to the United Counties of Leeds–Grenville is provided by Provincial Highways 401, 15 and 416. Access to Toronto and Montreal is via Highway 401; access to Ottawa is provided by Highway 416. Travel throughout the county is provided by a well-developed network of county and township roads.

Table A - Area and Population

United Counties of Leeds–Grenville

Municipality	Area in 2006 (Hectares)	2001 Population	2006 Population
Township of Athens	12 646	3 053	3 086
Township of Augusta	31 406	7 635	7 510
City of Brockville	2 074	21 375	21 957
Township of Edwardsburgh–Cardinal	31 183	6 674	6 689
Township of Elizabethtown–Kitley	55 424	10 039	10 201
Township of Front of Yonge	12 785	2 639	2 803
Town of Gananoque	701	5 167	5 285
Township of Leeds and The Thousand Islands	60 718	9 069	9 435
Village of Merrickville–Wolford	21 377	2 812	2 867
Municipality of North Grenville	35 014	13 581	14 198
Town of Prescott	495	4 228	4 180
Township of Rideau Lakes	71 025	9 687	10 350
Village of Westport	171	647	645
Total	**335 019**	**96 606**	**99 206**

SURFICIAL GEOLOGY AND PHYSIOGRAPHY

Chapman and Putnam (1984) provide an overview of the physiography of the United Counties of Leeds–Grenville. Approximately half of the central portion of the county is characterized as a limestone plain with the following occasional features: beach shoreline features; thin glaciolacustrine and marine sand, silt and clay deposits; modern alluvium; and organic deposits. Till overlies the bedrock in the eastern part of the county and is commonly overlain by a thin veneer of sand. These sand deposits have been reworked by the wind into sand dunes in several areas. Areas of marine sand, silt and clay, and organics occur in low-lying areas. The western portion of the county contains thin till overlying Precambrian metamorphic bedrock ridges with occasional low-lying pockets of sand, silt and clay.

Numerous workers have contributed to the compilation of the geological history of the area. Sharpe (1979) and Young, Gorrell and Fletcher (1983) have provided summaries of the geological history and aggregate resource distribution in the study area.

Glacial ice is believed to have covered the Leeds–Grenville area continuously from approximately 65 000 to 13 000 years before present. Sharpe (1979) suggests that the continual presence of ice for this extended period may account for a general lack of glaciofluvial deposits in the area. Till is commonly thin to absent over much of the central and western parts of the county and a significant thickness of till is generally restricted to the eastern part of the study area. The retreat and deterioration of the ice about 13 000 years ago allowed marine water to flood the St. Lawrence River Valley and much of the eastern portion of the county was inundated. The marine water wave-washed and eroded existing landforms, and deposited thin deposits of sand, silt and clay in many low-lying areas. Similar sand, silt and clay deposits occur throughout the western portion of the county, but these deposits are interpreted as glaciolacustrine in origin.

The county contains relatively few glaciofluvial deposits, but there are 2 major complexes that are important. One glaciofluvial complex extends in a northerly direction from west of Prescott to the Kemptville area. This feature is a striking linear ridge that is suggestive of an esker deposit. Many pit excavations in this feature expose well-sorted sand with 10 to 30% gravel. Several of the deeper pits expose coarse gravel, pebble and cobble size material. The upper part of the feature has been eroded and reworked during the incursion of marine waters in the area. Areas of marine beach material exist just east of Kemptville.

The second glaciofluvial complex is located in the western part of the county, along County Road 32 north of Gananoque. Chapman and Putnam (1984) identify several fragments of an esker ridge intermixed with areas of 'clay plain' and a small 'kame moraine' deposit between Morton and Taylor. Current exposures provide evidence that much of this material is an esker with associated sandy outwash flanks. Pit exposures at Berryton confirm a well-developed coarse gravel core with thick flanks of sand which thin outward. Pit exposures at Taylor, in the area of 'kame moraine', are generally glaciofluvial sand with lenses of gravel. The southern portion of this feature appears flanked by sand, silt and clay of probable glaciolacustrine origin.

Occasional small thin deposits of till, fine sand and gravelly sand have been identified in the rock-dominated northern portion of the county. These features are found in the lee of rock knobs and in bedrock depressions. They are generally of very limited area and thickness.

SAND AND GRAVEL EXTRACTIVE ACTIVITY

At the time of writing, there were 83 licenced sand and gravel pits operating in the United Counties of Leeds–Grenville. This licence information was provided by the Ministry of Natural Resources (MNR) in the summer of 2005. MNDM would like to gratefully acknowledge the co-operation of MNR staff in providing this information. Production in 2005 from these operations was approximately 2.3 million tonnes of aggregate. Production in the county has ranged between 1.9 and 4.2 million tonnes over the previous decade (Tables B and C). Overall production has remained close to 2 million tonnes per year over the last decade, with the exception of 1998 and 2000, when a major construction project occurred on Highway 416 at the east end of the county. Population and aggregate production trends over the last decade have been relatively stable and this suggests that similar production rates may be expected for the foreseeable future.

Although there are many pits in the county, relatively few of the pits are currently able to produce a wide range of aggregate products. Significant aggregate production occurs from the 2 major glaciofluvial deposits in the county, but supplies of gravel are nearing depletion in many areas. Many operators are screening sand and gravel to increase gravel content and a greater dependence on crushed bedrock is expected over the next decade for coarse aggregate. Many small pits in the county produce pit-run sand products to meet local construction needs and it is expected that this type of production will continue at current levels.

Table B - Aggregate Production, United Counties of Leeds–Grenville (1996–2005)*

Year	Production (000s tonnes)
1996	2000
1997	2100
1998	4200
1999	2200
2000	3000
2001	2300
2002	2000
2003	1900
2004	2200
2005	2300

*The Ontario Aggregate Resource Corporation (TOARC) (2006)

Table C - Aggregate Production by Municipality, United Counties of Leeds–Grenville (2005)*

Municipality	Wayside Permits (tonnes)	Licenced Pits and Quarries (tonnes)	%
Township of Athens–Township of Front of Yonge	0	228 350	10.1
Township of Augusta	0	138 067	6.1
Township of Edwardsburgh–Cardinal	0	74 612	3.3
Township of Elizabethtown–Kitley	0	564 186	25.0
Township of Leeds and The Thousand Islands	0	582 383	25.8
Village of Merrickville–Wolford	0	55 331	2.5
Municipality of North Grenville	0	490 604	21.8
Township of Rideau Lakes	0	121 202	5.4
County Total	**0**	**2 254 735**	**100**

*The Ontario Aggregate Resource Corporation (TOARC) (2006)

Aggregate Quality

Significant changes have occurred in the testing and specifications applied to aggregates since the original Aggregate Resource Inventory Paper was completed for the United Counties of Leeds–Grenville (Young, Gorrell and Fletcher 1983). The Los Angeles abrasion test (LS-603) is no longer used in the Ontario Provincial Standard Specifications (OPSS) and the magnesium sulphate soundness test (LS-606) has been reduced to an alternate test. Two new tests, the micro-Deval abrasion test (LS-618 and LS-619) and the unconfined freeze–thaw test (LS-614) have been introduced. The mortar bar accelerated expansion test (or “accelerated mortar bar test”) (LS-620) has also become a standard test for the determination of potential alkali–silica reactivity in concrete aggregate.

Test data from MTO files have been used in the assessment of the resources of the county. Unfortunately, the MTO files commonly contain test results for the Los Angeles abrasion test that is no longer a current test in Ontario. However, these data are extensive and they are useful in assessing the general quality of the material, so they have been included in the current assessment. It is noted that a Los Angeles abrasion test loss of 35% or less generally indicates good physical quality in an aggregate.

SELECTED SAND AND GRAVEL RESOURCE AREAS

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 is located in the Township of Leeds and The Thousand Islands, near the intersection of Highway 15 and Sweets Corners Road. Selected Sand and Gravel Resource Area 1 is a portion of the Morton–Berryton esker. Seven licenced pits (Pit Nos. 98, 99, 102, 103, 104, 105 and 106) have been developed in this area, but there are still approximately 458 ha of unlicenced resource area remaining. Approximately 14 ha of the unlicenced area are constrained by cultural features and setbacks, leaving approximately 444 ha available for possible resource extraction. Approximately 70.7 million tonnes of sand and gravel are available from this deposit (Table 3).

Young, Gorrell and Fletcher (1983) indicated that the material in Selected Sand and Gravel Resource Area 1 is capable of manufacturing granular products. Exposures in this deposit indicate that there is an average of 25% gravel. It may be feasible to screen the gravel fraction. This approach was observed in several of the pits in the county and it is a common approach where gravel proportions are low. Exposures in depleted pit areas suggest that the core of the esker contains a greater proportion of gravel.

A limited amount of historical test data, obtained from the MTO, indicate that Los Angeles abrasion test results were approximately 35 to 45%, magnesium sulphate soundness losses were 9 to 21% and that petrographic numbers ranged from 125 to 220. These data suggest the deposit is potentially capable of producing granular and some grades of asphalt and concrete aggregate products. Site and product-specific testing will be required.

Selected Sand And Gravel Resource Area 2

Selected Sand and Gravel Resource Area 2 is located east of Sweets Corners in the Township of Leeds and The Thousand Islands. Two licenced pits (Pit Nos. 107 and 108) have been established in this deposit, but approximately 128 ha of the resource area are still available for extraction. Approximately 14 ha of this area are constrained by cultural features and setbacks. The remaining 114 ha are potentially available for licencing and extraction activity. Assuming a deposit thickness of

7 m, it is estimated that there are 14.1 million tonnes of sand and gravel available for extraction (*see* Table 3).

Selected Sand and Gravel Resource Area 2 is of glaciofluvial origin and is associated with the Morton–Berryton esker complex. Pit faces expose an average of 35 to 40% gravel, with considerable variability. The material from this deposit appears capable of producing a variety of granular, asphalt and possibly concrete products, with appropriate processing and quality control. The pit north of the township road (Pit No. 107) was active in the summer of 2005. The exposed faces in 2005 exhibited considerable variation in grain size, with abrupt changes, folding and faulting. The materials are suggestive of ice-contact sedimentation in a kame type deposit, as they lack the characteristic sedimentary character of an esker.

A limited amount of historical test data, obtained from MTO files, indicate that Los Angeles abrasion test results were approximately 35 to 60%, magnesium sulphate soundness losses were 7 to 28%, and that petrographic numbers ranged from 108 to 281. These data suggest the deposit is potentially capable of producing granular aggregate products. Site and product-specific testing will be required for asphalt or concrete products, but historical data indicate limitations based on the quality of the material.

Selected Sand and Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 is located in the Township of Leeds and The Thousand Islands and consists of the southern portion of the Morton–Berryton esker. Most of this portion of the esker is currently under licence and much of the central esker core has been removed.

The esker must have been a well-defined esker ridge that was at least 20 m and occasionally over 30 m in height prior to extraction. Current exposures show classic esker sedimentation and geomorphology, with a large central coarse gravel core and the lateral flanks decreasing in height and grain size moving away from the central ridge. Much of the central core of the feature has been mined and the sand flanks of the esker remain. A portion of the core material remains at the south end of the feature and the core at this point contains medium to coarse gravel, which are desirable for commercial use. The materials currently being extracted in the south part of the esker appear well suited to producing a variety of granular, asphalt and concrete products. Portions of the esker, where the gravel core has been removed, are being used for sand products and some parts of the previous excavations have been sloped and grassed. The majority of the esker has been mined and limited resources remain.

Once cultural, environmental and previously extracted areas have been considered, there are approximately 13 ha available for possible resource extraction. This represents a potential sand and gravel resource of 4.6 million tonnes (*see* Table 3). The remaining resources are fragmented into small parcels of land and it is questionable if any of the fragments are large enough to warrant the expense of licencing. It may be possible to establish a wayside pit, which is a temporary aggregate operation usually of fixed duration of time and/or for a specific construction or re-building project.

A limited amount of historical test data obtained from the MTO indicate that Los Angeles abrasion test results were approximately 25 to 39%, magnesium sulphate soundness losses were 6 to 23%, and petrographic numbers ranged from 112 to 205. These data suggest the deposit is potentially capable of producing granular and some grades of asphalt and concrete aggregate products. Site and product-specific testing will be required.

Selected Sand and Gravel Resource Area 4

Selected Sand and Gravel Resource Area 4 is located in the northeast corner of the county, east of Kemptville in the Municipality of North Grenville. Selected Sand and Gravel Resource Area 4, plus Selected Sand and Gravel Resource Areas 5, 6, 7, 8 and many of the secondary and tertiary resources in the eastern portion of the county, was deposited immediately after the ice retreated from the region, and during the incursion of the Champlain Sea up the St. Lawrence River Valley. The Champlain Sea extended up the valley into the map area to approximately the Merrickville–Brockville area (Sharpe 1979) and most of the surface sand and gravel materials in this eastern portion of the county were deposited in, or reworked by, marine waters at that time.

Selected Sand and Gravel Resource Area 4 is a subtle beach ridge located approximately 5 km due east of Kemptville, along County Road 43. It is referred to locally as the Loughlin Ridge. The deposit takes the form of a curved ridge, which stands several metres above the surrounding land. The landform is suggestive of a poorly developed beach ridge or bar. Several large pits have been excavated in the deposit and they expose well-bedded, gravelly sand. The gravel content decreases to the northwest and southeast, off the main ridge. Many exposures along the ridge indicate in excess of 10 m of gravelly sand, and one pit (Pit No. 62) is currently extracting additional material from below the water table, suggesting an overall thickness that may be in excess of 15 m. Exposures observed during the current survey showed well-laminated, horizontally to subhorizontally bedded gravelly sand to sand with trace gravel. These materials are interpreted as marine sediments deposited in the Champlain Sea. Sharpe (1979) and Young, Gorrell and Fletcher (1983) have suggested a possible glaciofluvial origin for some of the material, but there are no clear indications of this in current exposures.

There are 10 ha possibly available for resource extraction; however, cultural features and setbacks reduce this area to 7 ha. Assuming an average deposit thickness of 7 m, the 7 ha contain 0.9 million tonnes of sand and gravel (*see* Table 3). The larger portion of this deposit is located in the United Counties of Stormont, Dundas and

Glengarry where the deposit has been identified as a primary resource.

