NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Phase 1 Geoscientific Desktop Preliminary Assessment, Processing and Interpretation of Geophysical Data

MUNICIPALITIES OF ARRAN-ELDERSLIE, BROCKTON AND SOUTH BRUCE, TOWNSHIP OF HURON-KINLOSS AND TOWN OF SAUGEEN SHORES, ONTARIO

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For more information, please contact:
Nuclear Waste Management Organization
22 St. Clair Avenue East, Sixth Floor
Toronto, Ontario M4T 2S3 Canada
Tel 416.934.9814
Toll Free 1.866.249.6966
Email contactus@nwmo.ca
www.nwmo.ca

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

PROCESSING AND INTERPRETATION OF GEOPHYSICAL DATA

Municipalities of Arran-Elderlsie, Brockton, South Bruce, Township of Huron-Kinloss and Town of Saugeen Shores

Prepared for

Geofirma Engineering Ltd.
and
Nuclear Waste Management Organization (NWMO)

by

Paterson, Grant & Watson Limited
Consulting Geophysicists
www.pgw.on.ca

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EXECUTIVE SUMMARY

In Fall 2012, the municipalities of Arran-Elderslie, Brockton and South Bruce, the Township of Huron-Kinloss and the Town of Saugeen Shores (the Communities) individually expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Communities for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process.

The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessments of the Communities are reported in integrated reports (NWMO, 2014a; 2014b; 2014c; 2014d; 2014e). The objective of the Geoscientific Desktop Preliminary Assessment is to determine whether the Communities contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

The purpose of the geophysical interpretation was to provide additional information of the geological features associated with both the Paleozoic sedimentary units and the underlying crystalline rocks of the Precambrian basement within the Communities and their immediate periphery referred to as the Area of the Five Communities. Available geophysical data were assessed to determine potential lithological variations within the Precambrian basement, and identify broad lithological domains. An attempt was made using gravity data in the Area of the Five Communities to identify features within the Precambrian basement, as well as potential features such as pinnacle reef structures and the presence of thick salt occurrence within the overlying Paleozoic sedimentary sequence.

The geophysical data covering the Communities are of moderate to high dataset resolution. Moderate to high resolution magnetic, gravity and radiometric data were obtained from the Geological Survey of Canada (GSC) for the entire area of the Communities. These were supplemented by moderate resolution magnetic and high resolution gravity multi-client datasets acquired from industry sources. No electromagnetic data were available for the Communities.

In this study, available magnetic data were used to assess the lithological variations within the Precambrian basement, since the overlying sediments are magnetically transparent. The magnetics identified several broad lithological domains indicating variability in rock type or metamorphic grade. Magnetics and gravity data also identified ductile features in the Precambrian basement that are interpreted as being associated with the internal fabric of the crystalline basement and likely include tectonic foliation or gneissosity. The Bouguer gravity data were assessed in order to focus on identifying features within the overlying Paleozoic sedimentary sequence such as lateral variations in rock density associated with lateral changes in depositional environments, such as pinnacle reefs and salt units. This assessment suggests that there is no evidence of reef type anomalies within the Paleozoic sedimentary sequence in the Area of the Five Communities, further indicating that the sedimentary sequences are predominantly uniform and homogeneous across the area. Radiometric results show a strong correlation with the distribution of the mapped Quaternary deposits, as well as impacts from varying amounts of vegetation cover, soil moisture, and surface water. Radon risks throughout the Area of the Five Communities are considered to be low.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

In Fall 2012, the municipalities of Arran-Elderslie, Brockton and South Bruce, the Township of Huron-Kinloss and the Town of Saugeen Shores (the Communities) expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of each of the Communities for safely hosting a deep geological repository (Step 3). The overall preliminary assessments are multidisciplinary studies integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations (NWMO, 2014a; 2014b; 2014c; 2014d; 2014e).

This report summarizes the processing and interpretation of airborne magnetic and ground gravity geophysical data as part of the Geoscientific Desktop Preliminary Assessment for the Area of the Five Communities (Geofirma Engineering Ltd., 2014a). The objective of the Geoscientific Desktop Preliminary Assessment is to determine whether the Communities contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors. The assessment focused on the five Communities and their immediate periphery, referred to as the Area of the Five Communities (Figure 1).

