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Aggregate Resources Inventory
Paper 117

Aggregate Resources Inventory of the City of Port Colborne and Town of Fort Erie

Regional Municipality of Niagara Southern Ontario

By Staff of the Niagara District Office, Ontario Ministry of Natural Resources, and Staff of the Engineering and Terrain Geology Section, Ontario Geological Survey, Ministry of Northern Development and Mines

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Aggregate Resources Inventory of the City of Port Colborne and Town of Fort Erie Regional Municipality of Niagara

by Staff[1] of the Niagara District Office, Ontario Ministry of Natural Resources, and Staff[1] of the Engineering and Terrain Geology Section, Ontario Geological Survey, Ministry of Northern Affairs and Mines.

1. Project Supervisors: J.Z. Fraser and Dale W. Scott; field work and report by J.Z. Fraser; compilation and drafting by the Staff of the Niagara District Office, Ministry of Natural Resources, and the Staff of the Aggregate Assessment Office, Ontario Geological Survey, Ministry of Northern Affairs and Mines. The Mineral Resources Staff of Central Region of the Ministry of Natural Resources assisted in the collection of data, field checking and review of this report.

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Abstract

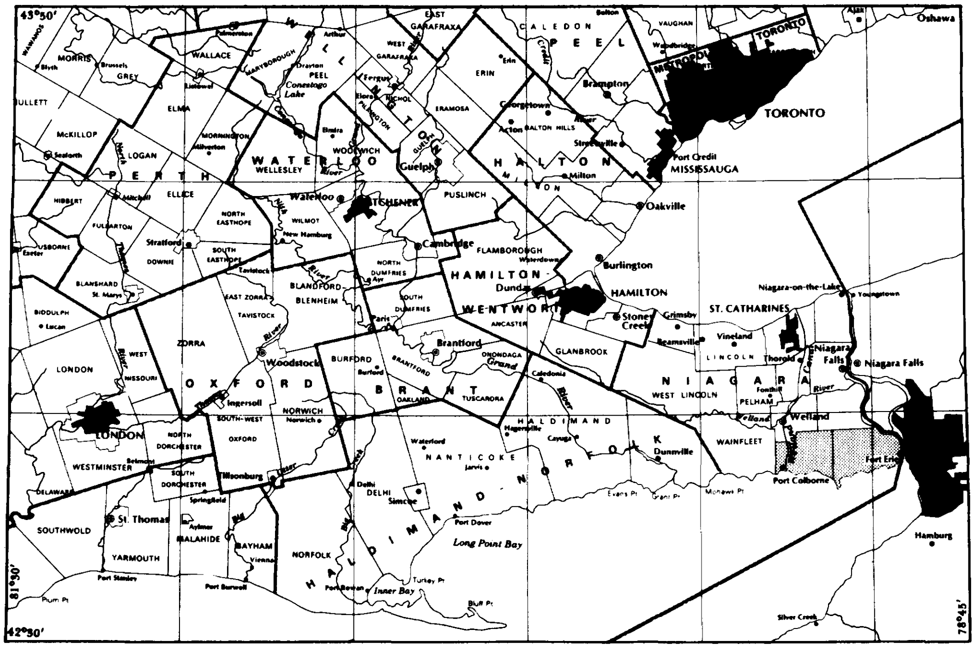


Figure 1: Key Map Showing the Location of the City of Port Colborne and Town of Fort Erie, Scale 1:1 800 000.

This report includes both an inventory and evaluation of sand and gravel as well as bedrock resources in the City of Port Colborne and the Town of Fort Erie. The report is part of the Aggregate Resources Inventory Program for townships and municipalities designated under the Pits and Quarries Control Act.

Several small glaciolacustrine beach sand and gravel deposits in both municipalities have been selected as resource areas of primary significance. The presently available parts of these areas occupy a total of 180 acres (73 ha) and contain possible resources of 4 million tons (4 million tonnes) of aggregate suitable for local road-maintenance aggregate and other low-specification uses. Large possible resources of fine sand may be available in parts of a large inland dune system along the Lake Erie shore. Because of the complexity of land use capability and environmental constraint in this area, these deposits of fine sand have not been selected for possible resource protection.

The bedrock in the two municipalities consists of Silurian and Devonian dolostones, shales, evaporites, and limestones. Bedrock from the Bertie and Bois Blanc Formations and part of the Onondaga Formation is suited for the production of a wide range of road-building and construction aggregates. These formations are exposed or thinly drift covered throughout the southern half of both municipalities and three large areas have been selected for possible resource protection. These areas occupy a total of 14,800 acres (6000 ha), of which 10,500 acres (4250 ha) are considered to be available for extraction. Total resource tonnage in these areas is estimated to be 2000 million tons (1810 million tonnes).

Selected Resource Areas are not intended to be permanent, single land use units which 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.

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. Very large amounts of these materials are used each year throughout the Province. For example, in 1982, the total tonnage of mineral aggregates extracted was 101 million tons (92 million tonnes), greater than that of any other metallic or nonmetallic commodity mined in the Province (Ontario Ministry of Natural Resources 1983).

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

Comprehensive planning and resource management strategies are required to make the best use of available resources, especially in those areas experiencing rapid development. Such 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 is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies and official plans. 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 a municipality's resources.

The report includes an assessment of sand and gravel resources as well as a discussion on the potential of 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 primarily involve the interpretation of published geological data such as bedrock and surficial geology maps and reports (see References) as well as field examination of potential resource areas. Field methods include the examination of natural and man-made exposures of granular material. Most observations are made at quarries and sand and gravel pits located from records held by the Ontario Ministry of Transportation and Communications, the Ontario Geological Survey, and by Regional and District Offices of the Ontario Ministry of Natural Resources. Observations made at pit sites include estimates of the total face height and the proportion of gravel- and sand-sized fragments in the deposit. Observations are also made of the shape and lithology of the particles. These characteristics are important in estimating the quality and quantity of the aggregate. In areas of limited exposure, test pitting, soil probing, hand augering and geophysical techniques are used to assess subsurface materials. Airphotos at various scales are used to determine the continuity of deposits, especially in areas where information is limited.

Deposits with potential for further extractive development or those where existing data are scarce, are studied in greater detail. Representative layers in these deposits are sampled in 25- to 100-pound (11 to 45 kg) units from existing pit faces or from test pits. The samples are analysed for grain size distribution and in some cases Los Angeles abrasion, absorption, and Magnesium Sulphate soundness tests along with petrographic analyses are performed.

Analyses are performed either in the laboratories of the Soils and Aggregates Section, Engineering Materials Office, Ontario Ministry of Transportation and Communications, or in the Geoscience Laboratories, Geoservices Section, Ontario Geological Survey. In areas of limited subsurface exposure, test holes are drilled and geophysical surveys using hammer seismic equipment are undertaken. The symbols for and locations of sample and test hole sites along with geophysical traverse lines are noted on Map 1.

In the office, the field data are supplemented by pit information on file with the Soils and Aggregates Section of the Ontario Ministry of Transportation and Communications. Data contained in these files include field estimates of the depth, composition and "workability" of deposits as well as laboratory analyses of the physical properties and chemical suitability of the aggregate. Information concerning the development history of the pits and acceptable uses of the aggregate is also recorded. The location, size, and depth of extraction of pits licenced under the Pits and Quarries Control Act are obtained from records held by Regional and District Offices of the Ontario Ministry of Natural Resources. The cooperation of the above-named groups in the compilation of inventory data is gratefully acknowledged.

Water well records, held by the Ontario Ministry of the Environment, are used in some areas to corroborate thickness estimates or to indicate the presence of buried granular material. These records are 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, prepared by the Cartography Section of the Lands and Waters Group, Ontario Ministry of Natural Resources, for presentation in the report.

RESOURCE TONNAGE CALCULATION TECHNIQUES

SAND AND GRAVEL RESOURCES

Once the interpretative boundaries of the aggregate units have been drawn, 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 acres. 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 logs. Original tonnage values can then be calculated by multiplying the volume of the deposit by 2500 (the density factor). This factor is approximately the number of tons in a one-foot (0.3 m) thick layer of sand and gravel, one acre (0.4 ha) extent, assuming an average density of 110 pounds per cubic foot (1766 kg per cubic metre).

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 acres 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 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 2500) to give an estimate of the sand and gravel tonnage (Column 7) presently available for extractive development and/or resource protection.

Reserve estimates are calculated for deposits of primary significance. Reserve 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 50 feet (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. 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 60 feet (18 m) is used for thickness. Volume estimates are then multiplied by the density factor (the estimated weight in tons of a one-foot (0. 3 m) thick section of rock, one acre (0.4 ha) in extent).

Resources of dolostone are calculated using a density factor of 165 pounds per cubic foot (2649 kg per cubic metre) or 3600 tons per acre (8070 tonnes per hectare). Sandstone resources are calculated using a density estimate of 146 pounds per cubic foot (2344 kg per cubic metre) and shale resources are calculated with a factor of 150 pounds per cubic foot (2408 kg per cubic metre).

UNITS AND DEFINITIONS

Although most of the measurements and other primary data available for resource tonnage calculations are given in Imperial units, Metric units have also been given in the text and on the tables which accompany the report. The Metric equivalent of the data is shown in brackets after or directly below the corresponding Imperial figures. Data are generally rounded off in accordance with the Ontario Metric Practice Guide (Metric Committee 1975).

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

Part II — Data Presentation and Interpretation

Three maps, each portraying a different aspect of the aggregate resources in the municipality, accompany the report. Map 1, "Distribution of Sand and Gravel Deposits", gives a comprehensive inventory of the sand and gravel resources in the report area. Map 2, "Selected Sand and Gravel Resource Areas", shows those deposits which are considered to represent the largest and/or highest quality resources in the area. Map 3, "Bedrock Resources" shows the distribution of bedrock formations, the thickness of overlying unconsolidated sediments, and identifies the Selected Bedrock Resource Areas.

MAP 1: DISTRIBUTION OF SAND AND GRAVEL DEPOSITS

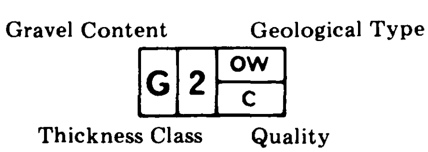
Map 1 is derived from existing surficial geology maps of the area or from airphoto interpretation in areas where surficial mapping is incomplete. The map shows the extent and quality of sand and gravel deposits within the study area and the present level of extractive activity.

On the map, gravel deposits are indicated by dark brown shading while sand deposits are shaded light brown. The present level of extractive activity is also indicated. Those areas which are licenced for extraction under the Pits and Quarries Control 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, location and licenced acreage of the pit, as well as the estimated face height and percentage gravel. A number of unlicenced pits (abandoned pits or wayside pits operating on demand under authority of a permit) are identified by a numbered dot on Map 1 and described in Table 2.

Map 1 also presents a summary of available information related to the quality of aggregate contained in all the known aggregate deposits in the study area. Much of this information is contained in the symbols which are found on the map. The Deposit Symbol appears for each mapped deposit and summarizes important genetic and textural data. The Texture Symbol is a circular proportional diagram which displays the grain size distribution of the aggregate in areas where bulk samples were taken.

DEPOSIT SYMBOL

The Deposit Symbol is similar to those used in soil mapping and land classification systems commonly in use in North America. The components of the symbol indicate the gravel content, thickness of material, origin (type), and quality limitations for every deposit shown on Map 1. These components are illustrated by the following example:



This symbol identifies an outwash deposit 10 to 20 feet (3 to 6 m) thick containing more than 35 percent gravel. Excess silt and clay may limit uses of the aggregate in the deposit.

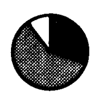
The "gravel content" and "thickness class" are basic criteria for distinguishing different deposits. The "gravel content" symbol is an upper case "S" or "G". The "S" indicates that the deposit is generally "sandy" and that gravel-sized aggregate (greater than 4.75 mm) makes up less than 35 percent of the whole deposit. "G" indicates that the deposit contains more than 35 percent 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 as shown in the legend for Map 1.

