ISSN 1916-6117 (online)
ISBN 978-1-4606-5577-1 (PDF)

ISSN 0826-9580 (print)
ISBN 978-1-4606-5576-4 (print)

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Aggregate and Industrial Mineral Potential of the Guelph Formation, Southern Ontario

2015

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ONTARIO GEOLOGICAL SURVEY

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Aggregate and Industrial Mineral Potential of the Guelph Formation, Southern Ontario

by

D.J. Rowell

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Abstract

The Guelph Formation of south-central and southwestern Ontario is a high-purity dolostone that can be extracted, processed and used in the manufacture of metallurgical flux, chemical stone and other industrial mineral applications. The Guelph Formation has also been tested extensively for use as a high-specification bedrock-derived aggregate source (i.e., for use in asphalt and concrete products). The results of the aggregate quality testing have been inconclusive, as the formation easily meets or exceeds some aggregate quality tests (e.g., Micro-Deval specifications), but consistently fails to meet other aggregate quality tests (e.g., absorption specifications).

Therefore, it was proposed that a two-year study be completed to collect additional Guelph Formation samples and perform geochemical analyses and “standard” aggregate testing to 1) provide the industrial mineral industry with some additional data and guidance as to the true potential of the Guelph Formation; and 2) provide the aggregate industry additional information on where the Guelph Formation may be competent enough to manufacture high-specification bedrock-derived aggregate products. The study was also completed to try to explain why the Guelph Formation consistently failed some of the “standard” aggregate testing.

“Introduction and Geological Setting” defines the Guelph Formation and discusses the location, thickness, stratigraphy and diagenesis of the formation. “Industrial Mineral Potential” provides the results of the geochemical analyses of the Guelph Formation, which confirms that this formation can be used by the industrial mineral sector. This part of the report also provides mineralogical and petrographic evidence to confirm the high-purity nature of this dolostone unit. “Aggregate Potential” provides the results of the aggregate quality testing that was completed as part of this study. This part of the report also provides an explanation as to why this formation consistently fails to meet aggregate product specifications. Conclusions that are important to the industrial mineral and aggregate industries are bolded within the regular text of this document, and are re-stated in “Summary”.

Aggregate and Industrial Mineral Potential of the Guelph Formation, Southern Ontario

D.J. Rowell[1]

Ontario Geological Survey
Open File Report 6307
2015

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[1] **Earth Resources and Geoscience Mapping Section, Ontario Geological Survey**

Introduction and Geological Setting

INTRODUCTION

Previous aggregate quality test results for the Guelph Formation confirm an interesting dilemma that representatives from the aggregate industry have been struggling with for some time. In some parts of southern Ontario, the Guelph Formation tests extremely well for the manufacture of high-specification bedrock-derived aggregate products, with some aggregate quality test results better than the premium aggregate producing formations in southern Ontario (e.g., Gasport Formation – the middle formation of what the aggregate industry commonly refers to as the Amabel Formation: Brunton (2009), Brunton and Brintnell (2011) and Rowell (2012a)). Elsewhere, the Guelph Formation fails miserably and is not capable of producing even low-specification bedrock-derived aggregate products (Rowell 2012a). An explanation for these diverse test results will be proposed later in this report.

The Guelph Formation is a high-purity dolostone that can be extracted, processed and used for the manufacture of metallurgical flux, chemical stone and other industrial mineral uses (Kelly 1996, 2002). Because the Guelph Formation can be so variable for the manufacture of high-specification bedrock-derived aggregate products, but is a source of high-purity dolostone, the industrial mineral industry was confused by the 2010 *Aggregate Resources Inventory for the City of Hamilton* (Marich 2010), which did not identify the Guelph Formation as a selected bedrock resource area. The 1984 *Aggregate Resources Inventory for the Regional Municipality of Hamilton–Wentworth* (Ontario Geological Survey 1984) did identify the Guelph Formation as a selected bedrock resource area of primary significance, if only for the production of metallurgical flux and chemical stone. Ontario Geological Survey (OGS) management made a decision in 2008 to no longer identify industrial minerals in Aggregate Resources Inventory Papers (ARIPs), leaving the Guelph Formation in limbo and land-use planners seeking direction as to the protection of this resource (D.J. Rowell, OGS, meeting with, and presentation to, City of Hamilton planners, Ministry of Municipal Affairs and Housing staff and industry representatives, December 2010).

Therefore, it was proposed that a two-year study (Project Unit 13-025) be completed to collect additional Guelph Formation samples and perform geochemical analyses and “standard” aggregate testing to 1) provide the industrial mineral industry with some additional data and guidance as to the true potential of the Guelph Formation; and, 2) provide the aggregate industry additional information on where the Guelph Formation may be competent enough to manufacture high-specification bedrock-derived aggregate products. Figure 1 shows the general location of the study area; Figures 2 and 3 (back pocket) show the locations of both the geochemical and aggregate test samples, respectively.

It is not the intent of this report to provide additional detailed scientific knowledge on such topics as lithification, diagenesis, dolomitization, dedolomitization and differential weathering of the Guelph Formation (dolostones), although these topics need to be discussed briefly within the context of this report. These topics are discussed in greater detail in a number of cited references. The intent is to provide additional geochemical and aggregate test results along the outcrop–subcrop belt of the Guelph Formation (*see* Figure 1), and offer a possible explanation for the diverse performance of the Guelph Formation in the manufacture of high-specification bedrock-derived aggregate products.

This study is limited to the outcrop–subcrop belt of the Guelph Formation because of the economics associated with industrial mineral and aggregate extraction (i.e., the economic feasibility of extracting in an area with a thick overburden cover or in an underground mining operation).

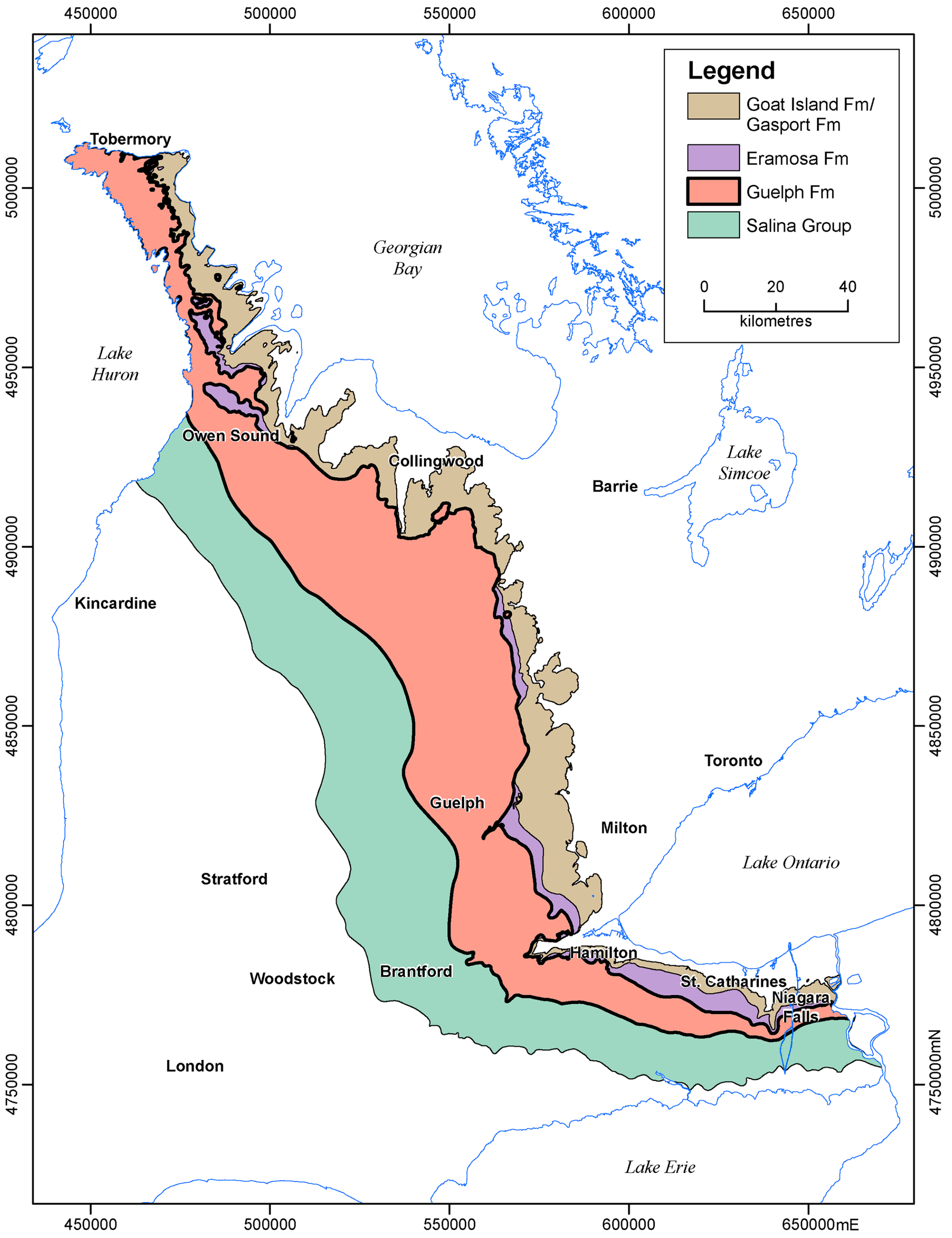


Figure 1. Location of the Guelph Formation outcrop–subcrop belt (salmon-pink colour) in south-central and southwestern Ontario. Geology based on Armstrong and Dodge (2007), Brett et al. (1995), Brunton (2009), Cramer et al. (2011), Brintnell (2012) and Brunton et al. (2012).

GEOLOGY OF THE STUDY AREA

The Guelph Formation is located at or near surface in a slightly southeast-trending band, west of the brow of the Niagara Escarpment in south-central to southwestern Ontario (the outcrop–subcrop belt area: *see* Figure 1). The outcrop–subcrop belt is approximately 15 to 30 km wide from the tip of the Bruce Peninsula to the Niagara Falls area. Outcrops are numerous and more prominent in the counties of Bruce, Grey and Wellington; the Regional Municipality of Waterloo and the City of Hamilton, as noted on Figures 2 and 3 (*see* back pocket). Thicker Quaternary sediments overlie the Guelph Formation in the Niagara Peninsula and in the County of Dufferin, resulting in fewer outcrops to examine and necessitating a greater reliance on drill core.

Based on preliminary results from a 2014 OGS drilling program along the Niagara Peninsula, the outcrop–subcrop belt of the Guelph Formation has a smaller geographic distribution than shown on Figures 1, 2 and 3, which represents current OGS Paleozoic mapping along the Niagara Peninsula. Preliminary results indicate that the Goat Island and Eramosa formations and the Salina Group occupy a larger area. **A thick overburden cover and a smaller geographic distribution along the Niagara Peninsula limit the economic extraction opportunities of the Guelph Formation in the Niagara region.**

Because of the gentle south-southwest regional dip of Paleozoic strata in southwestern Ontario, the Guelph Formation is located deeper in the subsurface further away from the brow of the Niagara Escarpment, buried under younger bedrock formations and a thickened overburden cover. For example, at the Bruce Nuclear site along the Lake Huron shoreline, an average of 23.4 m of Guelph Formation was intersected at approximately 337.6 m below surface (Raven et al. 2009). The Guelph Formation in these drill cores is a paleokarst breccia succession, commonly referred to as the inter-reefal Guelph. It is also not all Guelph Formation at this location, but also includes Goat Island Formation lithofacies (F.R. Brunton, OGS, personal communications). At Ingersoll, 84 m of Guelph Formation was intersected at 182 m below the Beachville quarry floor (Feenstra 1996). Feenstra (1996) may have included part of the Goat Island Formation as part of the Guelph Formation in his drill-core logs.

The sedimentologic, stratigraphic and diagenetic features of the Guelph Formation and the revision to the Early Silurian stratigraphy of the Niagara Escarpment area are part of 2 recent OGS projects: Project Unit 02-015 (Brunton, Dekeyser and Coniglio 2005) and Project Unit 08-004 (Brunton 2009; Brunton et al. 2010; Brunton and Brintnell 2011; Cramer et al. 2011; Brunton et al. 2012). These projects were an attempt to correlate Early Silurian stratigraphic units around the Great Lakes region of North America (mid-Continent region) with global stratotypes. Brunton (2009), Cramer et al. (2011), Brintnell (2012) and Brunton et al. (2012) provide a revised nomenclature for the Lockport Group of southern Ontario. From base to top, this group comprises the Gasport, Goat Island, Eramosa and Guelph formations (Figures 4 and 5). The geochemical and aggregate samples and test results presented in this study are based on, and integrated with, this revised stratigraphy (i.e., testing of the Wellington and Hanlon members where they have been clearly mapped and identified).

Michigan and Appalachian Basins

The Guelph Formation outcrop–subcrop belt as shown in Figure 1 straddles 2 sedimentary basins. The northwestern part of the study area includes the north-central and southeastern part of the Michigan Basin, whereas the southeastern part of the outcrop–subcrop belt lies along the northwestern distal margin of the Appalachian Basin. Between these basins is a broad, linear, southwest-trending feature, the Algonquin Arch, which is separated from another southwest-trending feature, the Findlay Arch, by the Chatham Sag.

The Michigan Basin is a roughly circular feature with its centre located in the lower peninsula of the State of Michigan, and has a radius of approximately 250 km (Howell and van der Pluijm 1990). The Michigan Basin is bounded on the north by Precambrian Shield rocks, on the west by the Wisconsin Arch, on the south by the Cincinnati and Findlay arches and on the east by the Algonquin Arch. Numerous mechanisms, processes and geological models have been proposed to explain the formation and existence of the Michigan Basin, including, but not limited to models provided by Sleep (1971), Haxby, Turcotte and Bird (1976), Nunn and Sleep (1984), Klein and Hsui (1987), Quinlan (1987), Mitrovica, Beaumont and Jarvis (1989) and Howell and van der Pluijm (1990). Luczaj (2013) provides a summary of the Michigan Basin structure in the Wisconsin area; Brunton et al. (2012) provide an overview of the Michigan Basin structure in southwestern Ontario. The approximately 4800 m thick succession of largely marine sediments deposited in the Michigan Basin represents rocks from Cambrian to Pennsylvanian age (Johnson et al. 1992).

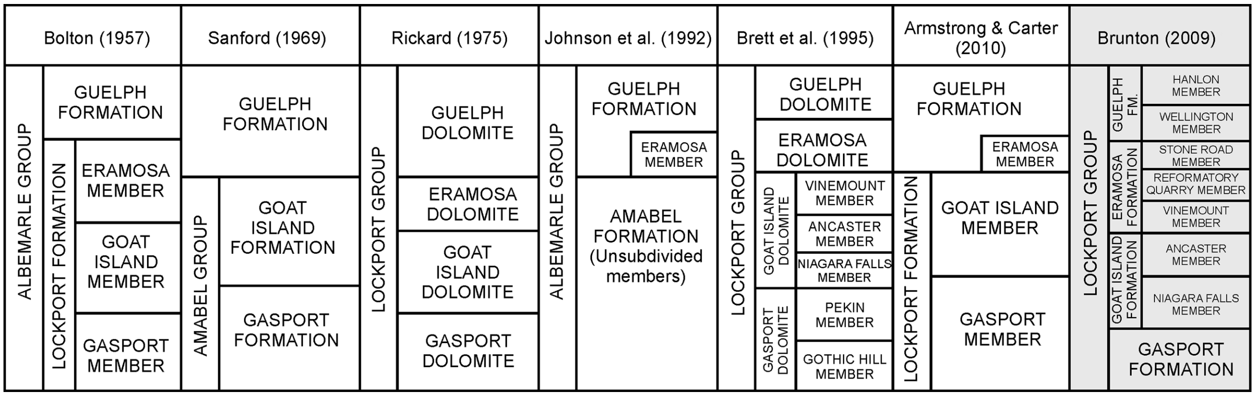


Figure 4. Summary showing the evolution of the nomenclature for the Lockport, Albemarle and Amabel formations and/or groups in the Guelph to Niagara Falls region (from Brintnell 2012). The nomenclature proposed by Brunton (2009) (indicated with grey shading) is used in this report. Note that Brunton (2009) proposes the Guelph, Eramosa and Goat Island formations are further subdivided into members.

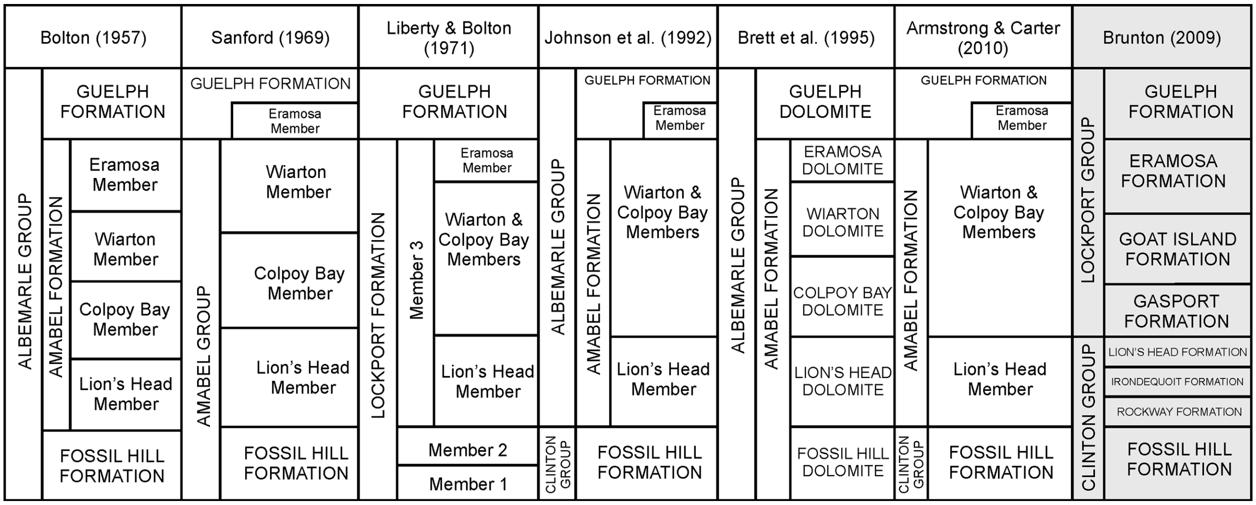


Figure 5. Summary showing the evolution of the nomenclature for the Lockport, Albemarle and Amabel formations and/or groups in the Bruce Peninsula (*from* Brintnell 2012). The nomenclature proposed by Brunton (2009) (indicated with grey shading) is used in this report. Stratigraphic members of the Guelph, Eramosa and Goat Island formations are shown in Figure 4 (*see* grey shading).

During the Silurian, the North American plate was located at approximately 10 to 25°S latitude as suggested by the fossil record (Sanford 1969; Van der Voo 1988). As a result of the location of the North American plate, the Michigan Basin was a tropical inland sea that was subjected to repeated transgression and regression, subtropical storms and periodic influxes of terrigenous detritus from the Appalachian Basin and windblown sources (Dekeyser 2006). Marine conditions during deposition of the Gasport to Guelph formations enabled episodic regional-scale development of crinoid-rich microbial mounds with portions of stromatoporoid and tabulate coral mega-invertebrates, and reefs associated with platformal carbonates, such as the crinoidal-rich shoal lithofacies of the Gasport, Goat Island and Guelph formations. As a general rule, the Gasport crinoidal-microbial mounds possess tabulate corals, whereas the Goat Island mounds are calcareous sponge dominated and the Guelph mounds are mixed tabulates with a greater volume of sponge faunas (Brunton et al. 2012).

The Appalachian Basin is approximately 1730 km long (southwest to northeast), stretching from southern Ontario and southern Quebec to northeastern Alabama, with a width of 30 to 500 km (southeast to northwest: Ettensohn 2008). The northwestern flank of the basin (including the southeastern portion of the Guelph Formation outcrop–subcrop belt) is a broad homocline that dips gently south-southeastward off the Cincinnati, Findlay and Algonquin arches. Ettensohn (2008) describes the basin as a foreland basin that formed by lithospheric subsidence in response to orogenically induced loading that took place along the eastern margin of Laurentia from Ordovician through Permian time.

The sediments deposited in the northwestern Appalachian Basin during this time period consist of mixed carbonate and orogenic-derived clastic sediments. Therefore, the Niagara Peninsula succession is more siliciclastic rich, reflecting its location on the northwestern flank of the Appalachian Basin and in closer proximity to the Appalachian Orogeny and associated erosional materials. Rapid lateral facies changes and depositional pinch-outs across the Niagara Peninsula suggest that the Algonquin Arch was a positive topographic relief feature at this time, forming the northwestern margin of the basin (Johnson et al. 1992). Another explanation is that this area is a forebulge region that was uplifted episodically during the Silurian (Brunton et al. 2012).

As relative sea levels fluctuated in relation to short-lived tectophases due to shifting depocentres along the Appalachian foreland basin, erosional disconformities developed and resulted in a complex succession of rock units (Brunton et al. 2012). Some of these units are thin, condensed, sparsely fossiliferous units that change character laterally (pinch-outs) or are cut by erosional disconformities (e.g., minor erosive storm events and paleokarst dissolution). Local facies relationships are often complex both laterally and vertically. In general, the regional stratigraphic architecture of these carbonate rock units is quite complex. Chronostratigraphic studies, using high-resolution stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope analyses, integrated with conodont and fossil evidence are being used to assist in relative dating of, and further stratigraphic identification and separation of, these carbonate deposits (Zheng 1999; Coniglio, Zheng and Carter 2003; Cramer, Saltzman and Kleffner 2006; Bancroft, Kleffner and Brunton 2008, 2009; Bergström et al. 2011; McLaughlin, Mikulic and Kluessendorf 2013).

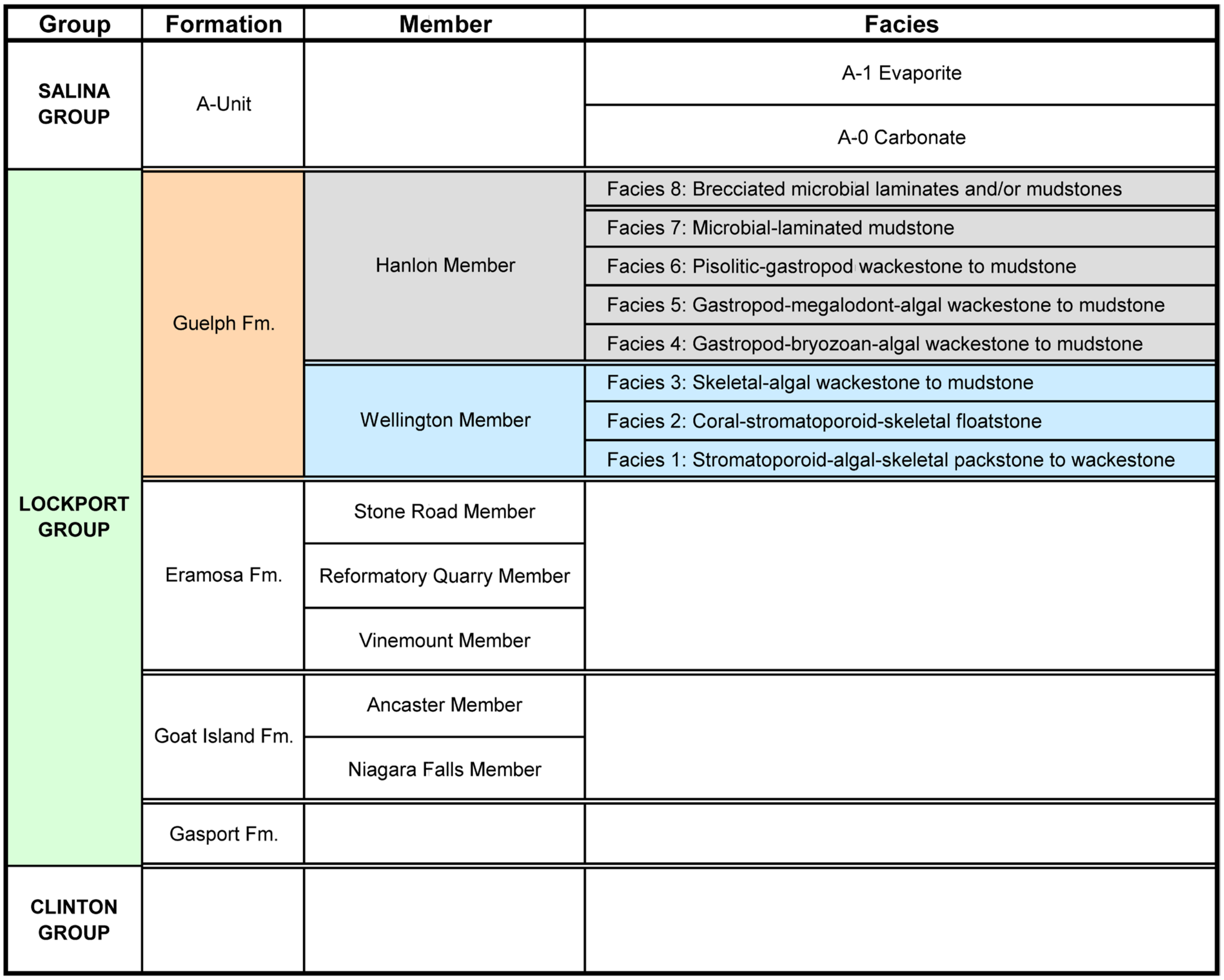
Guelph Formation

In general, the Guelph Formation can be described as a cream to buff to tan to tan-brown to brown; finely to medium crystalline; thinly to thickly bedded, moderately to very fossiliferous, saccharoidal dolostone (Johnson et al. 1992; Brunton and Dekeyser 2004; Brunton, Dekeyser and Coniglio 2005; Armstrong and Carter 2010). There are a number of biohermal or reef structures with a porous, coarse texture and numerous fossil fragments. Megafaunal fossils include tabulate corals, rugose corals, stromatoporoids, brachiopods, bryozoans, gastropods, megalodontid bivalves (*Megalomus canadensis*) and crinoids (Johnson et al. 1992; Brunton, Dekeyser and Coniglio 2005; Brunton 2009; Brintnell 2012). Beds are sometimes massive and lenticular.

Brunton (2009), Brunton and Brintnell (2011), Brintnell (2012) and Brunton et al. (2012) have taken this general description of the Guelph Formation and completed a more comprehensive study on the formation. As a result, Brunton (2009), Brunton and Brintnell (2011), Brintnell (2012) and Brunton et al. (2012) have suggested that the Guelph Formation should be divided into lower and upper members: the Wellington and Hanlon members, respectively (Figure 6).

The Wellington Member can generally be described as a carbonate-rich, reefal mound–bearing and more open-marine grainstone- to wackestone-dominated dolostone unit. Three facies have been identified within this lower member (Brunton 2009; Brintnell 2012) (*see* Figure 6) and are generally described, in ascending order, as

- Facies 1 – a stromatoporoid-algal-skeletal–dominated packstone to wackestone
- Facies 2 – a coral-stromatoporoid-skeletal–dominated floatstone
- Facies 3 – a skeletal-algal wackestone to mudstone



Group	Formation	Member	Facies
SALINA GROUP	A-Unit		A-1 Evaporite
			A-0 Carbonate
LOCKPORT GROUP	Guelph Fm.	Hanlon Member	Facies 8: Brecciated microbial laminates and/or mudstones
			Facies 7: Microbial-laminated mudstone
			Facies 6: Pisolitic-gastropod wackestone to mudstone
			Facies 5: Gastropod-megalodont-algal wackestone to mudstone
			Facies 4: Gastropod-bryozoan-algal wackestone to mudstone
		Wellington Member	Facies 3: Skeletal-algal wackestone to mudstone
			Facies 2: Coral-stromatoporoid-skeletal floatstone
			Facies 1: Stromatoporoid-algal-skeletal packstone to wackestone
	Eramosa Fm.	Stone Road Member	
		Reformatory Quarry Member	
		Vinemount Member	
	Goat Island Fm.	Ancaster Member	
		Niagara Falls Member	
	Gasport Fm.		
CLINTON GROUP			

Figure 6. Stratigraphy of the Guelph Formation, including members and facies (*after* Brintnell 2012, p.47); *see* text for further explanation. Note: The thickness of the members and facies as shown in this figure is not indicative of their real thickness. The Salina Group is not complete and continues upward. The Clinton Group is not complete and continues downward. A double line (═) indicates a disconformity.