1.1 Objective

The geophysical data provide supporting information useful for assessing the Area of the Five Communities to assist in the identification of potentially suitable general areas. The purpose of this study was to perform a review of available geophysical data for the Area of the Five Communities, followed by a detailed interpretation of all available geophysical data (e.g., magnetic, gravity and radiometric) to identify additional information that could be extracted from the data.

The role of the geophysical interpretation within the Area of the Five Communities is to provide additional information of the geological features associated with the Paleozoic sedimentary units and the underlying crystalline rocks of the Precambrian basement. In particular, the available data are assessed to determine the lithological variations within the Precambrian basement, and to identify broad lithological domains. Interpretations derived from the magnetic data are then compared to results from available literature on basement lithology of the Grenville Province in southern Ontario, as well as on the Precambrian basement rocks exposed further to the northeast of the Area of the Five Communities. Available gravity data in the Area of the Five Communities are utilized to identify features within the Precambrian basement, as well as potential features such as pinnacle reef structures and the presence of thick salt occurrence within the overlying Paleozoic sedimentary sequence. Where possible, the gravity data are compared to known features located in the Paleozoic formations, such as pinnacle reefs and variations in the thickness of salt units, both of which are known to occur within the Area of the Five Communities.

1.2 Assessment Area

The preliminary assessment focused on the area within the boundaries of the Communities (municipalities of Arran-Elderslie, Brockton and South Bruce, Township of Huron-Kinloss and Town of Saugeen Shores). Areas beyond the municipal boundaries of the five communities were not considered. For the purpose of the assessment, geoscientific information was collected and interpreted for the Communities and surrounding areas, referred to in this report as the Area of the Five Communities (Figure 1).

1.3 Qualifications of the Geophysical Interpretation Team

The team responsible for the geophysical review, processing and interpretation investigation component of the Phase 1 – Geoscientific Preliminary Assessment of Potential Suitability Study for the Communities and the Area of the Five Communities consisted of qualified experts from Paterson, Grant & Watson Limited (PGW). The personnel assigned to this study were as follows:

Dr. D. James Misener, Ph.D., P.Eng. – geophysical interpretation, report preparation and project manager.

Dr. Misener is President of PGW and a senior geophysicist with 37 years of experience in all aspects of geophysics and geophysics software applications. Dr. Misener founded Geosoft Inc. and led its development of world-leading geosciences software applications until he succeeded Dr. Paterson as President of PGW. He has directed implementation of geophysical data processing systems; initiated and managed major continental scale compilations of aeromagnetic/marine magnetic data in North America and worldwide including interpretation of aeromagnetic, radiometric, gravity and electromagnetic surveys in Algeria, Brazil, Cameroon, Niger, Ivory Coast, Zimbabwe, Malawi, Kenya, China, Suriname and Ireland. Dr. Misener acted as the Project Manager and chief Interpretation Geophysicist and co-ordinated the preparation of the Geophysical Report.

Stephen Reford, B.A.Sc., P.Eng. – alternate project manager

Mr. Reford is a senior consulting geophysicist and Vice-President of PGW. Mr. Reford has 31 years of experience in project management, acquisition and interpretation of airborne magnetic, electromagnetic, radiometric, gravity and digital terrain data for clients throughout Canada and around the world. Projects include management of the geophysical component of Operation Treasure Hunt for the Ontario Ministry of Northern Development and Mines as well as a similar role for the Far North Geoscience Mapping Initiative (2006-2009). Mr. Reford has served as a consultant to the International Atomic Energy Agency (IAEA) in gamma-ray spectrometry and is co-author of two books on radioelement mapping. Mr. Reford acted as assistant Project Manager.

Edna Mueller-Markham, M.Sc., P.Geo. – data processing and map preparation

Ms. Mueller-Markham is a senior consulting geophysicist for PGW. She has 18 years of experience in project management, acquisition, processing and modelling of airborne magnetic, electromagnetic, radiometric, gravity, digital terrain data and gamma-ray spectrometer surveys for clients throughout Canada and around the world. In recent years, she has provided management and quality control for a number of OGS magnetic, gravity and electromagnetic surveys, and has reprocessed numerous industry surveys published by OGS. Ms. Mueller-Markham acted as a chief data processor and prepared all geophysical maps.