Two smaller sets of letters, divided from each other by a horizontal line, follow the thickness class number. The upper series of letters identifies the geologic deposit type (the types are summarized with respect to their main geologic and extractive characteristics in Appendix C) and the lower series of letters identifies the main quality limitations that may be present in the deposit as discussed in the next section.

TEXTURE SYMBOL

The Texture Symbol provides a more detailed assessment of the grain size distribution in deposits where samples were taken for analysis during field study. The information from which these symbols are derived has been plotted in grain size distribution graphs. The relative amounts of gravel, sand, and silt and clay in the sampled material are shown graphically by the subdivision of a circle into proportional segments. The following example shows a hypothetical sample consisting of 30 percent gravel, 60 percent sand, and 10 percent silt and clay:



Test hole locations are shown on Map 1 by a solid drill hole symbol. Geophysics lines are shown on the map by a line symbol.

MAP 2: SELECTED SAND AND GRAVEL RESOURCE AREAS

Map 2 is an interpretative map derived from an evaluation of the deposits shown on Map 1. The deposits identified on Map 2 are those which are considered to be important in ensuring an adequate resource base for the future.

All the selected sand and gravel resource areas are first delineated by geological boundaries and then classified into three levels of significance: primary; secondary; and tertiary. Each area of primary significance is assessed as to its probable relative value as a resource in the municipality and is given a deposit number which denotes its ranking order. All such deposits are shown by dark shading on Map 2.

Deposits of secondary significance are not ranked numerically in this report, but are indicated by light red shading on Map 2. 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 quanitities of sand and gravel and should be considered as part of the aggregate supply of the area.

Areas of tertiary significance are outlined on the map by a solid line but have no shading. 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 but are unlikely to support large-scale development.

Selected Sand and Gravel Resource Areas of primary significance are not permanent, single, land use units which 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.

The process by which deposits are evaluated and selected involves the consideration of two 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 reserves in the rest of the municipality. Generally, deposits in Class 1, i.e. those thicker than 20 feet (6 m), and containing more than 35 percent gravel are considered to be most favourable for commercial development. Thinner deposits may be valuable in municipalities with low total resources.

Aggregate Quality

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

Four indicators of the quality of aggregate may be included in the symbol for each deposit on Map 1. They are: gravel content (G or S); fines (C); oversize (O); and lithology (L).

Three of the 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 percent gravel in addition to a minimum of 20 percent 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 percent may impede drainage in road sub-base 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 Symbol.

Deposits containing more than 20 percent oversize material (greater than 4 inches (10 cm) in diameter) may also have use limitations. The oversize component is unacceptable for all concrete aggregate and for road-building aggregate, 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 Symbol.

The other 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 Symbol.

If the Deposit Symbol indicates either "C", "O", or "L" or any combination, the quality of the deposit is considered to be reduced for some uses of the aggregate. No attempt has been made to quantify the degree of limitation imposed. Assessment of the four indicators is made from published data, from data contained in files of both the Ontario Ministry of Transportation and Communications and the Engineering and Terrain Geology Section of the Ontario Geological Survey, and from field observations.

Analyses of unprocessed samples obtained from test holes, pits or sample sites have been plotted on grain size distribution graphs. On the graphs are the gradation specification envelopes for Ontario Ministry of Transportation and Communications' products: Granular Base Course A, B and C; Hot-Laid Asphaltic Sand Nos. 1,2,3,4, and 8; and concrete sand. By plotting the gradation curves with respect to the specification envelopes, it can be determined how well the unprocessed sampled material meets the criteria for each product.

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 and man-made features which 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, powerlines, 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).

The assessment of sand and gravel deposits with respect to local land use and to private land ownership is an important component of the general evaluation process. 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 District Office of the Ontario Ministry of Natural Resources.

REGIONAL CONSIDERATIONS

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

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

The aggregate resources in the region surrounding a municipality should be assessed in order to properly evaluate specific resource areas and to adopt optimum resource management plans. For example, a municipality that has large resources in comparison to its surrounding region constitutes a regionally significant resource area. Municipalites 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 3: BEDROCK RESOURCES

Map 3 is an interpretative map derived from bedrock geology, drift thickness and bedrock topography maps, water well data from the Ontario Ministry of the Environment, oil and gas well data from the Petroleum Resources Section (Ontario Ministry of Natural Resources) and from geotechnical test hole data from various sources. Map 3 is based on concepts similar to those outlined for Maps 1 and 2, but displays both the inventory and evaluation on the one map.

The geological boundaries of the bedrock units are shown by a dashed line. Isolated outcrops are indicated by an "X". Three sets of contour lines delineate areas of less than 3 feet (1 m) of drift, areas of 3 to 25 feet (1 to 8 m) of drift, and areas of 25 to 50 feet (8 to 15 m) of drift. The extent of these areas of thin drift are shown by three shades of blue. The darkest shade indicates where bedrock outcrops or is within 3 feet (1 m) of the ground surface. These areas consitute potential resource areas because of their easy access. The medium shade indicates areas where drift cover is up to 25 feet (8 m) thick. Quarrying is possible in this depth of overburden and these zones also represent potential resource ares. The lightest shade indicates bedrock areas overlain by 25 to 50 feet (8 to 15 m) of overburden. These latter areas constitute resources which have extractive value only in specific circumstances. Outside of these delineated areas, the bedrock can be assumed to be covered by more than 50 feet (15 m) of overburden, a depth generally considered to be too great to allow economic extraction (unless part of the overburden is composed of economically attractive deposits).

Other inventory information presented on Map 3 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 Pits and Quarries Control Act are shown by a solid outline and identified by a number which refers to the quarry descriptions in Table 5. Each description notes the owner, location, licenced acreage 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 3 and described in Table 5. One additional symbol appears on the map: an open dot indicates the location of a selected drill hole which penetrates bedrock. The overburden thickness is shown in feet beside the open dot.

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 Ontario Ministry of Transportation and Communications. 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 approch. First, quality and quantity variations 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 3 by a line pattern and the calculated available tonnages are given in Table 6.

Selected Bedrock Resource Areas shown on Map 3 are not permanent, single land use units which must be incorporated in an official planning document. They represent areas in which a major bedrock 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.

Part III — Assessment of Aggregate Resources in the City of Port Colborne and Town of Fort Erie

LOCATION AND POPULATION

The City of Port Colborne and the Town of Fort Erie are located along the north shore of Lake Erie, west of the Niagara River, and are bounded on the north by the cities of Welland and Niagara Falls.The report area is shown on parts of the Fort Erie (30 L/15) and Welland (30 L/14) map sheets of the National Topographic System at a scale of 1:50 000.

The City of Port Colborne occupies an area of 28,545 acres (11 552 ha), west of the Town of Fort Erie, and south of the City of Welland (Ontario Ministry of Municipal Affairs and Housing 1983). The city was created from the former township of Humberstone in 1970 during the reorganization of Welland County to form part of the Regional Municipality of Niagara. The main urban area in the city is Port Colborne which flanks the Welland Canal. The population of the entire City of Port Colborne was 19,011 in 1982, a decline of approximately 9 percent since 1972 (Ontario Ministry of Municipal Affairs and Housing 1983; Ontario Ministry of Treasury, Economics and Intergovernmental Affairs 1974). Population projections for the regional municipality as a whole indicate that future growth rates are expected to be low (Regional Municipality of Niagara 1981). The city is served by a well developed network of municipal roads and regional roads as well as King's Highways 3, 58 and 140. The area is also bisected by the Welland Canal.

The Town of Fort Erie occupies an area of 40,670 acres (16 459 ha) on the west bank of the Niagara River (Ontario Ministry of Municipal Affairs and Housing 1983). The town was created from the former township of Bertie in 1970. In 1982, the Town of Fort Erie had a total population of 24 136 and past figures indicate that the population has remained relatively stable since 1972 (Ontario Ministry of Municipal Affairs and Housing 1983; Ontario Ministry of Treasury, Economics and Intergovernmental Affairs 1974). The two main urban centres in the town are Fort Erie and Ridgeway. These centres are delineated by urban area boundaries defined by the Policy Plan of the Regional Municipality of Niagara. The town is served by a well developed network of paved municipal roads and regional roads as well as King's Highway 3 and the Queen Elizabeth Way, which is the main route for travel in the area. Lines of Conrail and the Canadian National Railways traverse both municipalities.

PHYSIOGRAPHY AND SURFICIAL GEOLOGY

The physiography of the City of Port Colborne and the Town of Fort Erie generally reflects the topography of the local bedrock surface. Most of the area is flat and relatively featureless, except for the low, north-facing Onondaga Escarpment which forms an irregular east-west trending bedrock promontory in the southern third of the area. North of this escarpment, the bedrock is generally covered by more than 50 feet (15 m) of glacial sediments and forms part of the very flat, featureless Haldimand Clay Plain (Chapman and Putnam 1984, pp. 157-159). To the south of the escarpment, the drift thickness is generally less than 25 feet (8 m) and extensive exposures of bedrock are common. The topography of this area is also subdued but is broken by several irregular ridges.

The distribution of the sediments overlying the bedrock surface, including the sand and gravel deposits shown on Map 1, is the result of glacial activity which took place in the Late Wisconsinan Substage of the Pleistocene Epoch, informally known as the 'Great Ice Age'. This substage, which lasted from approximately 23 000 to 10 000 years before the present, was marked by the repeated advance and melting of extensive, continental ice sheets.

At the time of the maximum glacial extent, most of the Niagara Peninsula was covered by a large ice-mass which was centered in the Lake Ontario basin and had advanced to the south, over the Niagara Escarpment, into the Lake Erie basin. As the ice advanced it deposited a layer of glacial till over the bedrock surface. This material has a variable silt to clayey silt composition with a low stone content and is known as the Halton Till (Feenstra 1981, p. 87). Because of its high fines and low stone content, the Halton Till is not suitable for use as load-bearing aggregate.

The till has been buried by younger glaciolacustrine deposits throughout most of the study area, but is exposed in an area along the brow of the Onondaga Escarpment, and in two moraine ridges. The moraines consist of Halton Till which was deposited at the margin of the ice sheet during short halts in its recession to the north. The exposed portions of the Crystal Beach Moraine form a long, narrow ridge which extends more than 3 miles (5 km) from Sherkston to Crystal Beach and has local relief of 25 feet (8 m) (Feenstra 1981, p. 19). The second ridge is the Fort Erie Moraine which is best exposed within the Fort Erie urban area but also extends west to the Onondaga Escarpment.

Following the recession of the ice margin to a position below the brow of the Niagara Escarpment, most of the Niagara Peninsula was covered by glacial meltwaters which were dammed against the ice margin. Large amounts of silt and clay were deposited in these glacial lakes and most of the study area, north of the Onondaga Escarpment, was covered by up to 30 feet (9 m) of these materials. South of the Onondaga Escarpment, the sediments are generally thinner and there are extensive areas of wave-washed exposed bedrock, especially near the brow of the escarpment. The glaciolacustrine deposits are not suited for use as load-bearing aggregate, but have been extracted on a small scale for backfill at several now-abandoned pits in the northern part of the Town of Fort Erie (pit nos. 8 to 12) and in the City of Port Colborne (pit nos. 3 and 4). Clay has been extracted elsewhere in the peninsula for the manufacture of brick, tile and other structural clay products, and Feenstra (1981, p. 196) notes that clay exposed during the construction of the Welland bypass of the Welland Canal may be suitable for structural clay products.

The brief existence of several distinct glacial lakes at successively lower elevations can be interpreted from numerous small beach and deltaic sand and gravel deposits scattered throughout the City of Port Colborne and the Town of Fort Erie (Feenstra 1981, p. 165). The largest of the beach deposits is a well developed linear ridge which was formed at the crest of the Crystal Beach Moraine throughout much of its length, during the existence of glacial Lake Dana (Feenstra 1981). Similar, though smaller beach ridges are also found in the central portion of Port Colborne at slightly lower elevations than the Lake Dana levels. These deposits generally consist of less than 15 feet (5 m) of coarse sand and minor gravel. Similar Lake Dana and lower level beach deposits are also found in the Town of Fort Erie. These deposits are at the brow of the Onondaga Escarpment north of Ridgeway and on the crest of the Fort Erie Moraine in Fort Erie. The beach deposits generally contain small possible resources of sand and gravel suitable for low-specification load-bearing aggregates such as granular base course. The deposits are now so heavily constrained by competing land uses that very little material presently remains available for possible extraction.