The depositional model that has been suggested for the Wellington Member involves an initial transgression of the "Guelph" sea creating turbid shallow marine conditions. Low diversity biota, dominated by stromatoporoids and algae, facilitated the accumulation and bonding of muddy sediments (Brunton and Brintnell 2011). Fauna growth was stunted during this time period because of stresses imposed by hypersaline and eutrophic conditions. Small-scale transgressive pulses facilitated the development of stromatoporoid-microbial mounds. Periodic subaerial exposure occurred in the western part of the basin (Brintnell 2012). Pinnacle- and patch-reef studies suggest multiple episodes of subaerial exposure, based on laterally extensive enhanced porosity and permeability (Coniglio, Zheng and Carter 2003).

A disconformity represents the lower contact of the Guelph Formation with the underlying Eramosa Formation. The Guelph Formation may also directly overlie reefal Gasport Formation where these reefs are generally greater than 60 m thick (Brunton and Brintnell 2011). Although there is no physical evidence to suggest that in these circumstances that the Goat Island or Eramosa formations were deposited and eroded prior to Guelph Formation deposition (Brintnell 2012), it cannot be ruled out.

The Hanlon Member represents an upper mid-shelf, open-marine, lagoonal facies that changed through time to become a more restricted marine microbial–bearing sabkha-facies cycle that displays varying degrees of exposure (Brunton 2009; Brunton and Brintnell 2011). The upper member consists of 5 facies as described by Brintnell (2012) (*see* Figure 6):

- Facies 4 – a gastropod-bryozoan-algal–dominated wackestone to mudstone
- Facies 5 – a gastropod-megalodont-algal–dominated wackestone to mudstone
- Facies 6 – a pisolitic-gastropod–dominated wackestone to mudstone
- Facies 7 – a microbial-laminated–dominated mudstone
- Facies 8 – a brecciated microbial laminate and/or mudstone facies

The depositional model that has been suggested for the Hanlon Member involves the regression of the "Guelph" sea, creating hypersaline (40 to 50% salinity), oxygen-restricted, lagoonal conditions. Gastropods, algae and soft-bodied organisms dominated the muddy saline waters. As the sea level continued to fall, a flat coastal sabkha environment developed. The ramp area was blanketed by microbialite in highly saline waters (70% salinity). Subaerial conditions created erosive surfaces and the upper contact between the Guelph Formation and overlying Salina Group represents a significant erosional surface (disconformity), which was subject to karstification (Brunton 2009; Brunton and Brintnell 2011; Brintnell 2012; Brunton et al. 2012). These regionally restrictive seaways promoted an increase in evaporation, extreme salinity and periodic semi-arid climatic conditions, conducive to the deposition of gypsum, anhydrite and halite (Salina Group).

Brintnell (2012) relates the distribution of these members and their facies to specific paleogeographic areas within the Michigan and Appalachian basins (Figure 7):

- Area 1: east-central Michigan Basin including southwestern Ontario (Huron and Lambton county areas)
- Area 2: east Michigan Basin including the outcrop–subcrop belt between the Bruce Peninsula and the Kitchener–Waterloo–Guelph area
- Area 3: northwest Appalachian Basin: the Lake Erie, Kent and Elgin counties area and the Niagara region

There is considerable variation in the facies character, thickness, and presence or absence of these 2 members regionally within these 3 paleogeographic areas. Once again, this study will focus its attention to only the outcrop–subcrop areas (Area 2 and the eastern portion of Area 3), because the industrial mineral and aggregate industry will generally not extract bedrock that is buried by uneconomical thicknesses of overburden or other poor-quality bedrock units.

THICKNESS

The Guelph Formation is generally 15 to 22 m thick in the Kitchener–Waterloo to Guelph area, but thickens to over 100 m near Luther Lake (northeastern part of Wellington County, *see* Figures 2 and 3). The thickness of the Guelph Formation in the east-central part of the Michigan Basin (Area 1) varies from approximately 5 to 122 m thick, whereas the thickness of the Guelph Formation along the eastern part of the Michigan Basin has been reported as 7 to 122 m (Area 2), and 8 to 34 m thick in the Appalachian Basin (Area 3) (Brintnell 2012).

In addition to these regional thickness variations, the thickness of the Guelph Formation can also be extremely variable over relatively short distances; for example, 50 m of paleokarstic Guelph Formation in one borehole and less than 6 m of competent, bedded Guelph Formation in an adjacent borehole 5 km away. **This is an area of concern for the extraction industry, because the cost of purchasing and licensing a property is becoming increasingly financially prohibitive and the variation in deposit thickness will greatly influence ore calculations.**

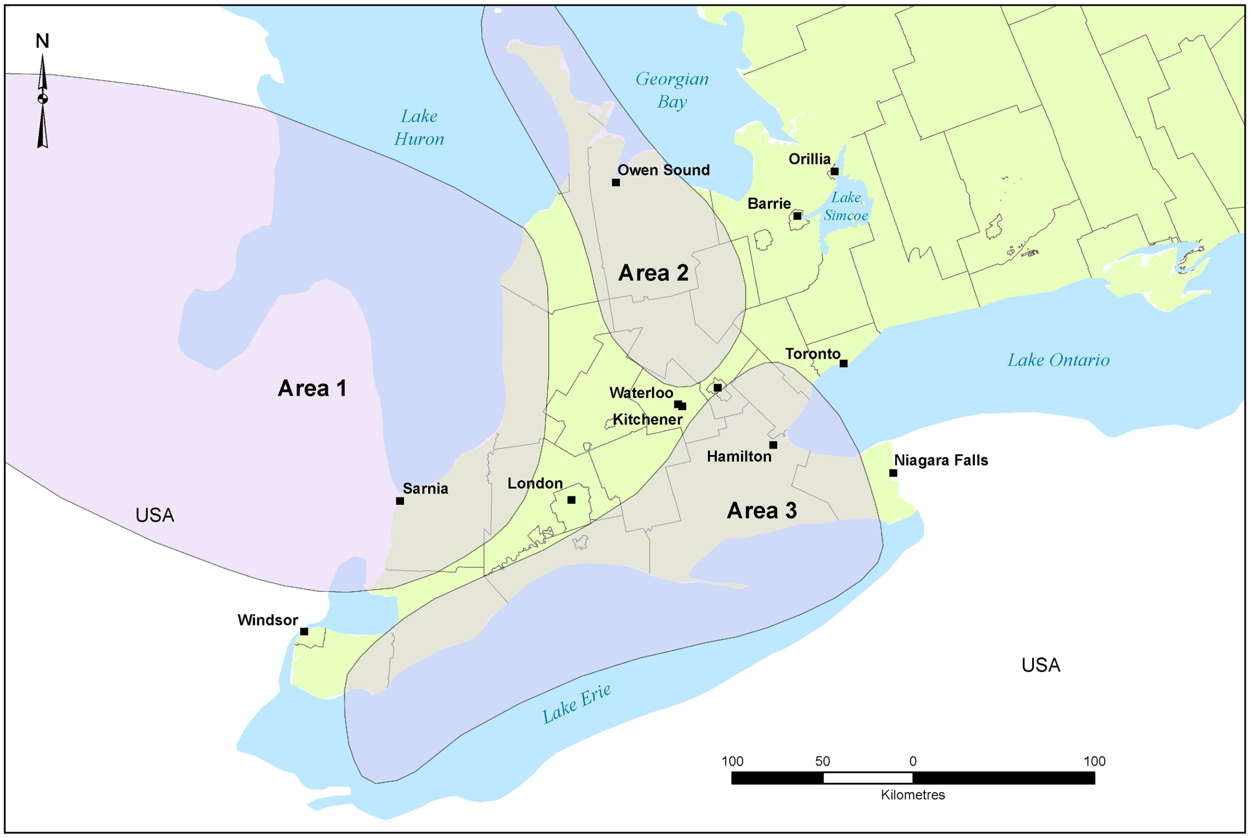


Figure 7. Paleogeographic areas within the Michigan and Appalachian basins (*from* Brintnell 2012); *see* text for further explanation.

Industrial Mineral Potential

CHEMISTRY, PURITY AND USES

A general geological definition of limestone is a sedimentary rock consisting of at least 50% calcite (or aragonite, which has the same chemical formula as calcite) and dolomite, with a predominance of calcite and less than 50% other minerals and rock material (Bates and Jackson 1987). Dolostone is defined similarly with dolomite as the dominant carbonate mineral (Harben 1999). Theoretically, pure limestone is 100% calcite ($CaCO_3$), whereas pure dolostone is theoretically 100% dolomite ($CaMg(CO_3)_2$). In nature, this purity is seldom achieved and, as a result, these carbonate sediments, more realistically, range anywhere from pure calcite to pure dolomite. The rock usually contains a variety of accessory minerals and materials, including, but not limited to, quartz, chert, clay minerals, fluorite, feldspar, sphalerite, pyrite and organic material.

Pure Calcite = 100% $CaCO_3$
(Pure Limestone) = 55.87% CaO + 44.13% CO_2

Pure Dolomite = 100% $CaMg(CO_3)_2$
(Pure Dolostone) = 21.85% MgO + 30.41% CaO + 47.74% CO_2
= CaO–MgO ratio is 1.39

Commercial definitions of limestone and dolostone generally require a higher percentage of calcite and dolomite than geological definitions (usually at least 80%); and a large percentage of impurities such as the accessory minerals and other materials as noted above are not acceptable (Hewitt 1960). High-purity limestone and dolostone provide a more consistent feed for the production of calcium and magnesium chemical compounds and other industrial mineral uses; and its behaviour is more consistent, reliable and predictable than limestone and dolostone with a high percentage of impurities. Commercial references to limestone and dolostone are usually defined (Hewitt 1960; Kelly 1996, 2002) as

Ultra-high calcium limestone = at least 97.5% $CaCO_3$
High-purity calcium limestone = >95.0% $CaCO_3$ and <3% $SiO_2+Al_2O_3+Fe_2O_3$ and <2.0% $CaMg(CO_3)_2$
Calcitic limestone = 90–95% $CaCO_3$ and 5–10% $CaMg(CO_3)_2$
Dolomitic limestone = 50–90% $CaCO_3$ and 10–50% $CaMg(CO_3)_2$
Calcitic dolostone = 10–50% $CaCO_3$ and 50–90% $CaMg(CO_3)_2$
Magnesium dolostone = 0–10% $CaCO_3$ and 90–100% $CaMg(CO_3)_2$
High-purity dolostone = > 97% $CaMg(CO_3)_2$ and <3% impurities (Figure 8)

The presence of magnesite ($MgCO_3$) and other magnesium-bearing accessory minerals means that some geochemical values for MgO in a high-purity dolostone can be greater than 21.85% and actually plot outside the left margin of the ternary diagram (*see* Figure 8).

Some of the important industrial mineral uses of high-purity limestone and dolostone include

- aggregate material for subbase, base and asphalt (also includes the production of such other products as riprap, gabion stone, manufactured sand, etc.)
- the manufacture of Portland cement mix, which, combined with a high-quality aggregate material, can be used to produce concrete
- aglime is a pulverized rock used as a soil conditioner to neutralize acidity, and can be used to add calcium and magnesium to the soil as nutrients
- quicklime (CaO) is used as a soil stabilizer, a flux in the manufacture of steel and ceramics, and to remove sulphur dioxide and hydrogen chloride from flue gas emissions

- hydrated lime ($Ca(OH)_2$, also known as slake lime) is used to filter potable water supplies and to treat solid and liquid waste. It can also be used as a soil stabilizer and as an additive in petroleum refining
- dimension and architectural stone (sometimes incorrectly or commercially referred to as "marble")
- manufacture of brick and tile
- filler material in synthetic flooring and the backing material for carpets
- carrier material in pesticide granules
- filler material in fungicides

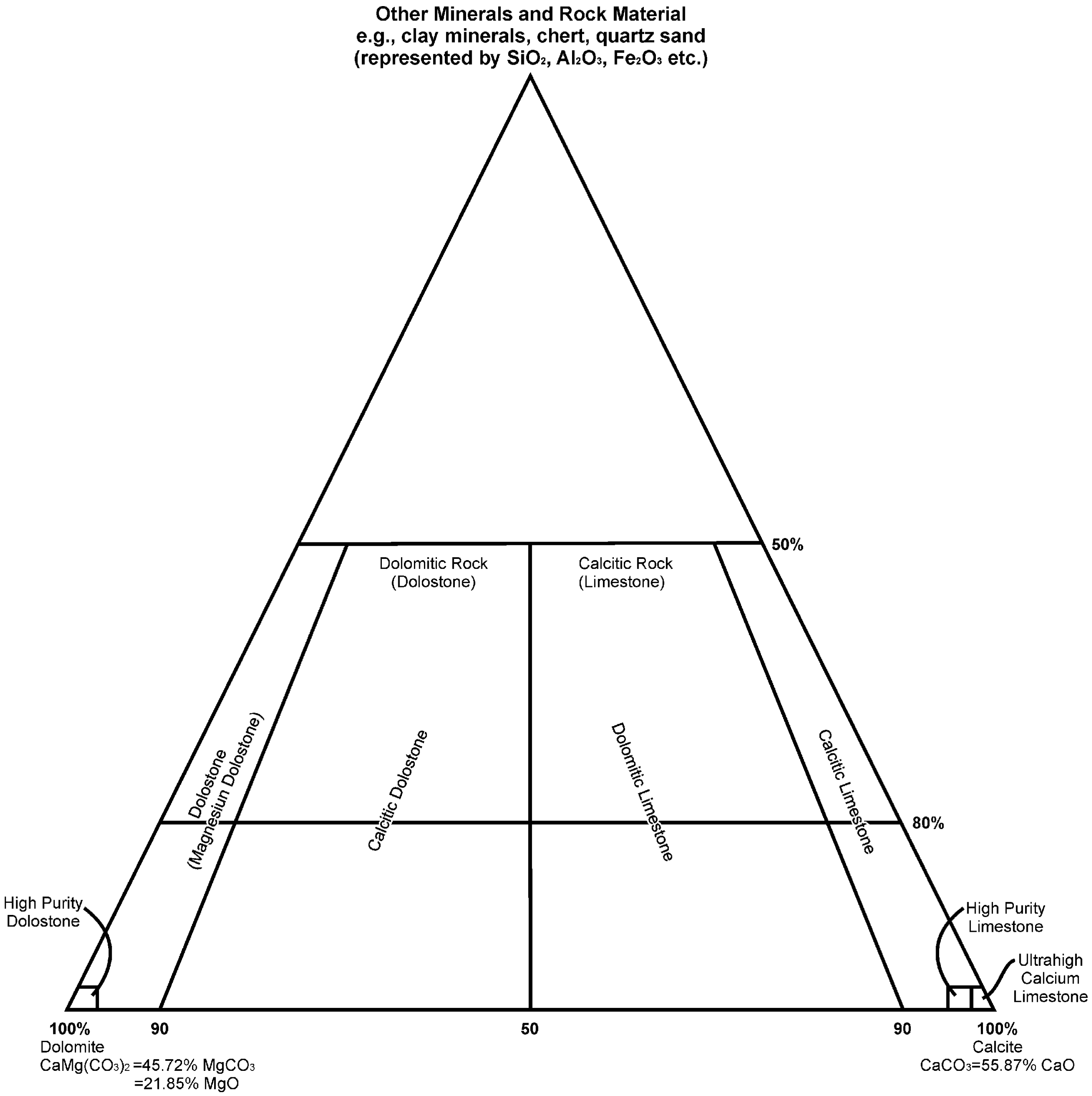


Figure 8. Ternary diagram showing geological and commercial definitions for limestone and dolostone (based on Hewitt (1960) and Harben (1999)).

- dusting agents to prevent explosions in underground coal mines or a dust suppressant used on gravel roads
- a source of calcium and magnesium for food and food supplements
- a source of calcium and magnesium for the pharmaceutical industry
- a source of calcium and magnesium for the production of chemical compounds, e.g., calcium carbide (CaC_2)
- used in the sugar extraction and refining process
- a refractory material used in the lining of metallurgical furnaces
- the manufacture of glass, paper, plastics, thermoplastics, rubber, ink, paint, dyes, adhesives, sealants and putty

Essentially, limestone and dolostone are used as fillers, binders, whiteners, and for their refractory properties; and for neutralization, coagulation, causticization, dehydration and absorption (Hewitt 1960; Kelly 1996, 2002; Harben 1999). Calcite and dolomite, the primary minerals in limestone and dolostone are non-toxic; however, quicklime is caustic.

GUELPH FORMATION SAMPLES AND GEOCHEMICAL ANALYSES

Appendix A of this report provides information with regard to the type (i.e., outcrop, drill-core sample) and location of Guelph Formation samples that were analyzed as part of this study. The sample locations are also shown on Figure 2 (back pocket). Outcrop samples were collected on surface and, therefore, indicate a “depth” of 0.00 m. Drill-core samples will either indicate the depth at which the geochemical sample was collected (e.g., 23.20 m) or the interval from which the sample was taken (e.g., 7.77–19.05 m).

Samples were analyzed at the Geoscience Laboratories of the Ontario Geological Survey using standard analytical techniques. Whole-rock (major oxides) and loss-on-ignition (LOI) were analyzed using X-ray fluorescence (XRF). Carbon dioxide (CO_2), sulphur (S), crystalline water (H_2O^+) and free water (H_2O^-) were analyzed using an infrared (IR) absorption method, whereas trace elements were analyzed using either inductively coupled plasma mass spectroscopy (ICP–MS) or flame atomic absorption (AAF) spectroscopy procedures. For greater detail on the sample preparation and analytical methods, please refer to the Geoscience Laboratories *Schedule of Fees and Services* (Ontario Geological Survey 2014).

Geochemical Results

Appendix B provides the individual sample results for the major oxides. These results are presented in a generally north-to-south geographic distribution (from Tobermory southward toward the Niagara Peninsula). Also included in the Appendix B data are the CaO–MgO ratio, $MgCO_3$, $CaCO_3$, total carbonate, and the percent impurities ($SiO_2 + Al_2O_3 + Fe_2O_3$) calculations. Table 1 is a summary of that data and includes the minimum and maximum values (thus the range), and average for each major oxide element.

Trace element geochemical results are presented in Appendixes C and D (trace elements analyzed by AAF and ICP–MS, respectively). Tables 2 and 3 are summaries of the raw data provided in these appendixes.

The MgO content of the Guelph Formation samples average 21.30% based on 124 samples with a range in values from 17.11 to 22.43%. The CaO content ranges from 27.73 to 34.86% with an average of 30.17% based on the same number of analysis; and CO_2 averages 45.85% (range from 42.77 to 51.10%) (*see* Table 1). The $SiO_2 + Al_2O_3 + Fe_2O_3$ is generally less than 0.40% (n = 124) with the highest value (maximum) only 1.94%. The calculated total carbonate averages 98.53%, with a range of 87.81 to 101.01% (*see* Table 1). As noted earlier, the presence of other magnesium-bearing minerals may result in calculation variations.

All of these analytical results clearly indicate that the Guelph Formation is a high-purity dolostone across the study area (>97% total carbonate and <3% impurities). The average MgO of 21.30% is just below the theoretical pure value of 21.85%, the CaO average of 30.17% is slightly lower than 30.41%, and the CO_2 value of 45.85% is close to 47.74%. The loss-on-ignition (LOI), which represents the loss of volatiles that includes CO_2, is closer to the pure value of 47.74%, with an average of 47.99%. In addition, the major oxide impurities are less than 3%. Figure 9 illustrates the results of MgO versus CaO analytical (raw) data from Appendix B in comparison with the theoretically pure value of dolomite.

Table 1. Summary of major oxide analyses of Guelph Formation samples (analyzed by X-ray fluorescence spectrometry (XRF)).

Major Oxide	**Number of Analyses (n)**	**Average Value (%)**	**Minimum Value (%)**	**Maximum Value (%)**
SiO_2	124	0.17	0.00	1.13
Al_2O_3	124	0.12	0.00	1.27
MnO	112	0.02	0.01	0.06
MgO	124	21.30	17.11	22.43
CaO	124	30.17	27.73	34.86
Na_2O *	112	–	<0.01	0.27
K_2O *	112	–	<0.01	0.13
P_2O_5 *	112	–	<0.01	0.02
TiO_2	112	0.01	<0.01	0.03
Fe_2O_3	124	0.12	0.00	0.41
LOI	112	47.99	46.44	52.92
S *	51	–	<0.01	0.01
CO_2	51	45.85	42.77	51.10
H_2O^+	51	0.24	0.00	0.89
H_2O^-	51	0.21	0.11	0.50
Other Data				
Ca/Mg Ratio	124	1.42	1.32	2.04
$MgCO_3$	124	44.52	35.76	46.88
$CaCO_3$	124	54.01	49.64	62.40
Total Carbonate	124	98.53	87.81	101.01
$SiO_2+Al_2O_3+Fe_2O_3$	124	0.40	0.06	1.94

**Average values were not calculated because the raw data are dominated by results that are less than the lower detection limit (LL) (*see *Appendix B). Individual analytical results (raw data) is provided in Appendix B.*

Table 2. Summary of trace element analyses of Guelph Formation samples (analyzed by atomic absorption (flame) spectroscopy (AAF)).

Trace Element	**Number of Analyses (n)**	**Average Value (ppm)**	**Minimum Value (ppm)**	**Maximum Value (ppm)**
Cd *	47	–	<5	<5
Co *	47	–	<30	<30
Cu *	47	–	<3	10
Li	47	17	14	22
Ni *	47	–	<6	10
Pb *	47	–	<12	26
Zn *	47	–	<6	103

**Average values were not calculated because the raw data are dominated by results that are less than the lower detection limit (LL) (*see *Appendix C). Individual analytical results (raw data) is provided in Appendix C.*

Table 3. Summary of trace element analyses of Guelph Formation samples (analyzed by inductively coupled plasma mass spectroscopy (ICP–MS)).

Trace Element	Number of Analyses (n)	Average Value (ppm)	Minimum Value (ppm)	Maximum Value (ppm)
Ba	51	3.8	0.9	22.8
Be	51	0.05	<0.04	0.18
Bi *	51	–	<0.15	1.70
Cd	51	0.034	<0.013	0.232
Ce	51	1.40	0.59	6.65
Co	51	0.52	0.26	2.26
Cr	51	4	<3	7
Cs	51	0.043	<0.013	0.239
Cu *	51	–	<1.4	5.5
Dy	51	0.140	0.049	1.342
Er	51	0.089	0.031	0.712
Eu	51	0.0339	0.0090	0.2948
Ga	51	0.21	0.05	0.81
Gd	51	0.149	0.053	1.555
Hf *	51	–	<0.14	0.89
Ho	51	0.0296	0.0110	0.2623
In *	51	–	<0.0018	0.0037
La	51	0.94	0.52	4.99
Li	51	1.6	0.7	4.6
Lu	51	0.0110	0.0040	0.0688
Mo	51	0.41	<0.08	8.21
Nb	51	0.133	0.029	0.619
Nd	51	0.72	0.27	5.46
Ni	51	6.3	3.1	10.4
Pb	51	3.6	0.6	22.8
Pr	51	0.185	0.071	1.243
Rb	51	1.07	<0.23	5.67
Sb	51	0.05	<0.04	0.80
Sc *	51	–	<1.1	7.7
Sm	51	0.140	0.048	1.250
Sn *	51	–	<0.16	0.24
Sr	51	56.9	42.8	94.8
Ta *	51	–	<0.023	0.042
Tb	51	0.0220	0.0070	0.2138
Th	51	0.118	0.019	0.513
Ti	51	38	7	177
Tl	51	0.013	0.003	0.063
Tm	51	0.0121	0.0050	0.0884
U	51	0.528	0.047	1.853
V	51	2.2	<0.8	9.4
W *	51	–	<0.05	0.58
Y	51	1.33	0.51	9.98
Yb	51	0.075	0.030	0.525
Zn	51	9	<7	59
Zr *	51	–	<6	44

**Average values were not calculated because the raw data are dominated by results that are less than the lower detection limit (LL) (*see *Appendix D). Individual analytical results (raw data) are provided in Appendix D.*

Also presented in Appendixes B, C and D are some quality-control (QC) data. For each batch of Guelph Formation samples that were submitted for geochemical analyses, a “standard” Guelph Formation and upper member of the Gull River Formation (high-purity limestone) sample were included in order to provide “blind” quality control (QC) of each batch. The results of the quality-control samples are presented in the appropriate Appendixes and are well within standard and acceptable analytical expectations (Ontario Geological Survey 2014).

The underlying Eramosa, Goat Island and Gasport formations are also reasonably pure dolostone units. Appendix E provides evidence to support this statement and also compares the Guelph Formation geochemical data with these underlying dolostone units. Older geochemical data for the Goat Island and Gasport formations did not distinguish between the 2 rock units, and simply referred to the samples as Amabel Formation samples. It is, therefore, difficult to separate the data now. Appendix E confirms that the Guelph Formation is the purest dolostone unit, based on the geochemical analyses completed (i.e., higher average values of MgO, CaO and CO_2; higher average value for the total calculated carbonate; and lower average values of $SiO_2 + Al_2O_3 + Fe_2O_3$).