Winnie Pun, M.Sc. – data processing

Ms. Pun has completed her first year as a consulting geophysicist for PGW after completing her M.Sc. in geophysics at the University of Toronto. She has prepared hundreds of geophysical maps for publication by government agencies in Nigeria and Botswana, and most recently has carried out several 2D/3D magnetic and gravity modelling studies on several iron ore projects. Ms. Pun assisted Ms. Mueller-Markham in data processing and presentation.

Nikolay Paskalev, M.Sc. – GIS preparation

Mr. Paskalev has been the Manager of Geomatics and Cartography for Watts, Griffis and McOuat Limited (geological consultants) since 2006 and has been with the company since 2001. His work there has included a nationwide GIS of geology, ores and industrial minerals for Egypt, a GIS compilation of geological maps for a large part of Saudi Arabia and a Radarsat and DEM study for gold exploration in Sumatra. He has also worked part-time for PGW for the last 12 years, and most recently prepared a nationwide GIS for the geophysical interpretation of Nigeria. In 2011, he incorporated World GeoMaps Inc. for consulting in geomatics, cartography and GIS. Mr. Paskalev prepared all final maps/ documents in proper GIS format(s) for inclusion in the final Geophysical Report.

2 SUMMARY OF PHYSICAL GEOGRAPHY AND GEOLOGY

2.1 Physical Geography

A detailed discussion of the physical geography of the Area of the Five Communities including physiography, topography, surface water/wetlands and built-up areas is provided in a separate Terrain and Remote Sensing Study Report (JDMA, 2014) and the following is a summary of that information.

The Area of the Five Communities is found within a set of landforms and landform complexes that resulted from the advance and retreat of the glaciers during the Late Wisconsinan glaciation. These landforms provide a map of the glacial and postglacial events that were largely responsible for producing the detailed topography of the area. The physiography of the Area of the Five Communities is classified into a set of ten physiographic units based on the presence of distinct landforms such as valleys, drumlins fields, escarpments and till plains (JDMA, 2014). The dominant physiographic units within the Communities are the Arran drumlin field (Municipality of Arran Elderslie), the Horseshoe moraines (municipalities of Brockton and South Bruce, Township of Huron-Kinloss), the Huron fringe (Town of Saugeen Shores), the Huron slope (Town of Saugeen Shores and Township of Huron-Kinloss), Saugeen clay plain (municipalities of Arran Elderslie and Brockton), and Teeswater drumlin field (Municipality of South Bruce). These physiographic units are in part reflected in the surficial geology of the area (Figure 5).

The large-scale topography in the Area of the Five Communities is controlled by bedrock topography whereas the detailed topography is often controlled by surficial landforms. The elevation gradient from east to west (Lake Huron) is from 400 to 176 m, with this elevation drop occurring over an approximate 70 km lateral distance. The elevation minimum is defined by the surface of Lake Huron, with a chart datum of 176 m. The highest points in the Area of the Five Communities with elevations of 400 m are located in the southeast corner of the area. Steep slopes which are rare in the Area of the Five Communities are associated with drumlins, river valleys, spillways, moraines, and raised shore bluffs.

Apart from Lake Huron, the Area of the Five Communities contains no large lakes (Figure 1). For example, the largest lake in the area is Arran Lake, which is located in the northern part of the Municipality of Arran-Elderslie, with an area of 3.9 km^2. Water bodies cover 38.7 km^2 or 0.8 % of the land within Area of the Five Communities. Wetlands cover 671.8 km^2 or 14.3 % of the land within the Area of the Five Communities.

Built-up areas are found in the villages and towns of the Communities. The largest of these built-up areas are associated with settlements of Walkerton, Port Elgin, Southampton, Mildmay, Formosa, Lucknow, Point Clark, Paisley, Chesley, Tara and Teeswater (Figure 1).

2.2 Bedrock Geology

The bedrock geology of southern Ontario and the Area of the Five Communities is described in detail in Geofirma Engineering Ltd. (2014a) and the following is a summary of that information.