The settlements of Crystal Beach and Ridgeway are built over a nearshore glaciolacustrine deposit which may consist of up to 20 feet (6 m) of sand and minor gravel. This deposit is now almost completely sterilized by competing development and is not a viable resource.

At the end of the glacial period, the Ontario ice lobe melted back into the Lake Ontario basin and allowed meltwaters to eventually drain down to modern lake levels. Recent erosional and depositional processes along the modern Lake Erie shoreline have produced a well developed sandy beach and associated inland dune system. The beach deposits generally consist of well sorted coarse sand and minor gravel. The backshore dune system consists predominantly of one segmented dune ridge oriented parallel to the present shoreline. The local relief varies from an average of 30 to 45 feet (9 to 14 m) up to a maximum of 90 feet (27 m) at the "Sugar Loaf" in Port Colborne. The dunes consist of uniform fine to medium sand which is suitable for a limited range of products including flux sand, and asphaltic blending sand. The deposits have been extracted at several localities in the past and three pits are presently licenced for extraction.

Other postglacial depositional processes have been of relatively minor importance in modifying the physiography of the study area, except for the infilling and subsequent development of a large peat bog, known as the Wainfleet Marsh, northwest of Port Colborne. A large commercial operation in this deposit presently extracts large amounts of sphagnum peat for horticultural use (Feenstra 1981, p. 198). Similar though smaller bog deposits have developed in back-beach lagoons inland from the dune system along the Lake Erie shoreline.

EXTRACTIVE ACTIVITY FOR SAND AND GRAVEL

Sand and gravel extraction has been a relatively low volume activity in the City of Port Colborne and the Town of Fort Erie, because of the small available resource base and the low quality of the aggregate. Three pits were opened in small glacial beach deposits and another three in backshore dune deposits near Lake Erie. After the designation of the area under the Pits and Quarries Control Act, several of these sources were abandoned. At the time of writing, only two sources located in the dune deposits were licenced for extraction under the Act. The total area licenced for extraction in these sources is 127.0 acres (51.4 ha), and aggregate from the pits is suitable for winter sand, backfill, asphaltic blending sand, and local road maintenance.

Most local aggregate needs and export opportunities are met by crushed stone production from several bedrock quarries, located in thinly drift covered bedrock south of the Onondaga Escarpment.

SELECTED SAND AND GRAVEL RESOURCE AREAS

The sand and gravel deposits selected for possible resource protection in the report area are shown on Map 2. Four locally significant deposits have been selected at the primary level of significance. These deposits consist of glaciolacustrine beach sand and gravel and occupy approximately 240 acres (97 ha). An estimated 180 acres (73 ha) are currently available for extraction, containing 4 million tons (4 million tonnes) of aggregate resources. The remaining deposits are relatively less important and have been classed at the tertiary level.

SELECTED SAND AND GRAVEL RESOURCE AREA 1

Selected Sand and Gravel Resource Area 1 is a glaciolacustrine beach deposit located northeast of Ridgeway in the Town of Fort Erie. The beach forms a broad indistinct ridge with local relief of less than 20 feet (6 m). No extraction has taken place in the deposit but a sample from a natural exposure (Sample No. W185-B; Feenstra 1981) indicates a gravel content of approximately 25 percent and a fines content of 4 percent or less. This material may be suitable for a range of road-building and construction aggregates.

The deposit occupies a total of 112 acres (45 ha), of which 75 acres (30 ha) are considered to be presently available for extraction. Assuming an average of 9 feet (3 m) of usable aggregate throughout the deposit, resources are estimated to be 2 million tons (2 million tonnes). Since parts of Resource Area 1 are developed on bedrock which has also been selected for possible resource protection, opportunities for the sequential extraction of both resources are available. This deposit has also been identified as an Area of Natural Scientific Interest for the earth sciences. The deposit was selected as a representative of beach landforms associated with the existence of glacial Lake Dana. Although large-scale extraction might destroy the feature, limited extraction on parts of the ridge might actually increase its interpretive and scientific value by exposing the internal structures for detailed study. Any proposals for extraction in this deposit would be carefully reviewed by the Niagara District Office of the Ontario Ministry of Natural Resources to ensure that its scientific and educational value would not be destroyed.

SELECTED SAND AND GRAVEL RESOURCE AREA 2

Selected Sand and Gravel Resource Area 2 consists of three separate glaciolacustrine beach deposits in the central part of the City of Port Colborne. The ridges are long linear features with local relief of generally less than 15 feet (5 m). Although the deposits have not been extracted, and surface exposures are rare, the aggregate is considered to consist predominantly of clean, well sorted coarse sand and minor gravel. Several textural analyses of samples from the westernmost beach ridge (Sample Nos. W334-A to -C; Feenstra 1981) indicate gravel contents ranging from 0 to 29 percent, and fines contents range from 2 to 4 percent. The deposits occupy 128 acres (52 ha), of which 105 acres (42 ha) are potentially available for extraction. Assuming an average deposit thickness of 7 feet (2 m), possible sand and minor gravel resources are estimated to be 2 million tons (2 million tonnes). As with Resource Area 1, Resource Area 2 is also located over bedrock which has been selected for resource protection. Consequently, there may be opportunities for the utilization of both resources in a single extractive operation.

SAND AND GRAVEL RESOURCE AREAS OF TERTIARY SIGNIFICANCE

The remaining aggregate deposits in the two municipalities have been selected at the tertiary level of significance for a variety of reasons. The beach ridge on the crest of the Crystal Beach Moraine served as a convenient road bed for the construction of the Sherkston Road, and it, along with subsequent residential development along the road, has completely eliminated any opportunity for extraction of the aggregate. Similarly, the glaciolacustrine plain deposit at Thunder Bay has been completely sterilized by the residential expansion of Crystal Beach and Ridgeway.

Large tonnages of fine dune sand are potentially available in the Lake Erie shore zone throughout the two municipalities and the only presently licenced sand pits in the area are located in these deposits. Sample analyses (Sample Nos. W2-A and W706-A; Feenstra 1981) indicate that the aggregate consists almost exclusively of fine sand, with small amounts of silt. The pits produce fine sand used for blending in asphaltic pavement mixes. The shore zone is not well suited for extraction, however, because of the uniqueness and environmental sensitivity of parts of the area, and also because of the extensive residential development and recreational potential of other parts. The number and complexity of the different resource potentials in the shore zone area make it very difficult to identify specific areas for aggregate resource protection. Because of the relatively low demand but strategic value of the aggregate in the dune deposits, care should be taken to ensure that the possibility of extractive development is not excluded.

BEDROCK GEOLOGY

The City of Port Colborne and the Town of Fort Erie are underlain by a succession of Silurian and Devonian shales, dolostones, evaporites (gypsum), and limestones. The formations occur beneath variable amounts of unconsolidated sediment, in a series of roughly parallel bands oriented in an east-west direction. The units occur in chronologic sequence, from the oldest in the north to the youngest in the south. Their distribution in the study area is shown on Map 3 (after Sanford 1969 and Telford and Tarrant 1975).

Although the formations have a gentle regional dip to the south, the bedrock surface is generally flat, except for the prominent face of the Onondaga Escarpment which extends in an east-west direction through the centre of the report area. The escarpment, which is formed from erosion-resistant dolostone of the Bertie Formation, is a locally prominent topographic feature north of Port Colborne and the village of Ridgeway, where relief is approximately 25 feet (8 m).

The escarpment divides the report area into two distinct physiographic units. North of the escarpment, soft erodible shales, dolostones and evaporites of the Salina Formation are overlain by considerable amounts of glaciolacustrine clay. Drift thickness is generally greater than 50 feet (15 m) and is more than 125 feet (38 m) thick in the valley of Beaver Creek (Feenstra 1981). There are no surface exposures of the Salina Formation in the report area. Although the Salina is mined at several localities in Ontario for gypsum, it does not meet specifications for use as load-bearing aggregate.

In contrast, the bedrock south of the brow of the Onondaga Escarpment is generally covered by thin drift and surface exposures of three formations are common. These units have been extensively extracted in the past and are important regional sources for a variety of aggregate products.

The Bertie Formation, whose erosion-resistant dolostones form the face of the Onondaga Escarpment, overlies the Salina Formation and occurs in a narrow band through the study area. The formation is generally thinly drift covered and its entire thickness is well exposed in two large quarries. At the Port Colborne Quarries (quarry no. Q1) the Bertie Formation is approximately 35 to 40 feet (11 to 12 m) thick although the total thickness of the unit is difficult to determine because of its gradational contact with the underlying Salina Formation. The Bertie is approximately 45 feet (14 m) thick in exposures at quarry no. Q3. The formation may be subdivided into two units, each of which has different lithologic character and different use-suitability. The lower 12 to 17 feet (4 to 5 m) consists of thick-bedded, dark brown, bituminous dolostone. This unit is crushed and used for a wide variety of load-bearing aggregates. It can be used for concrete aggregate, but because of its bitumen content, requires extra washing to remove adhering fines. Also, because of its dark colour, the rock is generally not used for exposed concrete, (a white concrete is more aesthetically attractive to buyers) but is suitable for applications where the concrete is not visible or the colour not important (D. Balzas, Chairman of the Board, Port Colborne Quarries Ltd., Port Colborne, personal communication, 1983). The overlying upper unit consists of approximately 20 feet (6 m) of grey, shaly-weathering, fine-crystalline dolostone, and mottled thin-bedded dolostone. This unit is well suited for use as concrete and road-building aggregate. The Bertie Formation is a high quality bedrock unit of regional importance for a variety of aggregate products and has been selected for possible resource protection in the report area.

The Bertie Formation is disconformably overlain by the Bois Blanc Formation which lies in a narrow east-west trending band paralleling the distribution of the Bertie Formation. The Bois Blanc Formation is thinly drift covered throughout most of its area of occurrence and is well exposed in quarry no. Q1 and the southern Ridgemount Quarry (quarry no. Q2). The lowest 1 to 4 feet (0.3 to 1.2 m) of the formation often consists of greenish (glauconitic) sandstone and conglomerate known as the Springvale Sandstone Member (Telford and Tarrant 1975). Above this member, the formation consists of irregularly layered, cherty, fossiliferous and shaly limestone and minor dolostone. It varies in thickness from 12 to 14 feet (3.6 to 4.2 m) in the two quarries. The Bois Blanc Formation is not well suited for concrete or asphaltic aggregate because of its chert content and variable lithology, but is suitable for several less demanding uses. Large amounts of Granular Base Course A have been produced from the Bois Blanc Formation and the formation has been selected for possible resource protection.

The Bois Blanc is disconformably overlain by the Middle Devonian Onondaga Formation, which generally lies under thin drift in the southern part of the report area. The formation is divided into three members, the Edgecliff, Clarence, and Moorehouse Members, which occur in the study area. The older Edgecliff Member is exposed in quarry no. Q2, while the overlying Clarence Member is exposed in several now-abandoned quarries in the southern part of the area. The Edgecliff consists predominantly of thinly and irregularly bedded fossiliferous limestone with abundant black chert nodules, and is exposed in an approximately 27-foot (8 m) thick section overlying the Bois Blanc Formation in quarry no. Q2. The Clarence Member consists of massive-bedded, unfossiliferous, extremely cherty limestone, with a total thickness of approximately 26 feet (8 m). The younger Moorehouse Member consists of medium-bedded, fossiliferous, variably cherty limestone which underlies two small areas along the shore of Lake Erie. Although the members are not suited for concrete or asphaltic aggregate because of their high chert content, they are suitable for crusher-run aggregates such as Granular Base Course A and B, and various sizes of crushed "clear stone" (predominantly a one-size construction aggregate).