Petrographic Studies

In the Bruce Peninsula (northwest corner of the outcrop–subcrop belt), petrographic analyses of the Guelph Formation revealed that the process of dolomitization was pervasive and complete, with no precursor limestone observed (Dekeyser 2006). Dekeyser (2006) identified 4 categories of replacement dolomite crystals based upon size, clarity and crystal development (Sibley and Gregg 1987): 1) very fine-crystalline, cloudy, anhedral dolomite crystals (<15 µm); 2) fine-crystalline, cloudy, subhedral dolomite crystals (15 to 60 µm); 3) clearer, medium-crystalline subhedral to euhedral dolomite crystals (60 to 250 µm); and 4) coarse-crystalline euhedral crystals (>250 µm). The cloudiness (clarity) of the crystals is related to micrometre- or sub-micrometre-sized organics, unidentified solids and/or liquid inclusions (Dekeyser 2006). The finer

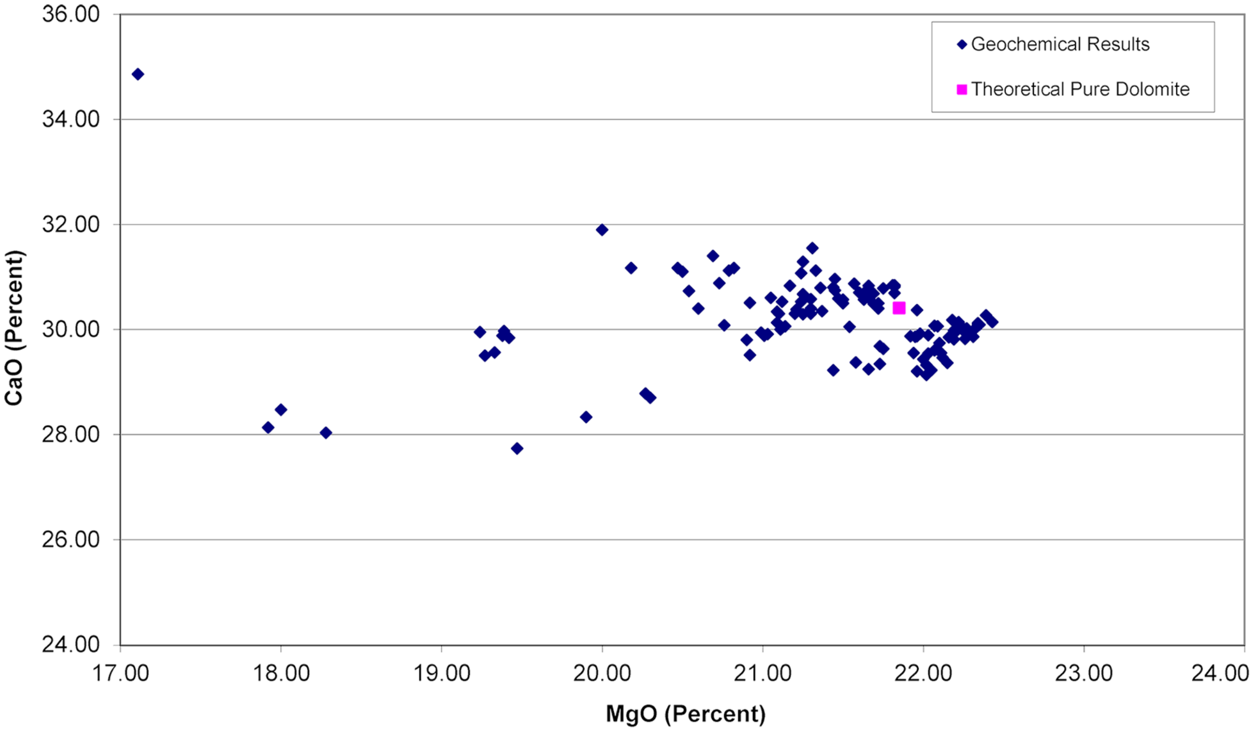


Figure 9. Plot of MgO versus CaO (*see* Appendix B for analytical (raw) data) for Guelph Formation samples in comparison with the theoretically pure value of dolomite.

crystalline dolomite crystals are more prevalent in the underlying dolostones (Gasport, Goat Island and Eramosa formations), whereas the medium- to coarse-crystalline crystals are more common in the Guelph Formation. Dekeyser (2006) concluded that the crystal structure of the Guelph Formation can generally be described as subhedral to euhedral, fine- to medium-crystalline (10 to 175 μm) dolomite with patches of more coarse–crystalline dolomite.

In southwestern Ontario, Zheng (1999) identified 3 replacive dolomite fabrics within the Guelph Formation. Type 1 dolomite consists of tightly packed, microcrystalline (20 to 50 μm), anhedral and equigranular crystals. Type 2 dolomite is typically composed of fine crystalline (50 to 150 μm) euhedral to subhedral crystals intergrown with rhombohedra crystals. Most Type 2 dolomite crystals exhibit inclusion-rich cloudy cores and relatively inclusion-free clear rims. Type 3 dolomite crystals are commonly loosely packed, sucrosic, medium to coarsely crystalline (150 to 400 μm) euhedral to anhedral crystals with intergrown rhombohedra crystals, with cloudy cores and clear rims. Type 2 dolomite is the most common fabric, accounting for 80% of replacive dolomites. Type 1 dolomite accounts for approximately 15%, whereas Type 3 accounts for less than 5% (Zheng 1999).

The importance of Zheng (1999) and Dekeyser's (2006) work to this study is that, in both geographic areas, the Guelph Formation was mineralogically and petrographically almost pure dolomite, with little or no calcite crystal remnants (grains or cement). Rameil (2008), studying dolomitization of Late Jurassic and Early Cretaceous platform carbonates in the Jura Mountains, found a similar dominance of dolomite crystals and identified 3 dolomite types based on crystal size and geometry.

Other important petrographic observations made by Zheng (1999) and Dekeyser (2006) include

- In the Guelph Formation, dolomite crystals or dolomite cement commonly replace fossils. Rarely does quartz or chert replace fossil fragments, in whole or in part, as it does in the underlying dolostone units.
- Intercrystalline porosity is common and may occur in close proximity to areas of relatively less porous texture.
- Intergranular cement includes dolomite cement. Calcite cement accounts for approximately 1% in the Guelph Formation, whereas calcite cement for the underlying dolostone units ranges from 2 to 3%.
- The presence of limpid dolomite cement consisting of white, euhedral to subhedral, fine to coarse crystalline (100 to 300 μm) dolomite was observed by Zheng (1999). This limpid dolomite cement commonly occurs in minor amounts (<2%) lining molds, vugs and fractures in Type 2 and Type 3 dolomite fabrics. Saddle dolomite occurs as a cement lining or filling vugs and fractures in porous dolostone. This cement is characterized by milky white, coarse crystalline (200 to 1000 μm) euhedral crystals.
- The general increase in crystal size in Type 2 and Type 3 dolomite suggests that dolomite crystal coarsening in these dolomites is largely related to partial dissolution of earlier dolomite crystals and precipitation of newer dolomite as overgrowths.
- Blade-shaped evaporite cement (gypsum or anhydrite) does occur in the Guelph Formation. This cement indicates crystallization under hypersaline seawater in a restricted environment or in semi-arid conditions (Dekeyser 2006). It has been suggested that the evaporite cement may have been formed contemporaneously with dolomitization. This blade-shaped evaporite cement is often replaced by calcite, dolomite or the space remains empty within the Guelph Formation.

The above petrographic observations (the presence of very minor amounts of quartz and calcite cement; and the minor amounts of quartz, chert or calcite crystals filling or replacing fossil fragments) help to explain the geochemical data; and, in combination with the geochemical results, confirms that the Guelph Formation is a high-purity dolostone.

Aggregate Potential

AGGREGATE TESTING

Significant changes have occurred in the testing and specifications applied to aggregate material since the original Aggregate Resource Inventory Papers were completed (1979 to 2000). The Los Angeles abrasion test (LS-603) is no longer used in the Ontario Provincial Standard Specifications (OPSS) and the magnesium sulphate soundness test (LS-606) has been reduced to an alternate test. Two newer tests, the Micro-Deval abrasion test (LS-618 and LS-619) and the unconfined freeze–thaw test (LS-614) have been added. The accelerated mortar bar test (LS-620) has also become a standard test for the determination of potential alkali–silica reactivity in concrete aggregate. Additional details of these tests are provided in Appendix G.

Previous aggregate quality test results from the Ministry of Transportation (MTO) files commonly contain test results for the Los Angeles abrasion and magnesium sulphate soundness tests. These data are still useful in assessing the general quality of the material, so they have been included in the current assessment, and are reported in Appendix F. For example, a Los Angeles abrasion test loss of 35% or less generally indicates good physical quality in an aggregate.

Geochemical analytical results (*see* discussion in “Industrial Mineral Potential”), were identified by a location and sample number. Aggregate quality test samples are identified by a “site number” and by the depth or interval from which the sample was collected, resulting in a unique sample (*see* Appendix F). The site numbers are arranged in Appendix F in a generally north-to-south direction (from Tobermory southward to the Niagara Peninsula) similar to the geochemical results. The site locations are shown on Figure 3 (back pocket).

As mentioned previously (*see* “Introduction”), some Guelph Formation samples (from different geographic and stratigraphic areas) test extremely well for the manufacture of high-specification bedrock-derived aggregate products, with some aggregate quality test results better than the premium aggregate-producing formations in southern Ontario (e.g., Gasport Formation: Rowell 2012a). In other areas, the Guelph Formation fails miserably and is not capable of meeting the specifications for lower quality bedrock-derived aggregate products.

During the course of this two-year study, additional Guelph Formation samples were collected from outcrops and drill core to be analyzed for “standard” aggregate quality tests. The samples were collected, washed and cleaned, photographed and forwarded to a laboratory approved and accredited by MTO for “standard” aggregate testing. The results of this testing are reported in Appendix F. Also included in Appendix F are previous Guelph Formation aggregate quality test results as summarized in Rowell (2012a). “Standard” aggregate testing information and current product specifications are provided in Appendix G.

Table 4. Summary of aggregate quality test results for the Guelph Formation.

Aggregate Quality Test	Number of Tests (n)	*Generally Acceptable If*	Minimum Value	Maximum Value	No. of Test Results Out of Specification
Petrographic Number (Granular and 16 mm)	11	–	100.0	293.0	**
Petrographic Number (Hot-Laid and Concrete)	39	<125–140	100.0	352.0	6
Magnesium Sulphate ($MgSO_4$) Soundness (CA)	39	<12–15%	0.5%	41.0%	2
Micro-Deval Abrasion (CA)	31	<14–17%	7.3%	29.7%	1
Los Angeles Abrasion	9	<35%	22.6%	62.0%	2
Absorption Capacity	37	<2%	0.309%	3.628%	18
Bulk Relative Density	36	>2.5	2.447	2.802	1
Freeze–Thaw	29	<6%	1.0%	6.8%	2
Polished Stone Value	1	>45	43.4	43.4	1
Aggregate Abrasion Value	1	<6	13.5	13.5	1
Accelerated Mortar Bar Expansion (CA)	28	<0.150%	0.002%	0.235%	1
Micro-Deval Abrasion (FA)	7	<15–25%	14.60%	25.05%	1

Abbreviations: As evaluated for coarse aggregate (CA) and fine aggregate (FA) products.
***It is becoming a common practice to no longer calculate the Petrographic Number for Granular and 16 mm, but to only calculate the Petrographic Number for Hot-Laid and concrete.*
Individual test results are provided in Appendix F.

AGGREGATE TEST RESULTS

The individual aggregate quality test results are presented in Appendix F. Where the aggregate quality test result fails to meet specification, the test result is indicated with underlined italics in Appendix F. Table 4 summarizes the results from Appendix F.

1. Petrographic Number (PN) values for the Guelph Formation vary from 100.0 to 293.0 for Granular and 16 mm crushed, and from 100.0 to 352.0 for Hot Laid (HL) and concrete coarse aggregate (CA). In general, many of the Petrographic Number test results indicate that the Guelph Formation is capable of meeting many high-specification aggregate products (*see* Appendixes F and G).

   This is a difficult test to assess because this test is subjective and dependant on the skill, knowledge and experience of the petrographer. Having identified the subjective nature of this test, most petrographers are very reliable, competent and consistent. Most Guelph Formation clasts are dolostone, but are the clasts competent (excellent or good aggregate) or soft, pitted or porous (fair or poor aggregate)? The assessment of these clast properties will directly influence the final PN results. As noted earlier, most of the PN test results do meet the specifications outlined in Appendix G.

2. Micro-Deval abrasion (CA) values range from 7.3 to 29.7%, with only 1 test result failing to meet specification (*see* Appendix F).

3. Two Los Angeles abrasion test results failed to meet specification (*see* Appendix F).

4. The Guelph Formation fails the absorption aggregate quality test more frequently than any other test due to the porous nature of the rock (18 of 37 test results failed). These test results have implications for use of the Guelph Formation as an aggregate source and particularly for asphalt and concrete products (i.e., high-specification aggregate products). A high porosity causes disintegration of the aggregate clasts when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate material. A higher porosity also means that more bituminous (asphalt) binder and cement mix will have to be added to Guelph Formation clasts to ensure that the clasts adhere to each other properly. Incomplete adhesion will decrease the overall strength of the asphalt and concrete and lead to premature deterioration of the structure.

5. The Guelph Formation passed the bulk relative density test except for 1 result (2.447; *see* Appendix F). In general, the formation met aggregate specification for the bulk relative density aggregate testing.
6. Freeze–thaw test results vary from 1.0 to 6.8%, with 2 test results (6.6 and 6.8) failing to meet specification (<6). Freeze–thaw is related to absorption and therefore porosity (Rogers, Senior and Boothe 1989). The older magnesium sulphate soundness test was designed to simulate the action of freezing and thawing on aggregate material. Only 2 samples failed to meet the magnesium sulphate soundness specifications as outlined in Appendix G. **Given the results of the absorption tests, the freeze–thaw and magnesium sulphate soundness results are quite surprising, since one would naturally assume a large number of failures in the freeze–thaw and magnesium sulphate soundness results. An explanation for these results will be offered (*see* "Summary") and will suggest that the Guelph Formation does indeed fall out of specification more often than indicated by the aggregate quality test results.**
7. The single polished stone value test result failed to meet specification. The value of 43.4 is less than an average value of greater than 45 and preferably greater than 50. Therefore, the rock is generally too soft and polishes too quickly and easily. A single result can be unreliable and further testing is highly recommended, particularly since this test requires an average of greater than 50.
8. The single aggregate abrasion value test result failed to meet specification. The value of 13.5 is greater than the recommended value of less than 6. The rock is generally too soft and, therefore, does not offer good resistance to abrasion. A single result can be unreliable and more testing is recommended.

GUELPH FORMATION POROSITY

The dolomitization of carbonate sediments can begin to explain to some degree an increase in porosity between calcite-rich limestone and dolomite-rich dolostone (Harben and Bates 1984; Coniglio, Zheng and Carter 2003). There are other important processes that also greatly influence porosity. Post-dolomitization diagenetic events that include dolomite dissolution, dedolomitization (e.g., the conversion of dolomite to calcite), evaporite cement dissolution, and secondary mineralization (silica, calcite, pyrite, fluorite, sphalerite and glauconite) can all influence porosity. Greater detail on dolomitization and these subsequent processes are provided in Carpenter (1980), Land (1980, 1985), Lumsden and Chimahusky (1980), Sperber, Wilkinson and Peacor (1984), Choquette and James (1990), Sibley (1990), Gregg, Howard and Mazzullo (1992), Mazzullo (1992), Purser, Brown and Aissaoui (1994), Vahrenkamp and Swart (1994), Sun (1995) and Lumsden and Caudle (2001).

In addition, several factors, including paleoclimate (Hird and Tucker 1988), sea level change and sequence stratigraphy (Tucker 1993), precursor limestone facies (Sun 1990), and the intensity of dolomitization (Murray 1960) have been shown to be important in controlling dolomite porosity. Porosity is related to and enhanced by subsequent alterations in intercrystalline pores, intergranular cements, fractures, intraskeletal dissolution and initial deposition.

Intercrystalline, Intergranular (Cement) and Fracture Porosity

Zheng (1999) observed that the Guelph Formation exhibits highly variable porosity (0.1 to 23.6%). The Type 1 dolomite as defined earlier had a low porosity of 0.1 to 6.6%, similar to low-porosity limestone. This would appear to indicate that the Type 1 dolomite preserves or mimics the original calcite crystal fabric. As noted earlier, Type 1 dolomite accounts for only 15% of the dolomite in Guelph Formation samples (Zheng 1999). Type 2 and Type 3 dolomite, which account for the bulk of Guelph Formation rock, have a porosity of 3.4 to 35.2%. Zheng (1999) suggests that porosity evolution in Type 2 and Type 3 dolomite were mainly controlled by dissolution and dolomite alteration. Dekeyser (2006) observed that intercrystalline pores within the Eramosa and Guelph formations commonly contain dolomite (replacement euhedral and subhedral crystals), minor silica or calcite; or they are empty.

Dekeyser (2006) noted in her petrographic studies that blade-shaped evaporite cement pores (intergranular cement pores that were likely filled with gypsum or anhydrite) would either be filled or partially filled with dolomite or calcite cement or empty. Empty intergranular spaces would certainly increase porosity. Dekeyser (2006) estimated intergranular porosity in the underlying Gasport and Goat Island formations at 1 to 2%; whereas intergranular porosity in the Eramosa and Guelph formations was 1 to 5%.

Small fractures within the Guelph Formation were probably the result of continued tectonic activity, differential compaction or subsidence. These small fractures increase the porosity of a rock unit, although fracture porosity is often difficult to calculate. Estimates are 1% for the underlying Gasport and Goat Island formations, 2 to 3% for the underlying Eramosa Formation and 3% for the Guelph Formation (Dekeyser 2006). Zheng (1999) estimated porosity due to fractures in the Guelph Formation in his study area to be less than 2%.

Biological

Prior to complete diagenesis, bioturbation (the churning and stirring of sediment by organisms) can increase the size and number of pore spaces and, thus, increase porosity significantly. Biomoldic porosity is the porosity resulting from the removal, usually by dissolution, of an individual constituent of rock, such as a shell. Vuggy porosity refers to porosity that is non-biological in origin. It is suggested that vuggy porosity is related to biomoldic porosity, but vuggy pores have been dissolution enhanced, thereby destroying the original size and character of the pore space, making the vuggy pore difficult to relate to a biomoldic pore. Complete void-filling dolomite in the Guelph Formation is comparatively rare, occurring mostly as minor linings around biomoldic and vuggy pores (Coniglio, Zheng and Carter 2003).

Dekeyser (2006) estimated the biomoldic and vuggy porosity of the Gasport and Goat Island formations at between 5 and 10%. The Eramosa Formation has a biomoldic and vuggy porosity of between 2 to 5% and the Guelph Formation has a biomoldic and vuggy porosity in the range of 2 to 25%, with some portions of the Guelph Formation in excess of 30%. Millimetre- to centimetre-sized biomoldic and vuggy pores were common in Type 2 and Type 3 dolomite (Photo 1), which constitute the bulk of the dolomite in the Guelph Formation (Zheng 1999). Zheng (1999) estimates the biomoldic porosity of Type 2 and Type 3 dolomite at between 5 to 40%, and the vuggy porosity of the same dolomite fabric at 10 to 50%.

The type, activity and density of colonies and communities of the biota within the carbonate sediments can greatly influence porosity. Appendix H is a list of fossils within the various Silurian dolostone units, as summarized *from* Brintnell (2012). The presence of gastropods (snails and slugs) and their activity tends to create a more open, porous, cavity-filled rock unit (F.R. Brunton, OGS, personal communications, April 3, 2014). Gastropods are noted in a number of facies within the Guelph Formation, as noted earlier in this report.

Intraskeletal porosity for the Guelph Formation along the Bruce Peninsula has been estimated at 1% (Dekeyser 2006) and up to 5% for southwestern Ontario (Zheng 1999). A summary of these porosity numbers is provided in Table 5. Fenestral and shelter porosity make little contribution to the total porosity of the Guelph Formation (Zheng 1999).

Table 5. Summary of porosity for the Guelph Formation (data *from* Dekeyser (2006) and *from* Zheng (1999)).

Formation(s)	Biomoldic and/or Vuggy (%)	Intercrystalline and/or Intergranular (%)	Fracture (%)	Intraskeletal (%)
Gasport–Goat Island*	5–10	1–2	1	–
Eramosa*	2–5	1–5	2–3	–
Guelph*	2–25	1–5	3	1
Guelph**	5–50	1–3	2	<5

* *Data* from *Dekeyser (2006).*
** *Type 2 and Type 3 dolomite: data* from *Zheng (1999).*

Photos 1, 2 and 3 show part of a typical drill-core sample from the Guelph, Goat Island and Gasport formations, respectively. The more porous nature and the larger size of the pores of the Guelph Formation are quite evident from these photos. In fact, measurement of the pores from the samples shown in Photos 1 to 3 indicate an average of <1 mm for the pores in the Gasport and Goat Island formations, with a range from less than 1 mm to approximately 4 mm. Guelph Formation pores average greater than 1 mm with a range from less than 1 mm to 12 mm (3 to 6 mm are not uncommon). The pores are also significantly deeper.

Supporting the conclusions of Dekeyser (2006) and Zheng (1999), Amthor and Friedman (1991), Montañez and Stefani (1993) and Montañez (1994) suggest that extensive dolomite alteration through fracturing, dolomite dissolution, dolomite precipitation as overgrowths and cement, and dolomite recrystallization promote the development of significant amounts of intercrystalline and vuggy porosity in many pervasive dolomites.

Photo 1. Photograph of a drill-core sample showing a typical example of the Guelph Formation. The diameter of the core is 7.5 cm (left to right).

Chemical Weathering

In combination with this potentially more open, porous framework due to diagenesis and dolomitization, the differential weathering of dolostone can also make a significant contribution to creating and enlarging an even more open, porous framework. Chemical attack upon a rock is a very important agent in their destruction. The process acts upon the individual minerals in the rock unit and either dissolves them away or converts them to other minerals. Eventually, the net result is a complete breakdown of the original character of the rock, usually resulting in its complete disintegration (Milligan 1977).

Water in contact with the atmosphere commonly absorbs carbon dioxide (CO_2) to form a weak solution of carbonic acid. Carbon dioxide can also be absorbed by water molecules from decaying plant and animal matter as water migrates through soil layers. The carbonic acid is unstable and ionizes readily, as indicated by Equation [1].

$$\underset{\textit{water}}{H_2O} + \underset{\textit{carbon dioxide}}{CO_2} \leftrightarrow \underset{\textit{carbonic acid}}{H_2CO_3} \leftrightarrow \underset{\textit{hydrogen cations}}{H^+} + \underset{\textit{bicarbonate anions}}{HCO_3^-} \qquad [\ 1\ ]$$

The free hydrogen (H^+) cations of this acidic solution from Equation [1] are now free to react with the limestone at the water-rock surface interface as expressed by Equation [2].

$$\underset{\textit{calcite}}{CaCO_3} \leftrightarrow \underset{\textit{calcium cations}}{Ca^{2+}} + \underset{\textit{carbonate anions}}{CO_3^{2-}} + \underset{\textit{hydrogen cations}}{H^+} \leftrightarrow \underset{\textit{calcium cations}}{Ca^{2+}} + \underset{\textit{bicarbonate anions}}{HCO_3^-} \qquad [\ 2\ ]$$

Photo 2. Photograph of a drill-core sample showing a typical example of the Goat Island Formation. The diameter of the core is 6.1 cm (left to right).

If the water is stagnant, these reactions would proceed until equilibrium is reached and the reactions would essentially stop. If the water is in motion over the surface of the rock, the rock is constantly exposed to a new supply of non-saturated, slightly acidic water and the reaction will continue (i.e., to the right side of the equation). A similar equation and process to Equation [2] is applicable to dolostone ($CaMg(CO_3)_2$). The crystal size of the dolomite can influence the speed of the reaction (Rameil 2008).

Photo 3. Photograph of a drill-core sample showing a typical example of the Gasport Formation. The diameter of the core is 6.1 cm (left to right).

Hajna (2003) studied carbonate weathering in a cave environment, a somewhat controlled environment, where detailed observations were made. Some of the conclusions from this study are

- Dissolution not only occurs at the rock surface, but also along open cracks, microfractures, along vein structures, and along the borders between grains.
- Dissolution is dependent on the size of individual mineral grains.
- The dissolving water (mild acid) is pulled into the interior of the rock by capillary forces and along interconnected pores and fissures.
- Dissolution advances into the rock's interior along the chosen structures and leaves in its wake ever larger and more interconnected pores.
- During dissolution, pores get larger and become more interconnected, so that aggressive slightly acidic water advance more easily and deeper into the rock's interior.
- Chemical weathering or dissolution is usually incomplete, but the dissolution process leaves behind a porous sponge-like weathered zone that becomes more susceptible to mechanical weathering. Mechanical weathering includes frost action, freeze–thaw processes, windblown sand (sand blasting), wave action, running water (just the force of the water), plants and animals (the movement and forces created and associated with biological activity, e.g., roots) and fire (heat).
- Chemical analysis of the weathered zone demonstrates that the amount of magnesium, strontium and uranium in the weathered zone of the carbonate rock consistently decreases. In essence, these elements are being lost during the weathering process.
- Mg^{2+} cations, owing to their low ionic potential, are more mobile and are the first to leave their place in the crystal structure, thereby weakening the crystal lattice and increasing the proneness to further dissolution and mechanical weathering.
- The dissolution rate is determined by the dissolution on the crystal's surface, the transportation of ions through the border layer and by the speed of the conversion of carbon dioxide and water as well as lithological parameters of the carbonate rock (e.g., grain size).
- Acid-saturated clay sediments in contact with the rock surface can absorb Ca^{2+} and Mg^{2+} cations from the rock surface, and provides another absorption or migration route for these cations.
- The degree of chemical weathering depends upon composition, concentration, temperature and presence of bacteria.
- The most weathered walls appear to be those wetted by percolating water, areas in contact with fluvial sediments, and walls that are subjected to condensation corrosion.

Karst mapping in southern Ontario completed by Brunton (Brunton, Dodge and Shirota 2005, 2006; Brunton and Dodge 2008; Brunton 2013) has identified the Silurian rock units (including the Guelph Formation), located along and west of the Niagara Escarpment, as one of the most vulnerable areas for karst development. Karst features such as sinkholes, sinking streams, springs, karren (solution pits and grooves) and caves are commonly the surface expression of a karstic area, but, below the surface, may be channels or conduits where groundwater flow can be quite significant and turbulent. The significance of this karst work for the current study is two-fold: 1) the Silurian rock units, including the Guelph Formation, are a vulnerable area for karst development; and, 2) the rock–water interface (surface area exposure) available for chemical dissolution and other forms of weathering are increased by the presence of these karst features. This would lead to greater dolomite dissolution, potentially larger pore space development within the Guelph Formation (a higher porosity) and a continued weakening of the rock for use in the manufacture of high-specification aggregate products.

The aggregate quality test results for absorption, and ultimately freeze-thaw and magnesium sulphate soundness testing, is related to the porosity of a rock unit. Zheng (1999) and Dekeyser (2006) have demonstrated the porous nature of the Guelph Formation through dolomitization, biological activity and subsequent processes. Chemical weathering processes (dissolution) would further enhance the porous nature of the Guelph Formation and increase the size of the pore spaces. The measurement and photographs of the pore spaces indicate a more open, porous framework in the Guelph Formation than the underlying rock strata. Photo 4 shows the Guelph Formation from the Elora drill core (Aggregate Test Site 21) and, once again, provides evidence of large pore spaces and missing (completely dissolved) core segments.

Photo 4. Photograph showing the Guelph Formation from the Elora drill core (aggregate test site 21: depth 20.15 to 21.25 m). The diameter of the core is 7.5 cm (left to right).

Summary

1. Based on preliminary results from an OGS 2014 drilling program along the Niagara Peninsula, the Guelph Formation has a smaller geographic distribution than shown on Figure 1 and as indicated on Figures 2 and 3 (*see* back pocket). Preliminary results indicate that the Goat Island and Eramosa formations and the Salina Group occupy a larger area. Therefore, both a thick overburden cover and a smaller geographic area along the Niagara Peninsula limit the economic extraction opportunities of the Guelph Formation in the Niagara region.

2. The thickness of the Guelph Formation can be extremely variable on both a regional scale, as well as over a short distance, along the outcrop–subcrop belt. This makes it difficult to identify important, economically feasible resource development areas. Extensive drilling may be required to delineate the thickness of the Guelph Formation and, therefore, its true economic potential. Alternatively, the underlying dolostone units—the Gasport, Goat Island and Eramosa formations—can provide additional development opportunities.

3. Previous geochemical analyses (Vos 1969), as well as the new geochemical analyses presented in this report, clearly indicate that the Guelph Formation is a high-purity dolostone that can be used for a number of industrial mineral applications. The geochemical data are supported by the mineralogical and petrographic studies that indicate the Guelph Formation is pervasively and extensively dolomitized with little remnant calcite and few secondary accessory minerals. Therefore, the Guelph Formation has excellent potential from an industrial mineral perspective. Aggregate Resources Inventory Papers (ARIPs) along the outcrop–subcrop belt indicate overburden thickness overlying the Guelph Formation. These reports will be useful to industry representatives (Rowell 2012b; Jagger Hims Limited and Rowell 2009; MacNaughton Hermsen Britton Clarkson Planning Limited, White LandScience, Robinson Consultants, Rowell and Brunton 2014; Planning and Engineering Initiatives Limited and Ontario Geological Survey 1999; Ontario Geological Survey and Planning and Engineering Initiatives Limited 1998; Rowell 2014; Marich 2010; Ontario Geological Survey 1980, 1985).