2.2.1 Geological Setting

The bedrock geology of southern Ontario consists of a thick Paleozoic sequence of sedimentary rocks ranging in age from Cambrian to Mississippian deposited between approximately 540 million and 323 million years ago (Johnson et al., 1992). This sedimentary sequence rests unconformably on an erosional surface of the Precambrian crystalline basement of the Grenville Province, the south-eastern most subdivision of the Canadian Shield. The Grenville Province comprises 2,690 million to 990 million year old metamorphic rocks deformed during orogenic events 1,210 million to 970 million years ago (Percival and Easton, 2007; White et al., 2000). The Grenville Province is considered to have been relatively tectonically stable for the past 970 million years (Williams et al., 1992).

Southern Ontario is underlain by two paleo-depositional centres referred to as the Michigan Basin and the Appalachian Basin. The Appalachian Basin is an elongate foreland basin that parallels the Appalachian orogen and comprises primarily siliciclastic sediments. The Michigan Basin is a broadly circular carbonate-dominated, evaporite-bearing intracratonic basin. These basins are separated by the northeast-trending Algonquin and Findlay arches which, along with the intervening east-southeast-trending Chatham Sag structural depression, define a regional basement high beneath southern Ontario and extending further southwestward into the northeastern United States.

The Paleozoic succession underlying the Area of the Five Communities was deposited within the Michigan Basin. Within the Michigan Basin the thickness of Paleozoic rocks range from a maximum of about 4,800 m at the centre of the basin to approximately to 450 m at the northeast corner of the Area of the Five Communities (OGSRL, 2013). The Paleozoic strata dip gently (3.5 to 12 m/km) to the west or southwest throughout the Ontario portion of the Michigan Basin (Armstrong and Carter, 2010).

Figure 2 shows the bedrock geological map for southern Ontario, and Figure 3 shows a vertically exaggerated cross-section constructed through the Area of the Five Communities. The location of the cross-section is shown on Figure 2. The geological cross-section (Figure 3) shows the west-southwesterly dip of the Paleozoic sedimentary formations from the Niagara Escarpment in the east to below Lake Huron in the west. The large vertical exaggeration of 50 times used in Figure 3 results in apparent moderate formation dips when, in reality, the sedimentary formations within the Area of the Five Communities are flat lying with dips of 1º or less. These moderate west-southwesterly dips result in outcrop or subcrop exposure of increasingly older sedimentary formations from west to east across southern Ontario, as shown on Figure 2.

2.2.2 Geological and Tectonic History

The structural and tectonic history of southern Ontario includes both Precambrian and Phanerozoic events. These events are described below and summarized in Table 1.

As mentioned above, the Paleozoic sedimentary sequence of southern Ontario lies unconformably on the Precambrian crystalline basement of the Grenville Province of the Canadian Shield. The Grenville Province is a complex orogenic belt that truncates several older geologic provinces. Basement rocks in southern Ontario have all been affected by an approximately 1,210 to 970 million year old orogenic event, the Grenville Orogeny. The Grenville Orogeny is generally interpreted to have involved northwest-directed thrusting and imbrication of the entire crust, presumably as a result of collision with another continental landmass originally located somewhere to the southeast. Older tectonic events including the approximately 2,700 million year old Kenoran Orogeny and the approximately 2,000-1,700 million year old Trans-Hudson/Penokean Orogen, built the proto-North American craton upon which Grenville deformation was imprinted (Easton, 1992). Post-Grenville extension associated with the initial opening of the Iapetus Ocean began approximately 970 million years ago (Thomas, 2006).

