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**Aggregate Resources Inventory of the**

# Regional Municipality of Halton

## Southern Ontario

Ontario Geological Survey
Aggregate Resources Inventory
Paper 184

**2009**

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By D.J. Rowell

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*** MicroSoft® Excel versions of these tables are available for downloading from GeologyOntario.**

**** The hard copy maps in the back pocket of this report are simplified somewhat, to depict information that is critical to the majority of users. More details on the aggregate resources for this study area (such as deposit type and texture data for the sand and gravel map) are contained in the ArcGIS® files of the maps, which are available for downloading from GeologyOntario.**

# Abstract


The Regional Municipality of Halton has potential aggregate resources (both sand and gravel and bedrock-derived aggregate) that are not only significant to local road building and construction needs but supply a great deal of aggregate to the western end of the Greater Toronto Area (GTA).

Three areas of sand and gravel resources of primary significance have been identified in the Regional Municipality of Halton. These areas have a total unlicenced area of 792 ha, with 644 ha remaining after accounting for cultural constraints and previously extracted areas. Possible remaining aggregate resources are estimated at 68.4 million tonnes. More detailed and extensive site investigations and aggregate testing should precede any future extractive development activities. In some areas, deleterious lithologies, the percentage of fines and the presence of oversized material can be of concern. Two of the recommended areas are within the Niagara Escarpment Plan area and development and extraction of the resource will be limited.

Bedrock of the Amabel Formation is identified as an important high-quality crushed stone resource. Much of the western half of the Regional Municipality of Halton is recommended for possible resource protection. This area consists of 14 952 ha, once cultural and physical constraints have been considered. The estimated volume of bedrock resources represented by this area is about 5941 million tonnes.

The Queenston Formation is a provincially significant bedrock resource used in the production and manufacture of brick and tile. Areas of the Queenston Formation with less than 8 m of overburden have not been selected in this report but are identified on Map 2.

The Clinton and Cataract groups have not been selected for bedrock resource protection, although their importance to the building and dimension stone industry must not be minimized. The areas where these groups are exposed or covered by less than 8 m of overburden should be considered carefully for protection during the planning process. Further site investigations and testing should proceed before bedrock resource areas are developed.

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

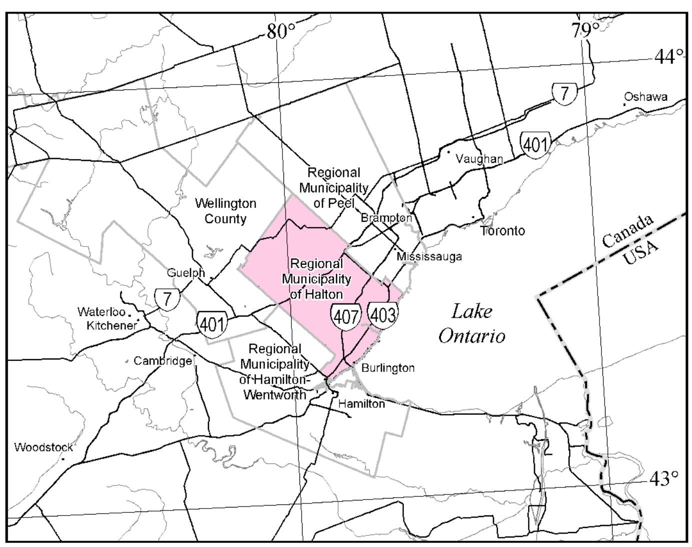




**Figure 1.** Key map showing the location of the study area.

# Aggregate Resources Inventory of the Regional Municipality of Halton

**By D.J. Rowell**

Fieldwork and report by D.J. Rowell.

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

# Introduction

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

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, non-renewable resources that can be exploited only in those areas where they occur. Mineral aggregates are characterised 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.

# Part I - Inventory Methods

## 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 and test pitting.

Deposits with potential for further extractive development, or those where existing data are scarce, were studied in greater detail. Representative sites in these deposits are evaluated by taking 11 to 45 kg samples from existing pit faces or from road cuts. 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 sources were obtained from records held by Regional, District and Area Offices of the Ontario Ministry of Natural Resources. In addition, reports on geological testing for type, quantity and quality of aggregates were also obtained from aggregate licence applications where these reports are on file with the MNR, and with specific 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 with information taken from the MNR's Natural Resources and Values Information System (NRVIS).

## RESOURCE TONNAGE CALCULATION TECHNIQUES

### Sand and Gravel Resources

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 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 17 700 (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$^3$.

**Tonnage = Area x Thickness x 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 x Column 6 x 17 700), 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, 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.

## Bedrock Resources

The method used to calculate resources of bedrock-derived aggregate is much the same as that described above. 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).

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).

## Units and Definitions

The measurements and other primary data available for resource tonnage calculations are given 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 made for sand and gravel deposits are termed possible resources (see Glossary, Appendix B) in accordance with terminology used by the Ontario Resource Classification Scheme (Robertson 1975, p.7) and the Association of Professional Engineers of Ontario (1976).

# Part II - 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”, gives a comprehensive 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.

## 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 which are licenced for extraction under the *Aggregate Resources Act* are shown by a solid outline and identified by a number which 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.

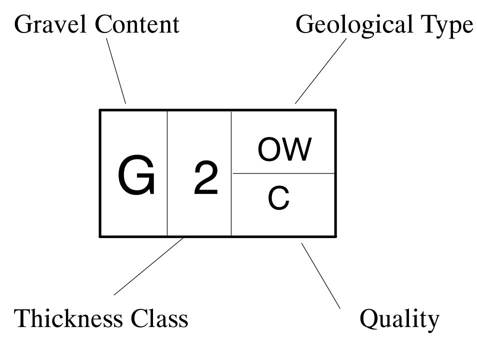
### Deposit Information

The Deposit Information label is similar to those used in soil mapping and land classification systems commonly in use in North America. The components of the label indicate the gravel content, thickness of material, origin (type) and quality limitations for every deposit shown on Map 1. **For the purpose of simplifying the hard copy version of this map, this information is contained in the ArcGIS® files; available for download from GeologyOntario.**

The “gravel content” and “thickness class” are basic criteria for distinguishing different deposits. The “gravel content” is an upper case “S” or “G”. The “S” indicates that the deposit is generally “sandy” and that gravel-sized aggregate (greater than 4.75 mm) makes up less than 35% of the whole deposit. “G” indicates that the deposit contains more than 35% gravel.

The “thickness class” indicates a depth range, which is related to the potential resource tonnage for each deposit. Four thickness class divisions have been established: Class 4 represents a sand and gravel deposit that is less than 1.5 m thick; Class 3 represents a deposit that is from 1.5 to 3 m thick; Class 2 sand and gravel deposits are from 3 to 6 m thick; and Class 1 deposits are greater than 6 m thick.

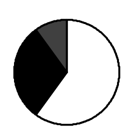
The next letters in the deposit label identify the geologic deposit type (the types are summarized with respect to their main geologic and extractive characteristics in Appendix C of the report). This appendix is also available as a Portable Document Format (pdf) file, available for downloading from GeologyOntario. The final set of letters identifies the main quality limitations that may be present in the deposit as discussed in a later section.




For example, G / 2 / OW / C in the label field would represent an outwash deposit 3 to 6 m thick containing more than 35% gravel. Excess silt and clay may limit the use of the aggregate in the deposit.

### 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 found in 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.



## SELECTED SAND AND GRAVEL RESOURCE AREAS

All the Selected Sand and Gravel Resource Areas are first delineated by geological boundaries and then classified into 3 levels of significance: primary, secondary and tertiary. Each area of primary significance is given a deposit number and all such deposits are coloured red on Map 1 and identified by a deposit number that corresponds to numbers in Table 3.

**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, primary, 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 aggregate supply of the area.

Areas 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.

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

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. Generally, deposits in Class 1 (greater than 6 m thick), 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. They are: gravel content (G or S), fines (C), oversize (O) and lithology (L). **For the purpose of simplifying the hard copy version of this map, this information is contained in the ArcGIS® files; available for download from Geology-Ontario.**

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 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.

Excess fines (high silt and clay content) 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 known to have a high fines content are indicated by a "C" in the quality portion of the Deposit Information.

Deposits containing more than 20% oversize material (greater than 10 cm in diameter) may also have use limitations. The oversize component is unacceptable for uncrushed road base, so it must be either crushed or removed during processing. Deposits known to have an appreciable oversize component are indicated by an "O" in the quality portion of the Deposit Information.

Another indicator of the quality of an aggregate is lithology. 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. Deposits known to contain objectionable lithologies are indicated by an "L" in the quality component of the Deposit Information.

If the Deposit Information in the ArcGIS® files 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. 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.

## 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 constraints applicable, anywhere from a minimum of 15 to 85% of the total resources in a municipality can become inaccessible (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. In most cases, however, the market demand for aggregate products, especially in urban areas, is greater than the amount of production found within the local market area. Consequently, conflicts often arise between the increasing demand for aggregates in such areas and the frequent pressures to restrict aggregate operations, especially in the near urban areas.

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.

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.

## MAP 2: BEDROCK MAP

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.

The geological boundaries of the Paleozoic bedrock units are shown by thick black lines. Isolated Paleozoic outcrops are indicated by an "X". Three sets of contour lines delineate areas of less than 1 m of drift, areas of 1 to 8 m of drift, and areas of 8 to 15 m of drift. The extent of these areas of thin drift are indicated on Map 2. The darkest shade of blue indicates where bedrock outcrops 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 which have extractive value in specific circumstances. These 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) can be produced from the resources; or part or all of the overburden is composed of an economically attractive deposit.

Other 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 which are 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. Two additional symbols may appear on the map. An open dot indicates the location of a selected water well that penetrates bedrock. The overburden thickness in metres is shown beside the open dot. Similarly, drill hole locations appear as a point symbol. The drill holes may be further described in Table 7.

## 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. 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.

## Selected 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.

**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.**

# Part III - Assessment of Aggregate Resources in the Regional Municipality of Halton

## LOCATION AND POPULATION

The Regional Municipality of Halton occupies 96 717 ha along the northwest shore of Lake Ontario. It is bounded to the east by the Regional Municipality of Peel, to the north and northwest by Wellington County and to the west by the Regional Municipality of Hamilton–Wentworth (*see* Figure 1). The study area is covered by all or parts of the Hamilton (30 M/5), Brampton (30 M/12), Cambridge (40 P/8) and Guelph (40 P/9) 1:50 000 scale map sheets of the National Topographic System (NTS).

The Regional Municipality of Halton consists of the towns of Halton Hills, Milton and Oakville, and the City of Burlington (Chart A). Documents that pre-date the regional municipal restructuring, which occurred January 1, 1974, refer to the old county structure consisting of the townships of Nassagaweya, Esquesing, Nelson and Trafalgar. Many of the north-trending roads are named after the previous township structure.

The population of the region was 439 256 in 2006 (Canadian Census Data 2006), which represents a 17.1% increase from 2001 (Canadian Census Data 2006). The region is experiencing unprecedented population growth due to its proximity to the City of Toronto and readily accessible transportation corridors. The Town of Milton had a 71.4% increase in population between 2001 and 2006 (*see* Chart A).

The region is served by 4 major provincial highways (Highways 401, 403, 407 and the Queen Elizabeth Way), as well as a number of smaller highways including Highways 2 and 7, and Regional Roads 1, 3, 5 and 25. These highways are complemented by well-maintained local roads, providing an extensive road network throughout the region.