4. From an aggregate perspective, previous aggregate test results (Rowell 2012a) as well as the new aggregate test results presented in this report would appear to indicate that the Guelph Formation may not be acceptable for the manufacture of high-specification, bedrock-derived aggregate products. The Guelph Formation met or exceeded the specifications for many of the aggregate quality tests, but frequently failed the absorption test, thereby limiting its potential as an aggregate source.

   This report presents evidence to suggest that the very nature of diagenesis and dolomitization, the nature of post-dolomitization events and processes (e.g., dedolomitization, biological activity), and chemical weathering and dissolution enhancement of pore spaces have an important influence on the physical properties of the Guelph Formation (particularly porosity) and, therefore, its ability to meet or exceed aggregate product specifications.

5. The Guelph Formation fails the aggregate absorption test 18 of 37 times. The magnesium sulphate soundness and freeze–thaw aggregate test results should be influenced by the porosity and, as a result, the Guelph Formation should fail these aggregate quality tests as frequently as it fails the absorption test.

   It is suggested that the Guelph Formation pore spaces are large enough that they drain well and actually lead to good magnesium sulphate soundness and freeze–thaw testing results. Stated another way, the pore spaces are so large that the fluids involved with the magnesium sulphate soundness and freeze–thaw aggregate testing procedures quickly drain from the test samples before they have an opportunity to simulate the freeze–thaw process, and essentially give a false positive. Personnel of MTO (R.G. Gorman, Ministry of Transportation, personal communications, December 2014) have suggested that this is a logical explanation because certain porous Ordovician rock units in south-central Ontario have shown a similar result (i.e., consistently failed the absorption test, but passed the magnesium sulphate soundness and freeze–thaw tests). Because laboratory testing may not provide the complete picture with regard to high-specification, bedrock-derived aggregate sources, MTO now requires potential asphalt aggregate producers to demonstrate asphalt aggregate performance *in situ* (i.e., asphalt mix placed along a provincial highway under natural conditions for a period of time).

Further detailed freeze–thaw and magnesium sulphate soundness testing should be completed on porous rock samples. The Guelph Formation should not have passed these aggregate quality tests as frequently as it did based on the absorption results and the porous nature of the rock.

6. The porosity of an aggregate is generally indicated by the amount of water it absorbs when soaked in water. A certain degree of porosity is desirable, as it permits the aggregate particle to absorb bituminous (asphalt) binder or cement mix, which then forms a bond between the neighbouring aggregate particles. The issue with highly porous aggregate is that a great deal of asphalt binder or cement mix is absorbed by the pore spaces and may not be available to coat the aggregate particle surface properly, weakening adhesion between particles.

   Aggregates that are very porous tend to require a significant amount of extra asphalt binder or cement mix to make up for the high absorption. Highly porous aggregates are not normally used unless they possess certain other qualities or properties that make them desirable in spite of the high absorption. For example, blast furnace slag can be a highly porous aggregate, but its lightness and wear-resistant properties frequently outweigh the high absorption consideration for pavement construction.

7. There are still areas where the Guelph Formation passes all aggregate quality testing and areas where the rock unit is quite competent. It is suggested that these areas may represent portions of the Guelph Formation where the lithification, diagenetic, dolomitization, biological activity and chemical weathering history has been different. Extensive aggregate quality testing of these areas should occur before the Guelph Formation is considered for aggregate extraction and use.

Appendix A.

Locations and Types of Samples Collected for Analyses

Notes:

Outcrop samples were collected on surface and, therefore, indicate a “depth” of 0.00 m.

Drill-core samples will indicate

1. the depth at which the geochemical sample was collected (e.g., 23.20 m), or
2. the interval from which the sample was taken (e.g., 7.77–19.05 m).

Appendix A. Locations and types of samples collected for geochemical analyses.

Location Number	Sample Number	Sample Type	Geochemical Sample Depth or Interval	Formation – Member (If Recorded)	Municipality
Location 01	01	Outcrop	0.00 m	Guelph Formation	Bruce County
Location 01	02	Outcrop	0.00 m	Guelph Formation	Bruce County
Location 01	03	Outcrop	0.00 m	Guelph Formation	Bruce County
Location 02	04	Outcrop	0.00 m	Guelph Formation	Bruce County
Location 03	05	Outcrop	0.00 m	Guelph Formation	Bruce County
Location 04	06	Outcrop	0.00 m	Guelph Formation	Grey County
Location 05	07	Outcrop	0.00 m	Guelph Formation	Grey County
Location 06	08	Drill Core	4.50 m	Guelph Formation	Dufferin County
Location 06	09	Drill Core	10.50 m	Guelph Formation	Dufferin County
Location 07	10	Drill Core	6.00 m	Guelph Formation	Dufferin County
Location 07	11	Drill Core	23.20 m	Guelph Formation	Dufferin County
Location 08	12	Drill Core	4.70 m	Guelph Formation	Dufferin County
Location 08	13	Drill Core	9.60 m	Guelph Formation	Dufferin County
Location 08	14	Drill Core	12.35 m	Guelph Formation	Dufferin County
Location 08	15	Drill Core	18.24 m	Guelph Formation	Dufferin County
Location 09	16	Drill Core	22.50 m	Guelph Formation	Dufferin County
Location 10	17	Drill Core	7.77 – 19.05 m	Guelph Formation	Dufferin County
Location 10	18	Drill Core	19.05 – 30.71 m	Guelph Formation	Dufferin County
Location 10	19	Drill Core	30.71 – 45.57 m	Guelph Formation	Dufferin County
Location 11	20	Drill Core	5.03 – 23.32 m	Guelph Formation	Wellington County
Location 11	21	Drill Core	23.32 – 38.56 m	Guelph Formation	Wellington County
Location 11	22	Drill Core	38.56 – 56.85 m	Guelph Formation	Wellington County
Location 12	23	Drill Core	3.56 m	Guelph Formation	Wellington County
Location 12	24	Drill Core	4.11 m	Guelph Formation	Wellington County
Location 12	25	Drill Core	5.49 m	Guelph Formation	Wellington County
Location 12	26	Drill Core	7.09 m	Guelph Formation	Wellington County
Location 12	27	Drill Core	8.53 m	Guelph Formation	Wellington County
Location 12	28	Drill Core	10.05 m	Guelph Formation	Wellington County
Location 12	29	Drill Core	11.58 m	Guelph Formation	Wellington County
Location 12	30	Drill Core	12.80 m	Guelph Formation	Wellington County
Location 12	31	Drill Core	14.63 m	Guelph Formation	Wellington County
Location 12	32	Drill Core	16.15 m	Guelph Formation	Wellington County
Location 12	33	Drill Core	17.68 m	Guelph Formation	Wellington County
Location 12	34	Drill Core	19.20 m	Guelph Formation	Wellington County
Location 12	35	Drill Core	20.72 m	Guelph Formation	Wellington County
Location 12	36	Drill Core	22.25 m	Guelph Formation	Wellington County
Location 12	37	Drill Core	23.77 m	Guelph Formation	Wellington County
Location 12	38	Drill Core	25.30 m	Guelph Formation	Wellington County
Location 12	39	Drill Core	27.43 m	Guelph Formation	Wellington County
Location 12	40	Drill Core	28.96 m	Guelph Formation	Wellington County
Location 13	41	Drill Core	10.36 m	Guelph Formation	Wellington County
Location 13	42	Drill Core	11.89 m	Guelph Formation	Wellington County
Location 13	43	Drill Core	13.41 m	Guelph Formation	Wellington County
Location 13	44	Drill Core	14.94 m	Guelph Formation	Wellington County
Location 13	45	Drill Core	16.46 m	Guelph Formation	Wellington County
Location 13	46	Drill Core	17.98 m	Guelph Formation	Wellington County
Location 13	47	Drill Core	19.20 m	Guelph Formation	Wellington County
Location 13	48	Drill Core	20.73 m	Guelph Formation	Wellington County
Location 13	49	Drill Core	22.25 m	Guelph Formation	Wellington County
Location 13	50	Drill Core	23.77 m	Guelph Formation	Wellington County
Location 13	51	Drill Core	25.30 m	Guelph Formation	Wellington County
Location 13	52	Drill Core	26.82 m	Guelph Formation	Wellington County
Location 13	53	Drill Core	28.34 m	Guelph Formation	Wellington County
Location 13	54	Drill Core	29.87 m	Guelph Formation	Wellington County

Location Number	Sample Number	Sample Type	Geochemical Sample Depth or Interval	Formation – Member (If Recorded)	Municipality
Location 13	55	Drill Core	31.39 m	Guelph Formation	Wellington County
Location 13	56	Drill Core	32.92 m	Guelph Formation	Wellington County
Location 13	57	Drill Core	34.44 m	Guelph Formation	Wellington County
Location 13	58	Drill Core	35.97 m	Guelph Formation	Wellington County
Location 13	59	Drill Core	37.49 m	Guelph Formation	Wellington County
Location 13	60	Drill Core	39.01 m	Guelph Formation	Wellington County
Location 13	61	Drill Core	40.54 m	Guelph Formation	Wellington County
Location 13	62	Drill Core	43.59 m	Guelph Formation	Wellington County
Location 13	63	Drill Core	45.11 m	Guelph Formation	Wellington County
Location 13	64	Drill Core	46.63 m	Guelph Formation	Wellington County
Location 13	65	Drill Core	48.16 m	Guelph Formation	Wellington County
Location 13	66	Drill Core	49.68 m	Guelph Formation	Wellington County
Location 13	67	Drill Core	51.57 m	Guelph Formation	Wellington County
Location 13	68	Drill Core	52.73 m	Guelph Formation	Wellington County
Location 13	69	Drill Core	54.56 m	Guelph Formation	Wellington County
Location 13	70	Drill Core	55.78 m	Guelph Formation	Wellington County
Location 13	71	Drill Core	57.30 m	Guelph Formation	Wellington County
Location 13	72	Drill Core	58.82 m	Guelph Formation	Wellington County
Location 13	73	Drill Core	60.35 m	Guelph Formation	Wellington County
Location 13	74	Drill Core	61.79 m	Guelph Formation	Wellington County
Location 14	75	Drill Core	27.00 – 30.05 m	Guelph Formation - Wellington Member	Wellington County
Location 15	76	Drill Core	34.75 – 37.80 m	Guelph Formation - Wellington Member	Dufferin County
Location 16	77	Drill Core	30.87 – 33.92 m	Guelph Formation - Wellington Member	Dufferin County
Location 17	78	Drill Core	33.15 – 36.20 m	Guelph Formation - Hanlon Member	Dufferin County
Location 18	79	Drill Core	19.55 – 22.60 m	Guelph Formation - Wellington Member	Dufferin County
Location 19	80	Drill Core	26.05 – 29.09 m	Guelph Formation	Reg’l. Municipality of Peel
Location 21	81	Drill Core	27.08 – 30.13 m	Guelph Formation - Wellington Member	Dufferin County
Location 22	82	Drill Core	44.00 – 47.05 m	Guelph Formation - Wellington Member	Dufferin County
Location 23	83	Drill Core	30.60 – 33.65 m	Guelph Formation - Wellington Member	Dufferin County
Location 24	84	Drill Core	31.25 – 34.30 m	Guelph Formation - Wellington Member	Wellington County
Location 27	85	Drill Core	49.92 – 52.97 m	Guelph Formation - Wellington Member	Dufferin County
Location 28	86	Drill Core	48.30 – 51.35 m	Guelph Formation - Wellington Member	Wellington County
Location 31	87	Drill Core	59.10 – 62.15 m	Guelph Formation - Wellington Member	Dufferin County
Location 32	88	Drill Core	55.00 – 58.05 m	Guelph Formation - Wellington Member	Dufferin County
Location 33	89	Drill Core	18.85 – 21.90 m	Guelph Formation - Wellington Member	Wellington County
Location 34	90	Drill Core	57.25 – 60.30 m	Guelph Formation - Wellington Member	Wellington County
Location 36	91	Drill Core	75.20 – 78.25 m	Guelph Formation - Wellington Member	Dufferin County
Location 37	92	Drill Core	75.70 – 78.75 m	Guelph Formation - Wellington Member	Dufferin County
Location 39	93	Drill Core	30.25 – 33.30 m	Guelph Formation - Hanlon Member	Wellington County
Location 42	94	Drill Core	15.55 – 19.60 m	Guelph Formation - Wellington Member	Wellington County
Location 20	95	Drill Core	60.60 – 63.65 m	Guelph Formation	Dufferin County
Location 26	96	Drill Core	35.60 – 38.65 m	Guelph Formation	Wellington County
Location 41	97	Drill Core	43.10 – 46.15 m	Guelph Formation	Wellington County
Location 40	98	Drill Core	41.75 – 44.80 m	Guelph Formation - Wellington Member	Wellington County
Location 25	99	Drill Core	49.95 – 53.00 m	Guelph Formation - Wellington Member	Wellington County
Location 38	100	Drill Core	37.50 – 40.55 m	Guelph Formation - Wellington Member	Wellington County
Location 30	101	Drill Core	58.15 – 61.20 m	Guelph Formation - Wellington Member	Dufferin County
Location 35	102	Drill Core	39.35 – 42.40 m	Guelph Formation - Wellington Member	Wellington County
Location 29	103	Drill Core	17.60 – 20.65 m	Guelph Formation - Wellington Member	Wellington County
Location 43	104	Drill Core	16.50 – 27.70 m	Guelph Formation	Wellington County
Location 43	105	Drill Core	27.70 – 39.60 m	Guelph Formation	Wellington County
Location 43	106	Drill Core	39.60 – 51.50 m	Guelph Formation	Wellington County
Location 43	107	Drill Core	51.50 – 62.80 m	Guelph Formation	Wellington County
Location 44	108	Drill Core	32.15 – 35.20 m	Guelph Formation - Hanlon Member	Wellington County
Location 45	109	Drill Core	18.70 – 21.75 m	Guelph Formation - Wellington Member	Wellington County

Location Number	Sample Number	Sample Type	Geochemical Sample Depth or Interval	Formation – Member (If Recorded)	Municipality
Location 46	110	Drill Core	34.75 – 37.80 m	Guelph Formation - Wellington Member	Wellington County
Location 47	111	Drill Core	18.70 – 21.75 m	Guelph Formation	Wellington County
Location 48	112	Outcrop	0.00 m	Guelph Formation	Wellington County
Location 48	113	Outcrop	0.00 m	Guelph Formation	Wellington County
Location 48	114	Outcrop	0.00 m	Guelph Formation	Wellington County
Location 48	115	Outcrop	0.00 m	Guelph Formation	Wellington County
Location 48	116	Outcrop	0.00 m	Guelph Formation	Wellington County
Location 49	117	Outcrop	0.00 m	Guelph Formation	Wellington County
Location 50	118	Outcrop	0.00 m	Guelph Formation	Wellington County
Location 51	119	Outcrop	0.00 m	Guelph Formation	City of Hamilton
Location 52	120	Drill Core	6.55 – 15.44 m	Guelph Formation	City of Hamilton
Location 52	121	Drill Core	15.44 – 24.38 m	Guelph Formation	City of Hamilton
Location 52	122	Drill Core	24.38 – 33.42 m	Guelph Formation	City of Hamilton
Location 52	123	Drill Core	33.42 – 42.37 m	Guelph Formation	City of Hamilton
Location 53	124	Outcrop	0.00 m	Guelph Formation	City of Hamilton

Appendix B.

Major Oxide Geochemical Analyses for Guelph Formation Samples

Appendix B. Geochemical analyses of Guelph Formation samples: major oxides analyzed by X-ray fluorescence spectrometry (XRF).

Location No.	Sample No.	SiO_2 (%)	Al_2O_3 (%)	MnO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	TiO_2 (%)	Fe_2O_3 (%)	LOI (%)	Total (%)	S (%)	CO_2 (%)	H_2O^+ (%)	H_2O^- (%)	CaO/ MgO	$MgCO_3$ (%)	$CaCO_3$ (%)	$Carb_{TOT}$ (%)	Si+Al+Fe (%)	Specific Gravity
Location 01*	01	0.36	0.19	–	21.44	30.80	–	–	–	–	0.11	–	–	–	–	–	–	1.44	44.81	55.13	99.94	0.66	–
Location 01*	02	0.08	0.08	–	21.44	30.80	–	–	–	–	0.10	–	–	–	–	–	–	1.44	44.81	55.13	99.94	0.26	–
Location 01*	03	0.18	0.14	–	21.05	30.60	–	–	–	–	0.11	–	–	–	–	–	–	1.45	43.99	54.77	98.77	0.43	–
Location 02	04	0.28	0.19	0.02	17.92	28.13	<0.01	0.02	<0.01	0.01	0.05	52.59	99.03	<0.01	47.20	0.80	0.50	1.57	37.45	50.35	87.81	0.52	2.717
Location 03	05	0.25	0.15	0.01	18.00	28.47	<0.01	0.01	<0.01	0.01	0.07	52.74	99.53	<0.01	45.90	0.89	0.49	1.58	37.62	50.96	88.58	0.47	–
Location 04*	06	0.18	0.05	–	20.82	31.17	–	–	–	–	0.00	–	–	–	–	–	–	1.50	43.51	55.79	99.31	0.23	–
Location 05	07	0.15	0.05	0.02	18.28	28.03	<0.01	<0.01	<0.01	0.02	0.09	52.92	99.36	0.00	45.50	0.49	0.43	1.53	38.21	50.17	88.38	0.29	2.551
Location 06	08	0.13	0.03	<0.01	21.60	30.70	0.04	<0.01	<0.01	<0.01	0.04	47.40	100.00	–	–	–	–	1.42	45.14	54.95	100.10	0.20	–
Location 06	09	0.25	0.06	<0.01	21.30	30.40	0.04	0.01	<0.01	<0.01	0.09	46.90	99.10	–	–	–	–	1.43	44.52	54.42	98.93	0.40	–
Location 07	10	0.32	0.11	0.01	20.60	30.40	0.08	0.04	<0.01	<0.01	0.32	47.40	99.40	–	–	–	–	1.48	43.05	54.42	97.47	0.75	–
Location 07	11	0.54	0.11	0.01	21.50	30.50	0.05	0.03	<0.01	<0.01	0.08	47.10	99.80	–	–	–	–	1.42	44.94	54.60	99.53	0.73	–
Location 08	12	0.24	0.09	0.02	21.60	30.70	0.06	0.02	<0.01	<0.01	0.14	47.50	100.50	–	–	–	–	1.42	45.14	54.95	100.10	0.47	–
Location 08	13	0.91	0.33	0.01	21.30	30.30	0.06	0.13	<0.01	0.01	0.19	47.10	100.40	–	–	–	–	1.42	44.52	54.24	98.75	1.43	–
Location 08	14	0.55	0.21	0.01	20.00	31.90	0.06	0.07	<0.01	<0.01	0.20	47.20	100.30	–	–	–	–	1.60	41.80	57.10	98.90	0.96	–
Location 08	15	0.48	0.16	0.02	21.10	30.30	0.06	0.06	<0.01	<0.01	0.19	47.40	99.70	–	–	–	–	1.44	44.10	54.24	98.34	0.83	–
Location 09	16	0.09	0.04	0.02	21.50	30.50	0.03	<0.01	<0.01	<0.01	0.15	47.20	99.60	–	–	–	–	1.42	44.94	54.60	99.53	0.28	–
Location 10	17	0.09	0.06	0.04	19.42	29.84	0.00	0.00	0.00	0.02	0.12	50.50	99.91	0.00	46.70	0.01	0.13	1.54	40.59	53.41	94.00	0.27	2.632
Location 10	18	0.07	0.06	0.02	19.24	29.95	0.00	0.00	0.00	0.01	0.09	50.67	99.92	0.00	46.10	0.20	0.16	1.56	40.21	53.61	93.82	0.22	2.603
Location 10	19	0.07	0.08	0.03	19.38	29.88	0.00	0.00	0.00	0.02	0.11	50.54	99.93	0.00	48.00	0.12	0.15	1.54	40.50	53.49	93.99	0.26	2.551
Location 11	20	0.06	0.06	0.02	19.27	29.50	0.00	0.00	0.00	0.00	0.08	50.59	99.40	0.00	48.10	0.00	0.13	1.53	40.27	52.81	93.08	0.20	2.638
Location 11	21	0.01	0.03	0.02	19.33	29.56	0.00	0.00	0.00	0.00	0.05	50.82	99.64	0.00	51.10	0.03	0.13	1.53	40.40	52.91	93.31	0.09	2.569
Location 11	22	0.02	0.04	0.02	19.39	29.97	0.00	0.00	0.00	0.00	0.06	50.71	100.02	0.00	46.10	0.05	0.14	1.55	40.53	53.65	94.17	0.12	2.691
Location 12	23	0.15	0.06	0.01	21.92	29.87	0.00	0.00	0.00	0.00	0.13	47.41	99.51	–	–	–	–	1.36	45.81	53.47	99.28	0.34	–
Location 12	24	0.05	0.01	0.02	21.44	29.22	0.27	0.00	0.00	0.00	0.06	47.65	98.75	–	–	–	–	1.36	44.81	52.30	97.11	0.12	–
Location 12	25	0.06	0.01	0.02	22.03	29.54	0.00	0.00	0.00	0.00	0.07	47.86	99.53	–	–	–	–	1.34	46.04	52.88	98.92	0.14	–
Location 12	26	0.02	0.01	0.03	21.09	30.13	0.00	0.00	0.00	0.00	0.13	47.68	99.02	–	–	–	–	1.43	44.08	53.93	98.01	0.16	–
Location 12	27	0.03	0.02	0.02	22.00	29.43	0.00	0.00	0.00	0.00	0.07	47.87	99.38	–	–	–	–	1.34	45.98	52.68	98.66	0.12	–
Location 12	28	0.04	0.02	0.02	22.11	29.55	0.00	0.00	0.00	0.00	0.06	47.83	99.61	–	–	–	–	1.34	46.21	52.89	99.10	0.12	–
Location 12	29	0.03	0.01	0.02	22.08	29.62	0.00	0.00	0.00	0.00	0.06	47.75	99.51	–	–	–	–	1.34	46.15	53.02	99.17	0.10	–
Location 12	30	0.00	0.00	0.02	22.02	29.32	0.00	0.00	0.00	0.00	0.06	47.85	99.21	–	–	–	–	1.33	46.02	52.48	98.50	0.06	–
Location 12	31	0.02	0.00	0.02	22.05	29.22	0.00	0.00	0.00	0.00	0.05	48.06	99.35	–	–	–	–	1.33	46.08	52.30	98.39	0.07	–
Location 12	32	0.02	0.01	0.02	21.96	29.20	0.00	0.00	0.00	0.00	0.09	48.11	99.34	–	–	–	–	1.33	45.90	52.27	98.16	0.12	–

**Geochemical results* from *Vos (1969).*

Appendix B, *continued*. Samples 33 to 65.

Location No.	Sample No.	SiO_2 (%)	Al_2O_3 (%)	MnO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	TiO_2 (%)	Fe_2O_3 (%)	LOI (%)	Total (%)	S (%)	CO_2 (%)	H_2O^+ (%)	H_2O^- (%)	CaO/ MgO	$MgCO_3$ (%)	$CaCO_3$ (%)	$Carb_{TOT}$ (%)	Si+Al+Fe (%)	Specific Gravity
Location 12	33	0.02	0.01	0.02	21.75	29.63	0.00	0.00	0.00	0.00	0.07	47.91	99.39	–	–	–	–	1.36	45.46	53.04	98.50	0.10	–
Location 12	34	0.03	0.01	0.02	21.66	29.24	0.00	0.00	0.00	0.01	0.08	48.37	99.35	–	–	–	–	1.35	45.27	52.34	97.61	0.12	–
Location 12	35	0.01	0.00	0.02	21.24	31.07	0.00	0.00	0.00	0.00	0.05	47.52	99.85	–	–	–	–	1.46	44.39	55.62	100.01	0.06	–
Location 12	36	0.02	0.00	0.02	22.26	29.82	0.00	0.00	0.00	0.00	0.06	47.76	99.88	–	–	–	–	1.34	46.52	53.38	99.90	0.08	–
Location 12	37	0.02	0.00	0.02	22.07	29.60	0.00	0.00	0.00	0.00	0.06	47.71	99.43	–	–	–	–	1.34	46.13	52.98	99.11	0.08	–
Location 12	38	0.02	0.00	0.02	20.54	30.73	0.00	0.00	0.00	0.00	0.08	47.73	99.06	–	–	–	–	1.50	42.93	55.01	97.94	0.10	–
Location 12	39	0.03	0.02	0.03	20.92	29.51	0.00	0.00	0.00	0.00	0.10	48.97	99.52	–	–	–	–	1.41	43.72	52.82	96.55	0.15	–
Location 12	40	0.04	0.01	0.03	17.11	34.86	0.00	0.00	0.00	0.00	0.32	46.74	99.04	–	–	–	–	2.04	35.76	62.40	98.16	0.37	–
Location 13	41	0.04	0.02	0.03	21.73	29.34	0.00	0.00	0.00	0.00	0.12	47.67	98.88	–	–	–	–	1.35	45.42	52.52	97.93	0.18	–
Location 13	42	0.03	0.02	0.04	21.94	29.55	0.00	0.00	0.00	0.00	0.13	47.62	99.26	–	–	–	–	1.35	45.85	52.89	98.75	0.18	–
Location 13	43	0.12	0.06	0.03	21.96	30.37	0.00	0.00	0.00	0.00	0.13	47.62	100.22	–	–	–	–	1.38	45.90	54.36	100.26	0.31	–
Location 13	44	0.01	0.01	0.02	21.95	29.86	0.00	0.00	0.00	0.00	0.07	47.68	99.54	–	–	–	–	1.36	45.88	53.45	99.32	0.09	–
Location 13	45	0.04	0.02	0.03	21.73	29.68	0.00	0.00	0.00	0.00	0.13	47.68	99.27	–	–	–	–	1.37	45.42	53.13	98.54	0.19	–
Location 13	46	0.07	0.03	0.02	22.07	30.07	0.00	0.00	0.00	0.00	0.10	47.76	100.05	–	–	–	–	1.36	46.13	53.83	99.95	0.20	–
Location 13	47	0.07	0.01	0.02	21.58	29.37	0.00	0.00	0.00	0.00	0.09	47.78	98.86	–	–	–	–	1.36	45.10	52.57	97.67	0.17	–
Location 13	48	0.07	0.02	0.02	22.12	29.46	0.00	0.00	0.00	0.00	0.07	47.72	99.40	–	–	–	–	1.33	46.23	52.73	98.96	0.16	–
Location 13	49	0.03	0.01	0.02	22.02	29.13	0.00	0.00	0.00	0.00	0.06	47.79	98.99	–	–	–	–	1.32	46.02	52.14	98.16	0.10	–
Location 13	50	0.05	0.02	0.02	22.15	29.36	0.00	0.00	0.00	0.00	0.06	47.77	99.37	–	–	–	–	1.33	46.29	52.55	98.85	0.13	–
Location 13	51	0.02	0.01	0.02	22.35	30.09	0.00	0.00	0.00	0.00	0.09	47.74	100.24	–	–	–	–	1.35	46.71	53.86	100.57	0.12	–
Location 13	52	0.03	0.01	0.02	22.10	29.74	0.00	0.00	0.00	0.00	0.06	47.82	99.72	–	–	–	–	1.35	46.19	53.23	99.42	0.10	–
Location 13	53	0.01	0.00	0.02	22.26	29.94	0.00	0.00	0.00	0.00	0.06	47.88	100.12	–	–	–	–	1.35	46.52	53.59	100.12	0.07	–
Location 13	54	0.07	0.03	0.02	22.19	29.98	0.00	0.00	0.00	0.00	0.11	47.81	100.14	–	–	–	–	1.35	46.38	53.66	100.04	0.21	–
Location 13	55	0.02	0.01	0.02	22.22	30.14	0.00	0.00	0.00	0.00	0.08	47.83	100.27	–	–	–	–	1.36	46.44	53.95	100.39	0.11	–
Location 13	56	0.02	0.01	0.02	22.25	30.02	0.00	0.00	0.00	0.00	0.05	47.94	100.25	–	–	–	–	1.35	46.50	53.74	100.24	0.08	–
Location 13	57	0.03	0.00	0.02	22.32	30.01	0.00	0.00	0.00	0.00	0.07	47.97	100.36	–	–	–	–	1.34	46.65	53.72	100.37	0.10	–
Location 13	58	0.01	0.00	0.02	22.39	30.27	0.00	0.00	0.00	0.00	0.07	47.93	100.62	–	–	–	–	1.35	46.80	54.18	100.98	0.08	–
Location 13	59	0.02	0.00	0.02	21.96	29.87	0.00	0.00	0.00	0.00	0.08	47.98	99.87	–	–	–	–	1.36	45.90	53.47	99.36	0.10	–
Location 13	60	0.02	0.00	0.02	22.09	30.06	0.00	0.00	0.00	0.00	0.07	47.84	100.04	–	–	–	–	1.36	46.17	53.81	99.98	0.09	–
Location 13	61	0.02	0.00	0.01	22.43	30.14	0.00	0.00	0.00	0.00	0.05	47.90	100.50	–	–	–	–	1.34	46.88	53.95	100.83	0.07	–
Location 13	62	0.03	0.00	0.02	22.34	30.10	0.00	0.00	0.00	0.00	0.05	47.92	100.40	–	–	–	–	1.35	46.69	53.88	100.57	0.08	–
Location 13	63	0.02	0.00	0.02	22.28	29.97	0.00	0.00	0.00	0.00	0.05	47.83	100.10	–	–	–	–	1.35	46.57	53.65	100.21	0.07	–
Location 13	64	0.01	0.00	0.02	22.27	30.02	0.00	0.00	0.00	0.00	0.07	47.71	100.05	–	–	–	–	1.35	46.54	53.74	100.28	0.08	–
Location 13	65	0.02	0.01	0.02	21.98	29.92	0.00	0.00	0.00	0.00	0.07	47.82	99.77	–	–	–	–	1.36	45.94	53.56	99.50	0.10	–

Appendix B, *continued*. Samples 66 to 98.