The material contained in the beach ridge generally contains less than 35% gravel, and there is only a modest amount of crushable gravel. The general lack of crushable gravel will limit the commercial potential of the deposit. Historical physical test data from the deposit, obtained from MTO files, indicate that Los Angeles abrasion losses are in the 35 to 45% range, magnesium sulphate soundness test results range from 14 to 51% and petrographic numbers range from 141 to 456. Test data indicate physical quality varies and the quality of the aggregate will limit the products that can be produced from the deposit. It is expected the deposit will be capable of manufacturing granular aggregates, but the physical quality of the gravel may limit the ability to make asphalt and concrete aggregates. Site specific testing will be required.

Selected Sand and Gravel Resource Areas 5 and 6

Selected Sand and Gravel Resources Areas 5 and 6 are located in the northeast corner of the county, west and southwest of Kemptville in the Municipality of North Grenville. Selected Sand and Gravel Resource Areas 5 and 6 are adjacent portions of an elongated beach ridge oriented in a northerly direction, approximately 3 km west of Kemptville. Several pits have been excavated in the deposit and they expose well-bedded gravelly sand to sand and gravel. The gravel content decreases to the west and east, away from the ridge. Exposures along the ridge indicate 8 to 10 m of well-laminated, horizontally to sub-horizontally bedded gravelly sand to sand and gravel. This material is interpreted as marine sediments deposited in the Champlain Sea. Sharpe (1979) and Young, Gorrell and Fletcher (1983) have suggested a possible glaciofluvial origin for some of the deposits. While there are no diagnostic indications of glaciofluvial materials in current exposures, some of the slumped materials in the base of several pits show the characteristic rounded pebbles, sorting and broad horizontal bedding often exhibited by glaciofluvial sediments. Therefore, it is possible that the lower part of the deposit is of glaciofluvial origin and the upper portion of the deposit has been reworked and redeposited by the Champlain Sea.

Historical test data from MTO files indicate that Los Angeles abrasion test results vary from 26 to 35% and that magnesium sulphate soundness test losses range from 7 to 26%. These data suggest variability in physical quality may be experienced, but granular aggregates and some asphalt and concrete product specifications can be produced. Variability in gravel content will be a factor in production planning. Site specific testing will be required.

Selected Sand and Gravel Resource Area 5 (the northern portion of the deposit) contains 99 ha of unlicenced resource. Approximately 68 ha remain after consideration of cultural features, setbacks and depleted areas. Assuming a thickness of 8 m, 9.6 million tonnes of sand and gravel should be available for extraction. There are houses immediately surrounding the deposit and these may complicate extraction plans.

Selected Sand and Gravel Resource Area 6 (the southern portion of the deposit) contains 33 ha of unlicenced resource. Approximately 30 ha remain after consideration of cultural features and setbacks. Available information suggests a thickness of 4 m. This means that approximately 2.1 million tonnes of sand and gravel are available for extraction. There are currently 4 licenced pits (Pit Nos. 52, 53, 54 and 55) in these deposits.

Selected Sand and Gravel Resource Area 7

Selected Sand and Gravel Resources Area 7 is located in the northeast portion of the county, on the boundary between the Municipality of North Grenville and the Township of Edwardsburgh–Cardinal, along Limerick Road. Selected Sand and Gravel Resource Area 7 is another subtle ridge in the area that was inundated by the Champlain Sea. The ridge is several metres above the surrounding land and the general flat nature of the surrounding terrain serves to emphasize the feature. Small surface exposures on the ridge show pebbles and cobbles at surface and one pit (Pit No. 179) exposes 5 m of sand and gravel. The relatively high gravel content and the rounded nature of the gravel suggest the material at surface may be a reworked glaciofluvial deposit, perhaps an esker.

Historical test data on several properties in the deposit, obtained from MTO files, indicate that Los Angeles abrasion test results vary from 22 to 36% and magnesium sulphate soundness test losses range from 3 to 24%. Petrographic numbers range from 111 to 202. These data suggest variability in physical quality may be experienced but granular aggregates and some asphalt and concrete product specifications may be achieved. Selected Sand and Gravel Resource Area 7 appears to have sufficient stone content to permit the manufacture of crushed, washed and screened products.

Selected Sand and Gravel Resource Area 7 contains 22 ha of unlicenced resource in the Municipality of North Grenville and an additional 3 ha in Township of Edwardsburgh–Cardinal (total 25 ha). Approximately 16 and 2 ha (total 18 ha) remain in the respective townships after consideration of cultural features and setbacks (*see* Table 3). Available information suggests a thickness of 6 m. This indicates 1.7 and 0.2 million tonnes of sand and gravel in the respective townships (total 1.9 million tonnes) are available for extraction.

Selected Sand and Gravel Resource Area 8

Selected Sand and Gravel Resource Area 8 is located on the eastern edge of Township of Augusta along Limerick Road. Selected Sand and Gravel Resource Area 8 is another subtle ridge in the area that was inundated by the

Champlain Sea. The ridge is several metres above the surrounding area and the general flat nature of the surrounding terrain serves to emphasize the feature. Surface exposures along the ridge show sand with pebbles and cobbles at surface and one recent excavation (Pit No. 143) exposes 10 m of sand and gravel. The relatively high gravel content and the rounded nature of the gravel suggests the material at surface may be a reworked glaciofluvial deposit, perhaps an esker.

Historical test data on several properties in the deposit, obtained from MTO files, indicate that Los Angeles abrasion test results vary from 23 to 34% and that magnesium sulphate soundness test losses range from 5 to 23%. Petrographic numbers range from 100 to 212. These data suggest variability in physical quality may be experienced, but granular aggregates and some asphalt and concrete product specifications can be produced. Selected Sand and Gravel Resource Area 8 appears to have sufficient stone content to permit the manufacture of crushed, washed and screened products.

Selected Sand and Gravel Resource Area 8 has 13 ha of possible resource area available for extraction after cultural features and setbacks have been considered. Available information suggests a thickness of 10 m, with approximately 2.3 million tonnes of sand and gravel in the deposit. Currently, there are few houses in the vicinity of Selected Sand and Gravel Resource Area 8.

Resource Areas of Secondary and Tertiary Significance

There are relatively few resource areas of secondary significance in the United Counties of Leeds–Grenville. Some of these features are currently being extracted and it is expected that the secondary deposits will receive greater attention in the foreseeable future as primary deposits become depleted. Secondary deposits are generally smaller and thinner than primary resources and they commonly contain modest amounts of gravel.

Three deposits of secondary significance are identified in the Village of Merrickville–Wolford near Merrickville. Two of the secondary deposits are small eskers that contain sand with occasional lenses of gravel and one is an area of sandy outwash associated with an esker. Observed thickness is 4 m or less and some of the material in the central core of the eskers has been previously removed. Some sand with a limited amount of gavel remains.

Five secondary deposits have been identified in the Municipality of North Grenville. They are located around and south of Selected Sand and Gravel Resource Area 4, east of Selected Sand and Gravel Resource Area 5 and 6, and north of Selected Sand and Gravel Resource Area 7. These deposits are related to the adjacent selected resource areas, but exposures indicate significantly less gravel within the deposits.

There are 3 resource areas of secondary significance in the Township of Leeds and The Thousand Islands. All 3 deposits are of ice-contact glaciofluvial origin and are hummocky ridges trending easterly. All contain sand with modest and varying amounts of gravel and all are currently being mined. The 3 secondary deposits are located on Briar Hill Road east of Morton, along Highway 15 at Seeleys Bay and on the north side of Taylor Road.

Two resource areas of secondary significance were identified in the Township of Augusta. Both are likely continuations of the inferred esker that contains Selected Sand and Gravel Resource Areas 5, 6, 7 and 8. The 2 areas are located at Roebuck on County Road 18 and west of Prescott along the St. Lawrence River. Previous extraction has removed the majority of the esker core and the flanks are predominantly sand material with only a modest amount of gravel. Both deposits expose coarse gravel material that is likely the core of the original esker. Coarse esker material is present in Pit No. 154 west of Prescott and gravel with numerous boulders are present in Pit No. 145 at Roebuck.

Three areas of secondary sand and gravel resource have been identified in the Township of Edwardsburgh–Cardinal. These deposits are marine sediments deposited in the Champlain Sea and the material is predominantly sand with 10 to 25% gravel. The gravel content has allowed several operators to screen the gravel and make modest amounts of coarse aggregate.

Tertiary deposits are abundant in the eastern portion of the county where the Champlain Sea deposited a surficial layer of sand. The sand has been blown into sand dunes in several areas and both the marine sand and the wind-blown sand are extracted in a number of small licenced pits for use in local construction projects. Sand is also found in western portions of the county in areas adjacent to ice-contact deposits and a small amount of silt and sand is common in bedrock depressions throughout the county. Small pockets of till and/or sand and gravel have been used for local construction projects throughout the county prior to the implementation of the *Pits and Quarries Act*. These features are seldom more than a hectare in size, or more than 3 m thick, and the volume of material seldom warrants the effort of obtaining a licence under current legislation.

BEDROCK GEOLOGY

The study area is underlain by Precambrian rocks, the Cambro–Ordovician Potsdam Group, and the Ordovician March, Oxford and Gull River formations. The central and eastern portion of the study area is part of the Ottawa–St. Lawrence Lowlands, a large basin lying between the Canadian Shield to the north and west and the Adirondack Mountains to the south. The western boundary of this basin is the Frontenac Axis, which trends southeast through the Thousand Islands area and underlies the western part of the county. The eastern extent of the basin is at the Beauharnois Anticline near the junction of the Ottawa and St. Lawrence rivers.

The western part of the United Counties of Leeds–Grenville is underlain by metamorphic and igneous Precambrian rock of the Grenville Province. This area makes up part of the Frontenac Axis, which extends from south-central Ontario into the northeastern United States. The Precambrian rocks include metamorphosed volcanic rocks, clastic and chemical sediments, and plutonic rocks. The rocks tend to be foliated and tightly folded. There are also isolated Precambrian inliers within the younger rock units.

Unconformably overlying the Precambrian basement is the Covey Hill Formation. This formation is the lower formation of the Potsdam Group. The formation consists of interbedded, non-calcareous, feldspathic conglomerate and sandstone. The sandstone consists of fine to coarse quartz and feldspar grains in beds up to 3 m thick. The conglomerate contains pebble- and boulder-size, subangular to well-rounded clasts derived from Precambrian rock; typically quartzite, marble, granite and gneiss. The conglomerate matrix is predominantly fine- to coarse-grained quartz and feldspar. The thickness of the formation is variable from 0 to 14 m. The upper contact with the Nepean Formation is defined as the upper limit of the common occurrence of feldspar (Williams 1991).

Unconformably overlying the Precambrian basement, and in certain areas the Covey Hill Formation, is the Nepean Formation. This Cambro–Ordovician formation represents the upper formation of the Potsdam Group. The formation occurs in the west-central part of the study area and appears to be transitional between the Precambrian rocks to the west and the Ordovician March Formation to the east. The Nepean Formation consists of fine- to coarse-grained quartz sandstone with interbeds of quartz-pebble conglomerate. The conglomerate beds can be up to a few metres thick. The sandstone is poor to well sorted, laminated and generally light grey to white, green and brown. Greater detail on the origin, structure and lithology of the Covey Hill and Nepean formations is provided in Wolf and Dalrymple (1984, 1985). Areas of the Potsdam Group have not been identified on the map nor have drift thickness or depth of overburden been calculated because the group has no potential for use in aggregate production.

The Ordovician March Formation is the lower unit of the Beekmantown Group. It crops out extensively in the central portion of the study area. The formation consists of interbedded quartz sandstone, dolomitic sandstone, sandy dolostone and dolostone. The sandstone beds can be up to 10 m thick and generally consist of fine- to coarse-grained quartz. The dolostone units are fine to medium crystalline. The intermediate lithologies (sandy dolostone and dolomitic sandstone) have characteristics of both the sandstone and the dolostone. The formation varies from white to light grey, brown, reddish brown and green. The lower contact with the Nepean Formation is defined as the appearance of dolostone or carbonate material (Williams 1991).

The upper formation in the Beekmantown Group is the Oxford Formation. The formation crops out extensively in the eastern part of the report area. The formation consists of light to dark grey, thin- to thick-bedded, sublithographic to medium crystalline dolostone, with thin shaly interbeds (Williams 1991). Scattered, quartz sand grains and sandy interbeds (up to 30 cm thick) are present in the lower part of the formation (Derry, Michener, Booth and Wall and Ontario Geological Survey 1989a, 1989b). Stomatolites and calcite-filled vugs are common throughout the formation and white chert nodules occur in some localized strata.

The Gull River Formation is divided into 2 members. The lower member consists of interbedded, pale grey to pale to medium brown, lithographic to fine-grained limestone, dolostone and dolomitic limestone. The upper member consists of thin-bedded, shaly limestone. "Birdseye" texture, a term that refers to small scatter lenses of white calcite, occur in some lithographic beds. The Gull River Formation crops out in the northwestern part of the Township of Rideau Lakes (formerly the Township of North Crosby).

Aggregate Suitability

Precambrian bedrock may exhibit wide variations with respect to aggregate quality over relatively short distances. Consequently, any site proposed for quarry development should be tested in detail before extraction occurs. Highly weathered, brittle and friable Precambrian bedrock, which is unacceptable for aggregate use, may occur in the report area. There are also areas underlain by more massive, hard and durable rock, which appears suitable for a variety of aggregate applications. However, some of the massive, coarse-grained felsic igneous rocks and gneisses with high mica, feldspar and quartz contents may have bonding problems because the smooth cleavage and fracture surfaces of these minerals hinder the adhesion of asphalt and cement mixes. This problem may be circumvented by weathering the rocks for a period of time in stockpiles or by adding chemicals (anti-stripping agents) that erode the smooth surfaces and allow better adhesion. Rogers (1985) reports that some granitic rocks can react slowly with alkalis from Portland cement resulting in premature concrete deterioration.

No specific areas of Precambrian bedrock have been selected for possible resource protection because Paleozoic bedrock is considered the preferred source of bedrock-derived aggregates in the area. The Precambrian rock is generally more varied and difficult to process. Precambrian bedrock is often quarried for use in the building and dimension stone industry, as is the case with the licenced quarries in the western part of the county.