## SURFICIAL GEOLOGY AND PHYSIOGRAPHY

The physiography and distribution of surficial material in the Regional Municipality of Halton, including the sand and gravel deposits shown on Map 1, are primarily the result of glacial activity that took place in the "Late Wisconsinan". This period, which lasted from approximately 23 000 to 10 000 years before present, was marked by the repeated advance and retreat of the margin of the massive Laurentide Ice Sheet (Barnett 1992).

The Niagara Escarpment dominates the physiography of the area. The Amabel Formation dolostone forms the caprock of the Niagara Escarpment, with the softer Queenston Formation shale defining the base of the escarpment. In the Regional Municipality of Halton, the main part of the escarpment consists of steep vertical cliffs. The escarpment trends northeast throughout the study area and divides the municipality into 2 regions. The western portion of the municipality lies above the Niagara Escarpment, while the eastern part is below the face of the escarpment. Below the escarpment, to the south and east, 3 physiographic regions have been identified: the South Slope; the Peel Plain; and the Lake Iroquois Plain (Chapman and Putnam 1984).

During the deglaciation of the Laurentide Ice Sheet margin, the ice split into glacial lobes that behaved semi-independently. At this time the study area was affected by the Ontario Lobe (Karrow 1968), which advanced to the northwest out of the Lake Ontario basin and overrode the Niagara Escarpment. The terminal position of this lobe was about 40 km west of the region. A thin, variable layer of till was deposited immediately west of the Niagara Escarpment face, covering an area in which bedrock is close to surface. The till that makes up this ground moraine, the Wentworth Till, is described as a strongly calcareous, silty-sandy till. The matrix of the till contains about 30 to 40% carbonate material with a clast content ranging from 7 to 10% (Karrow 1968; Barnett 1992).

**Chart A - Area and Population**

**REGIONAL MUNICIPALITY OF HALTON**

| Municipality | Land Area (ha) | 2001 Population | 2006 Population |
|---|---|---|---|
| Town of Milton | 36 661 | 31 471 | 53 939 |
| Town of Halton Hills | 27 626 | 48 184 | 55 289 |
| City of Burlington | 18 574 | 150 836 | 164 415 |
| Town of Oakville | 13 856 | 144 738 | 165 613 |
| **TOTAL** | **96 717** | **375 229** | **439 256** |

The Wentworth Till can be found in the Paris, Galt and Moffat moraines that are located in the northwest corner of the region. These moraines form part of the Horseshoe Moraine physiographic region (Chapman and Putnam 1984). The physiographic region is characterized by rolling to hummocky, irregular topography with local relief of 15 to 30 m. In addition to the Wentworth Till, much of the material in these moraines is ice-contact stratified sediments. The till has little value as aggregate because of its high fines content, but the ice-contact stratified deposits contain large amounts of sand and crushable gravel.

In the eastern and southern part of the study area, the Ontario Lobe deposited the Halton Till. The till is strongly calcareous and is primarily a sandy-silt to silty-clay till (Karrow 1991; Barnett 1992). Over the Georgian Bay Formation the color of the till tends to be greyish, while over the Queenston Formation the till is a reddish brown. The Waterdown moraine, located near the community of Waterdown on top of the Niagara Escarpment, is cored by the Halton Till. The South Slope physiographic region is also predominantly underlain by Halton Till, as this till drapes the land between the Niagara Escarpment and the Lake Ontario basin.

Large volumes of sediment-laden meltwater flowed from the ice margin while the Ontario Lobe stood at, or just east of, the escarpment and laid down outwash deposits, such as those near Georgetown, Limehouse, Campbellville and Killbride. Small amounts of outwash sand and gravel were also deposited near Blue Springs Creek, but many of the other meltwater channels in that area are predominantly erosional in origin.

A relatively small glacial lake (glacial Lake Peel) formed between the ice sheet and the Niagara Escarpment to the west and the Oak Ridges moraine to the north. Glaciolacustrine sand and silt were deposited within this lake. The Ontario Lobe made one final advance, which resulted in the deposition of the Wildfield Till Complex and the formation of the Trafalgar moraine. The Wildfield Till Complex is a strongly calcareous silty-clay till with the matrix having a carbonate content of 35% (Barnett 1992). The till is often interbedded with glaciolacustrine sediments from glacial Lake Peel, leading to the term Wildfield Till Complex. Some researchers now consider the Wildfield Till Complex to be part of the Halton Till package.

The Ontario Lobe margin retreated for the last time into the Lake Ontario Basin; however, water levels in front of the ice were still elevated, leading to the formation of glacial Lake Iroquois. Glacial Lake Iroquois drained southeastward via an outlet at Rome, New York. This lake deposited glaciolacustrine silt and sand, which can be found in the vicinity of Oakville and Burlington, as shown on Map 1. There are a few remnant glaciolacustrine beach deposits from glacial Lake Iroquois, but they are generally small and poorly formed.

Surficial geology mapping and detailed stratigraphy of the study area has been completed by Karrow (1967, 1968, 1987a, 1987b, 1987c, 1991), White (1975), Cowan (1976) and Sharpe (1980).

## EXTRACTIVE ACTIVITY

The Regional Municipality of Halton has had a long history of aggregate production. Not only does the area supply much of the material for local construction projects, but also for the rapidly growing Greater Toronto Area (GTA) market. The resources in the study area are strategically located with respect to minimizing the cost of construction within the immediate area and in the western part of the GTA.

Historically, the towns of Milton and Halton Hills are 2 of the largest aggregate producing municipalities in the province. In 2006, the province consumed 177 million tonnes of aggregate, with 9.7 million tonnes being produced in the Regional Municipality of Halton. Production has varied in Halton from a high of about 17 million tonnes in the late 1980s to a low of just under 8 million tonnes in 1992-93 (The Ontario Aggregate Resources Corporation 2007; Aggregate and Roadbuilding Magazine 2007). The continuing availability of some of these resources is threatened by commercial, residential and other development activities. Therefore, comprehensive resource management plans are required to ensure the availability of as much of the remaining aggregate resource as possible.

## SAND AND GRAVEL EXTRACTIVE ACTIVITY

Forty-three licenced and abandoned sand and gravel pits are located throughout the Regional Municipality of Halton, of which 15 are licenced (see Table 2). The total area licenced for sand and gravel extraction in the region is 517.84 ha, with all of the licenced areas located in the towns of Milton and Halton Hills.

The Town of Halton Hills has sand and gravel resources in the form of ice-contact and outwash deposits in the northern portion of the municipality. Large scale sand and gravel extraction is concentrated in the outwash deposits at Limehouse, Glen Williams and Silver Creek. Large ice-contact deposits in the study area also contain considerable resources of sand and crushable gravel. The pits in these deposits, and some of the surrounding deposits, contain sand and gravel suitable for a variety of aggregate products. Historically, extraction in the Town of Milton has occurred primarily in the discontinuous outwash deposits between Campbellville and the northern part of the City of Burlington.

There are some quality constraints on the use of the sand and gravel aggregate resources in the Regional Municipality of Halton, although high-quality aggregate products, such as concrete and certain hot mix asphalt paving aggregates, have been produced in the past. These constraints include high quantities of fine and oversized particles, cementation of particles in indurated zones, and undesirable lithologies. Some of these can be remedied, but beneficiation and selection add to the cost of aggregate production.

Both excessive quantities of fine and oversized material are undesirable. When excessive amount of fines are encountered, selection and washing of zones with high fines content may be required. Washing out small quantities of fines may be necessary especially for the production of concrete sand. Excessive fines reduce the drainage capacity of granular base material, which can eventually result in deterioration of roads constructed with this aggregate. While material suitable for crushing is required to produce concrete, hot mix and asphalt paving aggregate, excessive amounts and sizes of oversized material can increase processing costs.

Several deposits in the region contain zones of cemented sand and gravel. Such zones have been noted beneath tills, such as have been reported in the Bronte Creek stream bed just north of the Queen Elizabeth Way (Karrow 1987a). Where the cemented sand and gravel are exposed to weathering, spectacular “flower-pot” structures can result.

# AGGREGATE QUALITY

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

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

The quality test data for specific samples listed below are only for those samples. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit—particularly where some of the deposits may be quite large and extensive. MTO test results presented below represent samples collected over the entire deposit and over a number of years. Therefore, these test results apply to the deposit and not a specific site location. Thus the range of test values reported.

# SELECTED SAND AND GRAVEL RESOURCE AREAS

Map 1 shows the geographic distribution of sand and gravel in the Regional Municipality of Halton. The total area occupied by these deposits is approximately 17 107 ha, representing 17.7% of the total land area of the region (*see* Table 1). These deposits contain sand and gravel resources of approximately 1085 million tonnes. **The above figures represent a comprehensive inventory of all granular materials in the map area, although some of the material included in the estimate has no potential for use in aggregate production.**

Three areas have been chosen as Selected Sand and Gravel Resource Areas of primary significance and are indicated on Map 1 by dark red shading. Two of these are located wholly within the towns of Milton and Halton Hills, while one area straddles the boundary between the Town of Milton and the City of Burlington. These areas consist of ice-contact and outwash deposits. No selected areas were identified in the Town of Oakville. The Selected Sand and Gravel Resource Areas of primary significance occupy a possible resource area of 644 ha with an estimated resource of 68.4 million tonnes (*see* Table 3). Other deposits have been selected as Sand and Gravel Resource Areas of secondary significance. These are shown on Map 1 as orange-coloured areas.

Areas selected at the secondary level are not the best quality aggregate resources, but should nevertheless be considered an integral part of the region’s aggregate supply. The extractive development and/or protection of any part of these resource areas should be planned in conjunction with the geological evidence, and physical and environmental concerns. It should be noted that parts of some of the Selected Sand and Gravel Resource Areas coincide with the Niagara Escarpment Plan area, therefore the availability of the resource may be significantly less than indicated above. Some of these secondary deposits may be ideal for a wayside pit that is developed for a specific project over a set amount of time.

## Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 lies along the northern boundary of the Regional Municipality of Halton and extends northward into Eramosa Township, Wellington County. This deposit consists largely of undifferentiated ice-contact material and a small esker deposit that may overlie the undifferentiated ice-contact sediments (Karrow 1968). The deposits are an extension of the Paris moraine.

No licenced pits have been developed in the Regional Municipality of Halton portion of this deposit. In Eramosa Township, one unlicenced pit and one licenced source expose 5 to 8 m of texturally variable aggregate. Pit data indicate that good quality crushable gravel is available in portions of the deposit. In other areas, the deposit is primarily sand with a high silt content, making the material unsuitable for most aggregate products. Testing of a site in the Eramosa Township portion of this deposit exposed up to 8 m of sand and gravel, with the gravel content ranging from 20 to 50% (Planning and Engineering Initiatives Limited and the Ontario Geological Survey 1999, p.51). Water well records indicate variable thickness of gravel, from 5 to 16 m above bedrock. Pit No. 8 is a small pit located in the Halton portion of this selected resource area. The pit exposes good quality sand and gravel material.

In parts of this deposit, the sand and gravel deposits are shallow and overlie bedrock of the Amabel Formation. The Amabel Formation is a high-quality bedrock resource, which is suitable for the production of many aggregate products. As a result, extraction of the sand and gravel resource in those areas may be followed by the subsequent extraction of bedrock material. Drift over bedrock is thinnest (between 1 and 8 m) in the southwestern part of the deposit, but thickens gradually to the northeast. Since detailed investigations are not available for the Town of Milton portion of this deposit, it is recommended that further testing be performed before any development occurs.

Selected Sand and Gravel Resource Area 1 has a total area of 220 ha. After considering cultural, physical and environmental constraints, the potential area available for possible resource protection and development is about 177 ha. Assuming an average thickness of 6 m, the area is estimated to contain a possible resource of 18.8 million tonnes (*see* Table 3).