Location No.	**Sample No.**	**SiO_2 (%)**	**Al_2O_3 (%)**	**MnO (%)**	**MgO (%)**	**CaO (%)**	**Na_2O (%)**	**K_2O (%)**	**P_2O_5 (%)**	**TiO_2 (%)**	**Fe_2O_3 (%)**	**LOI (%)**	**Total (%)**	**S (%)**	**CO_2 (%)**	**H_2O^+ (%)**	**H_2O^- (%)**	**CaO/ MgO**	**$MgCO_3$ (%)**	**$CaCO_3$ (%)**	**$Carb_{TOT}$ (%)**	**Si+Al+Fe (%)**	**Specific Gravity**
Location 13	66	0.01	0.00	0.02	22.20	29.95	0.00	0.00	0.00	0.00	0.08	47.94	100.14	–	–	–	–	1.35	46.40	53.61	100.01	0.09	–
Location 13	67	0.01	0.00	0.02	22.18	30.18	0.00	0.00	0.00	0.00	0.07	48.03	100.43	–	–	–	–	1.36	46.36	54.02	100.38	0.08	–
Location 13	68	0.01	0.00	0.02	22.34	30.12	0.00	0.00	0.00	0.00	0.06	47.97	100.45	–	–	–	–	1.35	46.69	53.91	100.61	0.07	–
Location 13	69	0.01	0.00	0.02	21.54	30.05	0.00	0.00	0.00	0.00	0.10	47.69	99.36	–	–	–	–	1.40	45.02	53.79	98.81	0.11	–
Location 13	70	0.02	0.00	0.02	22.16	29.85	0.00	0.00	0.00	0.00	0.05	47.84	99.89	–	–	–	–	1.35	46.31	53.43	99.75	0.07	–
Location 13	71	0.04	0.00	0.02	21.72	30.40	0.00	0.00	0.00	0.00	0.06	47.95	100.13	–	–	–	–	1.40	45.39	54.42	99.81	0.10	–
Location 13	72	0.03	0.01	0.02	22.31	29.86	0.00	0.00	0.00	0.00	0.05	47.99	100.21	–	–	–	–	1.34	46.63	53.45	100.08	0.09	–
Location 13	73	0.02	0.00	0.02	22.03	29.89	0.00	0.00	0.00	0.00	0.08	47.85	99.83	–	–	–	–	1.36	46.04	53.50	99.55	0.10	–
Location 13	74	0.08	0.01	0.02	22.19	29.81	0.00	0.00	0.00	0.00	0.06	47.90	100.00	–	–	–	–	1.34	46.38	53.36	99.74	0.15	–
Location 14	75	0.22	0.21	0.02	21.72	30.50	<0.01	0.01	<0.01	0.03	0.13	47.27	100.07	<0.01	46.44	0.20	0.16	1.40	45.39	54.60	99.99	0.56	–
Location 15	76	0.37	0.24	0.01	21.45	30.74	<0.01	0.02	<0.01	0.03	0.14	47.16	100.14	<0.01	46.46	0.34	0.15	1.43	44.83	55.02	99.86	0.75	–
Location 16	77	0.14	0.17	0.02	21.69	30.68	<0.01	0.01	<0.01	0.01	0.11	47.26	100.05	<0.01	44.45	0.13	0.13	1.41	45.33	54.92	100.25	0.42	–
Location 17	78	0.09	0.09	0.02	20.76	30.08	<0.01	<0.01	<0.01	0.01	0.12	47.50	98.65	<0.01	47.20	0.06	0.14	1.45	43.39	53.84	97.23	0.30	–
Location 18	79	1.13	0.61	0.02	21.01	29.88	0.02	0.05	<0.01	0.03	0.20	46.70	99.65	<0.01	44.88	0.21	0.20	1.42	43.91	53.49	97.40	1.94	–
Location 19	80	1.12	0.40	0.06	21.17	30.83	<0.01	0.02	<0.01	0.01	0.26	46.44	100.35	<0.01	44.91	0.25	0.16	1.46	44.25	55.19	99.43	1.78	–
Location 21	81	0.48	0.34	0.02	21.63	30.57	<0.01	0.03	<0.01	0.01	0.15	47.00	100.20	<0.01	46.05	0.20	0.17	1.41	45.21	54.72	99.93	0.97	–
Location 22	82	0.34	0.26	0.02	21.69	30.49	<0.01	0.02	<0.01	0.03	0.13	47.13	100.09	<0.01	46.22	0.32	0.17	1.41	45.33	54.58	99.91	0.73	–
Location 23	83	0.42	0.30	0.02	21.82	30.69	<0.01	0.02	<0.01	0.01	0.17	47.06	100.48	<0.01	46.09	0.12	0.18	1.41	45.60	54.94	100.54	0.89	–
Location 24	84	0.09	0.08	0.02	21.75	30.78	<0.01	<0.01	<0.01	0.02	0.13	47.49	100.34	<0.01	45.48	0.30	0.19	1.42	45.46	55.10	100.55	0.30	–
Location 27	85	0.09	0.10	0.02	21.67	30.66	<0.01	<0.01	<0.01	0.02	0.12	47.34	99.99	<0.01	46.42	0.20	0.16	1.41	45.29	54.88	100.17	0.31	–
Location 28	86	0.29	0.21	0.01	21.33	31.12	<0.01	0.01	<0.01	0.01	0.10	47.10	100.15	<0.01	45.48	0.21	0.14	1.46	44.58	55.70	100.28	0.60	–
Location 31	87	0.31	0.20	0.01	21.82	30.84	<0.01	0.02	<0.01	0.01	0.15	47.11	100.44	0.01	45.85	0.31	0.18	1.41	45.60	55.20	100.81	0.66	–
Location 32	88	0.16	0.11	0.02	21.82	30.81	<0.01	<0.01	<0.01	0.01	0.19	47.30	100.38	<0.01	45.28	0.29	0.17	1.41	45.60	55.15	100.75	0.46	–
Location 33	89	0.14	0.13	0.02	21.81	30.84	<0.01	<0.01	<0.01	0.02	0.11	47.21	100.25	<0.01	46.19	0.24	0.15	1.41	45.58	55.20	100.79	0.38	2.715
Location 34	90	0.21	0.15	0.02	21.31	31.55	<0.01	0.01	<0.01	0.01	0.09	47.13	100.44	<0.01	46.00	0.19	0.13	1.48	44.54	56.47	101.01	0.45	–
Location 36	91	0.08	0.45	0.01	21.25	30.67	<0.01	0.04	<0.01	0.02	0.19	46.74	100.16	0.01	45.50	0.29	0.14	1.44	44.41	54.90	99.31	0.72	–
Location 37	92	0.04	0.05	0.04	21.45	30.96	<0.01	<0.01	<0.01	0.01	0.17	47.31	99.99	<0.01	47.11	0.15	0.13	1.44	44.83	55.42	100.25	0.26	2.601
Location 39	93	0.29	0.23	0.01	21.65	30.75	<0.01	0.01	<0.01	0.01	0.09	47.00	100.02	<0.01	46.83	0.15	0.13	1.42	45.25	55.04	100.29	0.61	–
Location 42	94	0.38	0.32	0.02	21.25	31.29	<0.01	0.01	<0.01	0.01	0.15	46.95	100.35	<0.01	43.47	0.09	0.14	1.47	44.41	56.01	100.42	0.85	–
Location 20	95	0.60	0.19	0.05	21.12	30.53	<0.01	0.01	<0.01	0.02	0.41	47.29	100.19	<0.01	45.53	0.25	0.20	1.45	44.14	54.65	98.79	1.20	–
Location 26	96	0.04	0.27	0.02	21.25	30.29	<0.01	<0.01	<0.01	<0.01	0.10	47.65	99.58	<0.01	46.03	0.23	0.21	1.43	44.41	54.22	98.63	0.41	–
Location 41	97	0.04	0.10	0.03	20.90	29.80	<0.01	<0.01	<0.01	<0.01	0.12	47.69	98.60	<0.01	44.09	0.23	0.18	1.43	43.68	53.34	97.02	0.26	2.595
Location 40	98	0.04	0.16	0.05	21.47	30.59	<0.01	<0.01	<0.01	<0.01	0.22	47.60	100.07	<0.01	46.20	0.00	0.11	1.42	44.87	54.76	99.63	0.42	–

Appendix B, *continued*. Samples 99 to 124.

Location No.	**Sample No.**	**SiO_2 (%)**	**Al_2O_3 (%)**	**MnO (%)**	**MgO (%)**	**CaO (%)**	**Na_2O (%)**	**K_2O (%)**	**P_2O_5 (%)**	**TiO_2 (%)**	**Fe_2O_3 (%)**	**LOI (%)**	**Total (%)**	**S (%)**	**CO_2 (%)**	**H_2O^+ (%)**	**H_2O^- (%)**	**CaO/ MgO**	**$MgCO_3$ (%)**	**$CaCO_3$ (%)**	**$Carb_{TOT}$ (%)**	**Si+Al+Fe (%)**	**Specific Gravity**
Location 25	99	0.57	0.32	0.01	20.92	30.51	<0.01	0.02	<0.01	0.01	0.13	47.29	99.77	<0.01	46.66	0.30	0.19	1.46	43.72	54.61	98.34	1.02	–
Location 38	100	0.32	0.17	0.02	21.20	30.30	<0.01	0.01	<0.01	0.02	0.10	47.54	99.65	<0.01	44.72	0.24	0.19	1.43	44.31	54.24	98.55	0.59	–
Location 30	101	0.04	0.04	0.02	21.11	30.00	<0.01	<0.01	<0.01	<0.01	0.12	47.67	98.96	<0.01	44.68	0.15	0.18	1.42	44.12	53.70	97.82	0.20	–
Location 35	102	0.65	0.35	0.02	21.50	30.57	<0.01	0.03	<0.01	0.02	0.16	47.23	100.51	<0.01	45.31	0.28	0.21	1.42	44.94	54.72	99.66	1.16	–
Location 29	103	0.22	0.31	0.03	21.37	30.35	<0.01	<0.01	<0.01	0.03	0.19	47.38	99.84	<0.01	43.88	0.31	0.24	1.42	44.66	54.33	98.99	0.72	–
Location 43	104	0.08	0.13	0.01	21.24	30.53	<0.01	<0.01	<0.01	0.01	0.14	47.66	99.77	<0.01	44.75	0.26	0.32	1.44	44.39	54.65	99.04	0.35	2.704
Location 43	105	0.41	0.31	0.01	21.21	30.38	<0.01	0.01	<0.01	0.02	0.15	47.41	99.89	<0.01	44.27	0.32	0.36	1.43	44.33	54.38	98.71	0.87	2.612
Location 43	106	0.03	0.06	0.02	20.50	31.10	<0.01	<0.01	<0.01	0.01	0.10	47.62	99.39	<0.01	42.77	0.23	0.23	1.52	42.85	55.67	98.51	0.19	2.667
Location 43	107	0.03	0.05	0.01	21.36	30.79	<0.01	<0.01	<0.01	0.01	0.08	47.80	100.07	<0.01	42.77	0.26	0.27	1.44	44.64	55.11	99.76	0.16	2.631
Location 44	108	0.04	0.44	0.02	21.03	29.91	<0.01	<0.01	<0.01	0.02	0.14	47.48	99.04	<0.01	46.40	0.24	0.18	1.42	43.95	53.54	97.49	0.62	2.613
Location 45	109	0.04	0.03	0.02	20.99	29.94	<0.01	<0.01	<0.01	0.02	0.08	47.72	98.78	<0.01	45.74	0.20	0.16	1.43	43.87	53.59	97.46	0.15	–
Location 46	110	0.05	0.41	0.03	21.54	30.49	<0.01	<0.01	<0.01	0.01	0.09	47.51	99.79	<0.01	46.01	0.19	0.16	1.42	45.02	54.58	99.60	0.55	–
Location 47	111	0.66	0.34	0.04	21.30	30.58	<0.01	0.02	0.02	0.03	0.29	47.01	100.27	0.01	45.42	0.29	0.17	1.44	44.52	54.74	99.26	1.29	–
Location 48*	112	0.26	0.19	–	20.79	31.12	–	–	–	–	0.23	–	–	–	–	–	–	1.50	43.45	55.70	99.16	0.68	–
Location 48*	113	0.20	0.01	–	20.73	30.88	–	–	–	–	0.34	–	–	–	–	–	–	1.49	43.33	55.28	98.60	0.55	–
Location 48*	114	0.34	0.33	–	21.09	30.34	–	–	–	–	0.27	–	–	–	–	–	–	1.44	44.08	54.31	98.39	0.94	–
Location 48*	115	0.16	0.19	–	21.66	30.83	–	–	–	–	0.11	–	–	–	–	–	–	1.42	45.27	55.19	100.46	0.46	–
Location 48*	116	0.12	0.13	–	21.57	30.87	–	–	–	–	0.24	–	–	–	–	–	–	1.43	45.08	55.26	100.34	0.49	–
Location 49	117	0.02	1.27	0.03	21.14	30.06	<0.01	<0.01	<0.01	<0.01	0.10	47.44	100.07	<0.01	45.40	0.27	0.36	1.42	44.18	53.81	97.99	1.39	2.573
Location 50*	118	0.28	0.07	–	20.69	31.40	–	–	–	–	0.17	–	–	–	–	–	–	1.52	43.24	56.21	99.45	0.52	–
Location 51*	119	0.66	0.36	–	20.18	31.17	–	–	–	–	0.32	–	–	–	–	–	–	1.54	42.18	55.79	97.97	1.34	–
Location 52	120	0.17	0.15	0.02	19.47	27.73	<0.01	0.01	<0.01	<0.01	0.11	51.88	99.54	0.01	45.30	0.32	0.34	1.42	40.69	49.64	90.33	0.43	2.680
Location 52	121	0.04	0.12	0.02	20.30	28.70	<0.01	<0.01	<0.01	<0.01	0.09	50.49	99.75	<0.01	46.50	0.36	0.34	1.41	42.43	51.37	93.80	0.25	2.596
Location 52	122	0.04	0.09	0.02	19.90	28.33	<0.01	<0.01	<0.01	<0.01	0.09	50.62	99.06	<0.01	46.60	0.36	0.33	1.42	41.59	50.71	92.30	0.22	2.571
Location 52	123	0.05	0.12	0.04	20.27	28.78	<0.01	<0.01	<0.01	<0.01	0.17	50.53	99.97	<0.01	48.10	0.36	0.30	1.42	42.36	51.52	93.88	0.34	2.550
Location 53	124	0.86	0.46	–	20.47	31.17	–	–	–	–	0.40	–	–	–	–	–	–	1.52	42.78	55.79	98.58	1.72	–
Average		**0.17**	**0.12**	**0.02**	**21.30**	**30.17**	–	–	–	**0.01**	**0.12**	**47.99**		–	**45.85**	**0.24**	**0.21**	**1.42**	**44.52**	**54.01**	**98.53**	**0.40**	**–**
Minimum		**0.00**	**0.00**	**0.01**	**17.11**	**27.73**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.00**	**46.44**		**<0.01**	**42.77**	**0.00**	**0.11**	**1.32**	**35.76**	**49.64**	**87.81**	**0.06**	**–**
Maximum		**1.13**	**1.27**	**0.06**	**22.43**	**34.86**	**0.27**	**0.13**	**0.02**	**0.03**	**0.41**	**52.92**		**0.01**	**51.10**	**0.89**	**0.50**	**2.04**	**46.88**	**62.40**	**101.01**	**1.94**	**–**

**Geochemical results* from *Vos (1969).*

Appendix B, *continued*. Quality-control standards.

Standard Used	SiO_2 (%)	Al_2O_3 (%)	MnO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	TiO_2 (%)	Fe_2O_3 (%)	LOI (%)	Total (%)	S (%)	CO_2 (%)	H_2O^+ (%)	H_2O^- (%)	CaO/ MgO	$MgCO_3$ (%)	$CaCO_3$ (%)	$Carb_{TOT}$ (%)	Si+Al+Fe (%)	Specific Gravity
Guelph Formation																						
	0.03	1.16	0.02	21.07	30.54	<0.01	<0.01	<0.01	0.01	0.12	47.57	100.52	<0.01	46.10	0.31	0.41	1.45	44.04	54.67	98.70	1.31	–
	0.04	0.11	0.02	19.84	28.22	<0.01	<0.01	<0.01	<0.01	0.08	51.17	99.46	<0.01	45.90	0.29	0.27	1.42	41.47	50.51	91.98	0.23	–
	0.03	0.11	0.02	21.23	30.29	<0.01	<0.01	<0.01	0.01	0.08	47.75	99.45	<0.01	44.32	0.31	0.32	1.43	44.37	54.22	98.59	0.22	–
	0.04	0.05	0.01	21.51	30.57	<0.01	<0.01	<0.01	<0.01	0.07	47.47	99.65	<0.01	45.48	0.15	0.14	1.42	44.96	54.72	99.68	0.16	–
	0.04	0.08	0.03	21.61	30.75	<0.01	<0.01	<0.01	<0.01	0.10	47.71	100.26	<0.01	44.62	0.24	0.17	1.42	45.16	55.04	100.21	0.22	–
	0.04	0.02	0.02	21.14	30.29	<0.01	<0.01	<0.01	<0.01	0.08	47.74	99.26	<0.01	40.60	0.22	0.18	1.43	44.18	54.22	98.40	0.14	–
Average	**0.04**	**0.26**	**0.02**	**21.07**	**30.11**	–	–	–	–	**0.09**	**48.24**	**99.77**	–	**44.50**	**0.25**	**0.25**	**1.43**	**44.03**	**53.90**	**97.93**	**0.38**	–
Minimum	**0.03**	**0.02**	**0.01**	**19.84**	**28.22**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.07**	**47.47**	**99.26**	**<0.01**	**40.60**	**0.15**	**0.14**	**1.42**	**41.47**	**50.51**	**91.98**	**0.14**	–
Maximum	**0.04**	**1.16**	**0.03**	**21.61**	**30.75**	**<0.01**	**<0.01**	**<0.01**	**0.01**	**0.12**	**51.17**	**100.52**	**<0.01**	**46.10**	**0.31**	**0.41**	**1.45**	**45.16**	**55.04**	**100.21**	**1.31**	–
Standard Deviation	**0.005**	**0.406**	**0.006**	**0.581**	**0.861**	–	–	–	–	**0.017**	**1.316**	**0.461**	–	**1.859**	**0.057**	**0.095**	–	–	–	–	–	–
Gull River Formation																						
	1.54	0.51	0.08	0.62	51.01	0.01	0.02	<0.01	0.02	0.19	46.21	100.21	0.01	40.20	0.41	0.37	82.27	1.30	91.31	92.60	2.24	–
	1.20	0.27	0.07	0.59	51.56	0.02	0.03	<0.01	0.01	0.14	46.58	100.48	<0.01	39.60	0.39	0.32	87.39	1.23	92.29	93.53	1.61	–
	1.71	0.43	0.08	0.70	53.45	0.02	0.11	0.01	0.02	0.21	43.01	99.74	<0.01	40.74	0.31	0.31	76.36	1.46	95.68	97.14	2.35	–
	1.14	0.23	0.07	0.59	55.48	<0.01	0.04	0.01	0.02	0.13	43.12	100.82	<0.01	41.02	0.19	0.14	94.03	1.23	99.31	100.54	1.50	–
	1.43	0.39	0.75	0.71	55.25	0.02	0.08	0.01	0.01	0.19	43.18	101.34	0.01	42.09	0.23	0.17	77.82	1.48	98.90	100.38	2.01	–
	1.26	0.25	0.08	0.65	54.82	0.02	0.05	<0.01	0.01	0.16	43.32	100.61	0.01	41.80	0.23	0.17	84.34	1.36	98.13	99.49	1.67	–
Average	**1.38**	**0.35**	**0.19**	**0.64**	**53.60**	**0.02**	**0.06**	–	**0.02**	**0.17**	**44.24**	**100.53**	–	**40.91**	**0.29**	**0.25**	**83.70**	**1.34**	**95.94**	**97.28**	**1.90**	–
Minimum	**1.14**	**0.23**	**0.07**	**0.59**	**51.01**	**<0.01**	**0.02**	**<0.01**	**0.01**	**0.13**	**43.01**	**99.74**	**<0.01**	**39.60**	**0.19**	**0.14**	**76.36**	**1.23**	**91.31**	**92.60**	**1.50**	–
Maximum	**1.71**	**0.51**	**0.75**	**0.71**	**55.48**	**0.02**	**0.11**	**0.01**	**0.02**	**0.21**	**46.58**	**101.34**	**0.01**	**42.09**	**0.41**	**0.37**	**94.03**	**1.48**	**99.31**	**100.54**	**2.35**	–
Standard Deviation	**0.201**	**0.104**	**0.251**	**0.048**	**1.762**	**0.004**	**0.031**	–	**0.005**	**0.029**	**1.533**	**0.496**	–	**0.861**	**0.084**	**0.089**	–	–	–	–	–	–

Appendix C.

Trace Element Geochemical Analyses for Guelph Formation Samples

Appendix C. Geochemical analyses of Guelph Formation samples: trace elements analyzed by atomic absorption (flame) spectroscopy (AAF).

Location Number	Sample Number	Cd (ppm)	Co (ppm)	Cu (ppm)	Li (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
Location 02	04	<5	<30	<3	17	<6	<12	11
Location 03	05	<5	<30	<3	18	<6	<12	<6
Location 05	07	<5	<30	<3	17	<6	<12	8
Location 10	17	<5	<30	<3	17	<6	<12	19
Location 10	18	<5	<30	<3	16	<6	<12	24
Location 10	19	<5	<30	<3	15	<6	<12	21
Location 11	20	<5	<30	<3	19	<6	<12	19
Location 11	21	<5	<30	<3	21	<6	<12	22
Location 11	22	<5	<30	<3	14	<6	<12	21
Location 14	75	<5	<30	3	18	<6	<12	<6
Location 15	76	<5	<30	<3	17	<6	<12	<6
Location 16	77	<5	<30	<3	18	<6	<12	<6
Location 17	78	<5	<30	4	15	7	<12	103
Location 18	79	<5	<30	3	19	<6	<12	<6
Location 19	80	<5	<30	4	17	<6	15	33
Location 21	81	<5	<30	<3	15	<6	<12	15
Location 22	82	<5	<30	4	18	<6	<12	<6
Location 23	83	<5	<30	3	16	<6	<12	16
Location 24	84	<5	<30	3	16	<6	<12	<6
Location 27	85	<5	<30	<3	16	<6	<12	<6
Location 28	86	<5	<30	<3	17	<6	<12	<6
Location 31	87	<5	<30	3	16	<6	<12	8
Location 32	88	<5	<30	<3	15	<6	<12	<6
Location 33	89	<5	<30	<3	15	<6	<12	<6
Location 34	90	<5	<30	<3	18	<6	<12	20
Location 36	91	<5	<30	<3	18	<6	<12	6
Location 37	92	<5	<30	3	15	<6	<12	61
Location 39	93	<5	<30	<3	15	<6	<12	<6
Location 42	94	<5	<30	<3	15	<6	<12	10
Location 20	95	<5	<30	4	18	<6	<12	9
Location 26	96	<5	<30	3	16	6	<12	11
Location 41	97	<5	<30	3	15	6	<12	<6
Location 40	98	<5	<30	3	18	9	21	15
Location 25	99	<5	<30	4	20	10	<12	58
Location 38	100	<5	<30	4	18	<6	22	6
Location 30	101	<5	<30	5	19	<6	<12	9
Location 35	102	<5	<30	5	22	<6	24	<6
Location 29	103	<5	<30	5	18	<6	<12	<6
Location 44	108	<5	<30	4	15	<6	15	<6
Location 45	109	<5	<30	5	19	<6	<12	12
Location 46	110	<5	<30	3	15	7	<12	<6
Location 47	111	<5	<30	10	22	9	26	18
Location 49	117	<5	<30	<3	16	10	<12	8
Location 52	120	<5	<30	3	16	<6	<12	6
Location 52	121	<5	<30	<3	16	<6	<12	<6
Location 52	122	<5	<30	<3	16	<6	<12	<6
Location 52	123	<5	<30	3	16	<6	<12	<6
for n = 47								
Average		–	–	–	**17**	–	–	–
Minimum		**<5**	**<30**	**<3**	**14**	**<6**	**<12**	**<6**
Maximum		**<5**	**<30**	**10**	**22**	**10**	**26**	**103**

Appendix C, *continued*. Quality-control standards.

Standard Used	Cd (ppm)	Co (ppm)	Cu (ppm)	Li (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
Guelph Formation							
	<5	<30	<3	18	8	<12	11
	<5	<30	<3	17	<6	<12	<6
	<5	<30	<3	19	<6	17	<6
	<5	<30	5	17	<6	<12	<6
	<5	<30	4	15	7	<12	6
	<5	<30	4	14	6	<12	7
Average	–	–	–	**16.7**	–	–	–
Minimum	**<5**	**<30**	**<3**	**14**	**<6**	**<12**	**<6**
Maximum	**<5**	**<30**	**5**	**19**	**8**	**17**	**11**
Gull River Formation							
	<5	32	3	31	<6	<12	13
	<5	<30	3	29	<6	<12	<6
	<5	<30	4	36	<6	14	<6
	<5	<30	7	24	6	<12	<6
	<5	<30	8	31	8	<12	<6
	<5	<30	7	25	<6	<12	<6
Average	–	–	**5.3**	**29.3**	–	–	–
Minimum	**<5**	**<30**	**3**	**24**	**<6**	**<12**	**<6**
Maximum	**<5**	**<30**	**8**	**31**	**8**	**14**	**13**

Appendix D.