EXTRACTIVE ACTIVITY FOR BEDROCK

At least 14 quarries have been operated in the two municipalities, but most of these sources are now abandoned. Only four sources, Port Colborne Quarries (quarry no. Q1) and the Ridgemount Quarries of Walker Brothers Industries (quarry nos. Q2, Q3 and Q4) are presently licenced for operation. These sources have a combined licenced area of 825.0 acres (333.9 ha). The quarries are developed in bedrock of the Bertie, Bois Blanc and Onondaga Formations and produce large tonnages of crushed stone suitable for concrete and asphaltic aggregate, and for a range of other road-building and construction aggregates. Most of the stone production from the Port Colborne Quarry is shipped via the Welland Canal to markets in the United States.

Several sources in the municipalities were opened near the turn of the century in areas of exposed bedrock of the Onondaga Formation (quarry nos. Q5, Q8, Q9, Q11, Q12, Q13, and Q14). These areas were attractive for early extraction because the stone is "soft" and could be processed with the equipment available at the time. As more efficient extraction techniques and equipment became available, the harder, higher quality bedrock of the Bertie Formation became the focus for extraction, and the earlier sources were abandoned.

SELECTED BEDROCK RESOURCE AREAS

The Bertie and Bois Blanc Formations along with part of the Onondaga Formation have been selected for possible resource protection in areas where drift is less than 25 feet (8 m) thick. That part of the Onondaga Formation which has been selected includes a band of the Edgecliff Member and a small area belonging to the Clarence Member. A total of three bedrock resource areas have been selected containing resources of approximately 2000 million tons (1810 million tonnes).

Additional bedrock resources may be available from areas of thinly drift covered Clarence and Moorehouse Members of the Onondaga Formation. Although these members are similar in quality to the Bois Blanc and Edgecliff limestone, they have not been selected (with the exception of one small area of the Clarence Member) for two reasons. Towards the south, the thickness of the Onondaga strata overlying the Bois Blanc and Bertie Formations increases. As a result, the economic viability of extracting the underlying higher quality Bertie dolostone decreases. Secondly, very large possible resources of similar or higher quality bedrock have been selected elsewhere in the report area.

Bedrock of the three formations may be available for extraction inside the eastern urban limits of Port Colborne, however, no areas have been selected. The city may wish to investigate the feasibility of extraction in the predominantly rural area south of King's Highway 3 in this area.

SELECTED BEDROCK RESOURCE AREA 1

Selected Bedrock Resource Area 1 consists of bedrock of the Bertie Formation which is overlain by less than 25 feet (8 m) of overburden. The drift overlying the Bertie dolostone consists of glaciolacustrine clay and/or glacial till, neither of which poses significant restrictions for stripping. Surface exposures are common in the area along the brow of the Onondaga Escarpment. No quarries have been developed in Resource Area 1, although the Bertie Formation, underlying the Bois Blanc and Onondaga limestone to the south, has been extracted to produce a wide variety of aggregate products.

The Resource Area is divided into Areas 1a and 1b by a zone of thicker drift in the Beaver Creek valley near Ridgeway and Crystal Beach. The thicker drift occupies a depression in the bedrock surface which may be the remnant of a preglacial river valley (Feenstra 1981).

For the most part, Areas 1a and 1b are sparsely settled and land use is primarily agricultural. However, residential development along Chippawa Road, which runs north-south in the central part of the City of Port Colborne, may be a significant constraint on possible quarry locations. Similarly, Ridge Road, which runs along the escarpment brow, has considerable associated residential development which will significantly constrain possible extractive development in parts of Area 1b. Road access in Area 1a is provided by several city, town and regional roads, and by King's Highway 3. Parts of the area are also close to the Welland Canal and to aggregate loading facilities used by Port Colborne Quarries for lake transport. The local transportation network is also well developed in Area 1b and parts of the area are in close proximity to the Queen Elizabeth Way and a line of the Canadian National Railways.

Resource Area 1 totals 4300 acres (1740 ha), of which 3000 acres (1210 ha) are considered to be presently available for extraction. Assuming a total workable thickness of 40 feet (12 m), the total available resources of stone in Areas 1a and 1b are estimated to be 430 million tons (390 million tonnes).

SELECTED BEDROCK RESOURCE AREA 2

Selected Bedrock Resource Area 2 includes Areas 2a and 2b which consist of the Bois Blanc limestone and underlying Bertie dolostone. The bedrock is overlain by less than 25 feet (8 m) of glaciolacustrine clay and/or glacial till, and surface exposures are common especially near Ridgeway and Port Colborne. As with Resource Area 1, Areas 2a and 2b are separated by thicker drift occupying a depression of the bedrock surface near Ridgeway. Licenced quarries Q3, Q4 and part of Q1, along with three unlicenced quarries (quarry nos. Q6, Q7 and Q10), have been developed in Resource Area 2.

The predominant land use in Area 2 is agriculture and most of the land is sparsely populated, except for some recent residential development south of King's Highway 3, near Ridgeway. Part of Area 2b in the vicinity of quarry nos. Q3 and Q4 is especially well suited for future possible extractive development because of the thin drift cover, generally low agricultural potential, sparse population and proximity to major transportation routes. In addition, this area has been a traditional site for extraction for many years.

Resource Area 2 occupies a total of 4150 acres (1680 ha), exclusive of licenced properties. Cultural constraints and previous extraction reduce the area currently available to 3000 acres (1210 ha). Since the Bois Blanc Formation has a total thickness of only 15 feet (5 m), the underlying Bertie Formation which is approximately 40 feet (12 m) thick would also be available in any large-scale quarry operation in Area 2. Thus, for the purposes of resource tonnage calculation the workable thickness in Area 2 is estimated to be 55 feet (17 m) and total available resources of good quality bedrock are approximately 600 million tons (540 million tonnes).

SELECTED BEDROCK RESOURCE AREA 3

The Edgecliff Member of the Onondaga Formation and a small area of the Clarence Member are exposed on the bedrock surface in Selected Bedrock Resource Area 3. Drift cover varies from 0 to 25 feet (0 to 8 m) thick and consists predominantly of glaciolacustrine clay. The resource area has also been divided into two units (Areas 3a and 3b) east and west of Crystal Beach.

Quarry no. Q2 and part of quarry no. Q1 have been developed in the resource area. Since approximately 27 feet (8 m) of the Edgecliff Member are exposed in the upper levels of the two quarries, the underlying Bois Blanc and Bertie Formations may also be available for extraction. A quarriable thickness of 60 feet (18 m) has been estimated for the resource area, however, it may be necessary to extract to greater depths for the middle and lower sections of the high quality Bertie Formation. The stone would be suitable predominantly for lower specification crushed stone, although Bertie dolostone suitable for concrete and asphaltic aggregate would be available at greater depths.

Resource Area 3 occupies a total of 6300 acres (2550 ha), exclusive of licenced properties. Cultural constraints reduce the area presently available to 4500 acres (1820 ha). Residential and other forms of development along sections of King's Highway 3, notably south of the highway in Area 3b and in the vicinity of Gasline in Area 3a, are significant constraints on extraction. There exists, however, large areas of sparsely populated rural land in the resource area which are potentially available for extraction. The presently available resources of stone in Resource Area 3, assuming a 60-foot (18 m) workable thickness, are estimated to be 970 million tons (880 million tonnes).

SUMMARY

The City of Port Colborne and the Town of Fort Erie contain large possible resources of bedrock suitable for a wide range of road-building and construction aggregates. Three extensive areas of bedrock have been identified and selected for possible resource protection. Several attractive areas suitable for possible future extraction are located in the vicinity of large licenced quarries in both municipalities.

Possible resources of sand and gravel are very limited and are considerably constrained by use-suitability and competing land uses. Only two small resource areas have been identified and selected for possible protection. Specialty aggregate for products such as concrete and fine aggregate will have to be supplied from alternate sources.

Enquiries regarding the Aggregate Resources Inventory for the City of Port Colborne and the Town of Fort Erie should be directed to the Ontario Ministry of Natural Resources, either at the Niagara District Of-

fice, Highway 20, Box 1070, Fonthill, Ontario, L0S 1E0 (Tel. (416) 892-2656) or at the Central Region Office, 10670 Yonge Street, Richmond Hill, Ontario, L4C 3C9 (Tel. (416) 884-9203), or to the Aggregate Assessment Office, Ontario Geological Survey, Ministry of Northern Affairs and Mines, Room M1B-45, Macdonald Block, Queen's Park, Toronto, Ontario, M7A 1W3, (Tel.(416) 965-1663).

TABLE 1. TOTAL SAND AND GRAVEL RESOURCES, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE*.

1 Class No.	2 Deposit Type (see Appendix C)	3 Areal Extent Acres (Hectares)	4 Original Tonnage Millions of Tons (Tonnes)
CITY OF PORT COLBORNE			
1	S-WD	840 (340)	46 (42)
2	S-LB	80 (32)	3 (3)
3	S-LB	170 (69)	3 (3)
4	S-LB	16 (6)	<1 (<1)
	S-LP	104 (42)	1 (1)
		1210 (490)	53 (48)
TOWN OF FORT ERIE			
1	S-WD	510 (206)	31 (28)
2	S-LB	135 (55)	5 (4)
	S-LP	84 (34)	3 (3)
	S-WD	295 (119)	9 (8)
3	G-LB	112 (45)	2 (2)
4	S-LB	76 (31)	1 (1)
		1210 (490)	51 (46)
Total for Report Area:		2420 (980)	104 (94)

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

* Identified deposit areas within cultural constraint boundaries surrounding Port Colborne, Fort Erie, Ridgeway and Crystal Beach are omitted on all tables.

TABLE 2. SAND AND GRAVEL PITS, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE.

1 No.	2 MTC No.	3 Owner/ Operator	4 Lot	5 Con.	6 Licenced Areas Acres (Hectares)	7 Face Height Feet (Metres)	8 % Gravel
LICENCED PITS							
City of Port Colborne							
1	W3-13	Eberly Trucking Ltd. (Sherkston Beach)	3-7	1	118.0 (47.8)	45 (14)	- dune sand
Town of Fort Erie							
2	W3-17	Hard Rock Paving Ltd.	32	B.F.	9.0 (3.6)	60 (18)	- dune sand
Total for Report Area:					127.0 (51.4)		
UNLICENCED PITS*							
City of Port Colborne							
3	-	unknown	21	4		6 (2)	- clay
4	-	Hugh Cole Construction Ltd.	23	3			- rehabilitated clay pit
5	-	Inco	25	1		12 (4)	- dune sand, now plant site
6	-	Holman	5	1		20 (6)	- dune sand, now recreation site
Town of Fort Erie							
7	-	unknown	27	3		5 (1.5)	- beach, now golf course
8	-	G. Campbell Ltd.	16	10		6 (2)	- clay rehabilitated
9	-	G. Campbell Ltd.	23	ACC		6 (2)	- clay rehabilitated
10	-	G. Campbell Ltd.	16	9		4 (1.2)	- clay
11	-	G. Campbell Ltd.	15	7		4 (1.2)	- clay
12	-	G. Campbell Ltd.	13	8		6 (2)	- clay

*Abandoned pits or wayside pits operating on demand under authority of a permit.

TABLE 3. SELECTED SAND AND GRAVEL RESOURCE AREAS, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE.