## Selected Sand and Gravel Resource Area 2

Selected Sand and Gravel Resource Area 2 is located along the municipal boundary between the Town of Milton and the City of Burlington and consists of a gravel outwash deposit (Karrow 1987a). Three licenced pits (Pit Nos. 4, 5 and 6) occupy a large portion of the northern part of the outwash deposit. Face heights are greatest in the northern pit, ranging from 12 to 15 m, while pit faces in the southern-most pit range from between 2 and 11 m. All 3 licenced pits display calcium carbonate particle cementation. Some of these zones have proven to be resistant to mechanical extraction and blasting.

In addition, a layer of glacial till has been reported by previous authors in Pit Nos. 4, 5 and 6 (Ontario Geological Survey 1982a). This till layer was traced in road cuts and water well records to the north, possibly as far north as Campbellville. Since this till is a fine-grained till, some parts of the deposit may contain excessive fines. Many gravel-sized particles, particularly in Pit Nos. 4 and 5, were noted to be coated with a layer of loosely cemented, fine red clay material.

Previous MTO test results and historical records indicate that the material in these deposits has been used to produce Granular A and B, and some types of asphalt and concrete aggregate products. Washing, screening and blending with crushed bedrock-derived aggregate may be required to meet higher-quality aggregate specifications.

Selected Sand and Gravel Resource Area 2 consist of subareas 2a and 2b, which reflect the municipal boundary. The total resource area is 234 ha. Previous extractive activity (Pit Nos. 4, 5, 6, 15 and 16) cultural, physical and environmental constraints reduce the potential resource area to 162 ha. With an average deposit thickness of 6 m in subareas 2a and 2b, the estimated possible aggregate resource is approximately 17.2 million tonnes (*see* Table 3). Selected Sand and Gravel Resource Area 2 lies within the Niagara Escarpment Plan area, so development of the resource will be limited. This area is well served by existing roads and is capable of supplying local granular needs.

## Selected Sand and Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 consists of an outwash and part of an ice-contact deposit. This area is located below the brow of the Niagara Escarpment at Limehouse. The deposit is hummocky with irregular topography and has high relief.

Data obtained from the MTO indicates that the material in this selected area consists of well-graded sand and crushable gravel (Ontario Geological Survey 1983). Sample HA-SS-06, taken a few hundred metres south of the deposit, contained 22% gravel (Golder Associates Limited 1996, p.44 and 45). Testing of the western part of the deposit is recommended to determine the quality of material in this part of the deposit.

A large part of Selected Sand and Gravel Resource Area 3 is presently under licence (Pit Nos. 18, 19 and 20). Pit faces expose 3 to 9 m of sand and gravel suitable for the production of crushed aggregate, although sand control is required. Unlicenced Pit Nos. 28 and 29 exhibit face heights of between 2 and 6 m and between 30 to 60% gravel. While none of this material appears suitable for use as concrete or hot mix aggregate, it is suitable for other granular uses and should be considered for possible resource protection.

Selected Sand and Gravel Resource Area 3 has a total unlicenced area of 338 ha. Residential development and other cultural constraints reduce the potentially available area to 305 ha. Assuming an average deposit thickness of 6 m, possible sand and gravel resources are estimated to be 32.4 million tonnes (*see* Table 3). Selected Sand and Gravel Resource Area 3 lies within the Niagara Escarpment Plan area, so development of this resource will be limited. The selected resource area is accessible by a variety of regional roads.

## Resource Areas of Secondary Significance

In the northern part of the Town of Milton, several gravel outwash and ice-contact deposits have been selected at the secondary resource level. The bulk of these deposits lie within Wellington County where aggregate extraction within these deposits has been more active. Unlicenced Pit No. 7, located in a tertiary deposit to the east of these deposits, has been used to provide Granular A and hot mix paving aggregate in the past. The deposit where this pit is located is essentially depleted but it illustrates the quality of the material that is available in some of these deposits.

A series of outwash and ice-contact deposits in the Campbellville area have been selected at the secondary resource level. The outwash deposits form part of the extensive glacial meltwater channel. The selected resource area lies on the upper surface of the escarpment and drapes over the escarpment face. Three licenced sand and gravel pits (Pit Nos. 1, 2 and 3), as well as Pit Nos. 10, 12, 13 and 14 have been developed in this resource area. Pit faces range from 5 to 8 m and the gravel content ranges from 50 to 60%. The presence of excessive fines is a potential problem in this area, nevertheless, borehole information suggests that there may be a considerable depth of coarse material in the southern part of the deposit. Previous test results indicate that the material within these deposits can produce Granular A and B, and some types of asphalt and concrete aggregate products (Ontario Geological Survey 1982a). Washing, screening and blending with crushed bedrock-derived aggregate may be required to meet higher-quality aggregate specifications. The area lies within the Niagara Escarpment Plan area, so development of the resource will be limited. This area is readily accessible by both road and rail and is well-suited to meet local granular requirements.

An outwash deposit, in a glacial meltwater channel formed at the edge of the Niagara Escarpment, near the town of Killbride has been selected as a secondary resource area. While the portion of the deposit at the southern tip of this resource area may seem extremely small, it extends into the adjacent Township of Flamborough, where mapping by Karrow (1987a) shows that it is part of a large glacial outwash deposit. Pit No. 41 used to be a licenced pit. The pit face ranged from 6 to 8 m. Sample HA-SS-07 was taken from the south face of the former licenced pit. Gradation analysis indicates approximately 35% gravel and 7% fines (Golder Associates Limited 1996, p. 46 and 47), which is consistent with other published data (Ontario Geological Survey 1983). This pit was a source of aggregate for hot mix asphalt paving sand, some crushed granular aggregate and Select Subgrade Material (SSM). The area lies within the Niagara Escarpment Plan area, so development of the resource will be limited.

A series of outwash deposits situated just below the Niagara Escarpment in the northeastern part of the study area has been selected as a resource of secondary significance. These deposits have been a traditional aggregate source and a great deal of material has been removed. Five pits have been opened in the area, 2 of which are presently licenced for extraction (Pit Nos. 25 and 26). Pit faces expose 5 to 8 m of sandy gravel, best suited for Select Subgrade Material (SSM) and Granular B. Unlicenced Pit No. 38 has a face height of between 5 and 8 m and is predominantly sandy. This material is suitable for local construction needs and is well situated with respect to local markets and transport routes. The deposit becomes quite narrow at the municipal boundary between the Regional Municipality of Halton and the Regional Municipality of Peel, resulting in the deposit being selected as tertiary in the Regional Municipality of Peel. There is a licenced pit in this deposit just east of Halton. The presence of cemented blocks of sand and gravel, and elevated levels of shale and clay particles in the coarse aggregate, suggests that coarse aggregate produced at this site would not meet high-quality use specifications. The fine aggregate is clean, and may be suitable for use as Granular B and Select Subgrade Material (SSM). Previous test results indicate 40% gravel. Pit No. 37 is located in the community of Glen Williams and therefore any further development is greatly restricted.

A series of ice-contact and outwash deposits located west of Georgetown have been selected at the secondary significance level. Three unlicenced pits (Pit Nos. 32, 33 and 34) contain at least 35% gravel. Pit faces range from 2 to 8 m. Sample HA-SS-05 was taken immediately next to the outwash deposit in an area that has been mapped as an alluvial sand and gravel deposit. Textural analysis of this sample indicated that it contained only 15% gravel (Golder Associates Limited 1996, p.44 and 45).

A glaciolacustrine beach deposit just south of Selected Sand and Gravel Resource Area 2 in the City of Burlington has been selected at the secondary level. Previous MTO test results and historical records indicate that the material in these deposits has been used to produce Granular A and B, and some types of asphalt and concrete aggregate products. Washing, screening and blending with crushed bedrock-derived aggregate may be required to meet higher-quality aggregate specifications.

No secondary resource areas were identified in the Town of Oakville, where very few suitable deposit types occur. A potentially suitable deposit, consisting of an elongated glaciolacustrine beach, located near the City of Hamilton has essentially been sterilized by other land uses. At least some of this deposit was exploited for aggregate production as records are available that document the presence of at least one unlicenced pit (Pit No. 43) within the deposit.

## Resource Areas of Tertiary Significance

A series of ice-contact and outwash deposits, surrounding and to the east of Acton, have been selected at the tertiary level. Water well information indicates a deposit thickness that varies between 2 and 14 m. The resource area has a large potential, although residential development near Acton has sterilized much of the larger, central ice-contact deposit. Although detailed information concerning texture and thickness of the deposit is limited, large amounts of aggregate suitable for most local needs may be available. Material from unlicenced Pit No. 27

has been removed in the past. This area may provide resources for some short-term wayside type operation due to its proximity to Highway 7.

A series of glacial outwash and ice-contact stratified deposits occupy a meltwater channel developed along the Niagara Escarpment east of Acton. The deposit consists of an area of level topography at the brow of the escarpment, connected to a channel crossing the partially buried face of the escarpment. Licenced Pit No. 21 was developed in one of these deposits. This pit has a face height of about 5 m and exposes moderately stratified sand and gravel suitable for Granular A and B. Selection and sand control are often required because of the predominantly sandy texture of the material. The gravel content of the deposit is variable, although at Pit No. 21, gravel is reported as being between 55 to 65%. Unlicenced Pit No. 30 has a pit face of 2 to 3 m. The pit exposes good quality sand and gravel material.

Abandoned Pit No. 35 is located in an outwash deposit in the northeast corner of the Town of Halton Hills. The pit is badly overgrown but previous information on this pit, and road cut exposures near this pit, indicate that the material from this deposit is suitable for crushed aggregate, although deleterious lithologies may be of concern.

## BEDROCK GEOLOGY AND RESOURCE POTENTIAL

The Regional Municipality of Halton is underlain by Upper Ordovician and Lower to Middle Silurian-aged rocks. Shaley limestones, siltstones and shales of the Georgian Bay and Queenston formations are located to the southeast of the Niagara Escarpment. The escarpment face exposes a complex succession of shales, sandstones, limestones and dolostones of the Clinton and Cataract groups. Forming the brow or caprock of the escarpment is the Silurian-aged Amabel Formation dolostone. The location and distribution of the formations and their stratigraphic relationships are shown on Map 2, and illustrated in Figures D1 and D2 in Appendix D.

The thinly bedded Ordovician siltstones and shaley limestones of the Georgian Bay Formation comprise the oldest bedrock unit in the region. This formation occurs below the Niagara Escarpment, occupying a small portion in the southeastern corner of the study area. It consists of blue-grey and green-grey shales with sandstone interbeds, green-grey siltstone and grey shaley limestone. The Georgian Bay Formation is found predominantly under drift cover of between 1 and 8 m thick. Certain strata have been used for brick manufacture in the Toronto area and other strata have been investigated as a source of heat-expanded lightweight aggregate (Wilson 1980). The formation has little value as load-bearing road-building aggregate. As a result, the Georgian Bay Formation has not been selected for aggregate resource protection.

The Georgian Bay Formation is overlain by the red and green shales of the Queenston Formation. The Queenston Formation underlies a large portion of the Regional Municipality of Halton. This includes parts of the towns of Halton Hills, Milton, Oakville and the City of Burlington. There are many areas of drift cover between 1 and 8 m in the Burlington and Oakville areas and at the edge of the Niagara Escarpment. Where no cover exists, the rapidly weathering shales can lead to striking topography and badland development on a small scale (Karrow 1991). The Queenston Formation consists of red shales with siltstone interbeds; thin limestone beds occur near the base of the formation. While bands and splotches of green reduction zones are numerous, the dominant colour of the shale is red. Glacially eroded materials in the area are tinted various shades of red, from entrained Queenston shale (Karrow 1991).