Trace Element Geochemical Analyses for Guelph Formation Samples

Appendix D. Geochemical analyses of Guelph Formation samples: trace elements analyzed by inductively coupled plasma mass spectroscopy (ICP–MS).

Location No.	Sample No.	Ba (ppm)	Be (ppm)	Bi (ppm)	Cd (ppm)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cs (ppm)	Cu (ppm)	Dy (ppm)	Er (ppm)	Eu (ppm)	Ga (ppm)	Gd (ppm)	Hf (ppm)	Ho (ppm)	In (ppm)	La (ppm)	Li (ppm)	Lu (ppm)	Mo (ppm)	Nb (ppm)
Location 02	04	3.8	0.08	<0.15	0.232	1.04	0.52	5	0.037	1.4	0.089	0.059	0.0210	0.21	0.091	<0.14	0.0200	0.0020	0.84	1.4	0.0080	0.24	0.167
Location 03	05	3.6	0.09	<0.15	0.019	1.35	0.57	5	0.077	<1.4	0.109	0.069	0.0280	0.20	0.108	<0.14	0.0230	0.0030	0.87	2.4	0.0080	0.09	0.176
Location 05	07	1.2	0.10	0.20	0.014	0.80	0.54	5	<0.013	<1.4	0.165	0.140	0.0290	0.12	0.127	<0.14	0.0406	0.0020	0.73	1.3	0.0153	0.94	0.037
Location 10	17	1.5	<0.04	<0.15	0.056	0.77	0.42	5	<0.013	<1.4	0.058	0.034	0.0110	0.07	0.065	<0.14	0.0120	<0.0018	0.59	1.2	0.0040	0.22	0.042
Location 10	18	2.1	<0.04	<0.15	0.072	0.62	0.41	4	0.013	<1.4	0.052	0.039	0.0090	0.07	0.053	<0.14	0.0110	<0.0018	0.58	1.7	0.0040	0.57	0.044
Location 10	19	1.3	<0.04	<0.15	0.023	0.72	0.44	3	<0.013	<1.4	0.058	0.036	0.0100	0.08	0.060	<0.14	0.0130	<0.0018	0.55	1.1	0.0040	0.37	0.042
Location 11	20	1.7	<0.04	<0.15	0.043	0.59	0.39	3	<0.013	<1.4	0.051	0.032	0.0900	0.07	0.061	<0.14	0.0110	<0.0018	0.57	1.1	0.0050	0.29	0.037
Location 11	21	1.4	<0.04	<0.15	0.038	0.68	0.43	6	<0.013	<1.4	0.055	0.031	0.0800	0.09	0.058	<0.14	0.0140	<0.0018	0.52	1.2	0.0040	0.39	0.035
Location 11	22	1.8	<0.04	<0.15	0.041	0.71	0.37	4	<0.013	<1.4	0.049	0.039	0.0120	0.06	0.062	<0.14	0.0120	<0.0018	0.58	1.5	0.0060	0.41	0.044
Location 14	75	3.4	<0.04	0.15	0.015	1.50	0.47	5	0.044	<1.4	0.114	0.071	0.0280	0.20	0.125	0.14	0.0226	0.0022	0.75	1.0	0.0105	0.17	0.148
Location 15	76	5.3	0.05	0.15	0.015	1.85	0.56	5	0.079	<1.4	0.134	0.076	0.0311	0.27	0.132	0.16	0.0243	0.0022	0.91	2.2	0.0101	0.11	0.225
Location 16	77	2.8	<0.04	<0.15	<0.013	1.06	0.48	4	0.035	<1.4	0.077	0.053	0.0180	0.14	0.091	<0.14	0.0163	0.0021	0.68	0.8	0.0064	0.08	0.105
Location 17	78	1.3	0.05	<0.15	0.110	1.35	0.41	4	<0.013	1.4	0.182	0.122	0.0342	0.11	0.190	0.28	0.0418	0.0019	0.86	1.6	0.0144	0.88	0.050
Location 18	79	16.6	0.10	<0.15	0.036	3.34	0.77	7	0.239	<1.4	0.220	0.137	0.0588	0.67	0.252	0.27	0.0452	0.0037	1.73	3.2	0.0200	0.13	0.619
Location 19	80	8.2	0.09	<0.15	0.014	6.65	0.64	6	0.203	<1.4	1.342	0.712	0.2948	0.47	1.555	0.17	0.2623	0.0035	4.99	2.8	0.0688	0.09	0.328
Location 21	81	5.9	0.05	<0.15	0.058	1.70	0.58	5	0.085	1.4	0.121	0.077	0.0313	0.33	0.127	0.14	0.0255	0.0021	0.93	1.7	0.0091	0.15	0.223
Location 22	82	4.5	0.06	<0.15	0.014	1.64	0.49	6	0.062	<1.4	0.138	0.083	0.0331	0.25	0.149	0.17	0.0277	0.0025	0.78	1.5	0.0101	0.29	0.211
Location 23	83	5.4	0.05	0.16	0.017	1.87	0.63	5	0.073	<1.4	0.143	0.088	0.0353	0.27	0.152	0.23	0.0288	<0.0018	1.00	1.5	0.0127	0.13	0.260
Location 24	84	2.1	0.04	<0.15	0.068	1.44	0.39	5	0.020	<1.4	0.113	0.065	0.0257	0.09	0.128	<0.14	0.0243	<0.0018	0.92	1.0	0.0090	0.17	0.053
Location 27	85	2.2	0.04	<0.15	<0.013	1.37	0.39	4	0.021	<1.4	0.091	0.057	0.0227	0.11	0.103	<0.14	0.0189	0.0020	0.86	0.9	0.0067	0.09	0.080
Location 28	86	4.2	0.06	<0.15	0.014	1.84	0.52	5	0.069	<1.4	0.117	0.078	0.0298	0.20	0.144	<0.14	0.0238	0.0019	1.06	1.3	0.0102	0.10	0.161
Location 31	87	5.0	0.05	<0.15	0.019	1.54	0.59	5	0.057	<1.4	0.100	0.071	0.0261	0.22	0.114	<0.14	0.0207	0.0018	0.89	1.9	0.0096	0.17	0.213
Location 32	88	2.3	0.04	<0.15	0.027	1.11	0.53	5	0.035	<1.4	0.092	0.061	0.0191	0.12	0.093	<0.14	0.0190	0.0019	0.78	0.8	0.0075	0.08	0.101
Location 33	89	2.0	0.04	<0.15	<0.013	1.09	0.40	7	0.033	1.7	0.092	0.053	0.0227	0.12	0.093	<0.14	0.0200	0.0018	0.63	0.8	0.0074	0.22	0.110
Location 34	90	3.1	<0.04	<0.15	0.150	1.16	0.41	5	0.042	<1.4	0.097	0.067	0.0239	0.14	0.108	<0.14	0.0202	<0.0018	0.85	0.8	0.0078	0.19	0.168
Location 36	91	10.2	0.06	<0.15	0.031	2.63	0.78	6	0.171	<1.4	0.192	0.119	0.0471	0.43	0.186	0.20	0.0369	0.0030	1.38	2.3	0.0170	0.30	0.452
Location 37	92	1.1	<0.04	<0.15	0.075	0.83	0.90	4	<0.013	1.6	0.116	0.088	0.0212	0.06	0.112	<0.14	0.0305	<0.0018	0.66	1.1	0.0107	0.97	<0.028
Location 39	93	3.8	0.06	<0.15	0.014	1.10	0.44	5	0.048	<1.4	0.092	0.063	0.0193	0.21	0.097	<0.14	0.0192	<0.0018	0.71	1.5	0.0089	0.08	0.151
Location 42	94	5.5	0.06	<0.15	0.056	2.09	0.53	5	0.079	<1.4	0.170	0.106	0.0399	0.27	0.175	<0.14	0.0346	0.0023	1.31	1.2	0.0146	0.11	0.213
Location 20	95	6.5	0.04	<0.15	<0.013	2.38	0.56	3	0.088	<1.4	0.317	0.173	0.0686	0.26	0.359	<0.14	0.0620	0.0037	1.50	2.6	0.0191	0.12	0.161
Location 26	96	1.6	0.04	<0.15	<0.013	1.04	0.41	4	0.015	<1.4	0.088	0.064	0.0195	0.23	0.095	0.25	0.0182	<0.0018	0.68	1.0	0.0080	0.13	0.052
Location 41	97	1.0	<0.04	<0.15	<0.013	0.77	0.30	4	<0.013	<1.4	0.120	0.091	0.0187	0.09	0.109	<0.14	0.0311	<0.0018	0.78	0.7	0.0112	0.51	0.032
Location 40	98	1.2	<0.04	<0.15	0.059	0.98	0.26	3	<0.013	<1.4	0.136	0.095	0.0210	0.14	0.127	<0.14	0.0310	<0.0018	0.92	1.0	0.0109	0.23	<0.028
Location 25	99	22.8	0.07	<0.15	0.047	1.93	0.46	5	0.084	<1.4	0.128	0.075	0.0336	0.33	0.148	0.19	0.0261	0.0020	1.05	2.0	0.0108	0.11	0.303
Location 38	100	3.8	0.04	<0.15	0.027	1.32	0.38	3	0.055	<1.4	0.100	0.061	0.0234	0.20	0.103	<0.14	0.0223	<0.0018	0.78	2.4	0.0087	0.11	0.136
Location 30	101	0.9	<0.04	<0.15	0.013	0.73	0.42	3	<0.013	<1.4	0.073	0.048	0.0170	0.06	0.081	<0.14	0.0145	<0.0018	0.54	0.8	0.0059	0.08	0.055

Appendix D, *continued***.** Samples 04 to 101, *continued.*

Location No.	Sample No.	Nd (ppm)	Ni (ppm)	Pb (ppm)	Pr (ppm)	Rb (ppm)	Sb (ppm)	Sc (ppm)	Sm (ppm)	Sn (ppm)	Sr (ppm)	Ta (ppm)	Tb (ppm)	Th (ppm)	Ti (ppm)	Tl (ppm)	Tm (ppm)	U (ppm)	V (ppm)	W (ppm)	Y (ppm)	Yb (ppm)	Zn (ppm)	Zr (ppm)
Location 02	04	0.53	8.0	1.4	0.172	1.17	0.05	<1.1	0.102	<0.16	44.8	<0.023	0.0130	0.080	49	0.015	0.0090	0.384	1.8	<0.05	0.71	0.055	10	<6
Location 03	05	0.68	8.4	0.6	0.196	1.71	0.04	1.1	0.116	<0.16	63.3	<0.023	0.0180	0.076	58	0.009	0.0090	0.181	3.5	<0.05	0.85	0.054	<7	<6
Location 05	07	0.57	8.9	3.2	0.144	0.23	0.04	1.2	0.103	<0.16	53.7	<0.023	0.0237	0.035	14	0.032	0.0158	0.950	2.5	<0.05	2.04	0.096	<7	<6
Location 10	17	0.34	3.9	2.0	0.095	0.26	0.04	<1.1	0.060	0.24	57.4	<0.023	0.0100	0.039	25	0.005	0.0050	0.574	3.0	0.58	0.57	0.031	12	<6
Location 10	18	0.27	4.5	2.7	0.086	0.37	0.09	<1.1	0.048	<0.16	63.9	<0.023	0.0070	0.058	28	0.012	0.0050	0.490	2.0	0.06	0.64	0.032	20	<6
Location 10	19	0.33	3.8	1.8	0.094	<0.23	0.04	<1.1	0.056	<0.16	49.3	<0.023	0.0090	0.034	22	0.007	0.0050	0.402	<0.8	0.07	0.73	0.031	16	<6
Location 11	20	0.31	3.1	2.8	0.089	0.27	0.05	<1.1	0.057	0.21	51.4	<0.023	0.0080	0.031	23	0.009	0.0050	0.513	<0.8	0.07	0.61	0.030	12	<6
Location 11	21	0.32	3.8	1.7	0.091	0.25	0.07	<1.1	0.059	<0.16	49.7	<0.023	0.0070	0.045	21	0.007	0.0050	0.501	<0.8	0.21	0.63	0.035	17	<6
Location 11	22	0.38	4.2	1.9	0.087	0.31	0.04	<1.1	0.061	<0.16	52.3	<0.023	0.0070	0.046	24	0.006	0.0050	0.436	1.0	0.03	0.51	0.036	18	<6
Location 14	75	0.71	7.1	2.4	0.182	1.11	<0.04	1.1	0.136	<0.16	49.4	<0.023	0.0205	0.119	41	0.009	0.0093	0.303	3.0	<0.05	0.82	0.060	<7	6
Location 15	76	0.87	7.4	3.8	0.229	1.80	<0.04	1.2	0.152	<0.16	72.3	<0.023	0.0210	0.186	61	0.012	0.0120	0.605	3.0	<0.05	0.91	0.072	<7	7
Location 16	77	0.48	6.9	1.9	0.125	0.83	<0.04	<1.1	0.088	<0.16	43.2	<0.023	0.0133	0.083	27	0.008	0.0071	0.284	1.7	<0.05	0.82	0.043	<7	<6
Location 17	78	0.69	4.9	4.8	0.160	<0.23	<0.04	2.4	0.148	<0.16	55.1	<0.023	0.0291	0.050	12	0.017	0.0172	0.438	0.9	<0.05	1.86	0.106	13	11
Location 18	79	1.56	8.4	2.7	0.389	5.67	0.10	1.5	0.278	<0.16	54.7	0.042	0.0368	0.513	177	0.031	0.0207	0.456	5.9	0.07	1.42	0.143	<7	11
Location 19	80	5.46	7.5	3.8	1.243	3.66	<0.04	1.8	1.250	<0.16	57.9	<0.023	0.2138	0.468	79	0.024	0.0884	0.280	4.2	0.05	9.98	0.525	38	7
Location 21	81	0.77	7.5	16.9	0.192	2.09	0.05	<1.1	0.134	<0.16	52.7	<0.023	0.0175	0.113	66	0.015	0.0106	0.589	3.1	0.06	1.01	0.073	19	6
Location 22	82	0.72	7.1	2.4	0.206	1.54	<0.04	1.3	0.148	<0.16	49.5	<0.023	0.0211	0.172	60	0.010	0.0111	0.321	3.2	0.07	0.93	0.076	<7	7
Location 23	83	0.80	7.2	2.1	0.207	1.93	0.04	1.3	0.158	<0.16	52.0	<0.023	0.0230	0.209	70	0.011	0.0130	0.403	2.6	<0.05	1.01	0.082	19	9
Location 24	84	0.63	7.2	2.5	0.174	0.45	<0.04	<1.1	0.117	<0.16	61.1	<0.023	0.0177	0.075	14	0.006	0.0104	0.326	2.3	<0.05	1.11	0.058	7	<6
Location 27	85	0.57	7.1	0.8	0.150	0.51	<0.04	<1.1	0.100	<0.16	60.5	<0.023	0.0157	0.079	20	0.005	0.0080	0.371	1.7	<0.05	0.95	0.044	<7	<6
Location 28	86	0.84	7.2	2.1	0.199	1.42	<0.04	<1.1	0.149	<0.16	63.2	<0.023	0.0188	0.161	40	0.012	0.0098	0.373	2.2	<0.05	1.03	0.064	<7	<6
Location 31	87	0.69	7.4	5.1	0.175	1.44	0.05	<1.1	0.134	<0.16	61.1	<0.023	0.0161	0.157	57	0.024	0.0091	0.292	2.9	<0.05	0.87	0.059	12	<6
Location 32	88	0.51	7.4	2.9	0.126	0.74	0.06	<1.1	0.096	<0.16	51.0	<0.023	0.0135	0.086	22	0.016	0.0083	0.183	1.9	<0.05	0.93	0.052	8	<6
Location 33	89	0.50	6.7	0.9	0.129	0.72	<0.04	<1.1	0.108	<0.16	49.4	<0.023	0.0152	0.095	25	0.007	0.0086	0.432	1.7	<0.05	0.80	0.050	<7	<6
Location 34	90	0.56	6.9	8.8	0.143	0.95	<0.04	<1.1	0.100	<0.16	51.2	<0.023	0.0155	0.133	40	0.011	0.0097	0.311	2.2	<0.05	1.14	0.059	20	<6
Location 36	91	1.16	8.4	4.1	0.294	3.76	0.08	1.2	0.219	<0.16	66.9	0.029	0.0299	0.350	115	0.031	0.0170	1.348	4.5	0.06	1.30	0.110	9	8
Location 37	92	0.51	8.2	10.6	0.119	<0.23	0.26	<1.1	0.086	<0.16	62.0	<0.023	0.0179	0.019	<7	0.010	0.0118	1.620	9.4	<0.05	1.52	0.069	59	<6
Location 39	93	0.56	6.8	1.1	0.134	1.22	<0.04	1.1	0.105	<0.16	48.0	<0.023	0.0141	0.151	42	0.012	0.0098	0.462	1.9	0.10	0.95	0.057	<7	<6
Location 42	94	0.86	7.0	4.9	0.230	1.82	0.06	<1.1	0.165	<0.16	69.0	<0.023	0.0266	0.244	49	0.012	0.0152	0.192	2.1	<0.05	1.55	0.102	13	<6
Location 20	95	1.45	4.5	1.5	0.355	1.88	0.09	1.8	0.310	<0.16	65.2	<0.023	0.0526	0.171	43	0.010	0.0235	0.047	1.3	0.05	2.38	0.131	9	<6
Location 26	96	0.44	4.4	2.1	0.113	0.32	<0.04	2.1	0.077	<0.16	54.1	<0.023	0.0136	0.054	14	0.004	0.0084	0.179	0.9	0.06	1.03	0.053	10	11
Location 41	97	0.42	4.9	2.3	0.115	0.13	0.05	<1.1	0.080	<0.16	44.1	<0.023	0.0166	0.025	7	0.011	0.0121	1.853	4.2	<0.05	1.92	0.076	6	<6
Location 40	98	0.51	4.6	4.8	0.136	0.18	0.04	<1.1	0.094	<0.16	43.4	<0.023	0.0185	0.023	<7	0.003	0.0130	1.391	5.1	<0.05	1.87	0.074	12	<6
Location 25	99	0.83	4.9	3.6	0.224	2.46	<0.04	1.1	0.163	<0.16	76.1	<0.023	0.0222	0.270	80	0.016	0.0118	0.608	2.6	<0.05	1.08	0.073	49	8
Location 38	100	0.61	4.7	22.8	0.156	1.43	0.05	<1.1	0.111	<0.16	64.7	<0.023	0.0161	0.142	42	0.011	0.0083	1.412	3.6	<0.05	0.93	0.055	6	<6
Location 30	101	0.36	6.2	1.3	0.101	0.23	<0.04	<1.1	0.073	<0.16	44.0	<0.023	0.0102	0.035	10	0.005	0.0059	0.240	0.9	<0.05	0.87	0.038	8	<6

Appendix D, *continued***.** Samples 102 to 123 and quality-control standards.

Location No.	Sample No.	Ba (ppm)	Be (ppm)	Bi (ppm)	Cd (ppm)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cs (ppm)	Cu (ppm)	Dy (ppm)	Er (ppm)	Eu (ppm)	Ga (ppm)	Gd (ppm)	Hf (ppm)	Ho (ppm)	In (ppm)	La (ppm)	Li (ppm)	Lu (ppm)	Mo (ppm)	Nb (ppm)
Location 35	102	8.1	0.07	<0.15	<0.013	2.43	0.58	5	0.129	<1.4	0.168	0.111	0.0396	0.42	0.180	0.19	0.0355	0.0019	1.46	3.2	0.0151	0.15	0.385
Location 29	103	2.9	0.05	<0.15	<0.013	1.63	0.47	3	0.042	<1.4	0.130	0.076	0.0319	0.24	0.144	<0.14	0.0265	<0.0018	0.94	1.3	0.0102	0.10	0.119
Location 43	104	2.2	0.04	1.70	0.048	1.24	0.42	5	<0.013	<1.4	0.109	0.078	0.0242	0.27	0.119	0.89	0.0256	<0.0018	0.86	1.7	0.0115	0.38	0.061
Location 43	105	5.6	0.08	1.33	0.028	1.87	0.54	4	0.085	<1.4	0.186	0.120	0.0416	0.48	0.173	0.78	0.0377	0.0018	1.06	2.5	0.0184	0.26	0.256
Location 43	106	1.7	0.05	0.90	0.023	1.26	0.36	3	<0.013	<1.4	0.121	0.083	0.0234	0.17	0.128	0.62	0.0274	<0.0018	0.93	2.3	0.0115	0.22	0.035
Location 43	107	1.7	0.07	1.68	0.019	0.92	0.47	3	<0.013	<1.4	0.098	0.076	0.0168	0.21	0.098	0.86	0.0233	<0.0018	0.85	2.2	0.0125	0.29	0.045
Location 44	108	1.4	<0.04	<0.15	0.022	0.83	0.44	<3	<0.013	<1.4	0.076	0.045	0.0178	0.25	0.083	<0.14	0.0154	<0.0018	0.68	0.9	0.0065	<0.08	0.031
Location 45	109	1.0	<0.04	<0.15	0.020	0.60	0.29	4	<0.013	<1.4	0.068	0.053	0.0133	0.05	0.063	<0.14	0.0164	<0.0018	0.60	0.8	0.0069	0.10	0.029
Location 46	110	1.6	<0.04	<0.15	<0.013	0.83	0.32	4	<0.013	<1.4	0.076	0.043	0.0143	0.21	0.068	<0.14	0.0147	<0.0018	0.64	1.1	0.0058	0.11	0.031
Location 47	111	8.9	0.06	<0.15	0.027	2.32	2.26	3	0.156	5.5	0.266	0.166	0.0539	0.40	0.301	<0.14	0.0558	0.0020	1.83	4.6	0.0185	8.21	0.279
Location 49	117	1.0	<0.04	0.55	0.066	0.77	0.52	5	<0.013	<1.4	0.078	0.061	0.0184	0.81	0.066	0.40	0.0171	<0.0018	0.72	1.2	0.0074	0.37	0.031
Location 52	120	2.4	0.18	<0.15	0.021	1.26	0.66	6	0.039	<1.4	0.091	0.057	0.0262	0.17	0.104	<0.14	0.0205	0.0021	0.77	1.8	0.0081	0.28	0.103
Location 52	121	1.5	0.13	<0.15	0.013	0.66	0.54	5	<0.013	<1.4	0.065	0.051	0.0127	0.09	0.063	<0.14	0.0140	<0.0018	0.57	1.1	0.0047	0.12	0.040
Location 52	122	0.9	0.17	0.19	<0.013	0.59	0.50	4	<0.013	<1.4	0.071	0.053	0.0133	0.10	0.070	<0.14	0.0159	<0.0018	0.56	0.9	0.0055	0.15	0.042
Location 52	123	1.2	0.10	0.20	0.014	0.80	0.54	5	<0.013	<1.4	0.165	0.140	0.0290	0.12	0.127	<0.14	0.0406	0.0020	0.73	1.3	0.0153	0.94	0.037
Average (n=51)		**3.8**	**0.05**	–	**0.034**	**1.40**	**0.52**	**4**	**0.043**	**-**	**0.140**	**0.089**	**0.0339**	**0.21**	**0.149**	–	**0.0296**	–	**0.94**	**1.6**	**0.0110**	**0.41**	**0.133**
Minimum		**0.9**	**<0.04**	**<0.15**	**<0.013**	**0.59**	**0.26**	**<3**	**<0.013**	**<1.4**	**0.049**	**0.031**	**0.0090**	**0.05**	**0.053**	**<0.14**	**0.0110**	**<0.0018**	**0.52**	**0.7**	**0.0040**	**<0.08**	**0.029**
Maximum		**22.8**	**0.18**	**1.70**	**0.232**	**6.65**	**2.26**	**7**	**0.239**	**5.5**	**1.342**	**0.712**	**0.2948**	**0.81**	**1.555**	**0.89**	**0.2623**	**0.0037**	**4.99**	**4.6**	**0.0688**	**8.21**	**0.619**
Guelph Formation		2.1	<0.04	0.19	0.042	0.91	0.56	4	0.015	<1.4	0.063	0.049	0.0197	0.28	0.068	<0.14	0.0178	<0.0018	0.69	1.3	0.0079	0.43	0.037
(standard)		1.1	0.04	<0.15	0.042	0.63	0.41	5	<0.013	<1.4	0.072	0.052	0.0148	0.11	0.075	<0.14	0.0167	<0.0018	0.58	0.8	0.0059	0.26	0.031
		1.9	0.04	1.87	0.052	0.79	0.46	4	<0.013	<1.4	0.093	0.072	0.0158	0.26	0.083	0.97	0.0209	<0.0018	0.60	1.6	0.0126	0.33	0.039
		0.8	0.05	0.16	0.084	0.64	0.40	5	<0.013	<1.4	0.076	0.058	0.0140	0.08	0.071	<0.14	0.0151	<0.0018	0.63	1.0	0.0079	0.12	0.039
		1.3	<0.04	<0.15	0.053	0.75	0.33	5	<0.013	<1.4	0.071	0.048	0.0118	0.08	0.069	<0.14	0.0166	<0.0018	0.62	0.7	0.0059	0.10	<0.028
		1.4	<0.04	<0.15	0.090	0.65	0.36	3	<0.013	<1.4	0.074	0.055	0.0138	0.05	0.077	<0.14	0.0155	<0.0018	0.57	1.1	0.0066	0.12	<0.028
Average		**1.4**	–	**0.37**	**0.061**	**0.73**	**0.42**	**4**	–	–	**0.075**	**0.056**	**0.0150**	**0.14**	**0.074**	–	**0.0171**	–	**0.62**	**1.1**	**0.0078**	**0.23**	**0.024**
Minimum		**0.8**	**<0.04**	**<0.15**	**0.042**	**0.63**	**0.33**	**4**	**<0.013**	**<1.4**	**0.063**	**0.048**	**0.0118**	**0.08**	**0.068**	**<0.14**	**0.0151**	**<0.0018**	**0.58**	**0.7**	**0.0059**	**0.10**	**<0.028**
Maximum		**2.1**	**0.050**	**1.87**	**0.084**	**0.91**	**0.56**	**5**	**0.015**	**<1.4**	**0.093**	**0.072**	**0.0197**	**0.28**	**0.083**	**0.97**	**0.0209**	**<0.0018**	**0.69**	**1.6**	**0.0126**	**0.43**	**0.039**
Gull River Formation		22.3	0.09	<0.15	0.026	0.12	0.98	6	0.178	<1.4	0.117	0.087	0.043	0.56	0.178	<0.14	0.0180	0.0030	1.76	1.8	0.0090	0.17	<0.028
(standard)		7.6	0.04	<0.15	0.014	2.85	0.72	3	0.082	<1.4	0.168	0.087	0.052	0.32	0.222	<0.14	0.0310	0.0020	1.57	1.6	0.0100	0.24	0.202
		13.4	0.09	<0.15	0.018	3.81	0.86	4	0.187	<1.4	0.227	0.121	0.070	0.55	0.277	0.14	0.0452	0.0039	1.96	2.8	0.0157	0.19	0.332
		7.4	0.06	0.21	0.020	2.75	0.83	4	0.069	<1.4	0.154	0.082	0.049	0.30	0.201	0.15	0.0308	0.0026	1.33	1.4	0.0103	0.14	0.156
		10.5	0.06	<0.15	<0.013	3.22	0.93	4	0.163	<1.4	0.191	0.100	0.059	0.50	0.220	<0.14	0.0363	0.0031	1.69	2.4	0.0122	0.33	0.245
		8.5	0.05	<0.15	<0.013	3.02	0.83	4	0.102	<1.4	0.179	0.091	0.053	0.32	0.234	0.14	0.0344	0.0023	1.56	1.6	0.0115	0.21	0.209
Average		**11.6**	**0.07**	–	**0.020**	**2.63**	**0.86**	**4**	**0.130**	–	**0.173**	**0.095**	**0.0542**	**0.43**	**0.222**	–	**0.0326**	**0.0028**	**1.65**	**1.9**	**0.0115**	**0.21**	**0.229**
Minimum		**7.4**	**0.04**	**<0.15**	**<0.013**	**0.12**	**0.72**	**3**	**0.069**	**<1.4**	**0.117**	**0.082**	**0.0430**	**0.30**	**0.178**	**<0.14**	**0.0180**	**0.0020**	**1.33**	**1.4**	**0.0090**	**0.14**	**<0.028**
Maximum		**22.3**	**0.09**	**0.21**	**0.026**	**3.81**	**0.98**	**6**	**0.187**	**<1.4**	**0.227**	**0.121**	**0.0696**	**0.56**	**0.277**	**0.15**	**0.0452**	**0.0039**	**1.96**	**2.8**	**0.0157**	**0.33**	**0.332**