The Nepean Formation sandstone has been used for building stone in the Perth area, just north of the county, and may also be extracted for silica. The sandstone can be quite varied with some beds being calcareous and argillaceous. In these areas, it is not considered to be a good source of high-grade silica. Historically, some of the beds may be suitable for dimension stone, whereas the waste might be utilized for foundry and blast sand. More information on the use of the Nepean Formation (Potsdam Group) for silica production is provided in Hewitt

(1963) and Klugman and Yen (1980). The sandstone is quite friable and would make poor-quality aggregate.

Of the Ordovician rock formations that underlie the county, the March, Oxford and Gull River formations are best suited for aggregate production (Derry, Michener, Booth and Wahl and Ontario Geological Survey 1989a, 1989b).

The March Formation makes a highly desirable skid resistant aggregate for highway surfacing. Rogers (1980) reported that based on laboratory tests, sandy dolostone from the March Formation has the best skid resistance of any aggregate currently available in southern Ontario. The March Formation can be alkali–silica reactive when used in Portland cement concrete, otherwise, the formation is quarried extensively throughout the county for a number of aggregate products (Table D).

The Oxford Formation is also quarried extensively throughout the United Counties of Leeds–Grenville, and indeed, throughout eastern Ontario, for use in the aggregate industry. Some shaly interbeds up to 30 cm thick do occur and have been characterized as low in quality and durability. However, the dolostone is able to meet quite a number of low- and high-end aggregate product specifications (*see* Table D).

The Gull River Formation is generally well suited for use as hot-laid asphalt, but polishing of the stone may be a problem if the rock is used in the asphaltic surface course. Beds of shaly, silty to sandy dolostone may require blending with more competent bedrock units for the production of granular base. Similarly, beds of calcitic dolostone at the base of the formation may only be suitable for granular base. Crushed stone from the Gull River Formation is used for a variety of aggregate products in southern and eastern Ontario, including concrete, asphalt and granular base. Aggregate quality testing of the bedrock is necessary because certain beds within the formation are chemically reactive when used in Portland cement concrete (Rogers 1985).

Table D - Aggregate Products from the March and Oxford Formations

March Formation Products	Oxford Formation Products
Shot rock	Shot rock
Gabion stone	Gabion stone
Granular A, B and subbase	Granular A, B and subbase
1.5 in clear	1.5 in clear
7/8 in clear	7/8 in clear
Screenings	Screenings
Hot-laid (HL) products	Hot-laid (HL) products
5/8 in crushed rock	Concrete stone

BEDROCK EXTRACTIVE ACTIVITY AND SELECTED BEDROCK RESOURCE AREAS

At the time of writing, there were 37 licenced quarries in the study area occupying 1390 ha (Table 5). This information was provided by the Ministry of Natural Resources in the summer of 2005. MNDM would like to gratefully acknowledge the co-operation of MNR staff for providing this information. The majority of the quarries are producing bedrock-derived crushed stone for use in the road building and construction industries. Quarries located over Precambrian and Potsdam Group bedrock are generally producing non-aggregate products.

Based on the quality of the aggregate produced, areas of the March, Oxford and Gull River formations that are covered by less than 8 m of overburden have been identified as Selected Bedrock Resource Areas. These areas occupy a possible resource area of 179 156 ha in the study area and have a possible aggregate resource of 71 188 million tonnes (Table 6).

The above figures represent a comprehensive inventory of all areas with less than 8 m of overburden overlying these formations. Other planning issues and constraints may prevent site development in these Selected Bedrock Resource Areas. Further site investigation and aggregate testing is highly recommended before the development of any potential property.

Selected Bedrock Resource Area 1

Selected Bedrock Resource Area 1 is located in the northwestern part of the Township of Rideau Lakes. The area overlies the Gull River Formation and has an areal extent of 471 ha. Cultural setbacks and previously extracted areas reduce the possible resource area to 391 ha with a possible bedrock resource of 155.4 million tonnes (*see* Table 6). G. Tackaberry and Sons Construction currently operates 2 licenced quarries (Quarry No. 1 and 2) in Selected Bedrock Resource Area 1.

Selected Bedrock Resource Area 2

An area of March Formation with less than 8 m of overburden that encircles Selected Bedrock Resource Area 1 has been chosen as Selected Bedrock Resource Area 2. A possible bedrock resource of 189.9 million tonnes has been estimated based on a possible resource area of 478 ha and a conservative bedrock thickness estimate of 15 m (*see* Table 6). There are currently no licenced operations or abandoned quarries located in Selected Bedrock Resource Area 2.

Selected Bedrock Resource Area 3

Selected Bedrock Resource Area 3 is located in the western part of the Township of Rideau Lakes. It is a 386 ha area of March Formation with less than 8 m of overburden. Cultural setbacks and previously extracted areas reduce the possible resource area to 301 ha with a possible bedrock resource of 119.6 million tonnes (*see* Table 6). There are currently no licenced or abandoned quarries located in this selected bedrock area.

Selected Bedrock Resource Area 4

Located east of Selected Bedrock Resource Area 3, Selected Bedrock Resource Area 4 is located in the central part of the Township of Rideau Lakes and is an area of March Formation with less than 8 m of overburden. Selected Bedrock Resource Area 4 has possible bedrock resources of 113.6 million tonnes, based on a possible resource area of 286 ha and a conservative bedrock thickness estimate of 15 m (*see* Table 6). There are no operating or abandoned quarries located in this selected area.

Selected Bedrock Resource Area 5

Selected Bedrock Resource Area 5 is large area of March Formation covered by less than 8 m of overburden. This area is located predominantly in the west-central portion of the United Counties of Leeds–Grenville between the St. Lawrence and Rideau rivers. It has a possible resource area of 93 023 with a possible bedrock resource of 36 962.7 million tonnes (*see* Table 6). There are already a number of licenced quarries located within Selected Bedrock Resource Area 5, from relatively small operations to large operating quarries.

Selected Bedrock Resource Area 6

This selected bedrock area is located near and south of Highway 401 in the Township of Elizabethtown–Kitley and the Township of Front of Yonge. It is an area of March Formation covered by less than 8 m of overburden. There is currently one licenced quarry in the area (Quarry No. 27) as well as 2 abandoned quarries (Quarry Nos. 28 and 29). Selected Bedrock Resource Area 6 occupies an area of 1097 ha; after considering physical, environmental and cultural constraints, it has a possible resource of 435.9 million tonnes (*see* Table 6).

Selected Bedrock Resource Area 7

Selected Bedrock Resource Area 7 is located over much of the east-central portion of the county. It is a large area covering the Oxford Formation that has less than 8 m of overburden. The possible resource area is 83 580 ha with a possible bedrock resource of 33 210.5 million tonnes (*see* Table 6). There are a number of licenced and abandoned quarries located within this selected resource area.

The March, Oxford and Gull River formations have proven to be suitable for making a number of bedrock-derived aggregate products throughout Ontario. There are a number of currently operating licenced operations and abandoned quarries throughout the county.

SUMMARY

Eight areas have been identified as sand and gravel resource areas of primary significance within the United Counties of Leeds–Grenville. These Selected Sand and Gravel Resource Areas occupy a total unlicenced area of 799 ha, which is reduced to 707 ha after applying cultural constraints and considering previous extractive activity. Combined, these selected sand and gravel resource areas have possible aggregate resources of 106.3 million tonnes. Reserves of sand and gravel are in very short supply in the county and it will be necessary to use crushed bedrock to meet the demand for most aggregate products in the near future.

A thin overburden cover over the Oxford, March and Gull River formations means that there is a large potential to quarry these rock units. Since sand and gravel material is not plentiful in the county, bedrock-derived aggregate material will play an important role in the region.

Enquiries regarding the Aggregate Resources Inventory of the United Counties of Leeds–Grenville should be directed to the Sedimentary Geoscience Section, Ontario Geological Survey, Mines and Minerals Division, Ontario Ministry of Northern Development and Mines, 933 Ramsey Lake Road, Level B7, Sudbury, Ontario P3E 6B5, Tel: (705) 670-5758; or to the Kemptville District Office, Ontario Ministry of Natural Resources, P.O. Box 2002, Concession Road, Kemptville, Ontario K0J 1J0, Tel: (613) 258-8204.

Table 1 - Total Sand and Gravel Resources
United Counties of Leeds–Grenville

1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
Township of Rideau Lakes			
1	S-LP	190	20.2
2	S-MP	42	3.3
	S-OW	38	3.0
3	S-LP	42	1.5
	S-OW	8	0.3
4	S-LP	779	13.8
	S-MP	6	0.1
	S-OW	118	2.1
Subtotal		**1223**	**44.3**
Village of Westport			
Subtotal		**0**	**0.0**
Township of Elizabethtown–Kitley			
2	S-MP	1140	90.8
3	S-MP	351	12.4
4	S-LP	101	1.8
	S-MP	2238	39.6
	S-OW	185	3.3
Subtotal		**4015**	**147.9**
Village of Merrickville–Wolford			
2	S-MB	194	15.5
	S-MP	92	7.3
4	S-MP	583	10.3
Subtotal		**869**	**33.1**
Municipality of North Grenville			
1	G-MP	18	1.9
	G-MP/E	143	15.2
2	G-MP/E	62	4.9
	S-MB	349	27.8
	S-MP	1028	81.9
3	S-MB	62	2.2
4	S-MB	67	1.2
	S-MP	11 934	211.2
Subtotal		**13 663**	**346.3**
Township of Leeds and The Thousand Islands			
1	G-E	215	22.8
	G-OW	64	6.8
	S-LP	251	26.7
	S-OW	361	38.3
2	S-LP	108	8.6
	S-OW	594	47.3
3	S-OW	15	0.5
4	S-LP	110	1.9
	S-OW	472	8.4
Subtotal		**2190**	**161.4**

Table 1 - Total Sand and Gravel Resources
United Counties of Leeds–Grenville

1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
Town of Gananoque			
Subtotal		**0**	**0.0**
Township of Athens			
Subtotal		**0**	**0.0**
Township of Front of Yonge			
4	S-MP	148	2.6
	S-OW	58	1.0
Subtotal		**206**	**3.6**
City of Brockville			
Subtotal		**0**	**0.0**
Township of Augusta			
1	G-E	30	3.2
	S-MP	145	15.4
2	S-MP	1065	84.8
3	S-MB	6	0.2
	S-MP	594	21.0
4	S-MB	94	1.7
	S-MP	7740	137.0
Subtotal		**9674**	**263.3**
Town of Prescott			
4	S-MP	288	5.1
Subtotal		**288**	**5.1**
Township of Edwardsburgh–Cardinal			
2	G-MP/E	23	1.8
	S-MP	160	12.7
4	S-MB	81	1.4
	S-MP	16 267	287.9
Subtotal		**16 531**	**303.9**
COUNTY TOTAL		**48 659**	**1308.9**

Explanation of Deposit Type:
First letter denotes gravel content:
G = >35% gravel; S = generally "sandy", gravel-size (>4.75 mm) aggregate <35% gravel
Letters after hyphen denote the geologic deposit type (*see also* Appendix C):
E = esker; LP = glaciolacustrine plain; MB = glaciomarine beach; MP = glaciomarine plain; OW = outwash.

Table 2 - Sand and Gravel Pits United Counties of Leeds–Grenville					
1 Pit No.	**2 Owner/Operator**	**3 Licenced Area (Hectares)**	**4 Face Height (Metres)**	**5 % Gravel**	**6 Remarks**
Township of Rideau Lakes					
Licenced					
1	Elaine Watters	2.12	7	-	partially overgrown
2	Craig Gifford	6.71	1	-	glaciofluvial deposit, bedrock near surface
Unlicenced					
3	-	-	-	-	overgrown
4	-	-	-	-	depleted
5	-	-	-	-	clay-silt deposit
6	-	-	1	-	bedrock exposed
7	-	-	-	-	shallow till deposit
8	-	-	-	-	shallow till deposit
9	-	-	4	5	variable from fine sand to fine gravel
10	-	-	-	-	fine to medium sand
11	-	-	2	10	fine sand, minor gravel
12	-	-	8	50	fine sand, minor gravel
13	-	-	-	-	overgrown
14	-	-	2	-	sand
15	-	-	10	50	pockets of sand and gravel on bedrock
16	-	-	2	10	minor gravel
17	-	-	-	-	primarily sand
18	-	-	-	-	primarily sand
19	-	-	2	30	gravelly sand
20	-	-	2	-	fine to medium sand
21	-	-	-	-	fine sand
22	-	-	-	-	primarily fine to medium sand
23	-	-	4	40	variable
24	-	-	5	40	variable sand and gravel; occasional boulder
Township of Elizabethtown–Kitley					
Licenced					
25	Lloyd Knapp	0.71	5	-	primarily sand
26	-	8.19	-	-	fine to medium sand
27	Bruce Davy	4.24	4	-	primarily sand
28	G. Tackaberry & Son Construction	7.31	3	-	fine to medium sand
29	G. Tackaberry & Son Construction	25.26	4	-	depleted
30	Jack Vandusen	15.29	3	-	fine to medium sand, some silt
31	Douglas H. Brown	1.34	10	-	primarily sand
32	Ken Miller	15.8	8	-	fine to medium sand
33	Zomer & Sons Landscaping	19.29	7	-	primarily sand
34	Ken Miller	10.88	2	-	fine to medium sand
Unlicenced					
35	-	-	2	40	variable medium sand with some medium gravel
36	-	-	-	-	pit converted to quarry
37	-	-	1	50	sand and gravel
38	-	-	-	-	overgrown
39	-	-	1.5	10	mostly sand with some gravel
40	-	-	1	-	overgrown