The Queenston Formation ranges in thickness from 50 m at the north end of Bruce County to over 300 m beneath Lake Erie. The Queenston shales are well suited for the production of structural clay products such as brick and tile, and are a resource of provincial significance for these products (Guillet and Joyce 1987). Shale has been extracted from quarries at the base of the Niagara Escarpment for this purpose since the turn of the century (Ontario Geological Survey 1982b). These shales have low load-bearing strength and are unsuitable for use as construction aggregate.

The Queenston Formation is unconformably overlain by the sandstones of the Whirlpool Formation or the dolostones of the Manitoulin Formation. The Whirlpool and Manitoulin formations as well as the Cabot Head Formation, Reynales Formation and other minor formations form the Clinton and Cataract groups, which form the face of the Niagara Escarpment. They have generally restricted lateral extent in the study area and are generally covered by more than 8 m of drift, except for areas of outcrop and thin drift cover at the edge of the escarpment.

The Whirlpool Formation is the lower unit of the Cataract Group. The formation has a thickness of 3 to 5 m (Hewitt 1969) and consists of thin- to massive-bedded, medium- to fine-grained calcareous quartz sandstone. The formation forms a low terrace at the base of the escarpment. South of Limehouse the terrace is over 1.6 km wide (Telford, Liberty and Bond 1976). The sandstone is suitable for building stone and flagstone, and has been extracted at several quarries in the area. The stone is commercially known as the “Credit Valley Sandstone” and has been used in the construction of such buildings as the main block of the Ontario Parliament Buildings and the Royal Ontario Museum (Hewitt 1969). The formation is not generally suitable for the production of crushed aggregate and has no history of such use. Other formations that form the Clinton and Cataract groups have little potential for use as crushed aggregate.

The Manitoulin Formation is a thin-bedded, blue-grey to buff-brown dolomitic limestone and dolostone. The Manitoulin Formation is reasonably resistant to erosion and as a result often forms minor scarps along the face of the Niagara Escarpment.

The brow and upper surface of the Niagara Escarpment is formed by the tough, erosion-resistant Amabel Formation, which also forms the bedrock surface throughout the northwestern part of the study area. The Amabel Formation consists mainly of medium crystalline, fossiliferous, medium- to massive-bedded dolostone that is well suited for the production of road-building and construction aggregate. It has also been used in high performance concrete. The Amabel Formation is considered to be a resource of provincial significance for these products (Telford, Liberty and Bond 1976).

The Eramosa Member of the Amabel Formation is located in the northwest corner of the study area. There has been an on-going debate as to whether the Eramosa Member represents the upper member of the Amabel Formation (Bolton 1957) or the lower member of the Guelph Formation (Sanford 1969). There has also been a suggestion that the Eramosa Member should be the Eramosa Formation (Brett et al. 1995). Nevertheless, the Eramosa is a thin- to thick- bedded, tan to black, fine- to medium-crystalline, variably fossiliferous, bituminous dolostone. The Eramosa has been quarried for use as dimension stone elsewhere in the province, particularly in the Owen Sound area.

# BEDROCK EXTRACTIVE ACTIVITY

The Regional Municipality of Halton has significant bedrock resources located along the Niagara Escarpment in the towns of Milton and Halton Hills, and the City of Burlington. The quarries of the region produce high-quality crushed bedrock aggregate suitable for all construction uses, including high-strength concrete and asphalt, but excluding skid-resistant surface paving aggregate.

The extraction of bedrock for crushed aggregate is concentrated in the Amabel Formation on the edge of the Niagara Escarpment. Of the 11 quarries licenced for commercial extraction in the Regional Municipality of Halton, 5 are licenced for the extraction of crushed dolomitic limestone and dolostone and have been developed in the Amabel Formation. The quarries have a combined area of 1027.85 ha and tend to be large, with only one of the 5 quarries less than 20 ha in size (Table 5).

Three quarries are licenced for extraction in the Clinton and Cataract groups along the face of the Niagara Escarpment. These quarries are worked to extract the Whirlpool sandstone, an important source for building stone and flagstone. These licenced sources have a combined area of approximately 59 ha. Three quarries are licenced to extract shale for use as brick-making material and structural tile.

# SELECTED BEDROCK RESOURCES

Portions of the Amabel Formation have been selected for possible bedrock resource protection because of its suitability in the road-building and construction industry. The Clinton and Cataract groups have not been selected for possible bedrock resource protection, although the use and importance of these groups in the building and dimension stone industry must not be minimized. While the Clinton and Cataract groups and the Queenston Formation may not be used in the mineral aggregate industry, they are important bedrock resources, and their significance should not be underestimated or minimized.

The availability of possible resources in the Selected Bedrock Resource Areas will be constrained by planning designations outlined in the Niagara Escarpment Plan.

## Selected Bedrock Resource Area 1

Selected Bedrock Resource Area 1 (subareas 1a and 1b) is a large area in the western part of the Regional Municipality of Halton where the Amabel Formation is overlain by less than 8 m of overburden. The eastern limit of this selected area is defined by the brow of the Niagara Escarpment, which trends northeast through the central part of the study area. Much of Selected Bedrock Resource Area 1 was identified by Vos (1969) as an area for future quarry development on the basis of thin drift thickness, good quality material, proximity to markets and accessible transportation routes. Three large quarries are presently licenced for extraction in bedrock resource area 1.

Quarries Nos. Q1, Q2 and Q8 (Quarry No. 2 consists of multiple parcels of land) have been developed in the Amabel Formation in Selected Bedrock Resource Area 1. Quarry Q8 was operated prior to 1930 to produce dolomitic lime (Hewitt and Vos 1972), but now produces crushed aggregate. The rock exposed in the quarry is light grey, fine- to medium-crystalline, medium- to thick-bedded dolostone of uniformly high quality (Hewitt and Vos 1972). Quarries Q1 and Q2 are located just west of the brow on the escarpment, just north of Highway 401, and expose similar rock.

Selected Bedrock Resource Area 1 has a total unlicenced area of 10 956 ha, of which 8636 ha are potentially available for extraction. Assuming an average workable thickness of 15 m throughout the area, possible resources of crushed stone are estimated to be 3432 million tonnes (Table 6). Quarries could be established at numerous locations in the generally sparsely populated area, particularly south of Acton. The glacial sediments that overlie the bedrock consist predominantly of Wentworth Till, which should not pose serious stripping problems. The irregularity of the bedrock surface in the reefal portions of the formation may hinder stripping (Vos 1969). Road access throughout bedrock resource area 1 is provided by paved regional roads and by Regional Road 25, which has a direct connection to Highway 401. Two of the quarries (Nos. 1 and 2) are located immediately to the north of Highway 401 and rail access could be provided by a line of the Canadian National Railway. The resource area is thus well situated with respect to the regional transport network in southern Ontario and is in a position to supply high-quality aggregate throughout the areas of highest demand. The Niagara Escarpment Plan will severely limit the development opportunities within bedrock resource area 1.

## Selected Bedrock Resource Area 2

Selected Bedrock Resource Area 2 is located in the northwest corner of the Regional Municipality of Halton and extends northward into Wellington County (Planning and Engineering Initiatives Limited and the Ontario Geological Survey 1999). In this area, the Amabel Formation is covered by less than 8 m of overburden.

As noted in Selected Sand and Gravel Resource Area 1, there are sand and gravel resources that overlie the Amabel Formation in this area. As a result, it may be possible to extract the unconsolidated sediments, followed by the extraction of the Amabel Formation bedrock.

Selected Bedrock Resource Area 2 has a total unlicenced area of 1511 ha, of which 1291 ha are potentially available for extraction. Assuming an average workable thickness of 15 m throughout the area, possible resources of crushed stone are estimated to be 513 million tonnes (Table 6).

## Selected Bedrock Resource Area 3

Selected Bedrock Resource Area 3 extends northeasterly from Acton into Wellington County. The area consists of Amabel Formation dolostone overlain by less than 8 m of overburden. There are no quarries currently located in this bedrock resource area. The proximity of the community of Acton poses a significant cultural constraint.

The total area of Selected Bedrock Resource Area 3 is 938 ha, which is reduced to 804 ha after consideration of cultural and other setbacks. Using 15 m as an estimate of the workable thickness the resource is estimated to be approximately 319 million tonnes (Table 6).

Transportation links to this area are not as favourable as Selected Bedrock Resource Areas 1 and 2, however, the area is still close to the Highway 7 corridor. The Niagara Escarpment Plan will limit development and extraction opportunities in this bedrock area.

## Selected Bedrock Resource Area 4

Three unlicenced quarries (Q13, Q14 and Q17) are located in Selected Bedrock Resource Area 4 (subareas 4a and 4b), where Quaternary mapping confirms that much of the overburden is thin (Karrow 1991). Little information is available concerning the products produced by these quarries; the shallowest operation operated with face heights of only 2 to 3 m, while the deepest quarry had face heights of 5 to 6 m.

Since the Amabel Formation produces excellent crushed stone, and this area is located within a provincial region of high demand, this area should be considered for resource protection.

Selected Bedrock Resource Area 4 occupies 1526 ha, but cultural, physical and environmental constraints reduce this area to 1306 ha. Assuming 15 m as an estimate of the workable thickness, the possible bedrock resource for this area is estimated at 519 million tonnes. Selected Bedrock Resource Area 4 is located within the Niagara Escarpment Plan, which will limit development opportunities.

## Selected Bedrock Resource Area 5

Selected Bedrock Resource Area 5 consists of an outlier (the Milton Outlier) of the Amabel Formation whose southern-most point is the well-known Rattlesnake Point. Here the Amabel dolostone is overlain by less than 8 m of overburden. Most of the land surface is thinly drift-covered. Unlicenced quarry Q4 used to be a licenced operation (the old Milton Limestone Quarry), which operated for a number of years just west of the Town of Milton.

The unlicenced area consists of 1041 ha, but the constraints posed by the presence of existing rural homes and roads reduce the possible available area to 782 ha. Using 15 m as an estimated resource thickness, the available resources represented by this area is approximately 311 million tonnes (Table 6). Selected Bedrock Resource Area 5 is located within the Niagara Escarpment Plan area, therefore, opportunities to develop the bedrock resource will be limited.

## Selected Bedrock Resource Area 6

Selected Bedrock Resource Area 6 is located in the western part of the City of Burlington. The area contains 2 licenced quarries (Quarry Nos. Q22 and Q23), as well as 2 unlicenced quarries, Nos. Q26 and Q27. Face heights in the licenced quarries are 11 to 14 m, and are as high as 21 m in the unlicenced quarries. This Selected Bedrock Resource Area is well served by both road and rail and constitutes an important possible aggregate resource.

Selected Bedrock Resource Area 6 has a total area of 2472 ha, which is reduced to 2133 ha due to physical and cultural constraints. The potential bedrock resource in this area is 847 million tonnes based on a workable thickness of 15 m (Table 6). The bedrock resource area is located within the Niagara Escarpment Plan, therefore opportunities for bedrock resource development will be limited.

## QUEENSTON FORMATION SHALE

In southern Ontario, the Queenston Formation maintains a fairly uniform lithological and sedimentological character, both vertically and laterally (Rutka and Vos 1993). Recent work completed by Armstrong (2001a) and Armstrong and Sergerie (2002a) has suggested that the Queenston Formation actually be subdivided into 3 parts: an upper part consisting mainly of massive red shale; a middle part consisting of varying proportions of red and green shale, light green and light red siltstone, sandstone, limestone and intraclastic conglomerate; and a lower part consisting of the same components as the middle unit but tending to be thinner bedded and locally interlaminated (Armstrong 2001a). Contacts between the 3 parts are gradational and are rarely exposed in a single outcrop. This 3-fold subdivision appears to be widespread and likely represents fluctuations in relative sea level (Brogly, Martini and Middleton 1998).