Appendix D, *continued.* Samples 102 to 123 and quality-control standards, *continued.*

Location No.	Sample No.	Nd (ppm)	Ni (ppm)	Pb (ppm)	Pr (ppm)	Rb (ppm)	Sb (ppm)	Sc (ppm)	Sm (ppm)	Sn (ppm)	Sr (ppm)	Ta (ppm)	Tb (ppm)	Th (ppm)	Ti (ppm)	Tl (ppm)	Tm (ppm)	U (ppm)	V (ppm)	W (ppm)	Y (ppm)	Yb (ppm)	Zn (ppm)	Zr (ppm)
Location 35	102	1.04	5.9	2.3	0.289	3.24	0.04	1.2	0.206	<0.16	82.1	0.023	0.0272	0.292	115	0.025	0.0158	0.324	3.1	0.05	1.42	0.093	3	8
Location 29	103	0.75	4.9	2.4	0.195	1.05	<0.04	<1.1	0.148	<0.16	72.0	<0.023	0.0224	0.124	34	0.007	0.0100	0.448	2.0	0.06	0.99	0.068	2	<6
Location 43	104	0.62	5.4	1.9	0.153	0.27	0.06	7.7	0.113	<0.16	57.1	<0.023	0.0162	0.064	20	0.005	0.0113	0.250	1.1	<0.05	1.15	0.073	8	39
Location 43	105	0.87	5.0	2.2	0.229	2.26	0.07	6.6	0.190	<0.16	55.9	<0.023	0.0309	0.289	77	0.011	0.0168	0.347	2.5	<0.05	1.54	0.112	10	34
Location 43	106	0.61	5.0	1.5	0.147	<0.23	0.06	5.8	0.112	<0.16	66.7	<0.023	0.0196	0.036	8	0.005	0.0113	0.216	<0.8	<0.05	1.54	0.070	<7	27
Location 43	107	0.44	5.2	1.2	0.118	<0.23	0.12	7.5	0.082	<0.16	57.4	<0.023	0.0137	0.039	10	0.005	0.0107	0.202	<0.8	<0.05	1.46	0.067	<7	44
Location 44	108	0.40	5.2	1.2	0.118	0.22	<0.04	<1.1	0.078	<0.16	50.3	<0.023	0.0124	0.027	10	0.003	0.0062	0.202	<0.8	<0.05	0.77	0.039	3	<6
Location 45	109	0.29	4.6	0.8	0.071	0.13	<0.04	<1.1	0.053	<0.16	52.9	<0.023	0.0117	0.035	7	0.003	0.0076	0.720	1.9	0.07	1.02	0.047	10	<6
Location 46	110	0.34	4.9	1.6	0.093	0.19	<0.04	<1.1	0.066	<0.16	68.1	<0.023	0.0100	0.035	10	0.005	0.0067	1.300	4.8	<0.05	0.88	0.039	3	<6
Location 47	111	1.32	10.4	15.3	0.324	3.23	0.80	<1.1	0.253	<0.16	94.8	<0.023	0.0395	0.200	73	0.063	0.0227	0.799	3.8	0.06	2.69	0.133	16	<6
Location 49	117	0.37	7.1	3.9	0.116	<0.23	0.06	2.6	0.056	<0.16	48.1	<0.023	0.0119	0.038	8	0.005	0.0079	0.441	<0.8	<0.05	1.00	0.068	<7	17
Location 52	120	0.58	8.6	1.7	0.162	0.95	0.04	<1.1	0.106	<0.16	50.5	<0.023	0.0156	0.103	36	0.015	0.0071	0.473	<0.8	<0.05	0.93	0.055	<7	<6
Location 52	121	0.32	7.5	1.6	0.104	<0.23	<0.04	<1.1	0.071	<0.16	42.8	<0.023	0.0094	0.035	10	0.005	0.0064	0.270	<0.8	<0.05	0.92	0.037	<7	<6
Location 52	122	0.33	7.5	0.9	0.097	<0.23	<0.04	<1.1	0.065	<0.16	43.0	<0.023	0.0092	0.031	12	0.005	0.0073	0.229	<0.8	<0.05	0.98	0.042	<7	<6
Location 52	123	0.57	8.9	3.2	0.144	0.23	0.04	1.2	0.103	<0.16	53.7	<0.023	0.0237	0.035	14	0.032	0.0158	0.950	2.5	<0.05	2.04	0.096	<7	<6
Average (n=51)		**0.72**	**6.3**	**3.6**	**0.185**	**1.07**	**0.05**	–	**0.140**	–	**56.9**	–	**0.0220**	**0.118**	**38**	**0.013**	**0.0121**	**0.528**	**2.2**	–	**1.33**	**0.075**	**9**	**<6**
Minimum		**0.27**	**3.1**	**0.6**	**0.071**	**<0.23**	**<0.04**	**<1.1**	**0.048**	**<0.16**	**42.8**	**<0.023**	**0.0070**	**0.019**	**7**	**0.003**	**0.0050**	**0.047**	**<0.8**	**<0.05**	**0.51**	**0.030**	**<7**	**<6**
Maximum		**5.46**	**10.4**	**22.8**	**1.243**	**5.67**	**0.80**	**7.7**	**1.250**	**0.24**	**94.8**	**0.042**	**0.2138**	**0.513**	**177**	**0.063**	**0.0884**	**1.853**	**9.4**	**0.58**	**9.98**	**0.525**	**59**	**44**
Guelph Formation (standard)		0.46	7.3	3.4	0.125	<0.23	0.05	1.9	0.061	<0.16	49.3	<0.023	0.0123	0.041	11	0.005	0.0081	0.397	<0.8	<0.05	0.91	0.059	<7	12
		0.33	6.7	0.7	0.096	<0.23	<0.04	<1.1	0.061	<0.16	42.1	<0.023	0.0092	0.031	9	0.005	0.0067	0.447	5.6	<0.05	0.92	0.041	<7	<6
		0.39	4.8	1.7	0.094	<0.23	0.06	8.3	0.067	<0.16	56.3	<0.023	0.0130	0.051	12	0.005	0.0112	0.365	1.9	<0.05	1.16	0.073	<7	44
		0.26	6.5	8.3	0.078	<0.23	<0.04	1.1	0.064	<0.16	50.4	<0.023	0.0093	0.029	9	0.005	0.0077	0.444	3.3	<0.05	0.97	0.046	<7	<6
		0.36	4.6	2.9	0.087	<0.23	<0.04	<1.1	0.062	<0.16	48.4	<0.023	0.0109	0.049	7	0.004	0.0070	0.524	2.2	<0.05	0.94	0.042	<7	<6
		0.32	6.3	3.2	0.082	<0.23	0.05	<1.1	0.050	<0.16	50.2	<0.023	0.0114	0.028	<7	0.005	0.0069	0.375	2.1	<0.05	0.98	0.041	7	<6
Average		**0.35**	**6.0**	**3.4**	**0.094**	–	–	**1.9**	**0.061**	–	**49.5**	–	**0.0110**	**0.038**	**8**	**0.005**	**0.0079**	**0.425**	**2.5**	–	**0.98**	**0.050**	–	**9**
Minimum		**0.26**	**4.6**	**0.7**	**0.078**	**<0.23**	**<0.04**	**<1.1**	**0.050**	**<0.16**	**42.1**	**<0.023**	**0.0092**	**0.029**	**<7**	**0.004**	**0.0067**	**0.365**	**<0.8**	**<0.05**	**0.91**	**0.041**	**<7**	**<6**
Maximum		**0.46**	**7.3**	**8.3**	**0.125**	**<0.23**	**0.06**	**8.3**	**0.067**	**<0.16**	**56.3**	**<0.023**	**0.0130**	**0.051**	**12**	**0.005**	**0.0112**	**0.524**	**5.6**	**<0.05**	**1.16**	**0.073**	**7**	**44**
Gull River Formation (standard)		0.97	10.1	0.8	0.241	3.23	0.07	<1.1	0.127	<0.16	182.4	0.026	0.0170	0.021	78	0.021	0.0080	0.194	2.2	0.12	0.36	0.047	<7	<6
		1.36	11.8	<0.6	0.365	1.74	<0.04	<1.1	0.265	<0.16	206.4	<0.023	0.0300	0.019	62	0.015	0.0100	0.248	<0.8	<0.05	0.93	0.074	<7	<6
		1.77	9.4	0.9	0.449	3.66	0.05	1.9	0.328	<0.16	260.8	<0.023	0.0389	0.357	120	0.032	0.0167	0.232	2.7	<0.05	1.35	0.109	<7	<6
		1.32	12.0	1.3	0.326	1.51	<0.04	1.6	0.251	<0.16	257.1	<0.023	0.0274	0.039	50	0.015	0.0115	0.334	2.7	<0.05	0.95	0.069	<7	6
		1.40	9.0	1.0	0.376	2.98	<0.04	1.1	0.264	<0.16	251.3	<0.023	0.0307	0.220	88	0.041	0.0136	0.255	2.5	<0.05	1.11	0.089	<7	<6
		1.44	11.3	0.7	0.366	2.11	<0.04	1.1	0.257	<0.16	233.9	<0.023	0.0315	0.170	67	0.011	0.0130	0.246	1.9	<0.05	1.07	0.079	<7	6
Average		**1.38**	**10.6**	**0.9**	**0.354**	**2.54**	**0.06**	**1.4**	**0.249**	–	**232.0**	–	**0.0293**	**0.138**	**78**	**0.023**	**0.0121**	**0.252**	**2.4**	–	**0.96**	**0.078**	–	–
Minimum		**0.97**	**9.0**	**<0.6**	**0.241**	**1.51**	**<0.04**	**<1.1**	**0.127**	**<0.16**	**182.4**	**<0.023**	**0.0170**	**0.019**	**50**	**0.011**	**0.0080**	**0.194**	**<0.8**	**<0.05**	**0.36**	**0.047**	**<7**	**<6**
Maximum		**1.77**	**12.0**	**1.3**	**0.449**	**3.66**	**0.07**	**1.9**	**0.328**	**<0.16**	**260.8**	**0.026**	**0.0389**	**0.357**	**120**	**0.041**	**0.0167**	**0.334**	**2.7**	**0.12**	**1.35**	**0.109**	**<7**	**6**

Appendix E.

Comparison of Geochemical Data for the Guelph, Eramosa and Amabel Formations

Appendix E. Comparison of geochemical data from the Guelph Formation, Eramosa Formation and Amabel Formation.

Major Oxides (XRF)	Guelph Formation			Eramosa Formation			Amabel Formation		
					(n = 12)			*(n = 39)* [1]	
	Average (%)	**Minimum (%)**	**Maximum (%)**	**Average (%)**	**Minimum (%)**	**Maximum (%)**	**Average (%)**	**Minimum (%)**	**Maximum (%)**
SiO_2	0.17	0.00	1.13	3.13	0.57	11.05	1.09	0.01	3.46
Al_2O_3	0.12	0.00	1.27	0.99	0.14	2.02	0.28	0.03	0.96
MnO	0.02	0.01	0.06	0.03	<0.01	0.17	0.04	<0.01	0.14
MgO	21.30	17.11	22.43	20.40	17.56	21.70	20.87	18.06	22.20
CaO	30.17	27.73	34.86	28.15	25.75	29.65	29.92	27.88	31.33
Na_2O	–	<0.01	0.27	–	<0.01	<0.01	–	<0.01	0.04
K_2O	–	<0.01	0.13	0.05	<0.01	0.37	0.05	<0.01	0.28
P_2O_5	–	<0.01	0.02	–	<0.01	0.04	0.01	<0.01	0.20
TiO_2	0.01	<0.01	0.03	0.01	<0.01	0.12	0.01	<0.01	0.04
Fe_2O_3	0.12	0.00	0.41	0.55	0.21	1.68	0.30	0.04	1.11
LOI	47.99	46.44	52.92	44.80	39.69	50.38	44.07	31.00	52.67
S	–	<0.01	0.01	0.12	<0.01	0.37	0.02	<0.01	0.07
CO_2	45.85	42.77	51.10	44.81	43.00	47.50	45.76	34.20	50.80
H_2O^+	0.24	0.00	0.89	0.32	0.06	0.55	0.29	0.04	0.57
H_2O^-	0.21	0.11	0.50	0.20	0.15	0.28	0.25	0.13	0.48

Other Data	Average (ppm)	Minimum (ppm)	Maximum (ppm)	Average (ppm)	Minimum (ppm)	Maximum (ppm)	Average (ppm)	Minimum (ppm)	Maximum (ppm)
CaO–MgO Ratio	1.42	1.32	2.04	1.38	1.28	1.54	1.44	1.31	1.56
$MgCO_3$	44.52	35.76	46.88	42.63	36.70	45.35	43.62	37.75	46.40
$CaCO_3$	54.01	49.64	62.40	50.38	46.09	53.07	53.55	49.91	56.08
Total Carbonate	98.53	87.81	101.01	93.01	82.79	96.04	97.17	88.13	100.63
$SiO_2+Al_2O_3+Fe_2O_3$	0.40	0.06	1.94	4.67	1.07	14.36	1.67	0.28	4.14

Trace Elements (AAF)		*(n = 47)*			*(n = 5)*			*(n = 14)* [2]	
	Average (ppm)	**Minimum (ppm)**	**Maximum (ppm)**	**Average (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**	**Average (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**
Cd	–	<5	<5	–	<5	9	–	<5	<5
Co	–	<30	<30	–	<30	<30	–	<30	<30
Cu	–	<3	10	11	<3	27	3.6	<3	10
Li	17	14	22	19.8	15	29	19.4	15	26
Ni	–	<6	10	7.4	<6	13	–	<6	9
Pb	–	<12	26	–	<12	15	–	<12	26
Zn	–	<6	103	1769	7	8478	8.8	<6	31

[1] *Amabel Fm. = Gasport and Goat Island formations: these formations were not identified separately for all geochemical testing. Some raw Amabel Formation geochemical data* from *Vos (1969) and* from *Wolf (2006).*

[2] *Amabel Fm. = Gasport and Goat Island formations: these formations were not identified separately for all geochemical testing.*

Appendix E, *continued.*

	Guelph Formation			**Eramosa Formation**			**Amabel Formation**		
	(n = 51)			*(n = 5)*			*(n = 14)*[2]		
Trace Elements (ICP–MS)	**Average (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**	**Average (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**	**Average (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**
Ba	3.8	0.9	22.8	68.8	3.2	312.6	6.9	2.8	12.3
Be	0.05	<0.04	0.18	0.11	<0.04	0.30	0.06	<0.04	0.11
Bi	–	<0.15	1.70	–	<0.15	<0.15	–	<0.15	0.19
Cd	0.034	<0.013	0.232	1.149	<0.013	4.000	0.025	<0.013	0.108
Ce	1.40	0.59	6.65	6.70	1.36	18.62	2.87	0.86	4.71
Co	0.52	0.26	2.26	1.60	0.32	3.82	0.77	0.45	2.26
Cr	4	<3	7	6	3	10	5	<3	10
Cs	0.043	<0.013	0.239	0.219	0.019	0.621	0.127	0.022	0.253
Cu	–	<1.4	5.5	9.5	<1.4	25.2	–	<1.4	5.5
Dy	0.140	0.049	1.342	0.888	0.152	2.322	0.307	0.070	0.589
Er	0.089	0.031	0.712	0.493	0.113	1.189	0.177	0.044	0.331
Eu	0.0339	0.0090	0.2948	0.1882	0.0310	0.5321	0.0698	0.0170	0.1290
Ga	0.21	0.05	0.81	1.13	0.13	2.49	0.35	0.11	0.68
Gd	0.149	0.053	1.555	0.943	0.167	2.593	0.346	0.085	0.634
Hf	–	<0.14	0.89	0.33	<0.14	1.12	–	<0.14	0.27
Ho	0.0296	0.0110	0.2623	0.1788	0.0360	0.4524	0.0628	0.0150	0.1210
In	–	<0.0018	0.0037	0.0053	<0.0018	0.0187	0.0022	<0.0018	0.0033
La	0.94	0.52	4.99	3.82	0.93	8.51	2.20	0.60	3.71
Li	1.6	0.7	4.6	4.9	1.4	8.9	3.9	1.1	10.9
Lu	0.0110	0.0040	0.0688	0.0581	0.0120	0.1395	0.0195	0.0060	0.0357
Mo	0.41	<0.08	8.21	1.18	0.18	2.42	0.87	0.08	8.21
Nb	0.133	0.029	0.619	0.646	0.060	2.122	0.295	0.094	0.628
Nd	0.72	0.27	5.46	3.86	0.75	10.59	1.64	0.47	2.60
Ni	6.3	3.1	10.4	8.1	3.7	12.7	6.3	3.7	10.4
Pb	3.6	0.6	22.8	8.5	2.2	17.1	3.7	1.0	15.3
Pr	0.185	0.071	1.243	0.911	0.181	2.470	0.414	0.133	0.632
Rb	1.07	<0.23	5.67	5.28	0.49	14.91	2.82	0.63	5.52
Sb	0.05	<0.04	0.80	0.08	<0.04	0.14	0.11	<0.04	0.80
Sc	–	<1.1	7.7	1.4	<1.1	3.1	–	<1.1	2.0
Sm	0.140	0.048	1.250	0.824	0.139	2.409	0.316	0.092	0.556
Sn	–	<0.16	0.24	–	<0.16	0.27	–	<0.16	0.39
Sr	56.9	42.8	94.8	372.8	54.7	1560	63.8	38.1	94.8
Ta	–	<0.023	0.042	0.037	<0.023	0.129	–	<0.023	0.034
Tb	0.0220	0.0070	0.2138	0.1407	0.0270	0.3869	0.0817	0.0100	0.5090
Th	0.118	0.019	0.513	0.547	0.054	1.871	0.245	0.030	0.566
Ti	38	7	177	186	19	589	75	27	150
Tl	0.013	0.003	0.063	0.106	0.009	0.244	0.026	0.005	0.063
Tm	0.0121	0.0050	0.0884	0.0672	0.0150	0.1626	0.0231	0.0070	0.0427
U	0.528	0.047	1.853	1.199	0.200	3.009	0.176	0.042	0.799
V	2.2	<0.8	9.4	6.5	<0.8	12.0	2.2	<0.8	4.4
W	–	<0.05	0.58	0.07	<0.05	0.16	0.07	<0.05	0.12
Y	1.33	0.51	9.98	6.24	1.55	13.63	2.56	0.48	4.53
Yb	0.075	0.030	0.525	0.416	0.092	1.000	0.140	0.040	0.258
Zn	9	<7	59	1609	8	7707	–	<7	27
Zr	–	<6	44	13	<6	44	–	<6	12

[2] *Amabel Fm. = Gasport and Goat Island formations: these formations were not identified separately for all geochemical testing.*

Appendix F.

Aggregate Quality Test Results for Guelph Formation Samples

Abbreviations:
Fm: Formation
Mbr: Member

Value in underlined *italics* indicates that the aggregate quality test result fails to meet specification.

Note: The quality test data refer strictly to a specific sample.

Appendix F. Aggregate quality test results for samples from the Guelph Formation.

Site No.	Sample Type	Sample Depth or Interval	Formation and Member (if recorded)	COARSE AGGREGATE											FINE AGGREGATE
				Petrographic Number											
				Granular and 16 mm	Hot Mix and Concrete	$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorption (%)	Bulk Relative Density	Aggregate Abrasion Value	Polished Stone Value	Accelerated Mortar Bar (14 days) (% Loss)	Micro-Deval Abrasion (% Loss)
			Generally Acceptable Values:		*<125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<6*	*≥50*	*<0.150%*	*<15–25%*
Site 01	Outcrop	0.00 m	Guelph Fm	100.0	100.0	1.8	–	22.6	–	0.309	2.802	–	–	–	–
Site 02	Outcrop	0.00 m	Guelph Fm	100.0	100.4	1.6	–	26.8	–	0.906	2.753	–	–	–	–
Site 03	Outcrop	0.00 m	Guelph Fm	*193.4*	*240.6*	6.0	–	*51.9*	–	*2.046*	2.620	–	–	–	–
Site 04	Outcrop	0.00 m	Guelph Fm	100.0	100.0	2.4	–	29.9	–	–	–	–	–	–	–
Site 05	Outcrop	0.00 m	Guelph Fm	100.0	103.4	3.1	–	28.5	–	0.870	2.716	–	–	–	–
Site 06	Outcrop	0.00 m	Guelph Fm	113.8	*140.3*	1.0	–	–	–	–	–	–	–	–	–
Site 07	Outcrop	0.00 m	Guelph Fm	100.0	115.9	–	7.3	–	3.7	0.980	2.717	–	–	–	–
Site 08	Outcrop	0.00 m	Guelph Fm	–	–	1.0	8.6	–	1.0	1.504	–	–	–	0.024	–
Site 09	Outcrop	0.00 m	Guelph Fm	–	*140.4*	7.6	13.1	–	1.9	*2.805*	2.551	–	–	0.008	*25.05*
Site 10	Drill core	5.80 – 15.80 m	Guelph Fm	–	104.0	9.4	15.5	–	5.3	*3.018*	2.530	–	–	0.015	–
Site 11	Drill core	5.60 – 15.60 m	Guelph Fm	–	103.0	7.5	13.3	–	6.6	*2.536*	2.559	–	–	0.019	–
Site 12	Drill core	4.00 – 14.00 m	Guelph Fm	–	105.0	5.5	16.6	–	3.5	*3.628*	*2.447*	–	–	0.017	–
Site 13	Drill core	3.90 – 13.90 m	Guelph Fm	–	100.0	8.0	15.1	–	4.6	*3.440*	2.507	–	–	0.016	–
Site 13	Drill core	21.70 – 31.70 m	Guelph Fm	–	*219.0*	12.6	9.6	–	6.8	*2.155*	2.618	–	–	*0.235*	–
Site 14	Drill core	4.60 – 14.60 m	Guelph Fm	–	104.0	5.2	11.3	–	4.5	1.970	2.588	–	–	0.014	–
Site 15	Drill core	7.77 – 19.05 m	Guelph Fm, Hanlon Mbr	–	105.4	5.0	12.3	–	2.3	1.736	2.632	–	–	0.002	16.60
Site 15	Drill core	19.05 – 30.71 m	Guelph Fm, Hanlon Mbr	–	107.1	5.6	11.4	–	3.4	1.870	2.661	–	–	0.031	17.29
Site 15	Drill core	30.71 – 45.57 m	Guelph Fm, Hanlon Mbr	–	108.6	4.3	12.9	–	2.5	*2.223*	2.603	–	–	0.080	15.28
Site 16	Drill core	5.03 – 23.32 m	Guelph Fm, Hanlon Mbr	–	114.2	4.2	9.6	–	2.7	1.921	2.638	–	*43.4*	0.012	21.50
Site 16	Drill core	23.32 – 38.56 m	Guelph Fm, Hanlon Mbr	–	118.6	6.5	14.7	–	3.7	*2.651*	2.569	–	–	0.015	14.60
Site 16	Drill core	38.56 – 56.85 m	Guelph Fm, Hanlon Mbr	–	116.4	2.2	8.9	–	2.1	1.356	2.691	–	–	0.009	16.30
Site 16	Drill core	3.56 – 14.72 m	Guelph Fm	101.6	107.6	3.0	–	27.0	–	1.535	2.665	–	–	–	–
Site 17	Drill core	75.70 – 78.75 m	Guelph Fm, Wellington Mbr	–	125.0	1.7	13.0	–	5.6	*2.390*	2.601	–	–	0.019	–
Site 18	Drill core	18.85 – 21.90 m	Guelph Fm, Wellington Mbr	–	107.0	1.5	10.9	–	5.4	0.940	2.715	–	–	0.018	–
Site 19	Drill core	43.10 – 46.15 m	Guelph Fm	–	124.0	2.8	13.5	–	5.2	*2.290*	2.595	–	–	0.021	–

Site No.	Sample Type	Sample Depth or Interval	Formation and Member (if recorded)	COARSE AGGREGATE: Petrographic Number: Granular and 16 mm	Petrographic Number: Hot Mix and Concrete	$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorption (%)	Bulk Relative Density	Aggregate Abrasion Value	Polished Stone Value	Accelerated Mortar Bar (14 days) (% Loss)	FINE AGGREGATE: Micro-Deval Abrasion (% Loss)
			Generally Acceptable Values:		*<125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<6*	*≥50*	*<0.150%*	*<15–25%*
Site 20	Drill core	32.15 – 35.20 m	Guelph Fm, Hanlon Mbr	–	108.0	1.5	12.1	–	3.7	*2.200*	2.613	–	–	0.020	–
Site 21	Drill core	16.50 – 27.70 m	Guelph Fm, Hanlon Mbr	–	105.0	0.5	10.2	–	2.1	1.340	2.704	–	–	0.025	–
Site 21	Drill core	27.70 – 39.60 m	Guelph Fm, Hanlon Mbr	–	108.0	0.5	14.7	–	4.6	*2.010*	2.612	–	–	0.026	–
Site 21	Drill core	39.60 – 51.50 m	Guelph Fm, Hanlon Mbr	–	104.0	0.8	10.1	–	2.0	1.810	2.667	–	–	0.012	–
Site 21	Drill core	51.50 – 62.80 m	Guelph Fm, Hanlon Mbr	–	101.0	0.5	9.3	–	1.5	*2.200*	2.631	–	–	0.013	–
Site 22	Quarry face	0.00 m	Guelph Fm	*148.0*	*180.0*	*22.0*	–	–	–	*2.380*	2.584	–	–	–	–
Site 23	Quarry face	0.00 m	Guelph Fm	*293.0*	*352.0*	*41.0*	*29.7*	*62.0*	–	–	–	–	–	–	–
Site 24	Outcrop	0.00 m	Guelph Fm	–	119.0	4.2	16.1	–	1.8	1.960	2.573	–	–	0.030	–
Site 25	Drill core	6.55 – 15.44 m	Guelph Fm	–	105.0	1.7	9.2	–	4.2	1.230	2.680	–	–	0.031	–
Site 25	Drill core	15.44 – 24.38 m	Guelph Fm	–	104.0	1.5	11.3	–	3.8	*2.100*	2.596	–	–	0.027	–
Site 25	Drill core	24.38 – 33.42 m	Guelph Fm	–	105.0	0.7	13.3	–	2.7	*2.300*	2.571	–	–	0.027	–
Site 25	Drill core	33.42 – 42.37 m	Guelph Fm	–	111.0	4.7	14.4	–	3.4	*2.280*	2.550	–	–	0.021	–
Site 26	Quarry face	0.00 m	Guelph Fm	100.0	107.6	2.0	8.6	–	1.0	0.954	2.712	–	–	0.007	–
Site 27	Quarry face	0.00 m	Guelph Fm	–	104.0	1.0	8.6	26.0	–	1.338	2.678	*13.5*	–	–	–
Site 27	Quarry face	0.00 m	Guelph Fm	–	102.0	1.0	–	26.5	–	1.300	2.670	–	–	–	–

Appendix G.