Table 2 - Sand and Gravel Pits
United Counties of Leeds–Grenville

1 Pit No.	2 Owner/Operator	3 Licenced Area (Hectares)	4 Face Height (Metres)	5 % Gravel	6 Remarks
41	-	-	1	-	mostly sand
42	-	-	2	-	fine sand
Village of Merrickville–Wolford					
Licenced					
43	P. McGrath Excavation	34.01	4	20	variable medium sand with some gravel
44	MAAP	2.22	4	40	variable medium sand gravel; boulders
Unlicenced					
45	-	-	-	-	
46	-	-	1	-	pit converted to quarry
47	-	-	2	-	sand
48	-	-	0.5	10	overgrown, some gravel along the pit face
49	-	-	3	40	medium to coarse sand and gravel
50	-	-	2	40	sand with fine to medium gravel; below water table
51	-	-	-	5	fine grain gravel; medium sand, trace gravel
Municipality of North Grenville					
Licenced					
52	-	68.86	-	-	no exposure
53	G. Tackaberry & Son Construction	9.19	5	60	medium to coarse sand; fine gravel present
54	G. Tackaberry & Son Construction	3.64	3	80	fine to medium gravel
55	J. Monkman & C. Comeau	5.65	-	-	completely rehabilitated
56	Raymond Finley	104.09	4	15	fine to medium sand; trace gravel
57	Corporation of the Township of North Grenville	10.06	3	15	fine to medium sand; rounded crushable gravel
58	Alma O’Reilly	28.50	6	25	fine to medium sand, trace of fine gravel.
59	Willis Kerr Contracting Ltd.	14.87	3	45	fine to medium sand; asphalt sand (no gravel); 1-2 inch washed clear stone; pit run
60	Robert and Ann Parent	20.50	4	5	fine to medium sand, trace gravel
61	Robert Parent	5.61	-	10	fine sand mixed trace gravel
62	Lafarge Canada Inc.	55.24	5	35	fine sand and fine to crushable gravel
63	Charles Moore Ltd.	172.46	4	20	fine sand
Unlicenced					
64	-	-	1	10	medium sand trace gravel
65	-	-	-	10	medium sand trace gravel
66	-	-	-	-	no exposure
67	-	-	5	50	medium to coarse sand and rounded crushable gravel
68	-	-	3	40	gravelly medium to coarse sand
69	-	-	1	-	completely rehabilitated
70	-	-	-	-	flat terrain; boulders at surface
71	-	-	-	-	lacustrine sand, thin drift
72	-	-	-	-	lacustrine sand, thin drift
73	-	-	-	-	trace sand and gravel over bedrock
74	-	-	1	15	fine to medium sand; trace crushable gravel
75	-	-	3	-	medium to fine sand
76	-	-	1	30	gravelly medium to coarse sand
77	-	-	-	-	fine to medium sand
78	-	-	1	-	fine sand

Table 2 - Sand and Gravel Pits United Counties of Leeds–Grenville					
1 Pit No.	2 Owner/Operator	3 Licenced Area (Hectares)	4 Face Height (Metres)	5 % Gravel	6 Remarks
79	-	-	-	10	medium to coarse sand, trace gravel
80	-	-	1	-	fine to medium sand
81	-	-	3	30	medium to coarse sand; fine gravel; variable
82	-	-	2	10	fine to medium sand, trace gravel
83	-	-	2	10	fine to medium sand, trace gravel
84	-	-	6	5	fine to medium sand, trace gravel
85	-	-	4	10	mixture of silt and sand, trace gravel
86	-	-	4	5	medium sand, trace fine gravel
87	-	-	2	-	fine to medium sand
Township of Leeds and The Thousand Islands					
Licenced					
88	G. Tackaberry & Sons Construction	8.75	5	-	sand
89	G. Tackaberry & Sons Construction	8.48	5	10	fine to medium sand trace fine gravel
90	G. Tackaberry & Sons Construction	8.89	10	10	variable, bedrock outcrops in the pit side and floor
91	941031 Ontario Inc.	16.04	7	-	sand
92	Gerald Best	16.08	5	5	sand, trace of fine gravel
93	Glen Carpenter	13.77	10	5	silty sand deposit; trace fine gravel
94	G. Tackaberry & Sons Construction	22.24	5	-	fine sand
95	G. Tackaberry & Sons Construction	34.72	7	10	sand with trace gravel
96	G. Tackaberry & Sons Construction	100.56	13	40	esker, much of central core has been removed, but sand flank material remains and some core material below water, numerous exposures over large area
97	G. Tackaberry & Sons Construction	33.4	10	40	esker core removed, sandy flank materials remain
98	G. Tackaberry & Sons Construction	54.8	10	25	sand, minor gravel
99	J. Gilbert & Sons Sand & Gravel	49.72	8	25	glaciofluvial, probable esker, mostly sand
100	G. Tackaberry & Sons Construction	7.09	5	-	primarily sand
101	W.P. Green & Sons Construction Co. Ltd.	17.62	20	40	variable
102	G. Tackaberry & Sons Construction	10.1	7	15	occasional gravel lenses and cobbles
103	Lafarge Canada Inc., Lyndhurst	19.74	-	-	no extraction to date
104	G. Tackaberry & Sons Construction	10.2	8	15	sand, occasional gravel
105	G. Tackaberry & Sons Construction	32.54	8	5	sand trace gravel
106	G. Tackaberry & Sons Construction	33.21	10	-	sand
107	G. Tackaberry & Sons Construction	62.81	8	35	sand and gravel production in progress
108	G. Tackaberry & Sons Construction	22.46	7	40	active rehabilitation in several areas

Table 2 - Sand and Gravel Pits
United Counties of Leeds–Grenville

1 Pit No.	2 Owner/Operator	3 Licenced Area (Hectares)	4 Face Height (Metres)	5 % Gravel	6 Remarks
109	G. Tackaberry & Sons Construction	13.69	7	5	mostly sand
110	A.G. Gamble Sand & Gravel	9.12	1	25	bedrock is exposed at surface
111	Jack Vandusen	20.15	10	15	sand
112	Jo-anne Best	10.24	2	5	stockpile of silt-sand material, trace fine gravel
113	-	18.3	5	-	sand with some silt lenses
Unlicenced					
114	-	-	3	-	mostly sand, covered in vegetation
115	-	-	2	-	overgrown
116	-	-	-	-	bedrock exposed
117	-	-	2	-	bedrock exposed
118	-	-	2	-	sand and gravel, some cobbles are seen at toe of pit
119	-	-	1	-	mostly sand
120	-	-	-	-	mostly sand
121	-	-	1	-	mostly sand
122	-	-	-	-	sand and gravel
123	-	-	-	-	primarily fine sand
124	-	-	-	-	sand and some gravel
125	-	-	-	-	primarily fine sand
126	-	-	-	-	depleted; overgrown
127	-	-	-	-	sand
128	-	-	3	-	primarily fine sand
129	-	-	-	-	primarily fine sand
130	-	-	-	-	depleted; overgrown
Township of Front of Yonge					
Licenced					
131	R. Hagerman	4.93	7	20	sand, some gravel poorly sorted
132	Terrance R. Avery	2.94	-	-	sand
133	Terrance R. Avery	3.34	5	35	variable deposit
Unlicenced					
134	-	-	1	10	variable fine sand trace gravel
Township of Augusta					
Licenced					
135	Elmer J. Covill	19.56	3	15	fine to medium sand, some gravel
136	Doug Moore	8.03	2	-	fine to medium sand; east third of pit contains primarily top soil
137	Corporation of the Township of Augusta	27.63	2	-	fine to medium sand
138	Knapp's Paving & Landscaping Ltd.	15.18	5	-	sand
139	Arnold Dixon	9.29	2	-	fine to medium sand
140	Ken Miller	23.80	2	-	fine to medium sand, no gravel
141	G. Tackaberry & Sons Construction	3.26	2	-	medium to coarse sand; rounded crushable and fine gravel
142	Henry Sicard	8.36	3	-	very fine sand, no gravel present
143	Corporation of the Township of Augusta	39.76	10	60	medium to coarse grain sand and crushable gravel
144	Polite Sand & Gravel Ltd.	16.08	4	-	horizontally bedded clean fine to medium sand
145	J. Anstead Sand & Gravel	10.57	5	22	fine to medium sand, some gravel

Table 2 - Sand and Gravel Pits
United Counties of Leeds–Grenville

1 Pit No.	2 Owner/Operator	3 Licenced Area (Hectares)	4 Face Height (Metres)	5 % Gravel	6 Remarks
146	J. Anstead Sand & Gravel	30.98	4	30	gradually fine to coarse sand
147	J. Anstead Sand & Gravel	7.76	3	13	variable deposit; fine to medium sand with pockets of fine sand and crushable gravel
148	Polite Sand & Gravel Ltd.	13.79	5	10	sand with gravelly sand and boulders
149	Marjorie Throop	2.57	-	-	field
150	Corporation of the Township of Augusta	23.56	4	-	sand
151	Polite Sand & Gravel Ltd.	19.42	3	50	remaining banks show 3-5 m of fine sand; below water
152	Robinson Farms	38.69	3	15	fine to coarse sand, some fine gravel
153	G. Tackaberry & Sons Construction	12.96	3	-	fine sand
154	Ronald W. Myers Ltd.	119.78	10	35	variable medium sand to crushable gravel; bed-rock outcrop in pit floor
155	Kenneth G. Dukelow	2.33	4	-	fine sand
156	Augusta Sand & Gravel Ltd.	20.25	2	-	fine sand
Unlicenced					
157	-	-	-	-	predominantly sand
158	-	-	4	-	fine to medium sand
159	-	-	6	-	fine to medium sand with a trace of fine gravel
160	-	-	1	-	fine to medium sand; traces of fine gravel
161	-	-	2	-	fine to medium sand; trace of gravel
162	-	-	2	-	fine to medium sand; bedrock outcrops visible
163	-	-	2	-	fine to medium sand
164	-	-	-	-	fine to medium sand
165	-	-	-	10	fine gravel with a trace gravel overlies bedrock
166	-	-	-	40	gravelly sand
167	-	-	-	40	bedrock at surface
168	-	-	-	-	fine to medium sand
169	-	-	-	-	fine to medium sand
170	-	-	2.5	40	gravelly sand underlain by bedrock
171	-	-	1	25	medium sand with some fine gravel
172	-	-	2	32	medium sand with some gravel; some cobbles
173	-	-	-	-	fine to medium sand
174	-	-	4	30	medium to coarse sand with pockets of fine gravel
175	-	-	2	10	primarily silt/clay mixed with sand and gravel
176	-	-	-	-	fine to medium sand
177	-	-	1	-	fine to medium sand
178	-	-	1	-	fine to medium sand
Township of Edwardsburgh–Cardinal					
Licenced					
179	Gibson H. Patterson	25.17	5	60	crushable gravel and medium to coarse grain sand
180	Bruno Kamenz	24.30	5	20	medium sand deposit, some crushable gravel overlies Paleozoic bedrock
181	Cleary, Elgin & Douglas	29.04	8	20	fine to medium sand, some gravel
182	Beck’s Construction Company Limited	5.79	7	-	fine to medium sand
183	Maynard Coons	14.67	4	45	sand and gravel underlain by Paleozoic bedrock

Table 2 - Sand and Gravel Pits
United Counties of Leeds–Grenville

1 Pit No.	2 Owner/Operator	3 Licenced Area (Hectares)	4 Face Height (Metres)	5 % Gravel	6 Remarks
184	Garry Moulton Sand & Gravel	7.00	2	-	medium to fine sand
Unlicenced					
185	-	-	3	-	fine sand
186	-	-	4	40	gravelly medium to fine sand overlies Paleozoic bedrock
187	-	-	-	-	fine sand
188	-	-	-	-	fine sand
189	-	-	-	-	fine sand
190	-	-	1	10	medium sand with trace fine to crushable gravel
191	-	-	5	5	medium to fine sand with trace fine to 1 inch gravel
192	-	-	6	-	fine to medium sand
193	-	-	5	-	fine to medium sand
194	-	-	-	-	unable to access pit
195	-	-	3	-	fine to medium sand with a layer of silt/clay at the surface
196	-	-	1.5	-	mixture of silt/clay with fine to medium sand
197	-	-	2	5	primarily sand
198	-	-	-	-	medium silty sand deposit

Table 3 - Selected Sand and Gravel Resource Areas

United Counties of Leeds–Grenville

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)
Municipality of North Grenville						
4	10	3	0	7	7	0.9
5	99	29	2	68	8	9.6
6	33	3	0	30	4	2.1
7	22	6	0	16	6	1.7
Subtotal	**164**	**41**	**2**	**121**		**14.3**
Township of Leeds and The Thousand Islands						
1	458	14	0	444	9	70.7
2	128	14	0	114	7	14.1
3	21	8	0	13	20	4.6
Subtotal	**607**	**36**	**0**	**571**		**89.5**
Township of Augusta						
8	25	12	0	13	10	2.3
Subtotal	**25**	**12**	**0**	**13**		**2.3**
Township of Edwardsburgh–Cardinal						
7	3	1	0	2	6	0.2
Subtotal	**3**	**1**	**0**	**2**		**0.2**
COUNTY TOTAL	**799**	**90**	**2**	**707**		**106.3**

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

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

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

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

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

Table 4 - Total Identified Bedrock Resources
United Counties of Leeds–Grenville

1 Drift Thickness (Metres)	2 Formation	3 Estimated Deposit Thickness (Metres)	4 Areal Extent (Hectares)	5 Original Tonnage (Million Tonnes)
1 - 8	Gull River	15	471	187.2
Subtotal			**471**	**187.2**
< 1	Oxford	15	22 118	8788.6
1 - 8		15	70 160	27 878.1
8 - 15		15	28 344	11 262.5
Subtotal			**120 622**	**47 929.2**
< 1	March	15	74 458	29 585.9
1 - 8		15	31 417	12 483.5
8 - 15		15	1055	419.2
Subtotal			**106 930**	**42 488.6**
COUNTY TOTAL			**228 023**	**90 605.0**