The Queenston Formation has been tested and reported on extensively throughout the study area—both geochemical and ceramic testing—by previous workers (Brady and Dean 1966; Guillet 1967, 1977, 1983; Guillet and Joyce 1987; Kwong, Martini and Narain 1985; Martini and Kwong 1986; Rutka and Vos 1993; Armstrong 2001a, 2001b; Armstrong and Frederic 2001; and Armstrong and Sergerie 2002a, 2002b, 2002c). The results of these studies indicate that the Queenston Formation can be used in the manufacture of brick and tile throughout the study area, as well as areas further to the east (Regional Municipality of Peel), north and south.

Mineralogical examination of the Queenston Formation indicates that 60% of the formation is clay minerals—predominantly illite. Quartz constitutes approximately 25% of the formation, with calcite averaging about 12% (Guillet 1967). Minor minerals include dolomite and feldspars.

The presence of gypsum ($CaSO_4 \cdot 2H_2O$) within the Queenston Formation can cause scum or efflorescence on the brick surface, therefore gypsum is an undesirable constituent. Sulphates of magnesium, iron, alkalies, chlorides, and soluble vanadium and molybdenum compounds can also cause scum and efflorescence (Guillet 1967; Rutka and Vos 1993). Fortunately, previous testing has indicated a reasonably low percentage of gypsum. The gypsum tends to occur as discreet units; nodules generally less than 2.5 cm in diameter; or as botryoidal masses. Selective quarrying or the addition of barium carbonate can render gypsum insoluble and therefore of little consequence.

Previous work on the Queenston Formation has also concluded that the color of the brick depends upon the lime (CaO) content. CaO generally occurs in the mineral calcite and therefore the brick color depends upon the percentage of calcite in the shale. It has been determined that a calcite content of less than 10% will produce red coloured bricks, while a calcite content of 10 to 15% will produce buff-coloured bricks. Generally, the percentage of calcite throughout the study area is less than 15%. The percentage of calcite increases with the presence of the grey-green shale layers, therefore the middle part as defined by Armstrong (2001a) will have a higher lime content. Weathering of the shale in a stockpile prior to use will reduce the percentage of calcite (CaO content).

In addition, the industry is very adept at dealing with variations in the shale geochemistry. Considering all of the above, the quality of the Queenston Formation in the Regional Municipality of Halton is acceptable for use by the brick industry. No areas underlain by the Queenston Formation have been selected for resource protection; however, overburden thickness over the Queenston Formation has been identified on Map 2. This map can be used for making land use planning decisions.

## SUMMARY

Three areas of sand and gravel resources of primary significance have been identified in the Regional Municipality of Halton. These areas have a total unlicenced area of 792 ha, with 644 ha remaining after accounting for cultural constraints and previously extracted areas. Possible remaining aggregate resources are estimated at 68.4 million tonnes (*see* Table 3). More detailed and extensive site investigations and aggregate testing should precede any future extractive development activities. In some areas, deleterious lithologies, the percentage of fines and the presence of oversized material can be of concern. Two of the recommended areas are within the Niagara Escarpment Plan area, and development and extraction of the resource will be limited.

Bedrock of the Amabel Formation is identified as an important high-quality crushed stone resource. Much of the western half of the Regional Municipality of Halton is recommended for possible resource protection. This area consists of 14 952 ha once cultural and physical constraints have been considered. The estimated volume of bedrock resource represented by this area is about 5941 million tonnes (*see* Table 6).

The Clinton and Cataract groups, and the Queenston Formation have not been selected for bedrock resource protection although their importance to the building and dimension stone industry, and the brick and tile manufacturing industry must not be underestimated. The areas where these groups are exposed or covered by less than 8 m of overburden should be considered carefully for protection during the planning process. Further site investigations and testing should proceed before bedrock resource areas are developed.

Care should be taken to ensure the continued availability of as much as possible of these selected resource areas. The resource calculations above do not take into account the effect of the Niagara Escarpment Plan, as this was not within the scope of this study.

Enquiries regarding the Aggregate Resources Inventory of the Regional Municipality of Halton may be directed to the Sedimentary Geoscience Section, Ontario Geological Survey, Ministry of Northern Development and Mines, 933 Ramsey Lake Road, Sudbury, Ontario, P3E 6B5.

| TABLE 1 - TOTAL SAND AND GRAVEL RESOURCES<br>Regional Municipality of Halton | | | |
|---|---|---|---|
| **1** | **2** | **3** | **4** |
| **Class Number** | **Deposit Type** | **Areal Extent (Hectares)** | **Original Tonnage (Million Tonnes)** |
| **Towns of Milton and Halton Hills** | | | |
| 1 | G-IC | 3087.0 | 327.8 |
| | G-OW | 1350.9 | 143.5 |
| | S-IC | 9.5 | 1.0 |
| | S-OW | 415.8 | 44.2 |
| 2 | G-IC | 748.7 | 59.6 |
| | G-OW | 749.4 | 59.7 |
| | S-AL | 20.4 | 1.6 |
| | S-IC | 128.4 | 10.2 |
| | S-OW | 52.7 | 4.2 |
| 3 | G-IC | 836.9 | 29.6 |
| | G-OW | 171.6 | 6.1 |
| | S-AL | 2558.5 | 90.6 |
| | S-IC | 106.1 | 3.8 |
| | S-LP | 571.9 | 20.2 |
| | S-OW | 97.5 | 3.5 |
| 4 | G-IC | 62.6 | 1.1 |
| | G-OW | 129.8 | 2.3 |
| | S-OW | 18.2 | 0.3 |
| Subtotal | | 11115.9 | 809.3 |
| **City of Burlington and the Town of Oakville** | | | |
| 1 | G-IC | 8.6 | 0.9 |
| | G-OW | 515.9 | 54.8 |
| | S-LP | 162.1 | 17.2 |
| 2 | G-LB | 186.1 | 14.8 |
| | S-LP | 76.3 | 6.1 |
| 3 | S-AL | 902.1 | 31.9 |
| | S-LP | 4116.2 | 145.7 |
| 4 | G-LB | 24.2 | 4.3 |
| Subtotal | | 5991.5 | 275.7 |
| **REGIONAL TOTAL** | | **17107.4** | **1085.0** |

**TABLE 2 - SAND AND GRAVEL PITS**
**Regional Municipality of Halton**

| Pit No. | Owner/Operator | Licenced Area (ha) | Face Height (m) | % Gravel | Remarks |
|---|---|---|---|---|---|
| **Town of Milton** | | | | | |
| **Licenced** | | | | | |
| 1 | Woodlawn Guelph Limited | 83.00 | 2-3 | 40 | - pit is generally overgrown and partially rehabilitated, little evidence of recent activity |
| 2 | 555816 Ontario Inc. | 22.19 | 5-6 | 50-60 | - rehabilitation activities are underway |
| 3 | 555816 Ontario Inc. | 15.88 | 5-8 | 50-60 | - pit is located immediately north of Highway 401 |
| 4 | Springbank Sand and Gravel Ltd. | 61.80 | 12-15 | 10-40 | - areas of cementation |
| 5 | Springbank Sand and Gravel Ltd. | 42.30 | 6-15 | 10-40 | - areas of cementation |
| 6 | The Warren Paving and Materials Group | 40.74 | 2-11 | 10-65 | - areas of cementation, pit is periodically active |
| **Town of Milton** | | | | | |
| **Unlicenced** | | | | | |
| 7 | - | - | 3-5 | 55-65 | - overgrown, previous test results indicate that material was suitable for HL2, HL4, CA and FA - required selection and blending |
| 8 | - | - | 1-2 | 25-45 | |
| 9 | - | - | 2-3 | - | - overgrown |
| 10 | - | - | 3-5 | 50-60 | - rehabilitated, overgrown |
| 11 | - | - | 2-4 | - | - badly overgrown, some trees of considerable age but still recognizable as a pit |
| 12 | - | - | 1-2 | Variable | - overgrown |
| 13 | - | - | 1-2 | Variable | - overgrown |
| 14 | - | - | 1-2 | Variable | - overgrown |
| 15 | - | - | 2-5 | 10-40 | - overgrown |
| 16 | - | - | 2-5 | 10-40 | - overgrown |
| 17 | - | - | 1-2 | 10-30 | - overgrown |
| **Town of Halton Hills** | | | | | |
| **Licenced** | | | | | |
| 18 | BOT Duff Resources Inc. | 57.60 | - | - | |
| 19 | St. Marys Cement Inc (Canada) | 79.18 | 3-8 | 25-35 | |
| 20 | St. Marys Cement Inc (Canada) | 26.33 | 6-9 | 55-65 | |
| 21 | J.C. Duff Limited | 42.49 | 5 | 50-60 | |
| 22 | Limestone Clay Products Ltd. | 12.80 | 2-4 | - | - shale property |
| 23 | Limestone Clay Products Ltd. | 3.24 | 3-4 | - | - shale property |
| 24 | 555816 Ontario Inc. | 17.42 | - | - | - property has been rehabilitated |
| 25 | David T. Anderson | 6.28 | 4-5 | 35-45 | - partially overgrown |
| 26 | 1294142 Ontario Limited | 6.59 | 8-10 | 30-50 | - predominantly a sand source |
| **Unlicenced** | | | | | |
| 27 | - | - | 1-2 | - | - overgrown |
| 28 | - | - | 5-6 | 60 | - overgrown |
| 29 | - | - | 2-4 | 30 | - overgrown, predominantly sand |
| 30 | - | - | 2-3 | 40-50 | - partially overgrown |
| 31 | - | - | 1-3 | - | - badly overgrown |
| 32 | - | - | 2-3 | 40-50 | - depleted and rehabilitated |
| 33 | - | - | 2-3 | 50 | - partially overgrown, previous test results indicate that material is acceptable for Gran A but not HL |
| 34 | - | - | 6-8 | 50 | - depleted and rehabilitated |
| 35 | - | - | - | Variable | - badly overgrown |
| 36 | - | - | 2-4 | 30-50 | |
| 37 | - | - | 5-11 | 5 | - overgrown |
| 38 | - | - | 5-8 | - | - overgrown |
| 39 | - | - | 2-4 | - | - badly overgrown |

| TABLE 2 - SAND AND GRAVEL PITS<br>Regional Municipality of Halton | | | | | |
|---|---|---|---|---|---|
| **Pit No.** | **Owner/Operator** | **Licenced Area (ha)** | **Face Height (m)** | **% Gravel** | **Remarks** |
| 40 | - | - | 2-4 | Variable | - overgrown |
| **City of Burlington and Town of Oakville Licenced** | | | | | |
| 41 | - | - | 5-6 | - | - this area was formerly a licenced pit that has been rehabilitated and the licence no longer in effect |
| 42 | - | | 4-6 | 0-20 | - formerly a licenced pit, now the pit is overgrown and rehabilitated. The pit was predominantly a source of sand |
| 43 | - | - | - | - | - overgrown, flat area just south of GO Transit system<br>- on other side of Waterdown Road - staging area for King Transport |