Aggregate Quality Test Specifications

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

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

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

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

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

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

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

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

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

Polished Stone Value (PSV) (British Standard 812): The PSV is a measure of the resistance of aggregate to the polishing action of a pneumatic tire under conditions similar to those occurring on the road surface. The actual relationship between skidding resistance and PSV varies depending on the type of road surface, age, amount of traffic and other factors. Nevertheless, an aggregate with a high PSV will generally provide higher skid resistance than one with a low PSV. This test is described in British Standard 812 (1975). Values less than 45 indicate marginal frictional properties, whereas values greater than 55 indicate excellent frictional properties (average value ≥50).

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

MATERIAL SPECIFICATIONS FOR AGGREGATES: BASE AND SUBBASE PRODUCTS

Table G1. Physical property requirements for aggregates: base, subbase, select subgrade and backfill material.

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

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

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

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

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

MATERIAL SPECIFICATIONS FOR AGGREGATES: HOT MIX ASPHALT PRODUCTS

Table G2. Physical property requirements for coarse aggregate (surface course): SMA, Superpave™ 9.5, 12.5, 12.5 FC1 and 12.5 FC2.

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

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

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

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

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

Table G3. Physical property requirements for coarse aggregate (binder course): Superpave™ 9.5, 12.5, 19.0, 25.0 and 37.5.

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

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

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

* *Designer fill-in, contact MTO.*

Table G4. Physical property requirements for fine aggregate: SMA, Superpave™ 9.5, 12.5, 12.5 FC1, 12.5 FC2, 19.0, 25.0 and 37.5.

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

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

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

MATERIAL SPECIFICATIONS FOR AGGREGATES: CONCRETE PRODUCTS

Table G5. Physical property requirements for coarse aggregate.

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

General Notes:

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

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

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

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

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

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

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

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

Table G6. Physical property requirements for fine aggregate.

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

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

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

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

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

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

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

Appendix H.

Fossil Record

Appendix H. List of fossils within the various Silurian dolostone units (summarized *from* Brintnell 2012).

Formation	Member	Fossils
Guelph Formation		Favosite corals
		Stromatoporoids
		Gastropods
		Bryozoan
		Megalodont
		Polygnathoides siluricus condonts
Eramosa Formation	Reformatory Quarry Member	Favosite corals
		Stromatoporoids
		Bryozoan
		Microbial - sponge mounds
Eramosa Formation	Vinemount Member	Brachiopods (*Whitefieldella*)
		Digitate tabular corals
		Cladoporoid corals
		Stromatoporoids
		Rhynchonellid Brachiopods
		Gastropods
Goat Island Formation	Ancaster Member	Rugose coral (*Enterolasma*)
		Gastropods
		Trilobites
		Brachiopods (*Whitefieldella*, *Stegerhynchus*, *Leptaena* and *Howellda*)
		Ozarkodina Sagitta to *Ozarkodina*
		Crassa to *Ancordella Ploeckensis* conodonts
Goat Island Formation	Niagara Falls Member	Crinoids
		Stromatoporoids
		Favosite corals
		Cladoporoid corals
Gasport Formation		Crinoids (*Periechocrinites*, *Eucalyptocrinites*)
		Rhynchonellid Brachiopods
		Bryozoan
		Ozarkodina Sagitta Conodonts

Fossil	Kingdom	Phylum	Class
Brachiopods	Animalia	Brachipoda	Numerous
Bryozoans	Animalia	Bryozoa	Numerous (Moss-like animals)
Crinoids	Animalia	Echinodermata	Crinoidea (Sea Lilies)
Conodonts (Extinct animals that resembled eels)	Animalia	Chordata	Conodonta
Favosite corals (Extinct genus of tabulate corals characterized by polygonal (honeycomb) corals)	Animalia	Cnidaria	Anthozoa
Gastropods	Animalia	Mollusca	Gastropoda (Snails and Slugs)
Stromatoporoid	Animalia	Porifera	Numerous (Sponges)

References

Armstrong, D.K. and Carter, T.R. 2010. The subsurface Paleozoic stratigraphy of southern Ontario; Ontario Geological Survey, Special Volume 7, 301p.

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

Amthor, J.E. and Friedman, G.M. 1991. Dolomite-rock textures and secondary porosity development in Ellenburger Group carbonates (Lower Ordovician), west Texas and southeastern New Mexico; Sedimentology, v.38, p.343-362.

Bancroft, A.M., Kleffner, M.A. and Brunton, F.R. 2008. Silurian conodont biostratigraphy and δ^{13} C stratigraphy of the Eramosa Formation, southwestern Ontario, Canada; abstract *in* 42nd North-Central Section Meeting, Evansville, Indiana, April 24-25, 2008, Geological Society of America, Abstracts with Programs, v.40, no.5, p.22.

——— 2009. Silurian conodont biostratigraphy and carbonate carbon isotope stratigraphy of the Eramosa, southwestern Ontario; *in* Canadian Paleontology Conference, Sudbury, Ontario, Proceedings No.7, p.7.

Bates, R.L. and Jackson, J.A. eds. 1987. Glossary of Geology, 3rd ed.; American Geological Institute, Alexandria, Virginia, 788p.

Bergström, S.M., Kleffner, M., Schmitz, B. and Cramer, B.D. 2011. Revision of the position of the Ordovician–Silurian boundary in southern Ontario: Regional chronostratigraphic implications of δ^{13}C chemostratigraphy of the Manitoulin Formation and associated strata; Canadian Journal of Earth Science, v.48, p.1447-1470.

Bolton, T.E. 1957. Silurian stratigraphy and paleontology of the Niagara Escarpment in Ontario; Geological Survey of Canada, Memoir 289, 145p.

Brett, C.E., Tepper, D.H., Goodman, W., LoDuca, S.T. and Eckert, B.Y. 1995. Revised stratigraphy and correlation of the Niagaran Provincial Series (Medina, Clinton and Lockport groups) in the type area of western New York; United States Geological Survey, Bulletin 2086, 66p.

Brintnell, C. 2012. Architecture and stratigraphy of the lower Silurian Guelph Formation, Lockport Group, southern Ontario and Michigan; unpublished MSc thesis, University of Western Ontario, London, Ontario, 255p.

Brunton, F.R. 2009. Update of revisions to the Early Silurian stratigraphy of the Niagara Escarpment integration of sequence stratigraphy, sedimentology and hydrogeology to delineate hydrogeologic units; *in* Summary of Field Work and Other Activities 2009, Ontario Geological Survey, Open File Report 6240, p.25-1 to 25-20.

——— 2013. Karst and hazard lands mitigation: Some guidelines for geological and geotechnical investigations in Ontario karst terrains; *in* Summary of Field Work and Other Activities 2013, Ontario Geological Survey, Open File Report 6290, p.37-1 to 37-24.

Brunton, F.R. and Brintnell, C. 2011. Final update of Early Silurian stratigraphy of the Niagara Escarpment and correlation with subsurface units across southwestern Ontario and in the Great Lakes Basin; *in* Summary of Field Work and Other Activities 2011, Ontario Geological Survey, Open File Report 6270, p.30-1 to 30-11.

Brunton, F.R., Brintnell, C., Jin, J. and Bancroft, A.M. 2012. Stratigraphic architecture of the Lockport Group in Ontario and Michigan – A new interpretation of Early Silurian "basin geometries" and "Guelph pinnacle reefs"; *in* Proceedings, Ontario Petroleum Institute, 51st Annual Conference, Niagara Falls, Ontario, v.51, Technical Paper 8, p.1-37.

Brunton, F.R., Brintnell, C., Priebe, E.H. and Bingham, M. 2010. Update of Early Silurian sequence stratigraphy, sedimentology and bedrock aquifer mapping of the Niagara Escarpment cuesta; *in* Summary of Field Work and Other Activities 2010, Ontario Geological Survey, Open File Report 6260, p.33-1 to 33-7.

Brunton, F.R. and Dekeyser, L-K. 2004. Industrial mineral potential of the Guelph Formation and the Eramosa member of the Amabel Formation, southwestern Ontario; *in* Summary of Field Work and Other Activities 2004, Ontario Geological Survey, Open File Report 6145, p.19-1 to 19-5.

Brunton, F.R., Dekeyser, L-K. and Coniglio, M. 2005. Regional industrial minerals and diagenetic study of the Guelph, Eramosa and Amabel formations, southwestern Ontario; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.35-1 to 35-7.

Brunton, F.R. and Dodge, J.E.P. 2008. Karst of southern Ontario and Manitoulin Island; Ontario Geological Survey, Groundwater Resources Study 5.

Brunton, F.R., Dodge, J.E.P. and Shirota, J. 2005. Karst in southern Ontario: *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.27-1 to 27-7.

——— 2006. Karst compilation for southern Ontario: An update; *in* Summary of Field Work and Other Activities 2006, Ontario Geological Survey, Open File Report 6192, p.31-1 to 31-9.

Carpenter, A.B. 1980. The chemistry of dolomite formation I: The stability of dolomite; *in* Concepts and models of dolomitization, Society of Economic Paleontologists and Mineralogists, Special Publication 28, p.215-236.

Choquette, P.W. and James, N.P. 1990. Limestones—The burial diagenetic environment; *in* Diagenesis, Geological Association of Canada, Geoscience Canada Reprint Series 4, p.75-111.

Coniglio, M., Zheng, Q. and Carter, T.R. 2003. Dolomitization and recrystallization of middle Silurian reefs and platformal carbonates of the Guelph Formation, Michigan Basin, southwestern Ontario; Bulletin of Canadian Petroleum Geology, v.51, p.177-199.

Cramer, B.D., Brett, C.E., Melchin, M.J., Männik, P., Kleffner, M.A., McLaughlin, P.I., Loydell, D.K., Munnecke, A., Jeppsson, L., Corradini, C., Brunton, F.R. and Saltzman, M.R. 2011. Revised correlation of Silurian Provincial Series of North America with global and regional chronostratigraphic units and $\delta^{13}C_{carb}$ chemostratigraphy; Lethaia, v.44, p.185-202.

Cramer, B.D., Saltzman, M.R. and Kleffner, M.A. 2006. Spatial and temporal variability in organic carbon burial during global positive carbon isotope excursions: New insight from high resolution $\delta^{13}C_{carb}$ stratigraphy from type area of the Niagaran (Silurian) Provincial Series; Stratigraphy, v.2, p.327-340.

Dekeyser, L-K. 2006. The Silurian Amabel and Guelph formation of the Bruce Peninsula: Insights into stratigraphy and diagenesis from petrography and ground-penetrating radar; unpublished MSc thesis, University of Waterloo, Waterloo, Ontario, 164p.

Ettensohn, F.R. 2008. The Appalachian foreland basin in eastern United States; *in* The sedimentary basins of the United States and Canada, Elsevier, Amsterdam, Sedimentary Basins of the World, v.5, p.105-179.

Feenstra, B.H. 1996. Recommendations for exploration – London Resident Geologist's District: Guelph Dolomite; *in* Summary of Field Work and Other Activities 1996, Ontario Geological Survey, Miscellaneous Paper 166, p.147-148.

Gregg, J.M., Howard, S.A. and Mazzullo, S.J. 1992. Early diagenetic recrystallization of Holocene (<3000 years old) peritidal dolomites, Ambergris Cay, Belize; Sedimentology, v.39, p.143-160.

Hajna, N.Z. 2003. Chemical weathering of limestones and dolomites in a cave environment; *in* Evolution of karst: from prekarst to cessation, Inštitut za raziskovanje krasa ZRC SAZU [Karst Research Institute ZRC SAZU], Založba ZRC [ZRC Publishing], Postojna–Ljubljana, Slovenia, p.347-356. [also available: republished with permission by Speleogenesis and Evolution of Karst Aquifers, v.1, no.3, p.1-6.]

Harben, P.W. 1999. The industrial minerals handybook, 3rd ed.; Industrial Minerals Information Limited, Surrey, United Kingdom, 296p.

Harben, P.W. and Bates, R.L. 1984. Geology of the nonmetallics; Metal Bulletin Incorporated, New York, 392p.

Haxby, W.F., Turcotte, D.L. and Bird, J.M. 1976. Thermal and mechanical evolution of the Michigan Basin; Tectonophysics, v.36, p.57-76.

Hewitt, D.F. 1960. Limestone industries of Ontario; Ontario Department of Mines, Industrial Mineral Circular 5, 177p.

Hird, K. and Tucker, M.E. 1988. Contrasting diagenesis of two carboniferous oolites from south Wales, a tale of climatic influence; Sedimentology, v.35, p.587-602.

Howell, P.D. and van der Pluijm, B.A. 1990. Early history of the Michigan Basin: Subsidence and Appalachian tectonics; Geology, v.18, p.1195-1198.

Jagger Hims Limited and Rowell, D.J. 2009. Aggregate resources inventory of Grey County, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 180, 71p.

Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G. and Rutka, M.A. 1992. Paleozoic and Mesozoic geology of Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.907-1008.

Kelly, R.I. 1996. High-purity calcite and dolomite resources of Ontario; Ontario Geological Survey, Open File Report 5954, 39p.

——— 2002. Known and potential sources of high-purity calcite and dolomite in Ontario; *in* Industrial minerals in Canada, Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 53, p.137-149.

Klein, G. and Hsui, A.T. 1987. Origin of cratonic basins; Geology, v.15, p.1094-1098.

Land, L.S. 1980. The isotopic and trace element geochemistry of dolomite: The state of the art; *in* Concepts and models of dolomitization, Society of Economic Paleontologists and Mineralogists, Special Publication 28, p.87-110.

——— 1985. The origin of massive dolomite; Journal of Geological Education, v.33, p.112-125.

Liberty, B.A. and Bolton, T.E. 1971. Paleozoic geology of the Bruce Peninsula area, Ontario; Geological Survey of Canada, Memoir 360, 163p.

Luczaj, J.A. 2013. Geology of the Niagara Escarpment in Wisconsin; Geoscience Wisconsin, v.22, pt.1, p.1-34.

Lumsden, D.N. and Caudle, G.C. 2001. Origin of massive dolostone: the Upper Knox model; Journal of Sedimentary Research, v.71, p.400-409.

Lumsden, D.N. and Chimahusky, J.S. 1980. Relationship between dolomite nonstoichiometry and carbonate facies parameters; *in* Concepts and models of dolomitization, Society of Economic Paleontologists and Mineralogists, Special Publication 28, p.123-187.

MacNaughton Hermsen Britton Clarkson Planning Limited, White LandScience, Robinson Consultants, Rowell, D.J. and Brunton, F.R. 2014. Aggregate resources inventory of Dufferin County, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 163—Revision 2, 64p.

Marich, A.S. 2010. Aggregate resources inventory in the City of Hamilton, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 181, 40p.

Mazzullo, S.J. 1992. Geochemical and neomorphic alteration of dolomite: A review; Carbonates and Evaporites, v.7, p.21-37.

McLaughlin, P.I., Mikulic, D.G. and Kluessendorf, J. 2013. Age and correlation of Silurian rocks in Sheboygan Wisconsin, using integrated stable carbon isotope stratigraphy and facies analysis; Geoscience Wisconsin, v.21, pt.2, p.15-30.

Milligan, G.C. 1977. The changing Earth – An introduction to geology; McGraw-Hill Ryerson Limited, Toronto, Ontario, 706p.

Mitrovica, J.X., Beaumont, C. and Jarvis, G.T. 1989. Tilting of continental interiors by the dynamical effects of subduction; Tectonics, v.8, p.1079-1094.

Montañez, I.P. 1994. Late diagenetic dolomitization of Lower Ordovician, Upper Knox carbonates: A record of the hydrodynamic evolution of the southern Appalachian Basin; American Association of Petroleum Geologists Bulletin, v.78, p.1210-1239.

Montañez, I.P. and Stefani, A.B. 1993. An overview of the factors contributing to the evolution and spatial distribution of reservoir properties in Knox cyclic carbonates; *in* Paleokarst, karst-related diagenesis, reservoir development, and exploration concepts: Examples from the Paleozoic section of the southern mid-continent, 1993 Annual Field Trip, Permian Basin Section–SEPM, Arbuckle Mountains, Oklahoma, Society of Economic Paleontologists and Mineralogists, Permian Basin Section, 1993 Annual Field Trip Guidebook, p.67-83.

Murray, R.C. 1960. Origin of porosity in carbonate rocks; Journal of Sedimentary Petrology, v.30, p.59-84.

Nunn, J.A. and Sleep, N.H. 1984. Thermal contraction and flexure of intracratonal basins: A three-dimensional study of the Michigan Basin; Geophysical Journal of The Royal Astronomical Society, v.76, p.587-635.

Ontario Geological Survey 1980. Aggregate resources inventory of the Town of Pelham, Regional Municipality of Niagara; Ontario Geological Survey, Aggregate Resources Inventory Paper 4, 33p.

——— 1984. Aggregate resources inventory of the Regional Municipality of Hamilton–Wentworth; Ontario Geological Survey, Aggregate Resources Inventory Paper 50, 53p.

——— 1985. Aggregate resources inventory of the towns of Grimsby and Lincoln and the Township of West Lincoln, Regional Municipality of Niagara; Ontario Geological Survey, Aggregate Resources Inventory Paper 104, 31p.

——— 2014. Geoscience Laboratories Schedule of Fees and Services; Ontario Geological Survey, unpublished document, 24p.

Ontario Geological Survey and Planning and Engineering Initiatives Limited 1998. Aggregate resources inventory of the Regional Municipality of Waterloo, townships of North Dumfries, Wellesley, Wilmot, and Woolwich and the cities of Cambridge, Kitchener, and Waterloo; Ontario Geological Survey, Aggregate Resources Inventory Paper 161, 64p.

Planning and Engineering Initiatives Limited and Ontario Geological Survey 1999. Aggregate Resources Inventory of Wellington County: Townships of Minto, Arthur, West Luther, Maryborough, Peel, West Garafraxa, Pilkington, Nichol, Guelph, Eramosa, Erin, Puslinch and the City of Guelph; Ontario Geological Survey, Aggregate Resources Inventory Paper 162, 73p.

Purser, B.H., Brown, A. and Aissaoui, D.M. 1994. Nature, origins and evolution of porosity in dolomites; *in* Dolomites, A volume in honour of Dolomieu, International Association of Sedimentologists, Special Publication No.21, p.283-308.

Quinlan, G. 1987. Models of subsidence mechanisms in intracratonic basins and their application to North American examples; Canadian Society of Petroleum Geologists, v.12, p.463-481.

Rameil, N. 2008. Early diagenetic dolomitization and dedolomitization of Late Jurassic and earliest Cretaceous platform carbonates: A case study from the Jura Mountains (NW Switzerland, E France); Sedimentary Geology, v.212, nos.1-4, p.70-85.

Raven, K., Sterling, S., Gaines, S., Wigston, A. and Frizzell, R. 2009. Regional and site geological frameworks–proposed deep geologic repository, Bruce County, Ontario; *in* GeoHalifax 2009, 62nd Canadian Geotechnical Conference and 10th Joint Canadian Geotechnical Society (CGS) and the International Association of Hydrogeologists (IAH)–Canadian National Chapter (CNC) Groundwater Conference, Halifax, Nova Scotia, September 20-24, Proceedings, p.1348-1355.

Rickard, L.V. 1975. Correlation of Silurian and Devonian rocks in New York State; New York State Museum and Science Service, Map and Chart Series No.24, 4 plates, 16p.

Rogers, C.A., Senior, S.A. and Boothe, D. 1989. Development of an unconfined freeze-thaw test for coarse aggregate; Ministry of Transportation and Communications, Engineering Materials Office, Toronto, Ontario, Paper EM-87, 31p.

Rowell, D.J. 2012a. Aggregate test results for various rock types in Ontario; Ontario Geological Survey, Miscellaneous Release—Data 297.

——— 2012b. Aggregate resources inventory of Bruce County, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 190, 94p.

——— 2014. Aggregate resources inventory of the County of Oxford and the County of Brant; Ontario Geological Survey, Aggregate Resources Inventory Paper 159, 107p.

Sanford, B.V. 1969. Silurian of southwestern Ontario; *in* Proceedings, Ontario Petroleum Institute, 8th Annual Conference, v.8, Technical Paper 5, 44p.

Sibley, D.F. 1990. Unstable to stable transformations during dolomitization; Journal of Geology, v.98, p.739-748.

Sibley, D.F. and Gregg, J.M. 1987. Classification of dolomite rock textures; Journal of Sedimentary Petrology, v.57, p.967-975.

Sleep, N.H. 1971. Thermal effects of the formation of Atlantic continental margins by continental breakup; Geophysical Journal of The Royal Astronomical Society, v.24, p.325-350.

Sperber, C.M., Wilkinson, B.H. and Peacor, D.R. 1984. Rock composition, dolomite stoichiometry, and rock/water reactions in dolomitic carbonate rocks; Journal of Geology, v.92, p.609-622.

Sun, S.Q. 1990. Facies-related diagenesis in a cyclic shallow marine sequence: The Corallian Group (Upper Jurassic) of the Dorset coast, southern England; Journal of Sedimentary Petrology, v.60, no.1, p.42-52.

——— 1995. Dolomite reservoirs: Porosity evolution and reservoir characteristics; American Association of Petroleum Geologists Bulletin, v.79, p.186-204.

Tucker, M.E. 1993. Carbonate diagenesis and sequence stratigraphy; *in* Chapter 4 *in* Sedimentology Review/1, Blackwell Scientific Publications, Oxford, United Kingdom, p.51-72.

Vahrenkamp, V.C. and Swart, P.K., 1994. Late Cenozoic dolomites of the Bahamas: metastable analogues for the genesis of ancient platform dolomites; *in* Dolomites, A volume in honour of Dolomieu, International Association of Sedimentologists, Special Publication No.21, p.133-153.

Van der Voo, R. 1988. Paleozoic paleogeography of North America, Gondwana, and intervening displaced terranes: Comparison of paleomagnetism with paleoclimatology and biogeographical patterns; Geological Society of America Bulletin, v.100, p.311-324.

Vos, M.A. 1969. Stone resources of the Niagara Escarpment; Ontario Department of Mines, Industrial Minerals Report 31, 68p.

Wolf, R.R. 2006. Paleozoic geology of Cockburn Island, Manitoulin area; Ontario Geological Survey, Open File Report 5424, 55p.

Zheng, Q. 1999. Carbonate diagenesis and porosity evolution in the Guelph Formation, southwestern Ontario; unpublished PhD thesis, University of Waterloo, Waterloo, Ontario, 265p.

Metric Conversion Table

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

OTHER USEFUL CONVERSION FACTORS

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

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

ISSN 0826-9580 (print)
ISBN 978-1-4606-5576-4 (print)

ISSN 1916-6117 (online)
ISBN 978-1-4606-5577-1 (PDF)

Figure 2. Geology of the study area showing the locations of geochemical samples collected for this study. Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83), Zone 17. Geology from Armstrong and Dodge (2007), with additional geology from Brett et al. (1995), Brunton (2009), Cramer et al. (2011), Brintnell (2012) and Brunton et al. (2012).

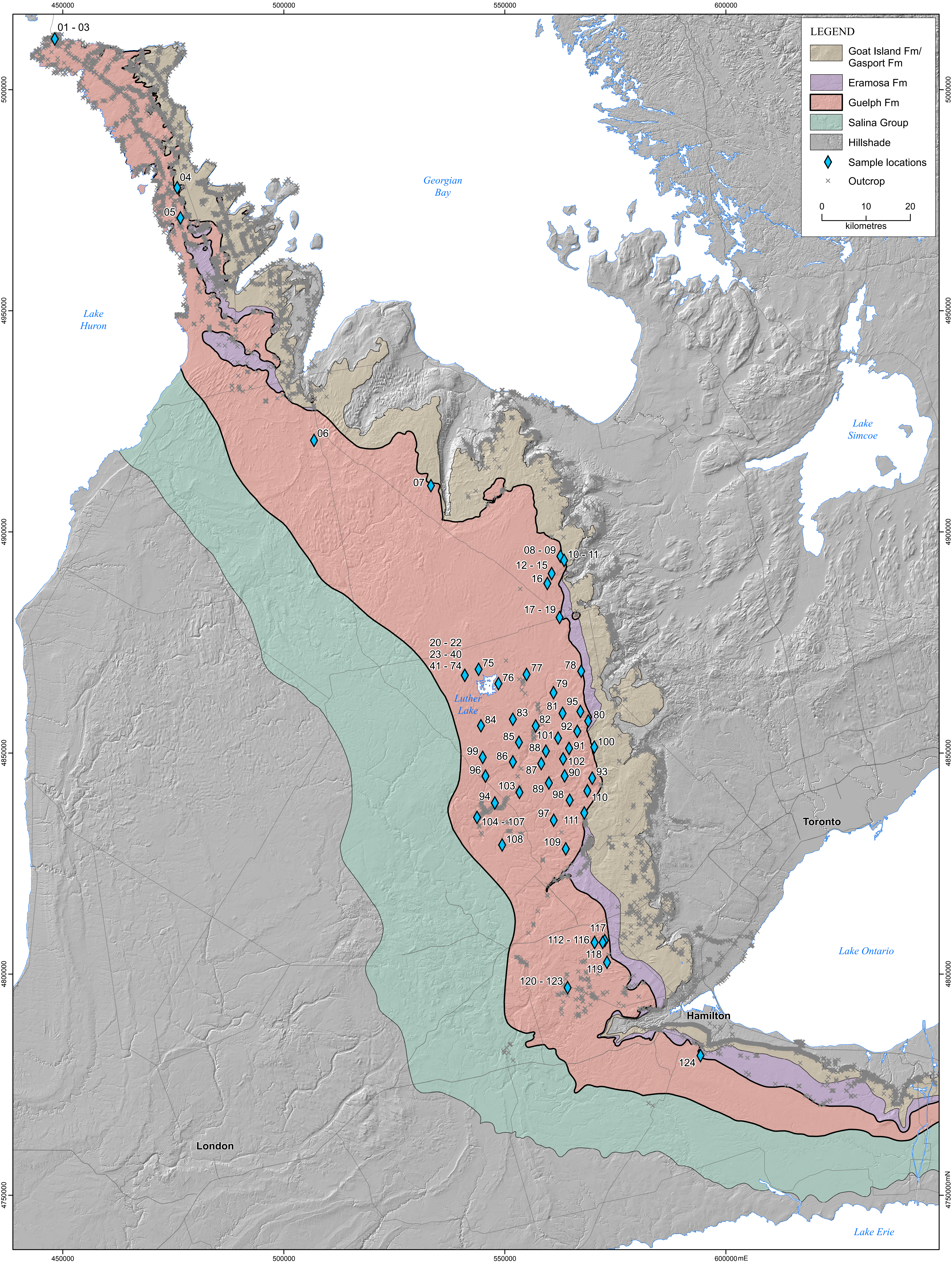


Figure 3. Locations of aggregate test sites. Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83), Zone 17. Geology from Armstrong and Dodge (2007), with additional geology from Brett et al. (1995), Brunton (2009), Cramer et al. (2011), Brintnell (2012) and Brunton et al. (2012).