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

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

Table 5 - Quarries
United Counties of Leeds–Grenville

No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	Remarks
Township of Rideau Lakes				
Licenced Quarries				
1	G. Tackaberry & Sons Construction (Westport Quarry)	13.0	15-16	Gull River Formation
2	G. Tackaberry & Sons Construction (Westport Quarry)	12.0	13-15	Gull River Formation
3	Donald H. Wills Construction Co. Ltd.	9.0	12-13	Covey Hill Formation, Potsdam Group
4	Lafarge Canada Inc. (Forfar)	45.0	2-3	Nepean Formation, Potsdam Group
5	Arriscraft International Limited Partnership	43.0	2-4	Nepean Formation, Potsdam Group
6	G. Tackaberry & Sons Construction (Harlem Quarry)	5.0	3-4	March Formation - water on quarry floor
7	G. Tackaberry & Sons Construction (O'Grady Quarry)	25.5	3-4	March Formation
8	Lafarge Canada Inc.	14.0	10-11	March Formation
Unlicenced Quarries				
9	-	-	1-2	Gull River Formation - water filled
10	-	-	1-2	(Freeland Quarry) badly, overgrown quarry
11	-	-	2-3	Oxford Formation - water filled - located behind Drummond gas station
12	-	-	2-3	Oxford Formation - badly overgrown - located behind houses
13	-	-	0.5-1	water filled - pond in front of house
Township of Leeds and The Thousand Islands				
Licenced Quarries				
14	Shabbir Hussain, 1319982 Ontario Limited	10.0	4-6	Precambrian - located on side of large outcrop
15	Upper Canada Stone Company Ltd.	8.0	4-6	Precambrian
16	Cruickshank Construction Limited	6.0	7-9	Precambrian
17	Lafarge Canada Inc.	18.0	8-10	Precambrian
18	71056 Ontario Ltd. Rideauview Contracts	17.0	8-10	Precambrian–Potsdam Group contact
19	941031 Ontario Inc.	3.0	2-3	Precambrian
20	Mulcair, Brian	7.0	2-3	Precambrian
Unlicenced Quarries				
Township of Athens				
Licenced Quarries				
21	G. Tackaberry & Sons Construction (Main Yard - Sheldon Corners Quarry)	37.0	7-8	March Formation
22	G. Tackaberry & Sons Construction (Athens Quarry)	187.0	12-18	March Formation
Unlicenced Quarries				
23	-	-	1-1.5	badly overgrown, water in quarry
24	-	-	1-1.5	located behind house, water filled, hard to establish actual face height
25	-	-	6-7	badly overgrown quarry
26	-	-	1-1.5	(Hawkes Quarry) - water-filled quarry, hard to establish actual face height
Township of Front of Yonge				
Licenced Quarries				
27	Canada Inc. (William Clow - Sherwood Springs Quarry)	11.0	4-5	March Formation
Unlicenced Quarries				
28	-	-	3-4	house built in old quarry floor
29	-	-	2-3	water-filled quarry

Table 5 - Quarries
United Counties of Leeds–Grenville

No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	Remarks
Township of Elizabethtown–Kitley				
Licenced Quarries				
30	G. Tackaberry & Sons Construction (Willows–Newbliss Quarry)	40.0	6-8	Oxford Formation
31	G. Tackaberry & Sons Construction (Ronan Quarry)	15.0	8-10	Oxford Formation - water in quarry
32	G. Tackaberry & Sons Construction (Frankville Quarry)	32.0	4-5	March Formation - badly overgrown
33	Cruickshank Construction Ltd.	85.0	8-10	March Formation
34	G. Tackaberry & Sons Construction (Woods–Tincap Quarry)	75.0	9-10	March Formation
35	Lafarge Canada Inc. (Permanent)	43.0	18-22	Oxford Formation over March Formation
36	Lafarge Canada Inc. (Permanent)	90.0	18-20	Oxford Formation over March Formation
Unlicenced Quarries				
37	-	-	1-1.5	swamp area - badly overgrown
38	-	-	1	old, badly overgrown quarry
39	-	-	1-2	March Formation - small, badly overgrown quarry
40	-	-	1-2	badly overgrown - water filled
41	-	-	1.5-3	house built in northeast corner of old quarry
42	-	-	1-2	badly overgrown quarry - almost looks like an escarpment
43	-	-	6-7	partially overgrown
44	-	-	0.5-1	overgrown
45	-	-	1.5-2	house built near quarry - water in north end - floor of quarry showing along south end
46	-	-	1-2	Tincap–Dodge Quarry - badly overgrown
Village of Merrickville–Wolford				
Licenced Quarries				
47	G. Tackaberry & Sons Construction (Jasper Quarry)	16.5	10-11	Oxford Formation
48	McConnell, Donald	90.0	2-3	licenced as both a pit and quarry
Unlicenced Quarries				
49	-	-	0.5-1.5	Easton Corners quarry - badly overgrown
Township of Augusta				
Licenced Quarries				
50	Knapp, L.	23.0	2-3	licenced as both a pit and quarry; no quarry activity yet - sand and gravel has been removed
51	G. Tackaberry & Sons Construction (Wings Maitland Quarry)	18.0	5-6	quarry on both sides of road
52	Ronald W. Myers Ltd.	130.0	2-3	licenced as both a pit and quarry
Unlicenced Quarries				
53	-	-	2	badly overgrown, quarry floor is wet
Municipality of North Grenville				
Licenced Quarries				
54	Forbes, Barry	50.0	3-5	inactive
55	Cruickshank Construction Ltd.	50.0	6-8	Oxford Formation - very active quarry
56	Cornwall Gravel Company Ltd.	50.0	-	licenced as both a pit and quarry; stripping has occurred; no quarrying activity yet
57	Forbes, Barry	12.0	6	face estimated because quarry is water filled

Table 5 - Quarries
United Counties of Leeds–Grenville

No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	Remarks
58	G. Tackaberry & Sons Construction (Maplegrove Quarry)	13.0	6-7	in the process of being licenced
Unlicenced Quarries				
59	-	-	5-6	Oxford Mills Quarry - a long quarry, water in quarry floor, garbage on quarry floor
Township of Edwardsburgh–Cardinal				
Licenced Quarries				
60	Gordon Mulligan	37.0	5-6	water filling in quarry
61	G. Tackaberry & Sons Construction	50.0	6-7	Oxford Formation
Unlicenced Quarries				
62	-	-	10-12	Mills Quarry - face estimated because quarry is partially water filled
63	-	-	1	old, badly overgrown quarry
64	-	-	2-3	water-filled quarry
65	-	-	0.5	badly overgrown, water-filled quarry

Table 6 - Selected Bedrock Resource Areas
United Counties of Leeds–Grenville

1 Area No.	2 Formation	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)
1	Gull River	471	50	30	391	15	155.4
2	March	552	74	-	478	15	189.9
3	March	386	85	-	301	15	119.6
4	March	343	57	-	286	15	113.6
5	March	102 925	9071	831	93 023	15	36 962.7
6	March	1383	275	11	1097	15	435.9
7	Oxford	91 837	7863	394	83 580	15	33 210.5
COUNTY TOTAL		**197 897**	**17 475**	**1266**	**179 156**		**71 187.6**

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

* Excludes areas licenced under the *Aggregate Resources Act* (1989).

** Cultural setbacks include heavily populated urban areas, roads (including a 100 m 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 contraints will further reduce the deposit area.

*** Extracted area is a rough estimate of areas that are not licenced, but, due to previous extractive activity, are largely depleted, such as abandoned and wayside quarries.

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

Table 7 - Previous Drill Hole and Roadcut Data*
United Counties of Leeds–Grenville

Stn. No: WE-01
UTM location: 407158E 4940913N
Type: Drill Hole
20.3 m of Nepean Formation

Stn. No: WE-02
UTM location: 404418E 4941403N
Type: Drill Hole
22.6 m of Nepean Formation

Stn. No: WE-03
UTM location: 399128E 4948303N
Type: Drill Hole
12.2 m of Nepean Formation

Stn. No: SWE-01
UTM location: 409528E 4943573N
Type: Roadcut
3.55 m of March Formation over
3.10 m of Nepean Formation

Stn. No: BR-01
UTM location: 437241E 4937991N
Type: Drill Hole
9.4 m of March Formation over
6.8 m of Nepean Formation

Stn. No: BR-02
UTM location: 436641E 4934621N
Type: Drill Hole
26.7 m of Nepean Formation

Stn. No: BR-03
UTM location: 450531E 4948401N
Type: Drill Hole
7.9 m of Oxford Formation over
1.2 m of March Formation

Stn. No: BR-04
UTM location: 447461E 4940071N
Type: Drill Hole
20.4 m of March Formation

Stn. No: BR-05
UTM location: 447371E 4941051N
Type: Drill Hole
4.9 m of Oxford Formation over
13.4 m of March Formation

Stn. No: BR-06
UTM location: 436871E 4929491N
Type: Drill Hole
5.8 m of March Formation over
3.4 m of Nepean Formation

Stn. No: SBR-01
UTM location: 427481E 4937471N
Type: Roadcut
10.47 m of Nepean Formation

Stn. No: SBR-02
UTM location: 436481E 4929871N
Type: Roadcut
6.4 m of March Formation

Stn. No: SBR-04
UTM location: 444531E 4938871N
Type: Roadcut
4.5 m of March Formation

Stn. No: SBR-05
UTM location: 455081E 4950021N
Type: Roadcut
8.15 m of Oxford Formation

Stn. No: ME-01
UTM location: 451991E 4980562N
Type: Drill Hole
9.1 m of Oxford Formation

Stn. No: ME-02
UTM location: 457521E 4959192N
Type: Drill Hole
5.8 m of Oxford Formation

* Greater detail is provided in Williams (1991).
Note: UTM co-ordinates provided using NAD83, Zone 18.

Table 8 - Summary of Geophysical Data United Counties of Leeds–Grenville
- NONE -

Table 9 - Aggregate Quality Test Data United Counties of Leeds–Grenville
- NONE -

References

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

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

Carson, D.M. 1982a. Paleozoic geology of the Kemptville area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2493, scale 1:50 000.

——— 1982b. Paleozoic geology of the Merrickville area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2494, scale 1:50 000.

——— 1982c. Paleozoic geology of the Brockville–Mallorytown area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2495, scale 1:50 000.

——— 1982d. Paleozoic geology of the Gananoque–Wolfe Island area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2496, scale 1:50 000.

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

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

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

Hewitt, D.F. 1963. Silica in Ontario; Ontario Department of Mines, Industrial Mineral Report No. 9, 36p.

Klugman, M.A. and Yen, W.T. 1980. Silica sand potential in eastern Ontario, preliminary report II – Beneficiation; Ontario Geological Survey, Open File Report 5305, 39p.

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

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

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

Rogers, C.A. 1980. Search for skid resistant aggregates in eastern Ontario; interim report: Ministry of Transportation and Communications, Engineering Materials Office, Soils and Aggregate Sections, Toronto, Ontario, Report EM-36, 72p.

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

Sharpe, D.R. 1979. Quaternary geology of the Merrickville area, southern Ontario; Ontario Geological Survey, Report 180, 54p. Accompanied by Maps 2387 and 2388.

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

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

The Ontario Aggregate Resources Corporation 2005. Mineral aggregates in Ontario, statistical update 2006; The Ontario Aggregate Resources Corporation, unpublished report, 20p.

——— 2008. Mineral aggregates in Ontario, statistical update 2007; The Ontario Aggregate Resources Corporation, unpublished report, 22p.

Williams, D.A. 1991. Paleozoic geology of the Ottawa–St. Lawrence Lowland, southern Ontario; Ontario Geological Survey, Open File Report 5770, 292p.

Williams, D.A. and Wolf, R.R. 1984. Paleozoic geology of the Westport area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2723, scale 1:50 000.

Williams, D.A., Wolf, R.R. and Carson, D.M. 1985. Paleozoic geology of the Morrisburg area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2722, scale 1:50 000.

Wolf, R.R. and Dalrymple, R.W. 1984. Sedimentology of the Cambro-Ordovician sandstones of eastern Ontario (Grant 187); *in* Geoscience Research Grant Program, Summary of Research, 1983–84, Ontario Geological Survey, Miscellaneous Paper 121, p.240-252.

——— 1985. Sedimentology of the Cambro-Ordovician sandstones of eastern Ontario (Grant 187); *in* Geoscience Research Grant Program, Summary of Research, 1984–85, Ontario Geological Survey, Miscellaneous Paper 127, p.112-118.

Young, A.F., Gorrell, G.A. and Fletcher, T.W. 1983. Sand and gravel assessment for the United Counties of Leeds and Grenville; Ontario Geological Survey, Open File Report 5432, 81p.

Appendix A – Suggested Additional Reading and References

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

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

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

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

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

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

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

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

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

Hewitt, D.F. and Vos, M.A. 1970. Urbanization and rehabilitation of pits and quarries; Ontario Department of Mines, Industrial Mineral Report No. 34, 21p.

Liberty, B.A. 1966. Geology of the Bruce Peninsula area, Ontario; Geological Survey of Canada, Paper 65-41, 8p. plus 13 maps.

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

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

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

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

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

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

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

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

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

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

Appendix B – Glossary

Abrasion resistance: Tests such as the Los Angeles abrasion test 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.

Absorption capacity: 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.

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.

Aggregate Abrasion Value: This test directly measures the resistance of aggregate to abrasion with silica sand and a steel disk. The higher the value, the lower the resistance to abrasion. For high-quality asphalt surface course uses, values of less than 6 are desirable.

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.

Bulk Relative Density: The density of a material related to water at 4°C and atmospheric pressure at sea level. 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.

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

Chert: Amorphous silica, generally associated with limestone. Often occur as irregular masses or lenses, but can also occur finally 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 that 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. Four types have been defined: 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 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).

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

Hot-laid (or Asphaltic) Paving Aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course (HL 1, 3 and 4), or as binder course (HL 2, 4 and 8) 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.

Los Angeles Abrasion and Impact Test: 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.

Magnesium Sulphate Soundness Test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates susceptible to freezing and thawing 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.

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 Era: 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.

Petrographic Examination: An aggregate quality test based on known field performance of various rock types. In Ontario, the test result is a petrographic number (PN). The higher the PN, the lower the quality of the aggregate.

Pleistocene: An epoch of the recent geological past including the time from approximately 2 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”.

Polished Stone Value: This test measures the frictional properties of aggregates after 6 hours of abrasion and polishing with an emery abrasive. The higher the PSV, the higher the frictional properties of the aggregate. Values less than 45 indicate marginal frictional properties, whereas values greater than 55 indicate excellent frictional properties.

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 unaccessible.

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 two 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 varied 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 which 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.