**TABLE 3 - SELECTED SAND AND GRAVEL RESOURCE AREAS**

**Regional Municipality of Halton**

| 1<br>Deposit No. | 2<br>Unlicenced Area (Hectares)* | 3<br>Cultural Setbacks (Hectares)** | 4<br>Extracted Area (Hectares)*** | 5<br>Possible Resource Area (Hectares) | 6<br>Estimated Deposit Thickness (Metres) | 7<br>Possible Aggregate Resources**** (Million Tonnes) |
|---|---|---|---|---|---|---|
| **Town of Milton** | | | | | | |
| 1 | 220 | 43 | 0 | 177 | 6 | 18.8 |
| 2a | 211 | 55 | 8 | 148 | 6 | 15.7 |
| Subtotal | 431 | 98 | 8 | 325 | | 34.5 |
| **City of Burlington** | | | | | | |
| 2b | 23 | 9 | 0 | 14 | 6 | 1.5 |
| Subtotal | 23 | 9 | 0 | 14 | 6 | 1.5 |
| **Town of Halton Hills** | | | | | | |
| 3 | 338 | 27 | 5 | 305 | 6 | 32.4 |
| Subtotal | 338 | 27 | 5 | 305 | | 32.4 |
| **TOTAL** | 792 | 134 | 13 | 644 | | 68.4 |

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 BEDROCK RESOURCES<br>Regional Municipality of Halton | | | | |
|---|---|---|---|---|
| **1<br>Drift<br>Thickness** | **2<br>Formation** | **3<br>Estimated<br>Deposit<br>Thickness<br>(Metres)** | **4<br>Areal<br>Extent<br>(Hectares)** | **5<br>Original<br>Tonnage<br>(Millions of Tonnes)** |
| **Towns of Milton and Halton Hills** | | | | |
| 1-8 | Eramosa | **15** | 29.43 | 11.7 |
| 8-15 | | **15** | 265.13 | 105.3 |
| <1 | Amabel | **15** | 1069.51 | 425.0 |
| 1-8 | | **15** | 15899.52 | 6317.7 |
| 8-15 | | **15** | 7250.70 | 2881.1 |
| <1 | Clinton-Cataract | **15** | 12.74 | 5.1 |
| 1-8 | | **15** | 1806.24 | 717.7 |
| 8-15 | | **15** | 1255.14 | 498.7 |
| <1 | Queenston | **15** | 315.06 | 113.8 |
| 1-8 | | **15** | 3436.05 | 1241.1 |
| 8-15 | | **15** | 14246.01 | 5145.7 |
| **Subtotal** | | | **45585.53** | **17462.8** |
| **City of Burlington and the Town of Oakville** | | | | |
| <1 | Amabel | **15** | 170.38 | 67.7 |
| 1-8 | | **15** | 2768.87 | 1100.2 |
| 8-15 | | **15** | 251.52 | 99.9 |
| <1 | Clinton-Cataract | **15** | 3.62 | 1.4 |
| 1-8 | | **15** | 367.81 | 146.1 |
| 8-15 | | **15** | 466.39 | 185.3 |
| <1 | Queenston | **15** | 538.98 | 194.7 |
| 1-8 | | **15** | 18302.02 | 6610.7 |
| 8-15 | | **15** | 5684.37 | 2053.2 |
| <1 | Georgian Bay | **15** | 15.85 | 5.7 |
| 1-8 | | **15** | 2099.41 | 758.3 |
| 8-15 | | **15** | 4.66 | 1.7 |
| **Subtotal** | | | **30673.88** | **11225.0** |
| **TOTAL** | | | **76259.41** | **28687.9** |

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

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

**TABLE 5 - QUARRIES**
**Regional Municipality of Halton**

| Quarry No. | Owner/Operator | Licenced Area (Hectares) | Face Height (Metres) | Remarks |
|---|---|---|---|---|
| **Town of Milton** | | | | |
| **Licenced** | | | | |
| Q1 | Halton Crushed Stone Ltd. | 121.50 | 10-15 | - Amabel Formation |
| Q2 | Dufferin Aggregates Ltd. | 467.67 | 14-17 | - Amabel Formation |
| Q3 | Hanson Brick Ltd. | 14.77 | Variable | - Queenston Formation |
| **Unlicenced** | | | | |
| Q4 | - | - | 20-25 | - old Milton Limestone Quarry |
| Q5 | - | - | 5 | - old Mohawk Quarry |
| Q6 | - | - | 5 | - old Warren Quarry |
| Q7 | - | - | 3 | - old Barnes Quarry |
| **Town of Halton Hills** | | | | |
| **Licenced** | | | | |
| Q8 | St. Lawrence Cement Inc | 222.28 | 15-20 | - Amabel Formation |
| Q9 | Rice & McHarg Quarries Ltd | 12.85 | Variable | - Clinton-Cataract Group (Whirlpool) |
| Q10 | Hilltop Stone and Supply Inc | 9.36 | Variable | - Clinton-Cataract Group (Whirlpool) |
| Q11 | Brockton Farms | 36.80 | - | - Clinton-Cataract Group (Whirlpool) |
| **Unlicenced** | | | | |
| Q12 | - | - | 2-3 | - overgrown |
| Q13 | - | - | 2-6 | - water filled (referred to as the old Armstrong Brothers Quarry) |
| Q14 | - | - | 2-3 | - water filled, surrounded by subdivision (referred to as the old Limehouse Quarry) |
| Q15 | - | - | 2 | - previously licenced |
| Q16 | - | - | 2-3 | - previously licenced, Queenston shale |
| Q17 | - | - | 5-6 | - overgrown (referred to as the old Glen Williams Quarry) |
| Q18 | - | - | 2-3 | - overgrown - Queenston Formation |
| Q19 | - | - | 5-8 | - partially overgrown, slabs being removed (referred to as the old Austin Corner's Quarry) |
| Q20 | - | - | 5-6 | - overgrown, water filled (referred to as the old Hilltop Quarry) |
| Q21 | - | - | 2-3 | - overgrown, Queenston shale (referred to as the old Martin Quarry) |
| **City of Burlington** | | | | |
| **Licenced** | | | | |
| Q22 | Nelson Aggregate Co. | 200.20 | 11-14 | - Amabel Formation |
| Q23 | Nelson Aggregate Co. | 16.20 | 11-14 | - Amabel Formation |
| Q24 | Hanson Brick Ltd. | 17.10 | 5-8 | - Queenston Formation |
| Q25 | Hanson Brick Ltd. | 72.50 | 5-8 | - Queenston Formation |
| **Unlicenced** | | | | |
| Q26 | - | - | 18 | - old Mount Nemo Quarry |
| Q27 | - | - | 12 | - old Nelson Quarry |

**TABLE 6 - SELECTED BEDROCK RESOURCE AREAS**
**Regional Municipality of Halton**

| 1 Area No. | 2 Depth of Overburden (Metres) | 3 Unlicenced 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) |
|---|---|---|---|---|---|---|---|
| **Towns of Milton and Halton Hills** | | | | | | | |
| Amabel Formation | | | | | | | |
| 1a | 0-8 | 10529.5 | 2238.9 | 0.0 | 8288.6 | 15.0 | 3293.5 |
| 1b | 0-8 | 426.2 | 78.9 | 0.0 | 347.3 | 15.0 | 138.0 |
| 2 | 0-8 | 1511.1 | 219.9 | 0.0 | 1291.2 | 15.0 | 513.1 |
| 3 | 0-8 | 938.3 | 134.4 | 0.0 | 803.9 | 15.0 | 319.4 |
| 4a | 0-8 | 1492.7 | 219.4 | 0.0 | 1273.3 | 15.0 | 505.9 |
| 4b | 0-8 | 33.1 | 0.0 | 0.0 | 33.1 | 15.0 | 13.2 |
| 5 | 0-8 | 1040.8 | 164.9 | 93.7 | 782.3 | 15.0 | 310.8 |
| Subtotal | | 15971.7 | 3056.4 | 93.7 | 12819.7 | | 5093.9 |
| **Town of Oakville and the City of Burlington** | | | | | | | |
| Amabel Formation | | | | | | | |
| 6 | 0-8 | 2471.7 | 337.1 | 0.0 | 2132.6 | 15.0 | 847.4 |
| Subtotal | | 2471.7 | 337.1 | 0.0 | 2132.6 | | 847.4 |
| **RM TOTAL** | | 18443.4 | 3393.5 | 93.7 | 14952.3 | | 5941.3 |

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 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 - DRILL HOLE INFORMATION**
**Regional Municipality of Halton**

**Additional Information Point 1**
OGS-00-A1 Drill Hole from OGS Publication OFR 6058
Reference: Armstrong 2001a
Easting: 597916 Northing: 4811095 NAD 83 Zone 17
4.65 m of overburden
Bedrock (Queenston Shale)

**Additional Information Point 2**
OGS-00-A2 Drill Hole from OGS Publication OFR 6058
Reference: Armstrong 2001a
Easting: 600367 Northing: 4814323 NAD 83 Zone 17
4.27 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 3**
OGS-89-08 Drill Hole from OGS Publication OFR 5842
Reference: Rutka and Vos 1993
Easting: 592613 Northing: 4820968 NAD 83 Zone 17
17.70 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 4**
OGS-00-A6 Drill Hole from OGS Publication OFR 6058
Reference: Armstrong 2001a
Easting: 592246 Northing: 4829873 NAD 83 Zone 17
6.02 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 5**
OGS-00-A8 Drill Hole from OGS Publication OFR 6058
Reference: Armstrong 2001a
Easting: 587059 Northing: 4826268 NAD 83 Zone 17
13.94 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 6**
OGS-00-A4 Drill Hole from OGS Publication OFR 6058
Reference: Armstrong 2001a
Easting: 596096 Northing: 4815637 NAD 83 Zone 17
7.46 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 7**
BH-2 from OGS Publication OFR 5819
Reference: Karrow 1991
Easting: 587100 Northing: 4826930 NAD 83 Zone 17
7.60 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 8**
BH-3 from OGS Publication OFR 5819
Reference: Karrow 1991
Easting: 585945 Northing: 4827905 NAD 83 Zone 17
16.50 m of overburden
Bedrock (Queenston Formation)

**TABLE 7 - DRILL HOLE INFORMATION**
**Regional Municipality of Halton**

**Additional Information Point 9**
BH-1 from OGS Publication OFR 5819
Reference: Karrow 1991
Easting: 587840 Northing: 4819520 NAD 83 Zone 17
28.50 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 10**
BH-5 from OGS Publication OFR 5819
Reference: Karrow 1991
Easting: 592700 Northing: 4832820 NAD 83 Zone 17
34.50 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 11**
Drill Hole Number: 08DJR-0001
Easting: 594117 Northing: 4827966 NAD 83 Zone 17
8.23 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 12**
Drill Hole Number: 08DJR-0002
Easting: 593426 Northing: 4828642 NAD 83 Zone 17
4.27 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 13**
Drill Hole Number: 08DJR-0003
Easting: 592883 Northing: 4829195 NAD 83 Zone 17
5.79 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 14**
Drill Hole Number: 08DJR-0004
Easting: 594101 Northing: 4830293 NAD 83 Zone 17
9.45 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 15**
Drill Hole Number: 08DJR-0005
Easting: 593480 Northing: 4826628 NAD 83 Zone 17
4.88 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 16**
Drill Hole Number: 08DJR-0006
Easting: 587441 Northing: 4826748 NAD 83 Zone 17
5.18 m of overburden
Bedrock (Queenston Formation)

**Additional Information Point 17**
Drill Hole Number: 08DJR-0007
Easting: 586579 Northing: 4825748 NAD 83 Zone 17
>15.00 m of overburden
Bedrock (Queenston Formation)

**TABLE 7 - DRILL HOLE INFORMATION**
**Regional Municipality of Halton**

**Additional Information Point 18**
Drill Hole Number: 08DJR-0008
Easting: 592403 Northing: 4830404 NAD 83 Zone 17
17.98 m of overburden
Bedrock (Queenston Formation)

**Additional overburden thickness information was also provided by:**
Holysh 1995, 1997; Funk 1979; Coward and Barouch 1978; Ostrey 1979; the Clay Brick Industry; and land developers (refer to reference list)

Note: Some UTM coordinates were converted from NAD 27, Zone 17

| TABLE 8 - SUMMARY OF GEOPHYSICAL DATA<br>Regional Municipality of Halton |
|---|
| - NONE - |

| TABLE 9 - RESULTS OF AGGREGATE QUALITY TESTS<br>Regional Municipality of Halton |
|---|
| - NONE - |

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# 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 alkalies 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 which 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 570 and 505 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 alkalies 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 which 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 408 and 360 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 whose constituents were transported and deposited by wind activity. Sand dunes are an example of an eolian landform.