1 Deposit No.	2 Unlicenced Area Acres (Hectares)	3 Cultural Setbacks Acres (Hectares)	4 Extracted Area Acres (Hectares)	5 Available Area Acres (Hectares)	6 Estimated Deposit Thickness Feet (Metres)	7 Available Aggregate Millions of Tons (Tonnes)
Town of Fort Erie						
1	112 (45)	37 (15)	0 (0)	75 (30)	9 (3)	2 (2)
City of Port Colborne						
2	128 (52)	23 (9)	0 (0)	105 (42)	7 (2)	2 (2)
Total for Report Area:						
	240 (97)	60 (24)	0 (0)	180 (73)		4 (4)

TABLE 4. TOTAL IDENTIFIED BEDROCK RESOURCES, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE

1 **DRIFT THICKNESS** Feet (Metres)	2 **FORMATION**	3 **ESTIMATED DEPOSIT THICKNESS** Feet (Metres)	4 **AREAL EXTENT** Acres (Hectares)	5 **ORIGINAL TONNAGE** Millions of Tons (Tonnes)
City of Port Colborne				
0-3 (0-1)	Onondaga (Moorehouse Member)	25 (8)	16 (6)	1 (1)
3-25 (1-8)	Onondaga (Moorehouse Member)	25 (8)	190 (77)	17 (15)
25-50 (8-15)	Onondaga (Moorehouse Member)	25 (8)	60 (24)	5 (4)
			265 (107)	23 (21)
0-3 (0-1)	Onondaga (Clarence Member)	25 (8)	365 (148)	33 (30)
3-25 (1-8)	Onondaga (Clarence Member)	25 (8)	2750 (1110)	248 (225)
25-50 (8-15)	Onondaga (Clarence Member)	25 (8)	500 (202)	45 (41)
			3600 (1460)	325 (295)
0-3 (0-1)	Onondaga (Edgecliff Member)	25 (8)	370 (150)	33 (30)
3-25 (1-8)	Onondaga (Edgecliff Member)	25 (8)	1930 (780)	174 (158)
25-50 (8-15)	Onondaga (Edgecliff Member)	25 (8)	350 (142)	32 (29)
			2650 (1070)	239 (217)
0-3 (0-1)	Bois Blanc	15 (5)	173 (70)	9 (8)
3-25 (1-8)	Bois Blanc	15 (5)	1280 (520)	69 (62)
25-50 (8-15)	Bois Blanc	15 (5)	40 (16)	2 (2)
			1490 (600)	80 (72)
0-3 (0-1)	Bertie	40 (12)	410 (166)	59 (54)
3-25 (1-8)	Bertie	40 (12)	1850 (750)	265 (240)
25-50 (8-15)	Bertie	40 (12)	2100 (850)	300 (270)
			4350 (1760)	620 (560)

TABLE 4. TOTAL IDENTIFIED BEDROCK RESOURCES, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE

1 DRIFT THICKNESS Feet (Metres)	2 FORMATION	3 ESTIMATED DEPOSIT THICKNESS Feet (Metres)	4 AREAL EXTENT Acres (Hectares)	5 ORIGINAL TONNAGE Millions of Tons (Tonnes)
25-50 (8-15)	Salina	60 (18)	295 (119)	58 (53)
			12,600 (5100)	1340 (1220)
Town of Fort Erie				
3-25 (1-8)	Onondaga (Moorehouse Member)	25 (8)	115 (46)	10 (9)
25-50 (8-15)	Onondaga (Moorehouse Member)	25 (8)	80 (32)	7 (6)
			195 (79)	17 (15)
0-3 (0-1)	Onondaga (Clarence Member)	25 (8)	1070 (435)	96 (87)
3-25 (1-8)	Onondaga (Clarence Member)	25 (8)	2090 (850)	188 (170)
25-50 (8-15)	Onondaga (Clarence Member)	25 (8)	450 (182)	40 (36)
			3600 (1460)	325 (295)
0-3 (0-1)	Onondaga (Edgecliff Member)	25 (8)	230 (93)	21 (19)
3-25 (1-8)	Onondaga (Edgecliff Member)	25 (8)	3900 (1580)	350 (320)
25-50 (8-15)	Onondaga (Edgecliff Member)	25 (8)	600 (243)	54 (49)
			4750 (1920)	425 (385)
0-3 (0-1)	Bois Blanc	15 (5)	550 (222)	30 (27)
3-25 (1-8)	Bois Blanc	15 (5)	2150 (870)	116 (105)
25-50 (8-15)	Bois Blanc	15 (5)	360 (146)	19 (17)
			3050 (1230)	165 (150)
0-3 (0-1)	Bertie	40 (12)	540 (218)	78 (71)
3-25 (1-8)	Bertie	40 (12)	1540 (620)	222 (201)

TABLE 4. TOTAL IDENTIFIED BEDROCK RESOURCES, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE

1 **DRIFT THICKNESS** Feet (Metres)	2 **FORMATION**	3 **ESTIMATED DEPOSIT THICKNESS** Feet (Metres)	4 **AREAL EXTENT** Acres (Hectares)	5 **ORIGINAL TONNAGE** Millions of Tons (Tonnes)
25-50 (8-15)	Bertie	40 (12)	1770 (720)	255 (231)
			3850 (1560)	560 (510)
3-25 (1-8)	Salina	60 (18)	325 (132)	64 (58)
25-50 (8-15)	Salina	60 (18)	6400 (2600)	1270 (1150)
			6700 (2700)	1330 (1210)
			22,100 (8900)	2800 (2550)
Total for Report Area:			34,500 (14 000)	4150 (3750)

TABLE 5. QUARRIES, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE.

1 NO.	2 MTC NO.	3 OWNER/ OPERATOR	4 LOT	5 CON.	6 LICENCED AREA Acres (Hectares)	7 FACE HEIGHT Feet (Metres)
LICENCED QUARRIES						
City of Port Colborne						
Q1	W3-19	Port Colborne Quarries	19,20	2	319.0 (129.1)	50 (15)
Town of Fort Erie						
Q2	W3-12	Walker Bros. (Ridgemount #1)	3,4	8	203.0 (82.2)	45 (14)
Q3	W3-7	Walker Bros. (Ridgemount #2)	5,6 7,8	8 NR	193.0 (78.1)	45 (14)
Q4	-	Walker Bros. (Ridgemount #3)	7,8	7 NR	110.0 (44.5)	20 (6)
					506.0 (204.8)	
Total for Report Area:					825.0 (333.9)	
UNLICENCED QUARRIES*						
City of Port Colborne						
Q5	-	Niagara Peninsula Conservation Authority (Canada Cement Quarry)	33	1		25 (8) partially water filled
Q6	-	Port Colborne Quarries	23,24	2		50 (15) now processing plant site for Q1
Q7	-	unknown	19	3		10 (3) now local dump site
Q8	-	unknown	4	1		10 (3) water filled
Q9	-	Sherkston Beach Ltd.	4,5	1		10 (3) water filled, recreational area

*Abandoned quarries or wayside quarries operating on demand under authority of a permit.

TABLE 5. QUARRIES, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE.

1 NO.	2 MTC NO.	3 OWNER/ OPERATOR	4 LOT	5 CON.	6 LICENCED AREA Acres (Hectares)	7 FACE HEIGHT Feet (Metres)
Town of Fort Erie						
Q10	-	unknown	21	3		10 (3) residential development on site
Q11	-	unknown	14	1		12 (4) water filled, recreational area
Q12	W3-10	unknown	13	1		6 (2) water filled, recreational area
Q13	-	unknown	12	2		5 (1.5) water filled
Q14	-	unknown	12	2		waterfilled

TABLE 6. SELECTED BEDROCK RESOURCE AREAS, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE.

1 DEPOSIT NO.	2 DEPTH OF OVERBURDEN Feet (Metres)	3 UNLICENCED AREA Acres (Hectares)	4 CULTURAL SETBACKS Acres (Hectares)	5 EXTRACTED AREA Acres (Hectares)	6 AVAILABLE AREA Acres (Hectares)	7 ESTIMATED WORKABLE THICKNESS Feet (Metres)	8 AVAILABLE RESOURCES Millions of Tons (Tonnes)
City of Port Colborne							
1a	0-25 (0-8)	2220 (900)	670 (270)	0 (0)	1550 (630)	40 (12)	223 (202)
2a	0-25 (0-8)	1450 (590)	290 (117)	<1 (<1)	1160 (470)	55* (17)	230 (209)
3a	0-25 (0-8)	2190 (890)	850 (345)	0 (0)	1340 (540)	60** (18)	290 (265)
		5900 (2390)	1810 (730)	<1 (<1)	4050 (1640)		740 (670)
Town of Fort Erie							
1a	0-25 (0-8)	680 (275)	140 (57)	0 (0)	540 (218)	40 (12)	78 (71)
1b	0-25 (0-8)	1400 (570)	490 (198)	0 (0)	910 (370)	40 (12)	131 (119)
2a	0-25 (0-8)	880 (355)	100 (40)	0 (0)	780 (315)	55* (17)	154 (140)
2b	0-25 (0-8)	1820 (740)	750 (305)	<1 (<1)	1070 (435)	55* (17)	212 (192)
3a	0-25 (0-8)	1830 (740)	430 (174)	0 (0)	1400 (570)	60** (18)	300 (270)
3b	0-25 (0-8)	2300 (930)	530 (214)	0 (0)	1770 (720)	60** (18)	380 (345)
		8900 (3600)	2440 (990)	<1 (<1)	6500 (2650)		1260 (1140)
Totals for Report Area							
1	0-25 (0-8)	4300 (1740)	1300 (530)	0 (0)	3000 (1210)	40 (12)	430 (390)
2	0-25 (0-8)	4150 (1680)	1140 (460)	2 (1)	3000 (1210)	55* (17)	600 (540)
3	0-25 (0-8)	6300 (2550)	1810 (730)	0 (0)	4500 (1820)	60** (18)	970 (880)
		14,800 (6000)	4250 (1720)	2 (1)	10,500 (4250)		2000 (1810)

* Workable thickness estimate in Area 2 includes both the Bois Blanc and Bertie Formations.

** Workable thickness estimate in Area 3 includes the Edgecliffe Member of the Onondaga Formation, the Bois Blanc Formation and part of the Bertie Formation.

TABLE 7. SUMMARY OF TEST HOLE DATA, CITY OF PORT COLBORNE AND TOWN OF FORT ERIE.

-NONE-

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Appendix A — Suggested Additional Reading

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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.

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

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

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

Cambrian: The first period of the Palezoic Era, thought to have covered the time between 570 and 500 million years ago. The Cambrian precedes the Ordovician Period.

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 percent coarse aggregate larger than the No. 4 sieve (4.75 mm) as well as a minimum of 20 percent 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 395 and 345 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest found 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 southern Ontario.

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

Granular base course: Components of the 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. Several types have been defined: Granular Base Course A consists of crushed and processed aggregate and has relatively stringent quality standards in comparison to Granular Base Course B and C which are usually pit-run or other unprocessed aggregate.

Hot-laid (or asphaltic) aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course (H.L. 1, 3 and 4), or as binder course (H.L. 2 and 8) used to bind the surface course to the underlying granular base course.

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

Magnesium sulphate soundness test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible will usually break down and give high losses in this test.

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

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

Paleozoic Era: One of the major divisions of the geologic time scale thought to have covered the time 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. The test result is a Petrographic Number (P.N.). The higher the P.N. 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".

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.

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.

Silurian: An early period of the Palezoic Era thought to have covered the time between 435 and 395 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 southern 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 southern 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 discontinuties. 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 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.

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 southern Ontario. Well developed lacustrine beaches are usually less than 20 feet (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 southern 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 base course 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 southern Ontario are derived from, and deposited on, pre-existing lacustrine sand plain deposits. Windblown sediments almost always consists 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

BEDROCK SUITABLE FOR CRUSHED STONE PRODUCTS

Bass Islands Formation (Upper Silurian)

(Includes the Bertie Formation of the Niagara Peninsula) Composition: Medium- to massive-bedded, aphanitic, brown dolostone with shaly partings. Thickness: 35 to 60 feet (11 to 18 m) near Hagersville. Uses: Quarried for crushed stone on the Niagara Peninsula at Fort Erie, Cayuga, Hagersville, and Dunnville. Los Angeles Abrasion Test: 17-35% loss; Absorption: 1.4%. Shaly parts are unsuitable for aggregate because of high soundness losses.

Bobcaygeon Formation (Middle Ordovician)

Composition: Compact, homogeneous, medium- to thin-bedded, fine-grained limestone with some argillaceous and shaly partings. Thickness: The lower unit is 40 to 72 feet (12 to 22 m) thick in the east and the remainder of the formation is 40 feet (12 m). Uses: Quarried at Kirkfield and Marysville for crushed stone. The Bobcaygeon Formation has consistently acceptable quality for granular base course materials and concrete.