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 the Geological Survey of Canada should be referred to for more detailed information. The composition, thickness and uses of the formations are discussed. 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 this data: PSV = Polished Stone Value, AAV = Aggregate Abrasion Value, $MgSO_4$ = Magnesium Sulphate Soundness Test (loss in percent), LA = Los Angeles Abrasion and Impact Test (loss in percent), Absn = Absorption (percent), BRD = Bulk Relative Density, PN (Asphalt & Concrete) = Petrographic Number for Asphalt and Concrete use. The ranges are intended as a guide only and care should be exercised in extrapolating the information to specific situations. Aggregate suitability test data has been provided by the Ontario Ministry of Transportation.

Covey Hill Formation (Cambrian)

STRATIGRAPHY: lower formation of the Potsdam Group. COMPOSITION: interbedded non-calcareous feldspathic conglomerate and sandstone. THICKNESS: 0 to 14 m. USES: has been quarried for aggregate in South Burgess Township, Leeds County.

Nepean Formation (Cambro-Ordovician)

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

March Formation (Lower Ordovician)

STRATIGRAPHY: lower formation of the Beekmantown Group. COMPOSITION: interbedded quartz sandstone, dolomitic quartz sandstone, sandy dolostone and dolostone. THICKNESS: 6 to 64 m. USES: quarried extensively for aggregate in area of subcrop and outcrop; alkali-silica reactive in Portland cement concrete; lower part of formation is an excellent source of skid-resistant aggregate. Suitable for use as facing stone and paving stone. AGGREGATE SUITABILITY TESTING: PSV = 55-60, AAV = 4-6, $MgSO_4$ = 1-17, LA = 15-38, Absn = 0.5-0.9, BRD = 2.61-2.65, PN (Asphalt & Concrete) = 110-150.

Oxford Formation (Lower Ordovician)

STRATIGRAPHY: upper formation of the Beekmantown Group. COMPOSITION: 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, $MgSO_4$ = 1-4, LA = 18-23, Absn = 0.7-0.9, BRD = 2.74-2.78, PN (Asphalt & Concrete) = 105-120.

Rockcliffe Formation (Middle Ordovician)

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

Shadow Lake Formation (Middle Ordovician)

STRATIGRAPHY: eastern Ontario - the basal unit of the Ottawa Group; central Ontario - overlain by the Simcoe Group. COMPOSITION: in eastern Ontario - silty and sandy dolostone with shale partings and minor interbeds of sandstone; in central Ontario - conglomerates, sandstones, and shales. THICKNESS: eastern Ontario - 2 to 3 m; central Ontario - 0 to 12 m. USES: potential source of decorative stone; very limited value as aggregate source.

Gull River Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and Ottawa Group (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. COMPOSITION: in central and eastern Ontario, the lower member consists of alternating units of limestone, dolomitic limestone and dolostone, the upper member consists of thin-bedded limestones with thin shale partings; west of Lake Simcoe, the lower member is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone, whereas the upper and middle members are dense microcrystalline limestones with argillaceous dolostone interbeds. THICKNESS: 7.5 to 136 m. USES: quarried in the Lake Simcoe, Kingston, Ottawa and Cornwall areas for crushed stone. Rock from certain layers in eastern and central Ontario has proven to be alkali-reactive when used in Portland cement concrete (alkali-carbonate reaction). AGGREGATE SUITABILITY TESTING: PSV = 41-49, AAV = 8-12, $MgSO_4$ = 3-13, LA = 18-28, Absn = 0.3-0.9, BRD = 2.68-2.73, PN (Asphalt & Concrete) = 100-153.

Bobcaygeon Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and the Ottawa Group (eastern Ontario), subdivided into upper, middle and lower members; members in eastern and central Ontario are approximately equivalent. COMPOSITION: homogeneous, massive to thin-bedded fine-crystalline limestone with numerous shaly partings in the middle member. THICKNESS: 7 to 87 m. USES: quarried at Brechin, Marysville and in the Ottawa area for crushed stone. Generally suitable for use as granular base course aggregate. Rock from certain layers has been found to be alkali-reactive when used in Portland cement concrete (alkali-silica reaction). AGGREGATE SUITABILITY TESTING: PSV = 47-51, AAV = 14-23, $MgSO_4$ = 1-40, LA = 18-32, Absn = 0.3-2.4, BRD = 2.5-2.69, PN (Asphalt & Concrete) = 100-320.

Verulam Formation (Middle Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa groups. COMPOSITION: fossiliferous, pure to argillaceous limestone interbedded with calcareous shale. THICKNESS: 32 to 65 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. May be unsuitable for use as aggregate in some areas because of its high shale content. AGGREGATE SUITABILITY TESTING: PSV = 43-44, AAV = 9-13, $MgSO_4$ = 4-45, LA = 22-29, Absn = 0.4-2.1, BRD = 2.59-2.70, PN (Asphalt & Concrete) = 120-255.

Lindsay Formation (Middle Upper Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa groups; in eastern Ontario is divisible into an unnamed lower member and the Eastview Member; in central Ontario is divisible into the Collingwood Member (equivalent to portions of the Eastview Member) and a lower member. COMPOSITION: eastern Ontario - the lower member is interbedded, very fine- to coarse-crystalline limestone with undulating shale partings and interbeds of dark grey calcareous shale, whereas the Eastview Member is an interbedded dark grey to dark brown calcareous shale and very fine- to fine-crystalline, petroliferous limestone; central Ontario – Collingwood Member is a black, calcareous shale, whereas the lower member is a very fine- to coarse-crystalline, thin-bedded limestone with very thin, undulating shale partings. THICKNESS: 25 to 67 m. USES: eastern Ontario - lower member is used extensively for aggregate production; central Ontario - quarried at Picton, Ogden Point and Bowmanville for cement. May be suitable or unsuitable for use as concrete and asphalt aggregate. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 2-47, LA = 20-28, Absn = 0.4-1.3, BRD = 2.64-2.70, PN (Asphalt & Concrete) = 110-215.

Blue Mountain and Billings Formations (Upper Ordovician)

STRATIGRAPHY: central Ontario – Blue Mountain Formation includes the upper and middle members of the former Whitby Formation; eastern Ontario – Billings Formation is equivalent to part of the Blue Mountain Formation. COMPOSITION: Blue Mountain Formation - blue-grey, noncalcareous shales; Billings Formation - 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 61 m; Billings Formation - 0 to 62 m. USES: Billings Formation may be a suitable source for structural clay products and expanded aggregate; Blue Mountain Formation may be suitable for structural clay products.

Georgian Bay and Carlsbad Formations (Upper Ordovician)

COMPOSITION: central Ontario – Georgian Bay Formation composed of interbedded limestone and shale; eastern Ontario – Carlsbad Formation composed of interbedded shale, siltstone and bioclastic limestone. THICKNESS: Georgian Bay Formation - 91 to 170 m. Carlsbad Formation - 0 to 186 m. USES: Georgian Bay Formation - used by several producers in 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. Carlsbad Formation - used as a source material for brick and tile manufacturing, has potential as a lightweight expanded aggregate.

Queenston Formation (Upper Ordovician)

COMPOSITION: red, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding. THICKNESS: 45 to 335 m. USES: There are several large quarries developed in the Queenston Formation in the Toronto–Hamilton region and one at Russell, near Ottawa. All extract shale for brick manufacturing. The Queenston Formation is the most important source material for brick manufacture in Ontario.

Whirlpool Formation (Lower Silurian)

STRATIGRAPHY: lower formation in the Cataract Group in the Niagara Peninsula and the Niagara Escarpment as far north as Duntroon. COMPOSITION: massive, medium- to coarse-grained, argillaceous white to light grey quartz sandstone with thin grey shale partings. THICKNESS: 0 to 8 m. USES: building stone, flagstone.

Manitoulin Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs north of Stoney Creek. COMPOSITION: thin-bedded, blue-grey to buff-brown dolomitic limestones and dolostones. THICKNESS: 0 to 25 m. USES: extracted for crushed stone in St. Vincent and Sarawak townships, Grey County, and for decorative stone on Manitoulin Island.

Cabot Head Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs in subsurface throughout southwestern Ontario and crops out along the length of the Niagara Escarpment. COMPOSITION: green, grey and red shales. THICKNESS: 10 to 39 m. USES: potential source of coated lightweight aggregate and raw material for use in manufacture of brick and tile. Extraction limited by lack of suitable exposures.

Grimsby Formation (Lower Silurian)

STRATIGRAPHY: upper formation of the Cataract Group, is identified on the Niagara Peninsula as far north as Clappison's Corners. COMPOSITION: interbedded sandstone and shale, mostly red. THICKNESS: 0 to 15 m. USES: no present uses.

Thorold Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on the Niagara Peninsula. COMPOSITION: thick-bedded quartz sandstone. THICKNESS: 2 to 3 m. USES: no present uses.

Neagha Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on the Niagara Peninsula. COMPOSITION: dark-grey to green shale with minor interbedded limestone. THICKNESS: 0 to 2 m. USES: no present uses.

Dyer Bay Formation (Middle Silurian)

STRATIGRAPHY: on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: highly fossiliferous, impure dolostone. THICKNESS: 0 to 7.5 m. USES: no present uses.

Wingfield Formation (Middle Silurian)

STRATIGRAPHY: on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: olive green to grey shale with dolostone interbeds. THICKNESS: 0 to 15 m. USES: no present uses.

St. Edmund Formation (Middle Silurian)

STRATIGRAPHY: occurs on Manitoulin Island and northernmost Bruce Peninsula, upper portion previously termed the Mindemoya Formation. COMPOSITION: pale grey to buff-brown, micro- to medium-crystalline, thin- to medium-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 (Asphalt & Concrete) = 105.

Fossil Hill and Reynales Formations (Middle Silurian)

STRATIGRAPHY: Fossil Hill Formation occurs in the northern part of the Niagara Escarpment and is approximately equivalent in part to the Reynales Formation that occurs on the Niagara Peninsula and the Escarpment as far north as the Forks of the Credit. COMPOSITION: Fossil Hill Formation - fine- to coarse-crystalline dolostone with high silica content; Reynales Formation - thin- to thick-bedded shaly dolostone and dolomitic limestone. THICKNESS: Fossil Hill Formation – 6 to 26 m; Reynales Formation – 0 to 3 m. USES: both formations quarried for aggregate with 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 (Asphalt & Concrete) = 370.

Irondequoit Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group on the Niagara Peninsula south of Waterdown. COMPOSITION: massive, coarse-crystalline crinoidal limestone. THICKNESS: 0 to 2 m. USES: not utilized extensively.

Rochester Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group along the Niagara Peninsula. COMPOSITION: black to dark grey calcareous shale with numerous limestone lenses. 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 (Asphalt & Concrete) = 400.

Decew Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group south of Waterdown along the Niagara Peninsula. COMPOSITION: sandy to shaly dolomitic limestone and dolostone. THICKNESS: 0 to 5 m. USES: too shaly for high-quality uses, but is quarried along with Lockport Formation in places. AGGREGATE SUITABILITY TESTING: PSV = 67, AAV = 15, $MgSO_4$ = 55, LA = 21, Absn = 2.2, BRD = 2.66, PN (Asphalt & Concrete) = 255.

Lockport and Amabel Formations (Middle Silurian)

STRATIGRAPHY: Lockport Formation occurs from Waterdown to Niagara Falls, subdivided into 3 formal members: Gasport, Goat Island and Eramosa members, and an informal member (the "Vinemount shale beds"); the approximately equivalent Amabel Formation, found from Waterdown to Cockburn Island, has been subdivided into Lions Head, Wiarton/Colpoy Bay and Eramosa members. On the Bruce Peninsula and in the subsurface of southwestern Ontario, the Eramosa Member is considered to be part of the overlying Guelph Formation. COMPOSITION: Lockport Formation is thin- to massive-bedded, fine- to medium-crystalline dolostone; Amabel Formation is thin- to massive-bedded, fine- to medium-crystalline dolostone with reef facies developed near Georgetown and on the Bruce Peninsula. The Eramosa Member is thin bedded and bituminous. THICKNESS: (Lockport–Amabel) 3 to 40 m. USES: both formations have been used to produce lime, crushed stone, concrete aggregate and building stone throughout their area of occurrence, and are a resource of provincial significance. AGGREGATE SUITABILITY TESTING: PSV = 36-49, AAV = 10-17, $MgSO_4$ = 2-6, LA = 25-32, Absn = 0.4-1.54, BRD = 2.61-2.81, PN (Asphalt & Concrete) = 100-105.

Guelph Formation (Middle Silurian)

STRATIGRAPHY: exposed south and west of the Niagara Escarpment from the Niagara River to the tip of the Bruce Peninsula, mostly present in the subsurface of southwestern Ontario. COMPOSITION: fine- to medium-crystalline, medium- to thick-bedded, porous dolostone, characterized in places by extensive vuggy, porous reefal facies of high chemical purity. 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. Main use is for dolomitic lime for cement manufacture. Quarried near Hamilton and Guelph.

Salina Formation (Upper Silurian)

STRATIGRAPHY: present in the subsurface of southwestern Ontario; only rarely exposed at surface. COMPOSITION: 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. THICKNESS: 113 to 330 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: Bertie Formation found in southern Niagara Peninsula; Bass Islands Formation, the Michigan Basin equivalent of the Bertie Formation, rarely crops out in Ontario, but is present in the subsurface in southwestern Ontario; Bertie Formation represented by Oatka, Falkirk, Scajaquanda, Williamsville and Akron members. COMPOSITION: medium- to massive-bedded, micro-crystalline, brown dolostone with shaly partings. THICKNESS: 14 to 28 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. Has also been extracted for lime. AGGREGATE SUITABILITY TESTING: PSV = 46-49, AAV = 8-11, $MgSO_4$ = 4-19, LA = 14-23, Absn = 0.8-2.8, BRD = 2.61-2.78, PN (Asphalt & Concrete) = 102-120.

Oriskany Formation (Lower Devonian)

STRATIGRAPHY: basal Devonian clastic unit, found in Niagara Peninsula. COMPOSITION: thick- to massive-bedded, coarse-grained, grey-yellow sandstone. THICKNESS: 0 to 5 m. USES: has been quarried for silica sand, building stone and armour stone. May be acceptable for use as rip rap, and well-cemented varieties may be acceptable for some asphaltic products. AGGREGATE SUITABILITY TESTING: (of a well-cemented variety of the formation) PSV = 64, AAV = 6, $MgSO_4$ = 2, LA = 29, Absn = 1.2-1.3, BRD = 2.55, PN (Asphalt & Concrete) = 107.