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

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

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

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

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

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

*Granular Base and Subbase:* Components of a pavement structure of a road, which are placed on the subgrade and are designed to provide strength, stability and drainage, as well as support for surfacing materials. 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 which are 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 505 and 438 million years ago.

*Paleozoic Era:* One of the major divisions of the geologic time scale thought to have covered the time period between 570 and 230 million years ago, the Paleozoic Era (or Ancient Life Era) is subdivided into six geologic periods, of which only four (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, while 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 438 and 408 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 crossbedded, poorly sorted sand and gravel. The present forms of the deposits include single mounds, linear ridges (crevasse fillings) or complex groups of landforms. The latter are occasionally described as “undifferentiated ice-contact stratified drift” (IC) when detailed subsurface information is unavailable. Since kames commonly contain large amounts of fine-grained material and are characterized by considerable variability, there is generally a low to moderate probability of discovering large amounts of good quality, crushable aggregate. Extractive problems encountered in these deposits are mainly the excessive variability of the aggregate and the rare presence of excess fines (silt- and clay-sized particles).

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

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

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

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

*Subaqueous Fans (SF):* Subaqueous fans are formed within or near the mouths of meltwater conduits when sediment-laden meltwaters are discharged into a standing body of water. The geometry of the resulting deposit is fan- or lobe-shaped. Several of these lobes may be joined together to form a larger, continuous sedimentary body. Internally, subaqueous fans consist of stratified sands and gravels which may exhibit wide variations in grain size distribution. As these features were deposited under glacial lake waters, silt and clay which 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. The sediments which 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 two 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 - 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 outcrops 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 - 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 which 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, Asbn = 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 shaley 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 eight 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 outcrops 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 - 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 - 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 bituminus 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, largely 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.

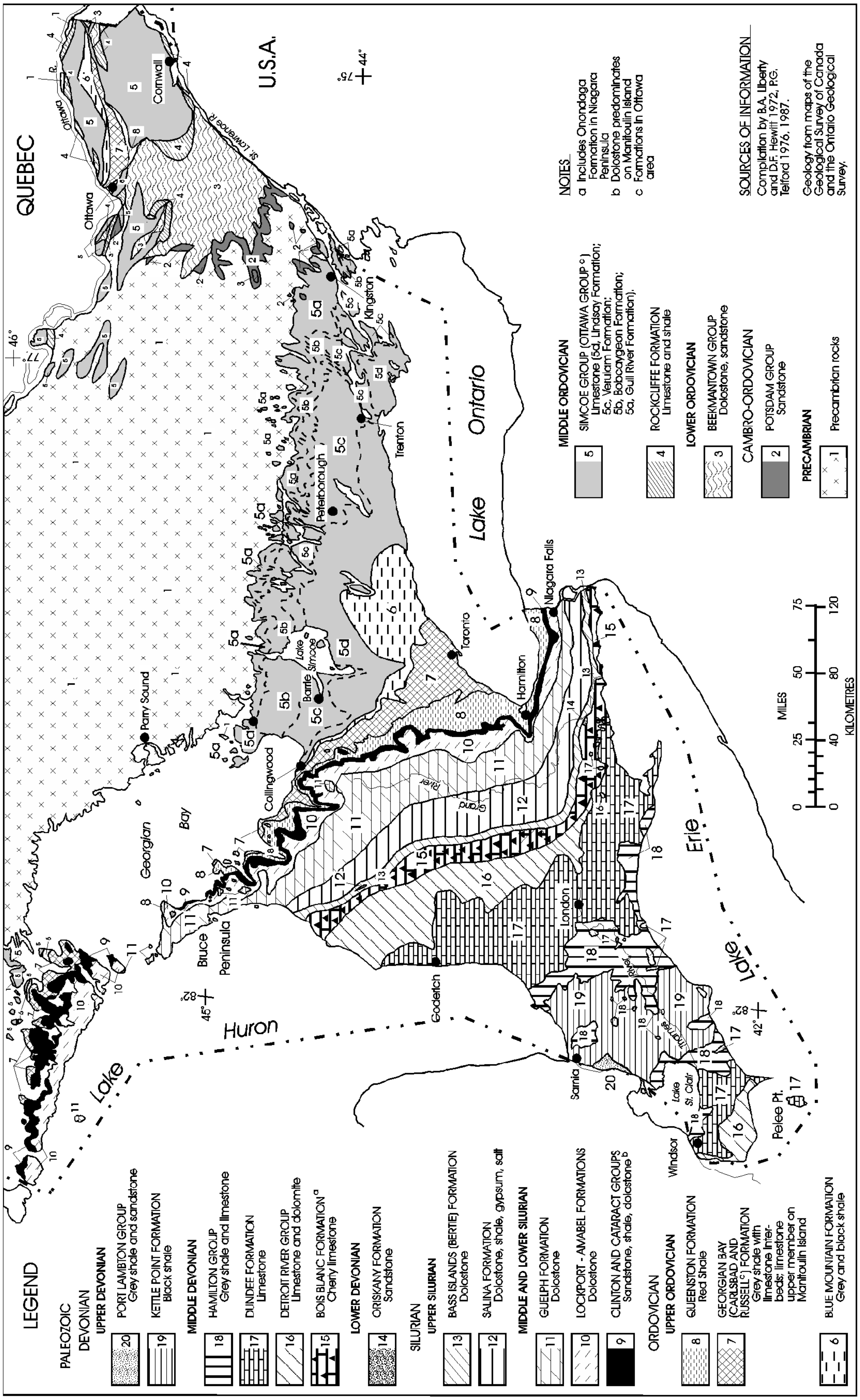


Figure D1. Bedrock geology of southern Ontario.

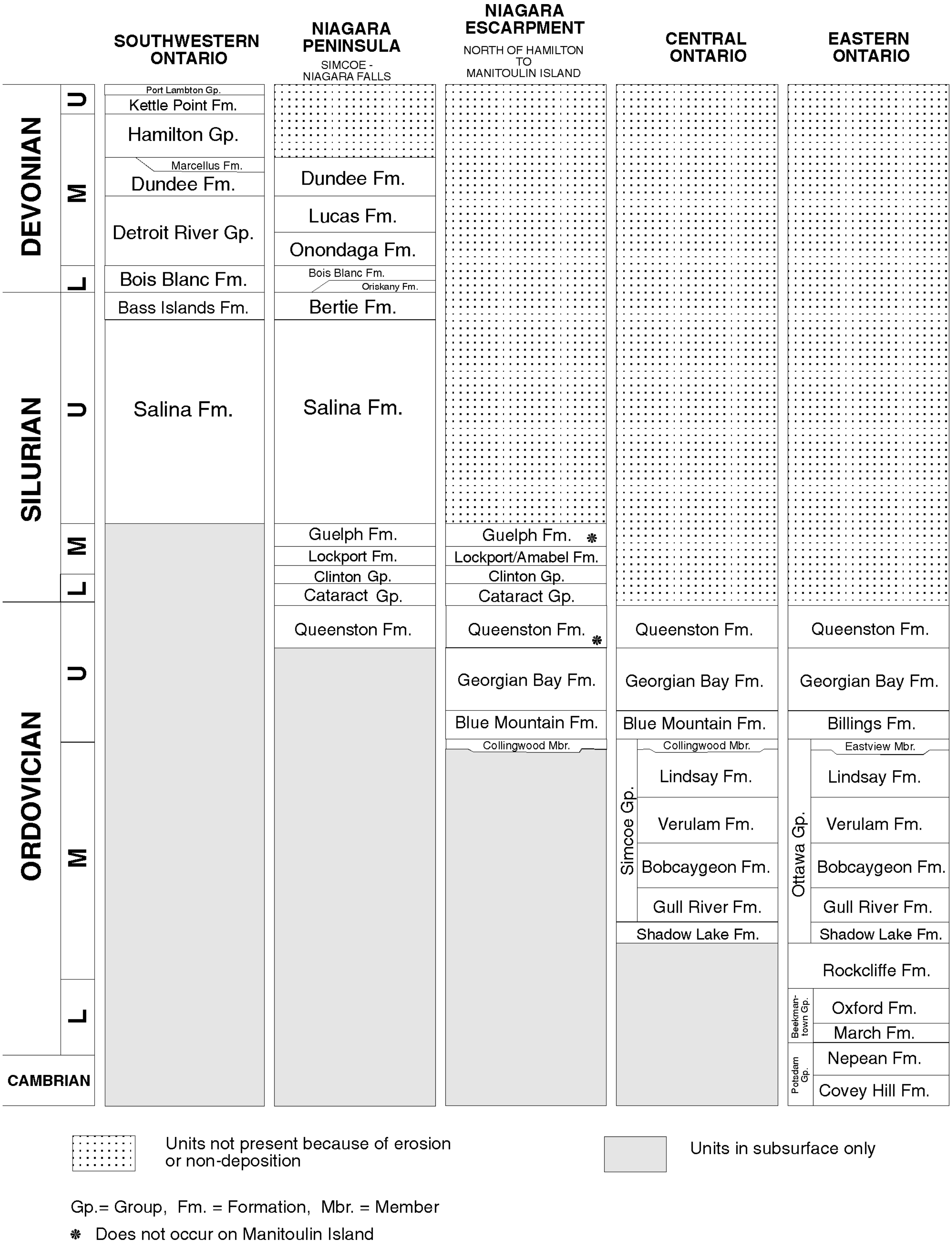


**Figure D2.** Exposed Paleozoic stratigraphic sequences in southern Ontario (*adapted from*: Bezys, R.K. and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario; The Can. Mining and Metallurgical Bulletin,v.81, no. 912, p.49-58.)