Bois Blanc Formation (Lower-Middle Devonian)

Composition: Brownish grey, medium-crystalline, medium- to thin-bedded, cherty limestone, commonly fossiliferous. Limestone may be silty or sandy in places. Thickness: 9 to 200 feet (3 to 61 m). Uses: Quarried at Hagersville, Cayuga, and Port Colborne for crushed stone. High cherty content makes much of the material unsuitable for concrete aggregate. Los Angeles Abrasion Test: 14-28% loss; Soundness Test: 4-10% loss; Absorption: 0.7-2.0%.

Dundee Formation (Middle Devonian)

Composition: Fine- to medium-crystalline, brownish grey, medium- to thick-bedded, dolomitic limestone with shaly partings, sandy layers, and chert in some areas. Thickness: 60 to 160 feet (18 to 49 m). Uses: Quarried near Port Dover and Pelee Island for crushed stone. Used at St. Marys as raw material for portland cement. Los Angeles Abrasion Test: 22-32% loss; Absorption: 0-4%.

Gull River Formation (Middle Ordovician)

Composition: Member A: thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone with a maximum thickness of 60 feet (18 m). Members B and C are dense, aphanitic limestones with argillaceous dolostone interbeds. Uses: Quarried at Kirkfield and Uhthoff for crushed stone. The product is generally fresh and compact with good cubic-shaped factor, low clay content, low absorption, and low soundness losses. Smooth particle surfaces may cause adhesion problems for asphalt. There is some alkali reactivity in a few of the layers.

Lockport and Amabel Formations (Middle Silurian)

Composition: Amabel Formation (Waterdown to the Bruce Peninsula): massive, fine-crystalline dolostone, with reef facies dolostone near Georgetown. Lockport Formation (lateral facies equivalent to the Amabel Formation from Waterdown to Niagara Falls): thin- to massive-bedded, fine-to medium-grained dolostone.

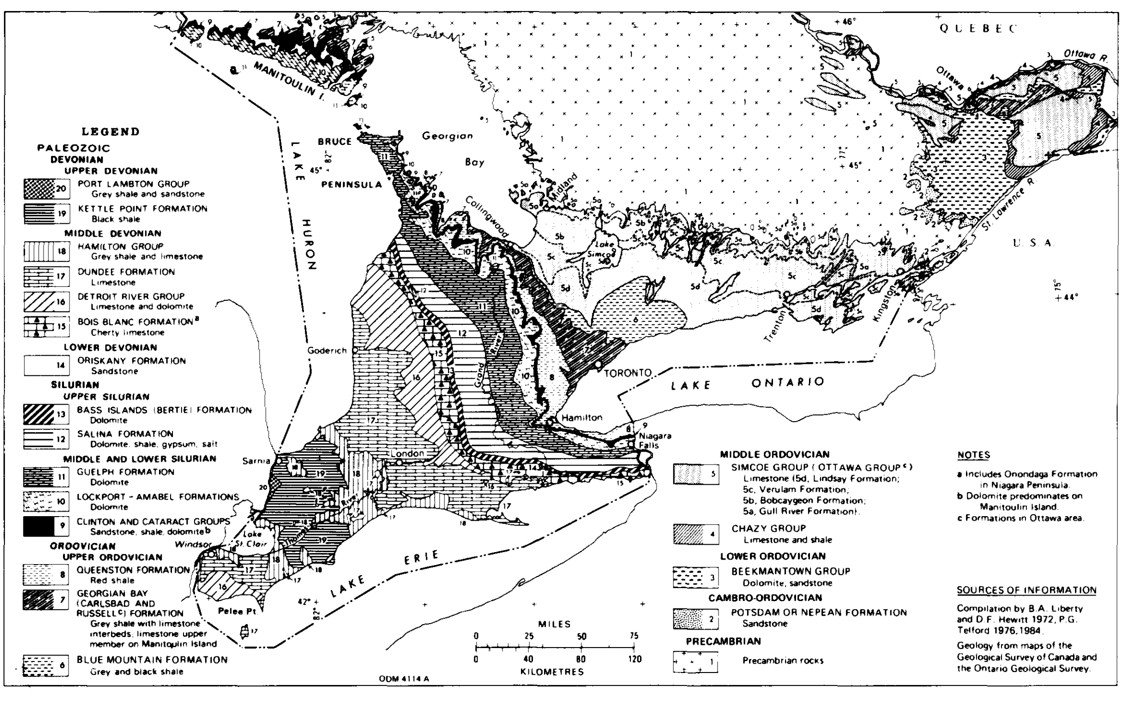

Figure 2. Bedrock Geology of Southern Ontario.

Thickness: Amabel Formation: maximum observed thickness of 84 feet (26 m). Lockport Formation: up to 130 feet (40 m). Uses: The Lockport and Amabel 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. Los Angeles Abrasion Test: 21-35% loss; Soundness Test: 2.0% loss; Absorption: 0.4-1.6%.

Onondaga Formation (Middle Devonian)

(Equivalent to the Detroit River Group, with a textural change) Composition: Edgecliff Member: medium-bedded, fine- to medium-grained, dark grey cherty limestone with an estimated thickness of 25 to 30 feet (8 to 9 m). Clarence Member: massive-bedded, dark grey-brown, fine-grained, very cherty limestone having estimated thickness of 26 feet (8 m). Moorehouse Member: medium-bedded, dark grey-brown or purplish brown, fine- to coarse-grained, variably cherty limestone with an estimated thickness of 15 to 25 feet (5 to 8 m). Uses: Quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne. High cherty content makes much of the material unsuitable for concrete aggregate.

Ottawa Formation (Middle Ordovician)

Composition: Lower Phase (Lowville and Pamela Beds): shale, some sandstone and dolostone. Thickness: 100 feet (30 m). Middle Phase (Hull, Rockland, and Leray Beds): pure, thick-bedded, crystalline limestone. Thickness: 150 feet (46 m) near Ottawa. Upper Phase (Cobourg and Sherman Fall Beds): pure and impure crystalline limestone with few to numerous shaly partings, 450 to 475 feet (137 to 145 m) thick near Ottawa. Uses: The Leray, Rockland, and Hull Beds have been quarried extensively for crushed stone and for building stone. In addition, the Hull Beds are an excellent source of limestone for cement production and agricultural uses.

Oxford Formation (Lower Ordovician)

Composition: Medium- to thick-bedded, grey dolostone, with some shaly partings. Thickness: 240 feet (73 m). Uses: Quarried for crushed stone (road and concrete aggregate) at Ottawa, Brockville, and Smiths Falls.

BEDROCK SUITABLE FOR LIME PRODUCTION AND OTHER CHEMICAL USES

Detroit River Group (Middle Devonian)

(Equivalent to the Onondaga Formation in the Niagara Peninsula, with a textural change) Composition: Near Beachville, the group consists of medium- to microcrystalline, medium-bedded, high-purity limestone. It grades northwards near St. Marys to soft, evenly bedded, fine-grained dolostone with bituminous laminae. Massive, porous, reef facies material also occurs to the north (Formosa Reef Limestone). Thickness: 100 feet (30 m) at Beachville, 350 feet (107 m) at Clinton. Uses: The most important source of high-purity limestone in Ontario is the Lucas Formation of the Detroit River Group at Beachville. Detroit River limestone produces much of Ontario's lime and cement. The Anderdon Member of the Lucas Formation is quarried at Amherstburg for crushed stone.

Grenville Marble (Precambrian)

Composition: Recrystallized fine- to coarse-grained white limestone and dolostone, usually of high chemical purity. Uses: Lime production, but also in small amounts for terrazzo chips, poultry grit, decorative stone, and building stone.

Guelph Formation (Middle Silurian)

Composition: Aphanitic to medium-crystalline, thick-bedded, soft, porous dolostone, characterized in places by extensive vuggy, porous reefal facies dolostone of high chemical purity. Thickness: 100 to 170 feet (30 to 52 m). Uses: The main use is for dolomitic lime in the construction industry. The formation is quarried near Hamilton and Guelph.

Lindsay Formation (Upper Ordovician)

Composition: fine-crystalline, rubbly, nodular-weathering limestone. Collingwood Member: organic-rich interbedded calcareous shales and limestones. Uses: Quarried at Picton, Ogden Point and Bowmanville for cement. The formation is generally unsuitable for crushed stone, concrete aggregate, or granular base course.

Verulam Formation (Middle Ordovician)

Composition: Fossiliferous, pure to argillaceous limestone and interbedded calcareous shale. The rock is not resistant to erosion and commonly weathers to rubble. Thickness: 200 to 300 feet (61 to 91 m). Uses: Quarried at Picton, Ogden Point, and Mara Township for use in cement manufacture. The formation is unsuitable for crushed stone because of clay impurities, many clayey interbeds, and low abrasion resistance, high soundness losses and poor freeze and thaw resistance.

BEDROCK SUITABLE FOR BRICK AND TILE MANUFACTURE

Georgian Bay Formation (Upper Ordovician) (Formerly known as the Meaford-Dundas and Blue Mountain shales in the Toronto and Bruce Peninsula areas) Composition: Soft, fissile, blue-grey shale with limey or sandy lenses in a few places. Thickness: 640 feet (195 m) at Toronto. Uses: Several producers in the vicinity of Metro Toronto produce brick and structural tile. Lightweight aggregate has been produced at Streetsville by heat expansion of the shale.

Hamilton Group (Middle Devonian)

Composition: Grey shale with interbeds of crystalline and cherty limestone. The group has six formations, but only the Arkona Formation is of commercial value. It is a soft, light grey, calcareous shale which is plastic and easily worked when wet. Thickness: 80 to 300 feet (24 to 91 m). The Arkona Formation has a thickness of 14 to 121 feet (4 to 37 m). Uses: The Arkona Formation is extracted at Thedford and near Arkona for production of drainage tile.

Queenston Formation (Upper Ordovician)

Composition: Red, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding. Thickness: 400 to 500 feet (122 to 152 m). Uses: There are several large shale quarries developed in the Queenston Formation in the Toronto-Hamilton region and one at Russell, near Ottawa. All produce brick for construction. The Queenston Formation is the most important source material for brick manufacture in the Province.

BEDROCK SUITABLE FOR OTHER INDUSTRIAL PRODUCTS

Nepean (Potsdam) Formation (Cambro-Ordovician)

Composition: Creamy, coarse-grained, silica sandstone. Uses: Quarried throughout its area of outcrop for building stone, decorative stone, abrasives, and for glass making.

Salina Formation (Upper Silurian)

Composition: Grey and red shale, brown dolomite, and, in places, salt, anhydrite, and gypsum. The formation consists predominantly of evaporite deposits with up to eight members identified. Uses: Gypsum is mined at Hagersville, Caledonia, and Drumbo. Salt is mined at Goderich and is produced from brine wells at Amherstburg, Windsor, and Sarnia.

Blue Mountain Formation (Upper Ordovician)

(Formerly known as the Whitby Formation) Composition: Blue-grey, predominantly non-calcareous shale. Uses: Quarried at Bowmanville for use in cement production.

(continued from right margin)

G 1 IC/C·O — Deposit symbol; see below.

Texture symbol; see below; see Figures

·GT·2 — Geophysical traverse line; Identification number: see Table 8.

TEXTURE SYMBOL

Fines: silt and clay (<.075 mm)
Gravel (>4.75 mm)
Sand (.075 - 4.75 mm)

The Texture Symbol provides quantitative assessment of the grain size distribution at a sampled location. The relative amounts of gravel, sand, silt and clay in the sampled material are shown graphically by the subdivision of a circle into proportional segments. The above example shows a hypothetical sample consisting of 45% gravel, 35% sand and 20% silt and clay.

DEPOSIT SYMBOL

Gravel Content — G; **Thickness Class** — 1; **Geological Type** — IC; **Quality Indicator** — C·O

Deposits are identified by Gravel Content, Thickness Class, Geological Type and Quality Indicator. Gravel Content is expressed as a percentage of gravel-sized material (i.e. material retained on the 4.75 mm sieve). Thickness Class is based on potential aggregate tonnage per acre. Geological Type refers to geologic origin. Quality Indicator describes objectionable grain size and lithology.

Gravel Content

- **G** Greater than 35% gravel.
- **S** Less than 35% gravel.