Bois Blanc Formation (Lower Devonian)

STRATIGRAPHY: Springvale Sandstone Member forms the lower portion of formation. COMPOSITION: a cherty limestone with shale partings and minor interbedded dolostones; Springvale Sandstone Member is a medium- to coarse-grained, green glauconitic sandstone with interbeds of limestone, dolostone and brown chert. THICKNESS: 3 to 40 m. USES: quarried at Hagersville, Cayuga and Port Colborne for crushed stone. Material generally unsuitable for concrete aggregate because of high chert content. AGGREGATE SUITABILITY TESTING: PSV = 48-53, AAV = 3-7, $MgSO_4$ = 3-18, LA = 15-22, Absn = 1.3-2.8, BRD = 2.50-2.70, PN (Asphalt & Concrete) = 102-290.

Onondaga Formation (Lower to Middle Devonian)

STRATIGRAPHY: correlated to part of the Detroit River Group; occurs on the Niagara Peninsula from Simcoe to Niagara Falls; contains the Edgecliff, Clarence and Moorehouse members. COMPOSITION: 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. High chert content makes much of the material unsuitable for use as concrete aggregate and asphaltic concrete. Has been used as a raw material in cement manufacture. AGGREGATE SUITABILITY TESTING: (Clarence and Edgecliff members) $MgSO_4$ = 1-6, LA = 16.8-22.4, Absn = 0.5-1.1, PN (Asphalt & Concrete) = 190-276.

Amherstburg Formation (Lower to Middle Devonian)

STRATIGRAPHY: part of Detroit River Group; correlated to Onondaga Formation in Niagara Peninsula; contains Sylvania Sandstone Member and Formosa Reef Limestone. COMPOSITION: bituminous, bioclastic, stromatoporoid-rich limestone with grey chert nodules; Formosa Reef Limestone - high-purity (calcium-rich) limestone; Sylvania Sandstone Member - quartz sandstone. THICKNESS: 0 to 60 m; Formosa Reef Limestone - up to 26 m. USES: cement manufacture, agricultural lime, aggregate. AGGREGATE SUITABILITY TESTING: PSV = 57, AAV = 19, $MgSO_4$ = 9-35, LA = 26-52, Absn = 1.1-6.4, BRD = 2.35-2.62, PN (Asphalt & Concrete) = 105-300.

Lucas Formation (Middle Devonian)

STRATIGRAPHY: part of the Detroit River Group in southwestern Ontario; includes the Anderdon Member which, in the Woodstock–Beachville area, may constitute the bulk of the formation. COMPOSITION: light brown or grey-brown dolostone with bituminous laminations and minor chert; Anderdon Member consists of very high-purity (calcium-rich) limestone and locally, sandy limestone. THICKNESS: 40 to 75 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. Anderdon Member is quarried at Amherstburg for crushed stone. AGGREGATE SUITABILITY TESTING: PSV = 46-47, AAV = 15-16, $MgSO_4$ = 2-60, LA = 22-47, Absn = 1.1-6.5, BRD = 2.35-2.40, PN (Asphalt & Concrete) = 110-160.

Dundee Formation (Middle Devonian)

STRATIGRAPHY: few natural outcrops, mostly in the subsurface of southwestern Ontario. COMPOSITION: fine- to medium-crystalline, brownish-grey, medium- to thick-bedded, dolomitic limestone with shaly partings, sandy layers, and chert in some areas. THICKNESS: 15 to 45 m. USES: quarried near Port Dover and on Pelee Island for crushed stone. Used at St. Marys as a raw material for Portland cement. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-28, LA = 22-46, Absn = 0.6-6.8, PN (Asphalt & Concrete) = 125-320.

Marcellus Formation (Middle Devonian)

STRATIGRAPHY: subsurface unit, mostly found below Lake Erie and extending into the eastern USA, pinches out in the Port Stanley area. COMPOSITION: black, bituminous shales. THICKNESS: 0 to 12 m. USES: no present uses.

Bell Formation (Middle Devonian)

STRATIGRAPHY: lowest formation of the Hamilton Group, no outcrop in Ontario. COMPOSITION: soft, blue and grey calcareous shale. THICKNESS: 0 to 14.5 m. USES: no present uses.

Rockport Quarry Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group; no outcrop in Ontario. COMPOSITION: grey-brown, very fine-grained limestone with occasional shale layers. THICKNESS: 0 to 6 m. USES: no present uses.

Arkona Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: blue-grey, plastic, clay shale with occasional thin and laterally discontinuous limestone lenses. 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: part of the Hamilton Group. COMPOSITION: grey crinoidal limestone and soft, fossiliferous calcareous shale. THICKNESS: 0 to 2 m. USES: suitable for some crushed stone and fill with selective quarrying.

Widder Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: mainly soft, grey, fossiliferous calcareous shale interbedded with blue-grey, fine-grained fossiliferous limestone. THICKNESS: 0 to 21 m. USES: no present uses.

Ipperwash Formation (Middle Devonian)

STRATIGRAPHY: upper formation of the Hamilton Group; very limited distribution. COMPOSITION: medium- to coarse-grained, grey-brown, bioclastic limestone. THICKNESS: 2 to 14 m. USES: no present uses.

Kettle Point Formation (Upper Devonian)

STRATIGRAPHY: occurs in a northwest-trending band between Sarnia and Erieau; small part overlain by Port Lambton Group rocks in extreme northwest. COMPOSITION: black, highly fissile, organic-rich shale with minor interbeds of grey-green silty shale. THICKNESS: 0 to 75 m. USES: possible source of material for use as sintered lightweight aggregate or fill.

Bedford Formation (Upper Devonian or Mississippian)

STRATIGRAPHY: lower formation of the Port Lambton Group. COMPOSITION: soft, grey shale. THICKNESS: 0 to 30 m. USES: no present uses.

Berea Formation (Upper Devonian or Mississippian)

STRATIGRAPHY: middle formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: grey, fine- to medium-grained sandstone, often dolomitic and interbedded with grey shale and siltstone. THICKNESS: 0 to 60 m. USES: no present uses.

Sunbury Formation (Upper Devonian or Mississippian)

STRATIGRAPHY: upper formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: black shale. THICKNESS: 0 to 20 m. USES: no present uses.

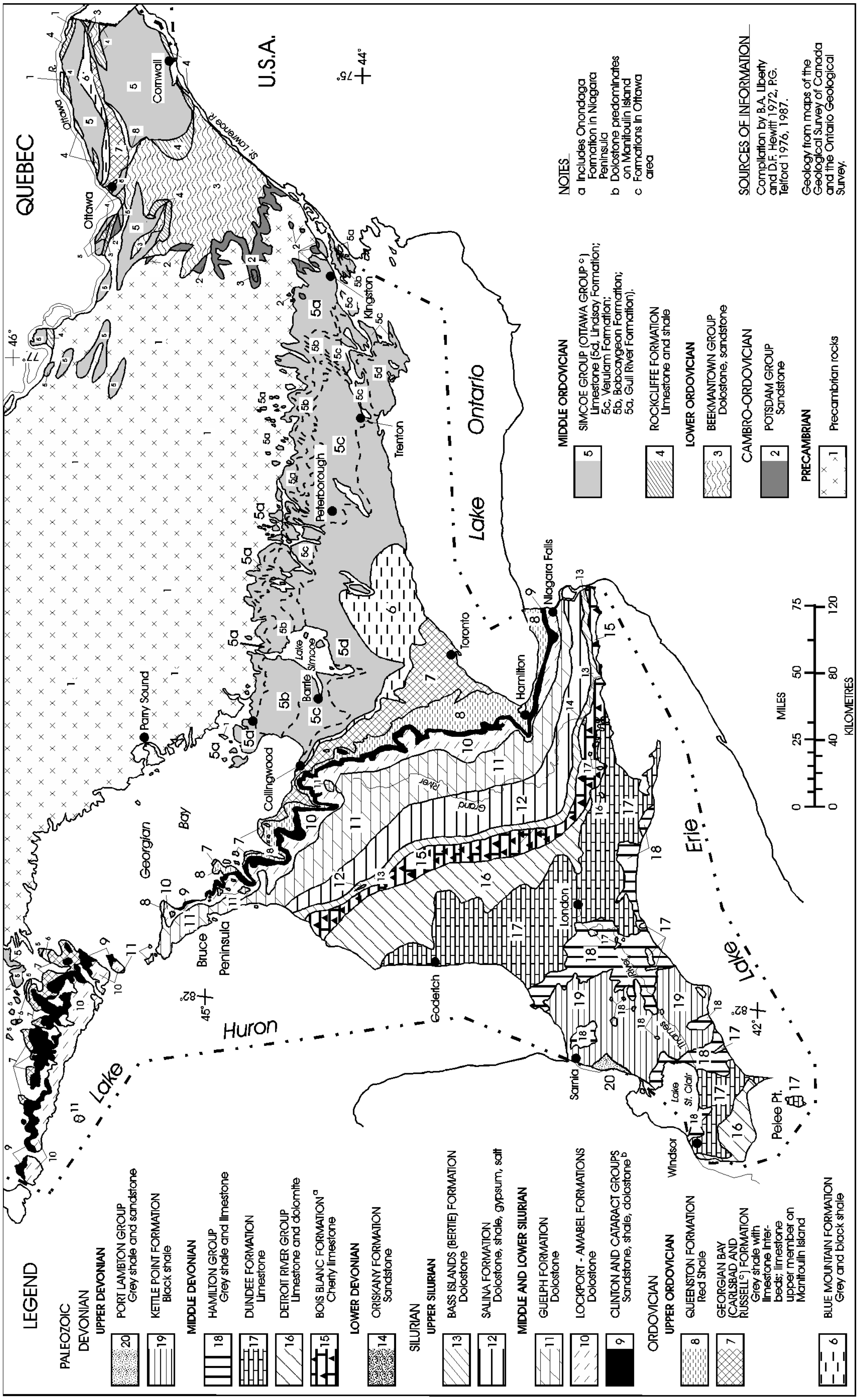


Figure D1. Bedrock geology of southern Ontario.

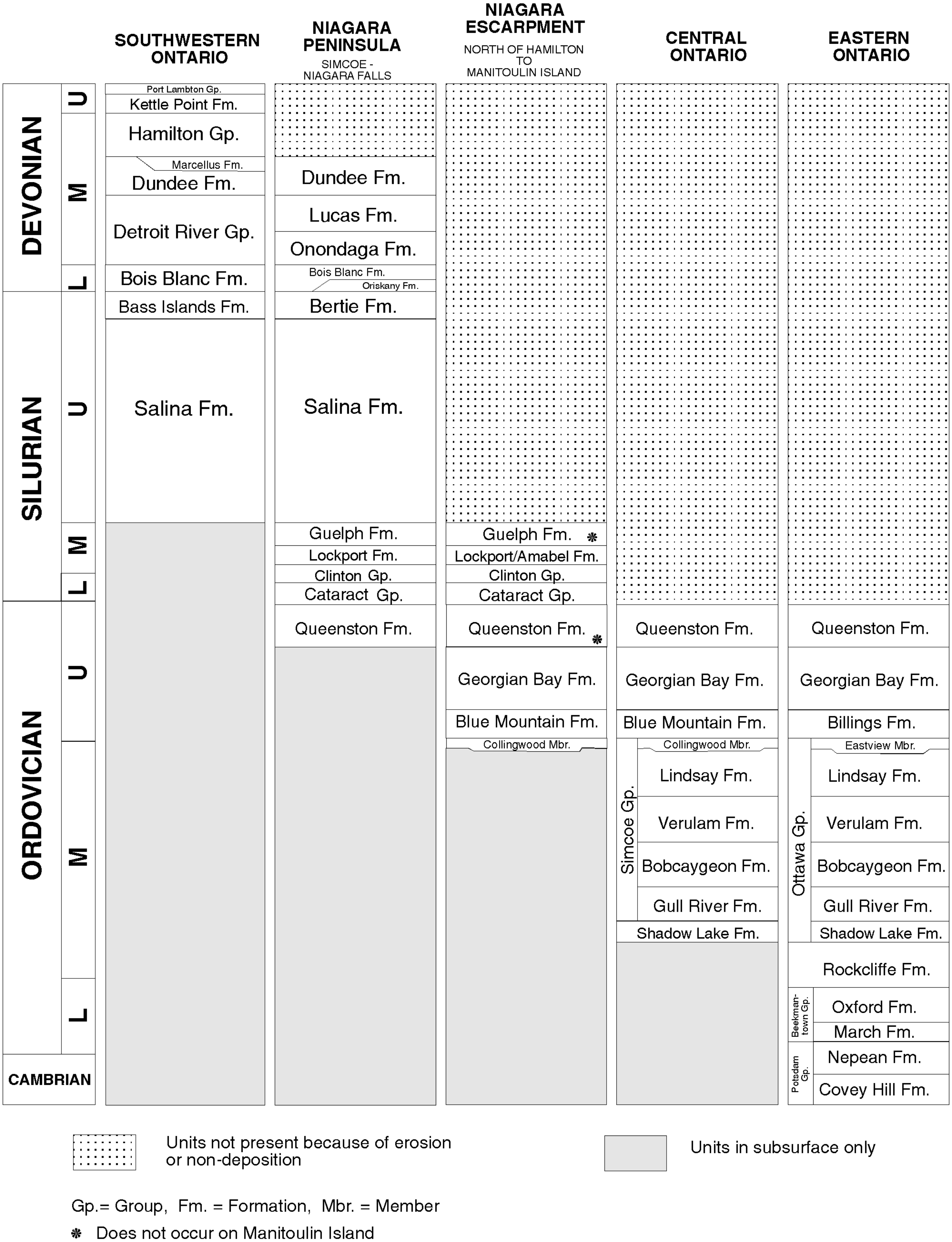


Figure D2. Exposed Paleozoic stratigraphic sequences in southern Ontario (*adapted from* Bezys, R.K. and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario; The Canadian Institute of Mining and Metallurgical, CIM Bulletin,v.81, no.912, p.49-58.)

Appendix E – Aggregate Quality Test Specifications

Six types of aggregate quality tests are often performed by the Ontario Ministry of Transportation on sampled material. A 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 6 tests listed in this appendix can be used to determine the suitability of an aggregate. The tests are performed by the Ontario Ministry of Transportation.