# 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 six 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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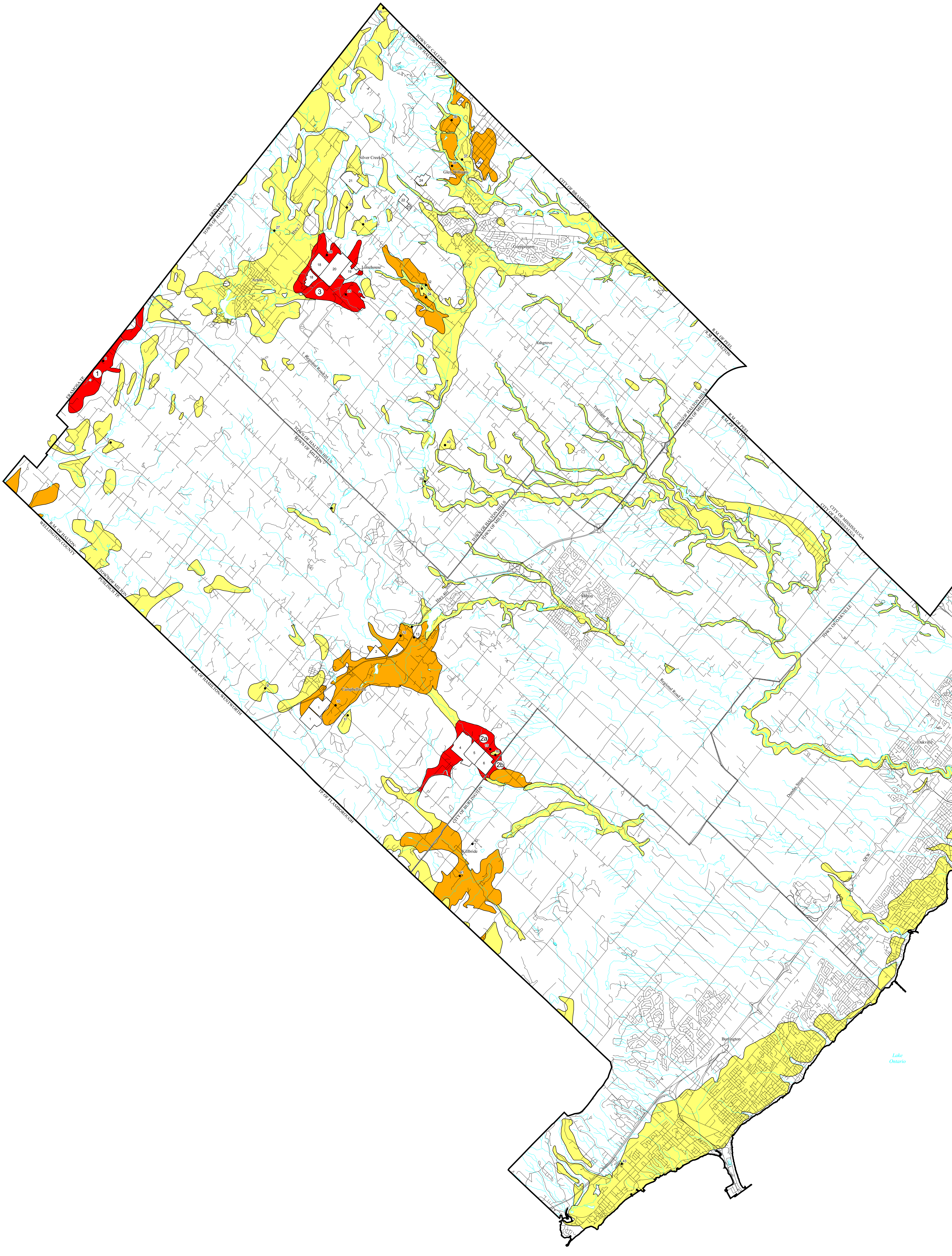



Ontario

Ontario Geological Survey

Aggregate Resources Inventory

# REGIONAL MUNICIPALITY OF HALTON

ARIM 184-1

SAND AND GRAVEL RESOURCES

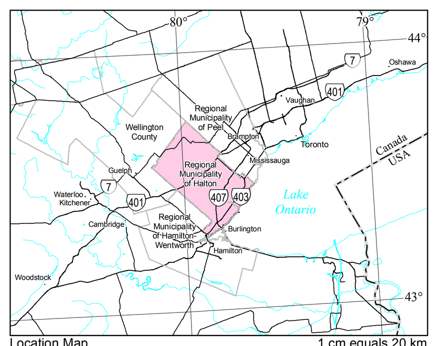
Scale 1:50 000

1000 m 0 1 2 km

NTS Reference: 30 M/5, 30 M/12, 40 P/8, 40 P/9



This map is published with the permission of the Director, Ontario Geological Survey.




Location Map 1 cm equals 20 km

This map contains references to data and/or information contained in Aggregate Resources Inventory Paper 184.

## LEGEND

(Some map units and symbols may not apply to this map)

- 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

- Township boundary
- Project area boundary
- Geographic township with township boundary
- County, District, Regional or District Municipal boundary
- City or town limits
- Geological and aggregate thickness boundary of sand and gravel deposits
- Buried geological and aggregate thickness boundary of sand and gravel deposits
- Licenced property boundary with property number (*see* Table 2)
- Unlicenced sand or gravel pit* with property number (*see* Table 2)
  *Abandoned pit or wayside pit operating on demand under authority of a permit
- Test hole location with identification number (*see* Table 7)
- Selected sample site with identification number
- Selected water well location
- Moraine

## SOURCES OF INFORMATION

This map is based on information taken from the Natural Resources and Values Information System (NRVIS).

Projection: NAD 83 Zone 17

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

Geology based on:

Cowan, W.R. 1976
Karrow, P.F., 1967, 1968, 1987a, 1987b, 1987c, 1991
White, O.L. 1975

Additional geology by Dave Rowell, 2008.

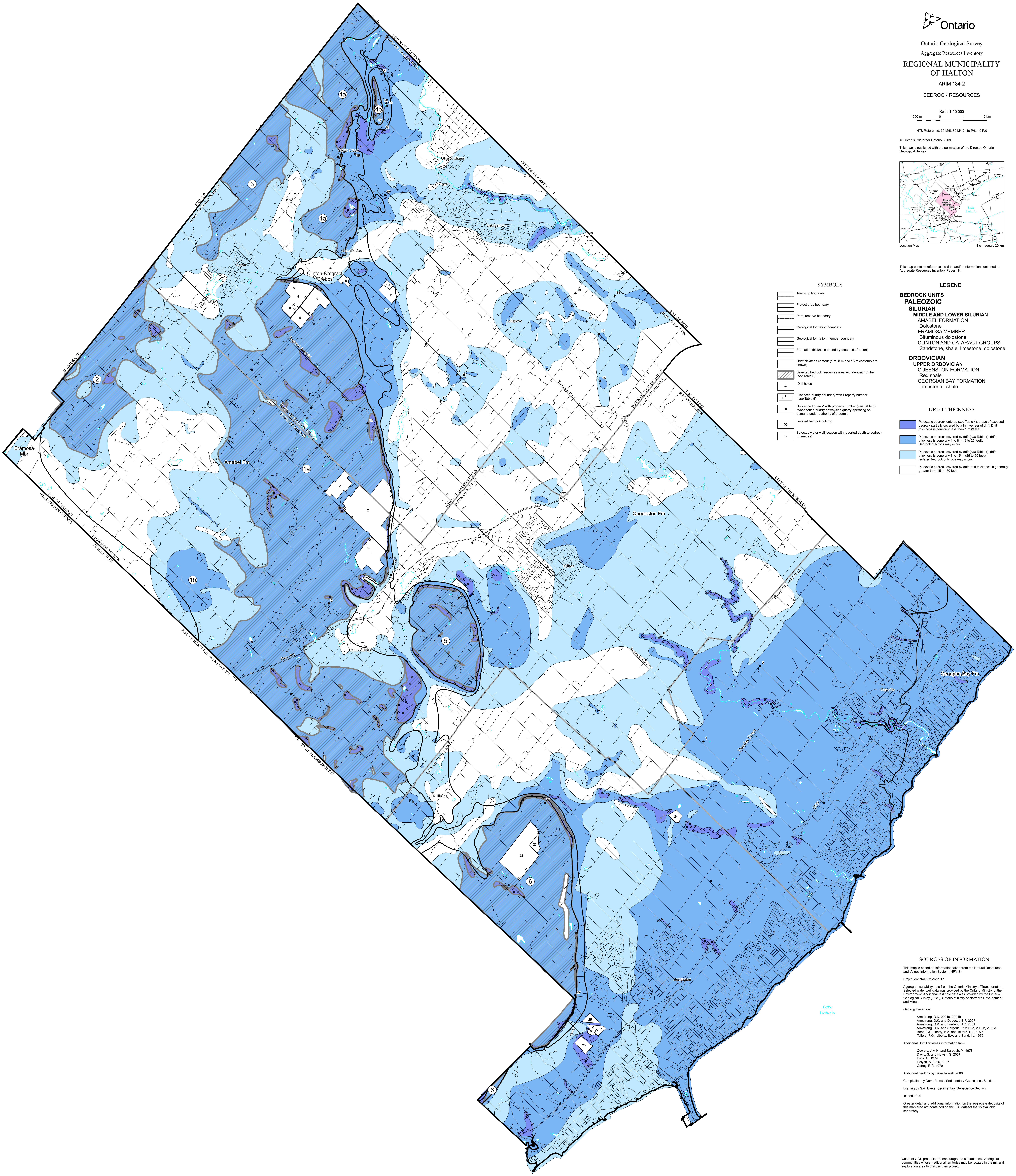
Compilation by Dave Rowell, Sedimentary Geoscience Section.

Drafting by S.A. Evers, Sedimentary Geoscience Section.

Issued 2009.

Aggregate deposits illustrated on this map, within each level of significance, may represent an amalgamation of sand and gravel deposits of different origin and character. Greater detail and additional information on the aggregate deposits of this map area are contained on the GIS dataset that is available separately.

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




Ontario

Ontario Geological Survey

Aggregate Resources Inventory

# REGIONAL MUNICIPALITY OF HALTON

ARIM 184-2

BEDROCK RESOURCES

Scale 1:50 000

1000 m 0 1 2 km

NTS Reference: 30 M/5, 30 M/12, 40 P/8, 40 P/9



Location Map 1 cm equals 20 km

This map contains references to data and/or information contained in Aggregate Resources Inventory Paper 184.

## SYMBOLS

- Township boundary
- Project area boundary
- Park, reserve boundary
- Geological formation boundary
- Geological formation member boundary
- Formation thickness boundary (see text of report)
- Drift thickness contour (1 m, 8 m and 15 m contours are shown)
- Selected bedrock resources area with deposit number (*see* Table 6)
- Drill holes
- Licenced quarry boundary with Property number (*see* Table 5)
- Unlicenced quarry* with property number (*see* Table 5)
  *Abandoned quarry or wayside quarry operating on demand under authority of a permit
- Isolated bedrock outcrop
- Selected water well location with reported depth to bedrock (in metres)

## LEGEND

**BEDROCK UNITS**

**PALEOZOIC**

**SILURIAN**

**MIDDLE AND LOWER SILURIAN**

AMABEL FORMATION
Dolostone
ERAMOSA MEMBER
Bituminous dolostone
CLINTON AND CATARACT GROUPS
Sandstone, shale, limestone, dolostone

**ORDOVICIAN**

**UPPER ORDOVICIAN**

QUEENSTON FORMATION
Red shale
GEORGIAN BAY FORMATION
Limestone, shale

## DRIFT THICKNESS

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

## SOURCES OF INFORMATION

This map is based on information taken from the Natural Resources and Values Information System (NRVIS).

Projection: NAD 83 Zone 17

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

Geology based on:

Armstrong, D.K. 2001a, 2001b
Armstrong, D.K. and Dodge, J.E.P. 2007
Armstrong, D.K. and Frederic, J.C. 2001
Armstrong, D.K. and Sergerie, P. 2002a, 2002b, 2002c
Bond, I.J., Liberty, B.A. and Telford, P.G. 1976
Telford, P.G., Liberty, B.A. and Bond, I.J. 1976

Additional Drift Thickness information from:

Coward, J.M.H. and Barouch, M. 1978
Davis, S. and Holysh, S. 2007
Funk, G. 1979
Holysh, S. 1995, 1997
Ostrey, R.C. 1979

Additional geology by Dave Rowell, 2008.

Compilation by Dave Rowell, Sedimentary Geoscience Section.

Drafting by S.A. Evers, Sedimentary Geoscience Section.

Issued 2009.

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