Thickness Class

Class	Average Thickness in Feet (Metres)	Tons per Acre	Tonnes per Hectare
1	greater than 20 (>6)	greater than 50,000	greater than 112 000
2	10 - 20 (3 - 6)	25,000 - 50,000	56 000 - 112 000
3	5 - 10 (1.5 - 3)	12,500 - 25,000	28 000 - 56 000
4	less than 5 (<1.5)	less than 12,500	less than 28 000

Geological Type

AL	Older Alluvium	K	Kame
E	Esker	LB	Lacustrine Beach
EM	End Moraine	LD	Lacustrine Delta
IC	Undifferentiated Ice-Contact Stratified Drift	LP	Lacustrine Plain
		OW	Outwash
ICT	Ice-Contact Terrace	WD	Windblown Forms

(see Appendix C for descriptions of Geological Types)

Quality Indicator

If blank, no known limitations present.

- **C** Clay and/or silt (fines) present in objectionable quantities.
- **L** Deleterious lithologies present.
- **O** Oversize particles or fragments present in objectionable quantities.

SOURCES OF INFORMATION

Base map by Surveys and Mapping Branch, Ontario Ministry of Natural Resources.
Licence data from District and Regional Offices, Ontario Ministry of Natural Resources.
Aggregate suitability data from the Engineering Materials Office, Ontario Ministry of Transportation and Communications.
Test hole data from Aggregate Assessment Office, Ontario Geological Survey, Ontario Ministry of Northern Affairs and Mines.
Selected water well data from the Ontario Ministry of the Environment.
Drilling data from the Petroleum Resources Section, Ontario Ministry of Natural Resources.
Geology by: B.H. Feenstra, 1972.

Compilation and Drafting by: Staff of the Aggregate Assessment Office, Ontario Geological Survey, Ontario Ministry of Northern Affairs and Mines.
This map is to accompany O.G.S. Aggregate Resources Inventory Paper 117.

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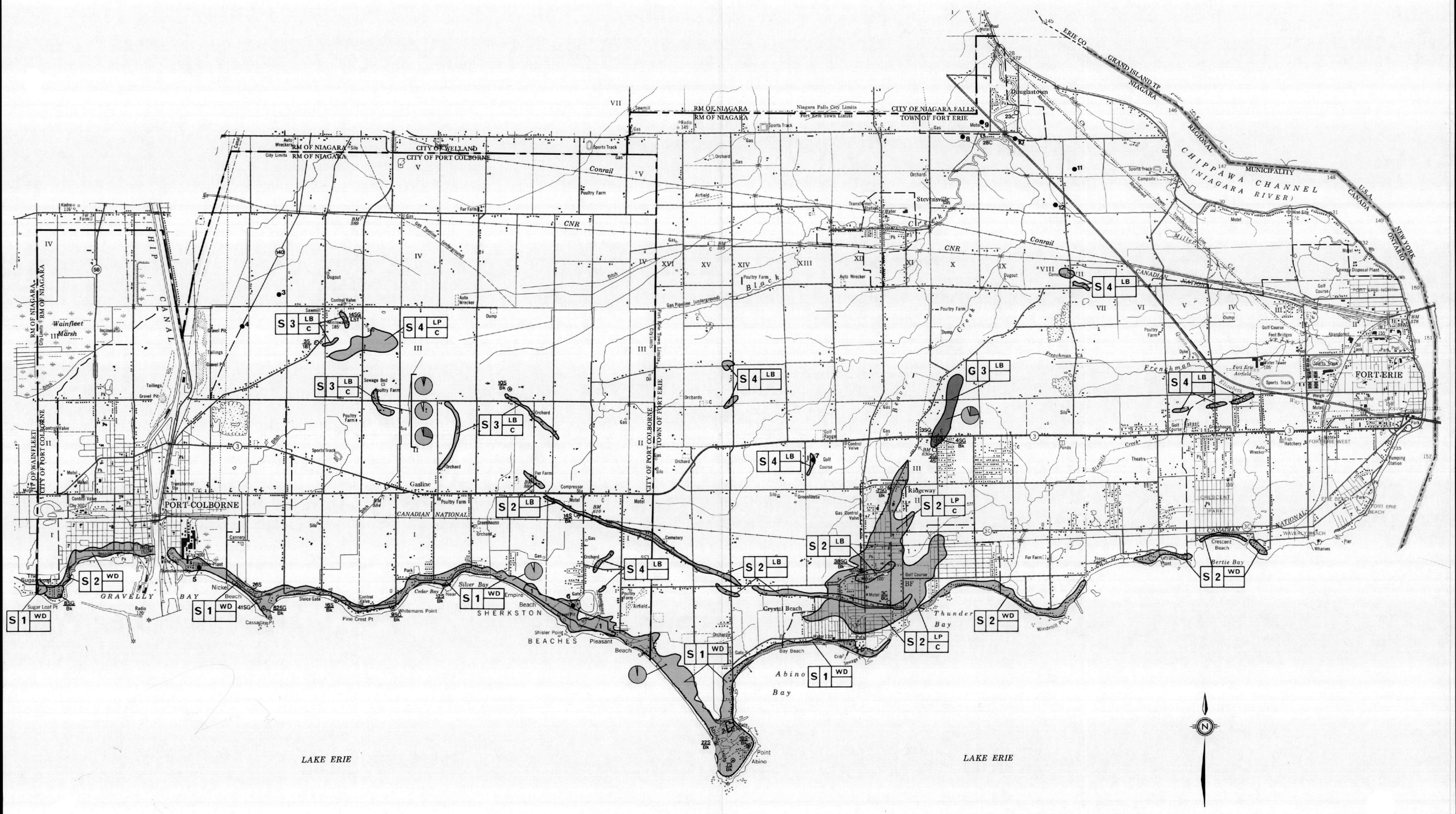
Issued 1985.

Information quoted for an individual test hole or pit refers to a specific sample or face. Care should be exercised in extrapolating such information to other parts of the deposit.



CITY OF PORT COLBORNE
TOWN OF FORT ERIE

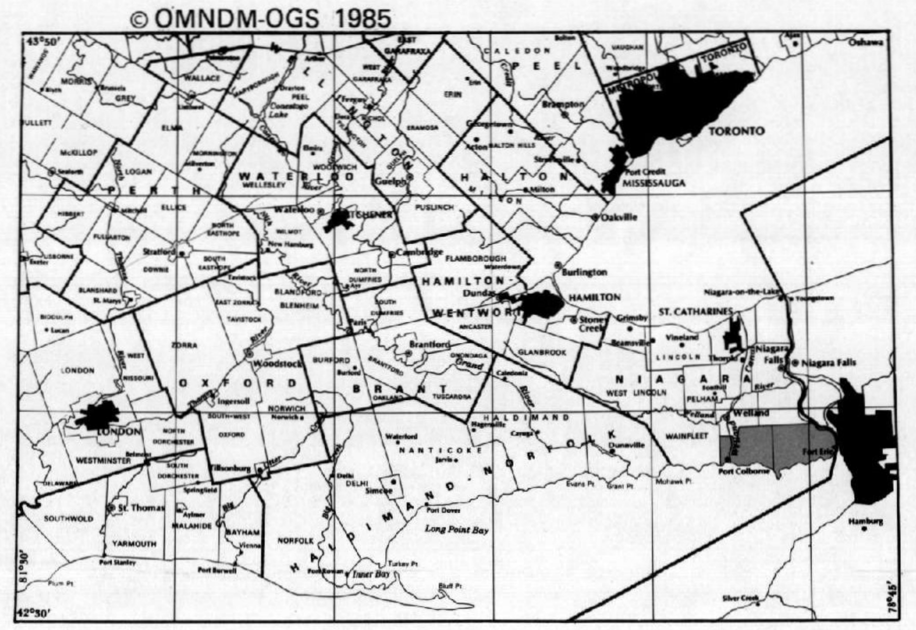
Ministry of Northern Development and Mines
Ontario

ONTARIO GEOLOGICAL SURVEY
AGGREGATE RESOURCES INVENTORY
CITY OF PORT COLBORNE AND TOWN OF FORT ERIE
REGIONAL MUNICIPALITY OF NIAGARA
MAP 1
DISTRIBUTION OF SAND AND GRAVEL DEPOSITS

Scale 1: 50 000

Mile 1 0 1 Mile
Metres 1000 0 1 Kilometre

NTS Reference: 30 L/14, 30 L/15



Location Map — Scale 1:1,800,000

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

MAP UNITS

- Gravel deposit.
- Sand deposit.
- Gravel overlain by other surficial material.
- Sand overlain by other surficial material.
- Other surficial deposits or exposed bedrock.

SYMBOLS

- Geological and aggregate thickness boundary of sand and gravel deposits.
- Municipal boundary.
- 2 — Licenced property boundary; Property number: see Table 2.
- ● 3 — Unlicenced sand or gravel pit*; Property number: see Table 2.
  *Abandoned pit or wayside pit operating on demand under authority of a permit.
- ·TH·2 — Test hole location; identification number; see Table 7.
- O 6/24G — Selected water well location. Layers of materials are described by: reported thickness of material (in feet); reported type of material (number only - overburden, G- gravel, S - sand, C - clay, T - till, B - boulders, Bk - bedrock).

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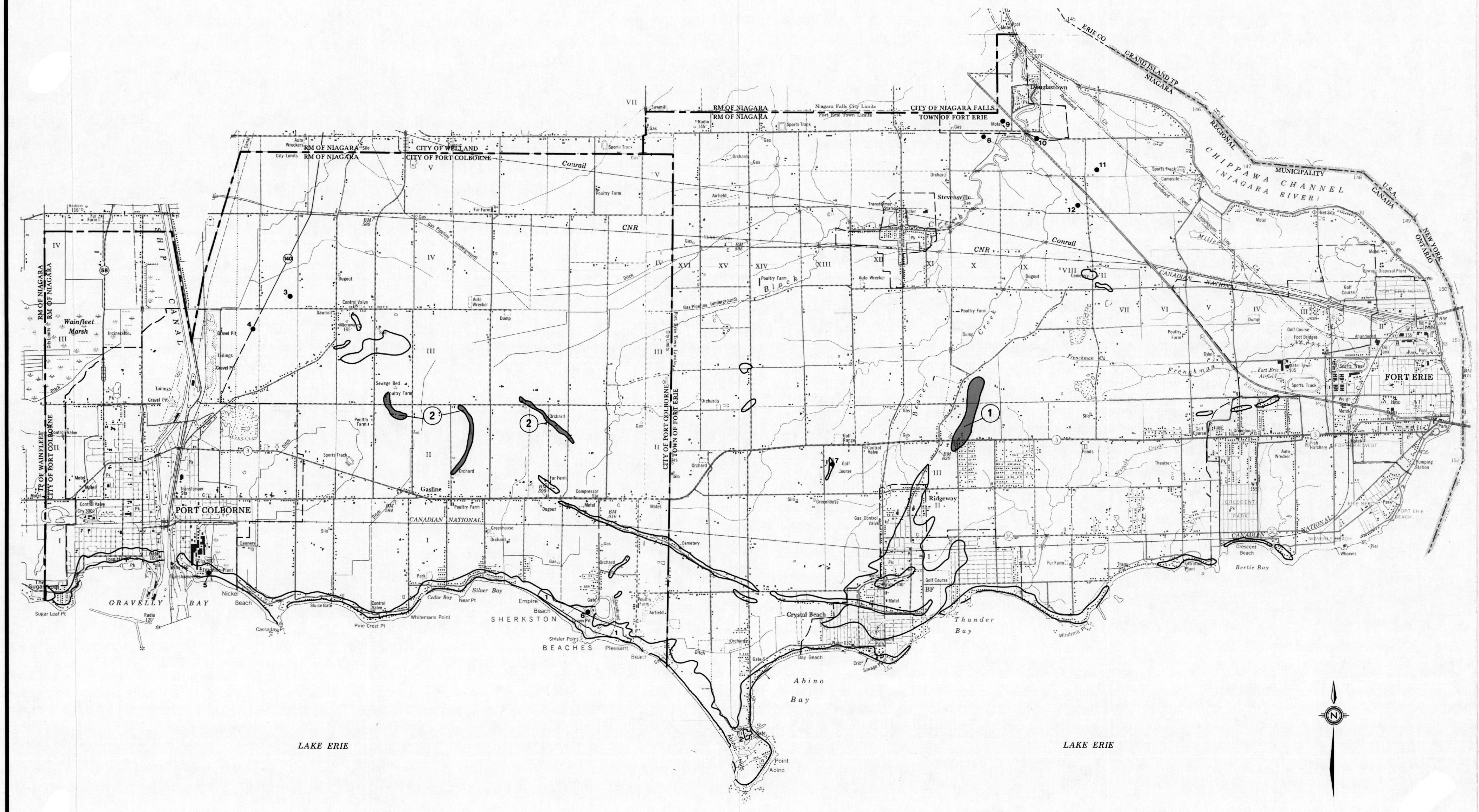