Absorption Capacity: 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.

Los Angeles Abrasion and Impact Test: 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.

Magnesium Sulphate Soundness Test: 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: The micro-Deval abrasion test 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 multilaboratory variation. The maximum loss for HL 1/HL 3 is 20%; for HL 2 and HL 4/HL 8, it is 25%; and for structural and pavement concrete, it is 20%. It is anticipated that this test will replace the fine aggregate magnesium sulphate soundness test.

Mortar Bar Accelerated Expansion Test: 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.

Petrographic Examination: 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.

Table E1. Selected quality requirements for major aggregate products.

TYPE OF TEST						
	COARSE AGGREGATE				FINE AGGREGATE	
TYPE OF MATERIAL	Petrographic Number Maximum	Magnesium Sulphate Soundness Maximum% Loss	Absorption Maximum%	Los Angeles Abrasion Maximum% Loss	Micro-Deval Abrasion Maximum % Loss	Magnesium Sulphate Soundness Maximum % Loss
Granular A	200	-	-	60		-
Granular B Type 1	250*	-	-	-		-
Granular B Type 2	250	-	-	60		-
Granular M	200	-	-	60		-
Granular S	200	-	-	-		-
Select Subgrade Material	250	-	-	-		-
Open Graded Drainage Layer (1)	160	15	2.0	35		-
Hot Mix-HL 1, DFC, OFC	See OPSS 1149 and Special Provision No. 313S10					
Surface Treatment Class 1	135	12	1.75	35		-
Surface Treatment Class 2	160	15	-	35		-
Surface Treatment Class 3	160	12	2.0	35		-
Surface Treatment Class 4	-	-	-	-		20
Surface Treatment Class 5	135	12	1.75	35		-
Hot Mix - HL 1	100	5	1.0	15	20	16
Hot Mix - HL 2	-	-	-	-	25	20
Hot Mix - HL 3	135	12	1.75	35	20	16
Hot Mix - HL 4	160	12	2.0	35	20	20
Hot Mix - HL 8	160	15	2.0	35	25	20
Structural Concrete, Sidewalk, Curb, Gutter and Base	140	12	2.0	50	20	16
Pavement Concrete	125	12	2.0	35	20	16

*** requirement waived if the material has more than 80% passing the 4.75 mm sieve**
(1) Hot mix and concrete petrographic number applies
(Ontario Provincial Standard Specifications OPSS 304, OPSS 1002, OPSS 1003, OPSS 1010 and OPSS 1149)

Metric Conversion Table

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

OTHER USEFUL CONVERSION FACTORS

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

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

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Aggregate Resources Inventory Paper 183

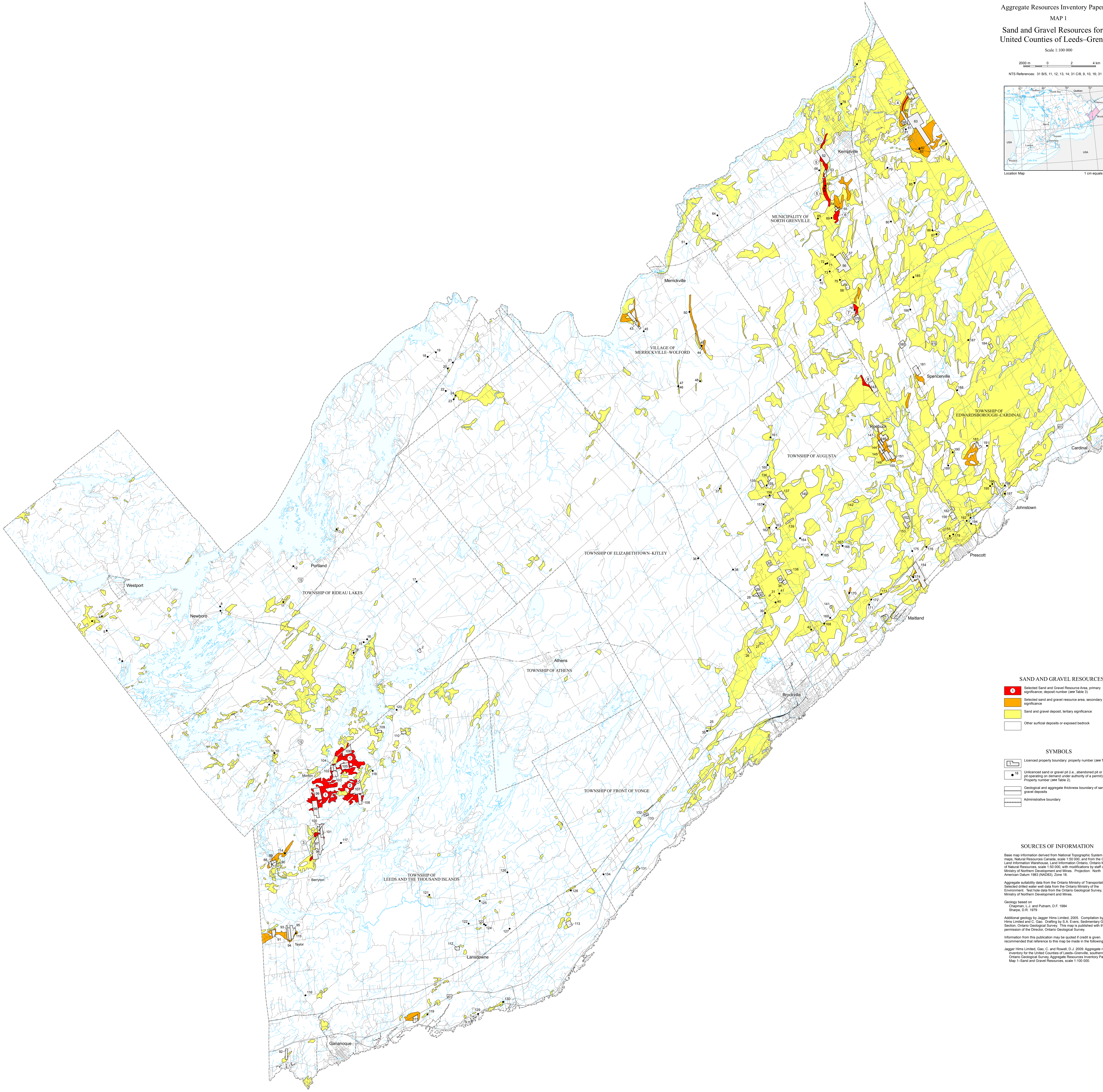
MAP 1

Sand and Gravel Resources for the United Counties of Leeds–Grenville

Scale 1:100 000

2000 m 0 2 4 km

NTS References: 31 B/5, 11, 12, 13, 14; 31 C/8, 9, 10, 16; 31 G/4



Location Map 1 cm equals 80 km

SAND AND GRAVEL RESOURCES

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

SYMBOLS

- 1 Licenced property boundary: property number (*see* Table 2)
- 18 Unlicenced sand or gravel pit (i.e., abandoned pit or wayside pit operating on demand under authority of a permit). Property number (*see* Table 2).
- 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 and Mines. Projection: North American Datum 1983 (NAD83), Zone 18.

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

Geology based on
Chapman, L.J. and Putnam, D.F. 1984
Sharpe, D.R. 1979

Additional geology by Jagger Hims Limited, 2005. Compilation by Jagger Hims Limited and C. Gao. Drafting by S.A. Evers, Sedimentary Geoscience Section, Ontario Geological Survey. This map is published with the permission of the Director, Ontario Geological Survey.

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Jagger Hims Limited, Gao, C. and Rowell, D.J. 2009. Aggregate resources inventory for the United Counties of Leeds–Grenville, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 183, Map 1–Sand and Gravel Resources, scale 1:100 000.

Aggregate Resources Inventory Paper 183

MAP 2

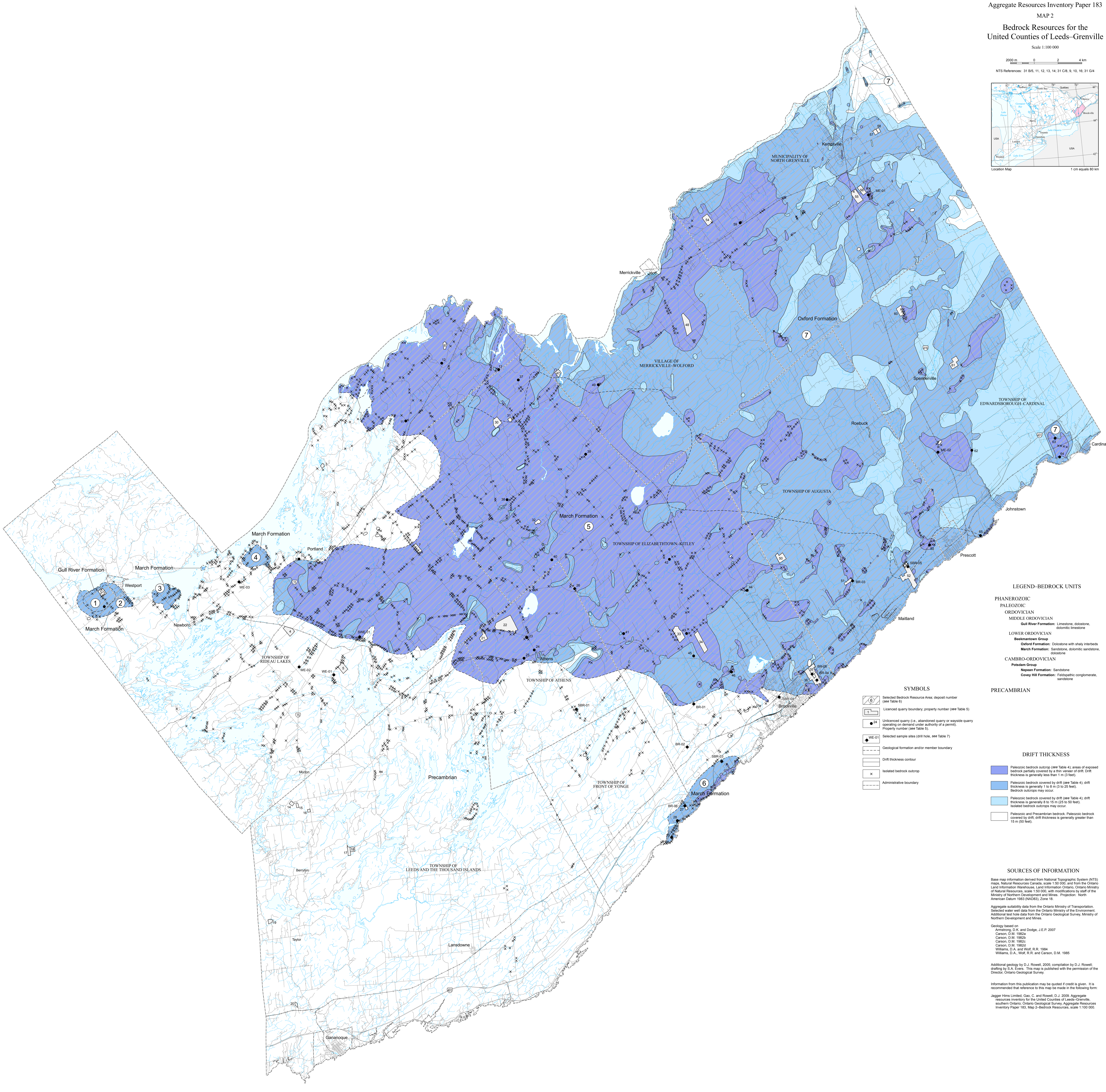
Bedrock Resources for the United Counties of Leeds–Grenville

Scale 1:100 000

2000 m 0 2 4 km

NTS References: 31 B/5, 11, 12, 13, 14; 31 C/8, 9, 10, 16; 31 G/4

Location Map 1 cm equals 80 km



SYMBOLS

- Selected Bedrock Resource Area; deposit number (*see* Table 6)
- Licenced quarry boundary; property number (*see* Table 5)
- Unlicenced quarry (i.e., abandoned quarry or wayside quarry operating on demand under authority of a permit). Property number (*see* Table 5).
- Selected sample sites (drill hole, *see* Table 7)
- Geological formation and/or member boundary
- Drift thickness contour
- Isolated bedrock outcrop
- Administrative boundary

LEGEND–BEDROCK UNITS

PHANEROZOIC

PALEOZOIC

ORDOVICIAN

MIDDLE ORDOVICIAN

Gull River Formation: Limestone, dolostone, dolomitic limestone

LOWER ORDOVICIAN

Beekmantown Group

Oxford Formation: Dolostone with shaly interbeds

March Formation: Sandstone, dolomitic sandstone, dolostone

CAMBRO-ORDOVICIAN

Potsdam Group

Nepean Formation: Sandstone

Covey Hill Formation: Feldspathic conglomerate, sandstone

PRECAMBRIAN

DRIFT THICKNESS

- Paleozoic bedrock outcrop (*see* Table 4); areas of exposed bedrock partially covered by a thin veneer of drift. Drift thickness is generally less than 1 m (3 feet).
- Paleozoic bedrock covered by drift (*see* Table 4); drift thickness is generally 1 to 8 m (3 to 25 feet). Bedrock outcrops may occur.
- Paleozoic bedrock covered by drift (*see* Table 4); drift thickness is generally 8 to 15 m (25 to 50 feet). Isolated bedrock outcrops may occur.
- Paleozoic and Precambrian bedrock. Paleozoic bedrock covered by drift; drift thickness is generally greater than 15 m (50 feet).

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 and Mines. Projection: North American Datum 1983 (NAD83), Zone 18.

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

Geology based on
Armstrong, D.K. and Dodge, J.E.P. 2007
Carson, D.M. 1982a
Carson, D.M. 1982b
Carson, D.M. 1982c
Carson, D.M. 1982d
Williams, D.A. and Wolf, R.R. 1984
Williams, D.A., Wolf, R.R. and Carson, D.M. 1985

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Jagger Hims Limited, Gao, C. and Rowell, D.J. 2009. Aggregate resources inventory for the United Counties of Leeds–Grenville, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 183, Map 2–Bedrock Resources, scale 1:100 000.