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ONTARIO GEOLOGICAL SURVEY

AGGREGATE RESOURCES INVENTORY

CITY OF PORT COLBORNE

AND TOWN OF FORT ERIE

REGIONAL MUNICIPALITY OF NIAGARA

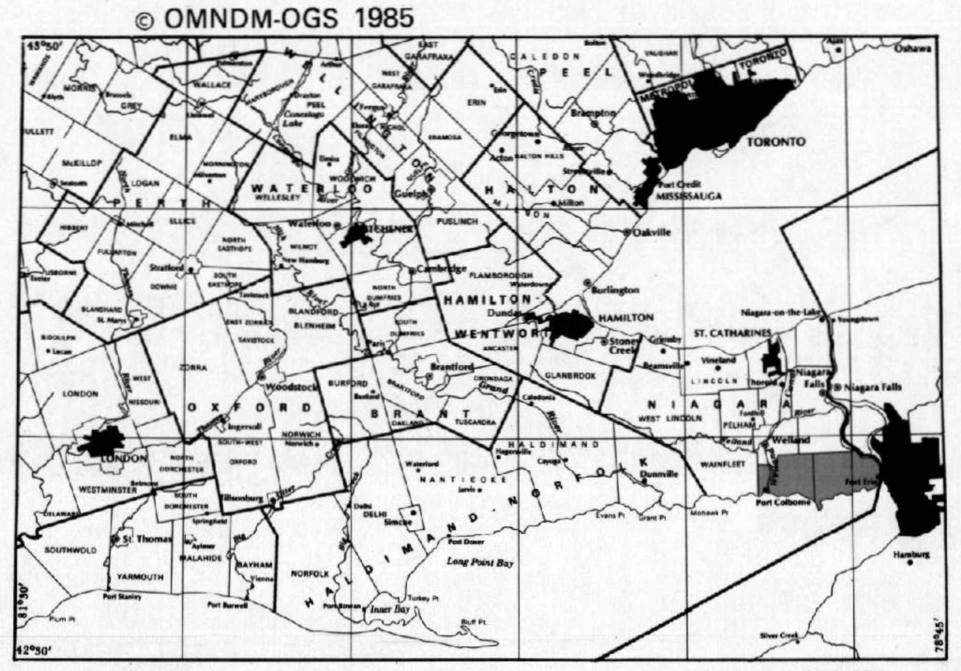
MAP 2
SELECTED SAND AND GRAVEL RESOURCE AREAS

Scale 1: 50 000

Mile 1 0 1 Mile

Metres 1000 0 1 Kilometre

NTS Reference: 30 L/14, 30 L/15



Location Map Scale 1:1,800,000

LEGEND

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

MAP UNITS

1 — Selected sand and gravel resource area, primary significance; deposit number; see Table 3.

Selected sand and gravel resource area, secondary significance.

Selected sand and gravel resource area, tertiary significance.

SYMBOLS

Geological and aggregate thickness boundary of sand and gravel deposits.

Municipal boundary

2 — Licenced property boundary; Property number: see Table 2.

● 3 — Unlicenced sand or gravel pit*; Property number: see Table 2.
*Abandoned pit or wayside pit operating on demand under authority of a permit.

SOURCES OF INFORMATION

Base map by Surveys and Mapping Branch, Ontario Ministry of Natural Resources.

Licence data from District and Regional Offices, Ontario Ministry of Natural Resources.

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Geology by: B.H. Feenstra, 1972.

Compilation and Drafting by: Staff of the Aggregate Assessment Office, Ontario Geological Survey, Ontario Ministry of Northern Affairs and Mines.
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DRIFT THICKNESS

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

SYMBOLS

- (1) Selected bedrock resource area; deposit number; see Table 6.
- Geological formation boundary.
- Geological formation member boundary.
- Formation thickness boundary (see text).
- 25 Drift thickness contour. (3-foot, 25-foot and 50-foot contours are shown).
- Municipal boundary.
- Q2 Licenced quarry boundary; Property number: see Table 5.
- ● Q3 Unlicenced quarry*; Property number: see Table 5. *Abandoned quarry or wayside quarry operating on demand under authority of a permit.
- x Isolated bedrock outcrop.
- O 24 Selected water well location; reported depth to bedrock (in feet).

SOURCES OF INFORMATION

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Drilling data from the Petroleum Resources Section, Ontario Ministry of Natural Resources.
Drift Thickness by: B.H. Feenstra and M. Troper, 1982.
Geology by: P.G. Telford and G.A. Tarrant, 1975.

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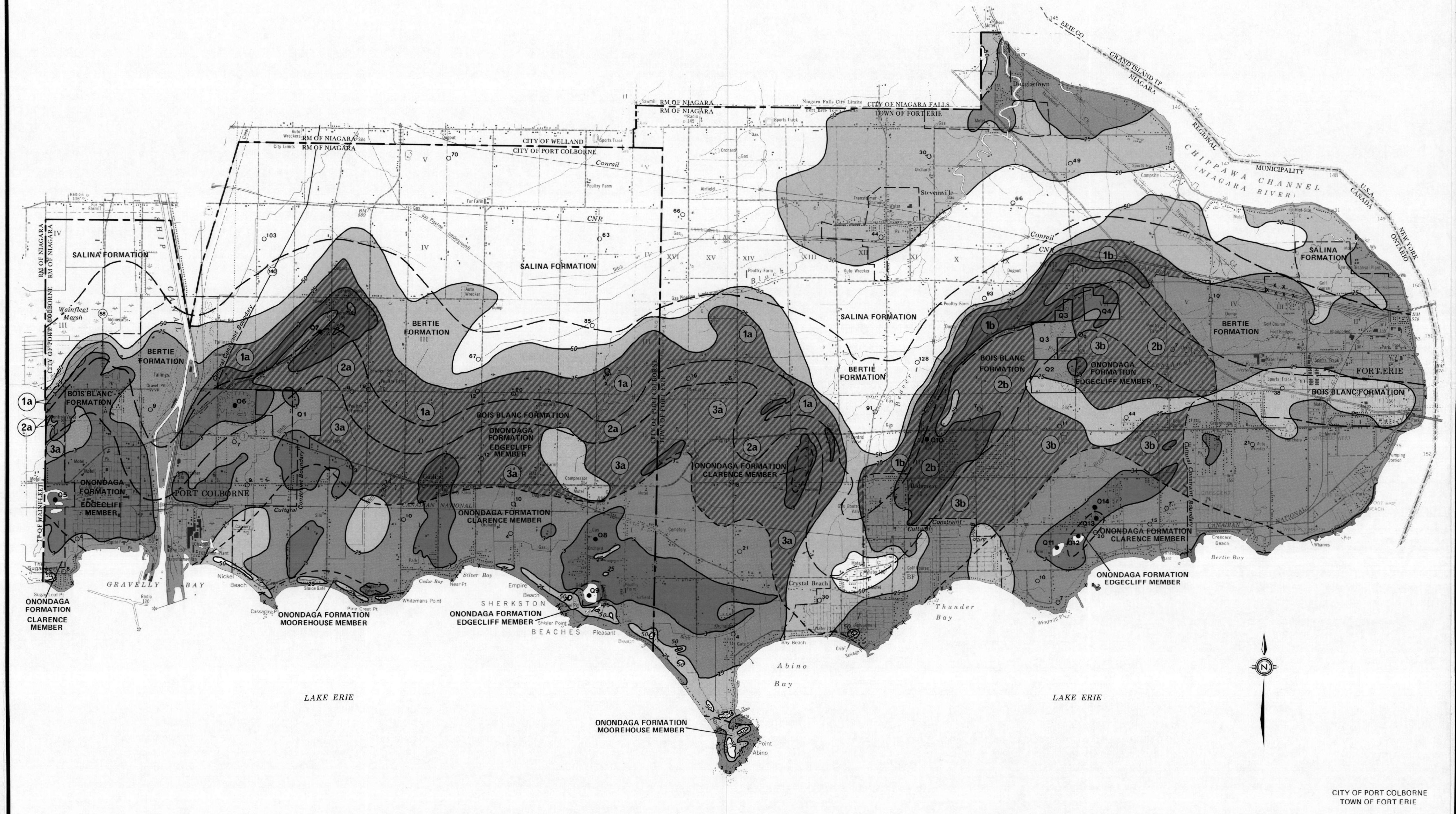

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ONTARIO GEOLOGICAL SURVEY

AGGREGATE RESOURCES INVENTORY

CITY OF PORT COLBORNE AND TOWN OF FORT ERIE

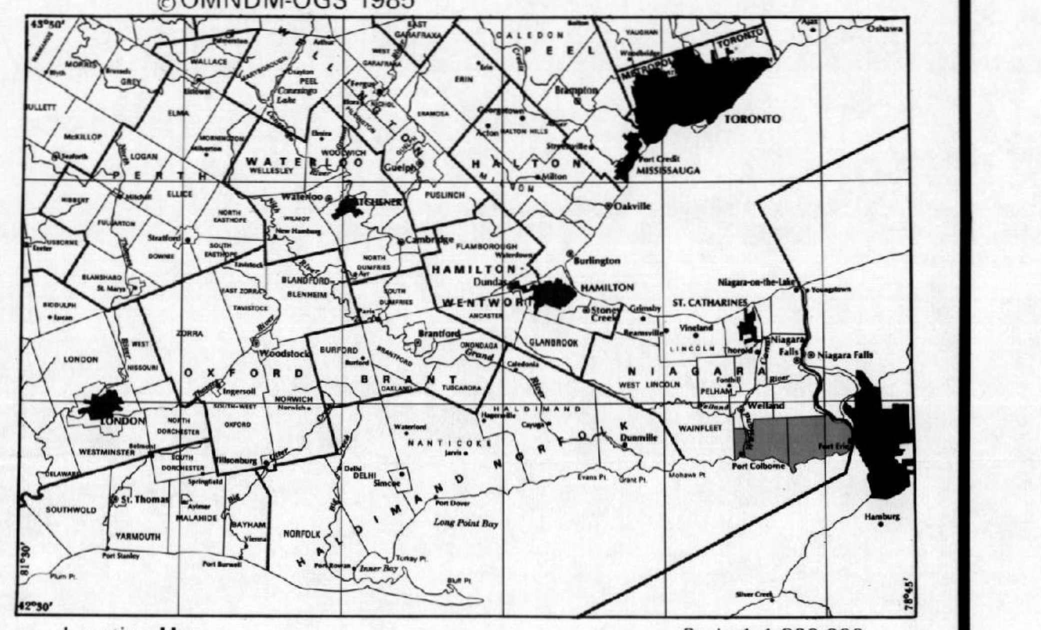
REGIONAL MUNICIPALITY OF NIAGARA

MAP 3
BEDROCK RESOURCES

Scale 1: 50 000

Mile 1 0 1 Mile
Metres 1000 0 1 Kilometre

NTS Reference: 30 L/14, 30 L/15



Location Map Scale 1:1,800,000

LEGEND

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

BEDROCK UNITS

PALEOZOIC

DEVONIAN

MIDDLE DEVONIAN

ONONDAGA FORMATION
Cherty Limestone

LOWER DEVONIAN

BOIS BLANC FORMATION
Cherty Limestone

SILURIAN

UPPER SILURIAN

BERTIE FORMATION
Dolostone

SALINA FORMATION
Dolostone, shale, gypsum, salt.

(continued at left margin)