Table 1. Timetable of major tectonic events in Southern Ontario

Million Years Before Present	***Tectonic Activity***	***Reference***
1,210 – 1,180	Regional metamorphism in Central Metasedimentary Belt Boundary Zone (proto-Grenville)	Easton (1992), Lumbers et al. (1990), Hanmer and McEachern (1992)
1,109 – 1,087	Magmatism and formation of Midcontinent Rift	Van Schmus (1992)
1,030 – 970	Main phase of Grenville Orogeny	Carr et al. (2000), White et al. (2000)
970 – 530	Rifting and opening of the Iapetus Ocean	Thomas (2006)
530 – 320	Subsidence of Michigan Basin and Uplift of Frontenac and Algonquin Arches (episodic)	Howell and van der Pluijm (1999), Sanford et al. (1985), Kesler and Carrigan (2002)
470 – 440	Taconic Orogeny • E-W to NW-SE compression, uplift in foreland (Frontenac and Algonquin Arches)	Quinlan and Beaumont (1984), Sloss (1982), McWilliams et al. (2007)
410 – 320	Caledonian/Acadian Orogeny • E-W to NW-SE compression, uplift (Frontenac and Algonquin Arches)	Gross et al. (1992), Marshak and Tabor (1989), Sutter et al. (1985), Kesler and Carrigan (2002)
300 – 250	Alleghenian Orogeny • E-W to NW-SE compression	Gross et al. (1992), Engelder and Geiser (1980)
200 – 50	• Opening of the Atlantic Ocean • St. Lawrence rift system created • Reactivation of Ottawa-Bonnechère Graben • NE-SW extension • Uplift	Kumarapeli (1976, 1985)
Pre-50 – Present	• NE-SW compression (from ridge push) • Post-glacial uplift	Barnett (1992)

The deposition of the sedimentary rocks within the Michigan and Appalachian basins was largely dependent on two tectonic influences (Johnston et al., 1992). These were: the orogenic activity at the eastern margin of North America, which provided clastic input to both the Appalachian and Michigan basins, and the resultant tectonic forces that controlled the positioning of the basins and arches separating the basins. The Algonquin Arch acted as a major structural control on depositional patterns, rising and falling with respect to the Michigan and Appalachian basins in response to epirogenic movements and horizontal tectonic forces during the course of several distinct Paleozoic orogenic episodes (Howell and van der Pluijm, 1999).

Coincident with sediment deposition, the bedrock of southern Ontario was subject to a complex history of Paleozoic tectonism that included the Taconic (Ordovician), Caledonian/Acadian (Devonian) and Alleghenian (Carboniferous) orogenies (Howell and van der Pluijm, 1999). Subsequent events include the Mesozoic initiation of far field stresses associated with the opening of the Atlantic Ocean (Jurassic), compression from global-scale plate reorganization and ridge push (late Cretaceous-Eocene), and finally post-glacial uplift (Quaternary).

2.2.3 Precambrian Geology

The geology of the Precambrian crystalline basement of the Grenville Province in southern Ontario has been well characterized by surface mapping north of the Paleozoic/Precambrian basement boundary, regional geophysical data (aeromagnetics and gravity), regional seismic reflection surveys and geochemical, geochronological and petrographic analyses of rock samples recovered from boreholes (O'Hara and Hinze, 1980; Green et al., 1988; Carr et al., 2000; Carter and Easton, 1990; Easton and Carter, 1995; Carter et al., 1996).

The Precambrian basement in southern Ontario has been grouped into two lithologic belts – the Central Gneiss Belt, located between the Grenville Front Tectonic Zone and the Central Metasedimentary Belt Boundary Zone, and the Central Metasedimentary Belt located southeast of the Central Metasedimentary Belt Boundary Zone. The Grenville Front Tectonic Zone and the Central Metasedimentary Belt Boundary Zone are major sub parallel shear zones several kilometres or more in width, characterized by strongly deformed rocks with northeast-trending, moderately to shallowly southeast-dipping tectonic layering and southeast plunging mineral lineations (Easton and Carter, 1995). Similar subparallel zones of intense deformation on a smaller scale form boundaries between lithotectonic terranes within both the Central Gneiss Belt and Central Metasedimentary Belt (Easton and Carter, 1995).

Major tectonic zones in southern Ontario are defined by extrapolation of the exposed basement structural boundaries beneath the Paleozoic cover. This process is aided by field mapping, borehole stratigraphic correlation, interpretation of seismic, aeromagnetic and gravity surveys (e.g., Boyce and Morris, 2002; Wallach et al., 1998), and by geochemical, geochronological and petrographic analyses of samples recovered from drill cuttings and core (Carter and Easton, 1990; Carter et al., 1996).

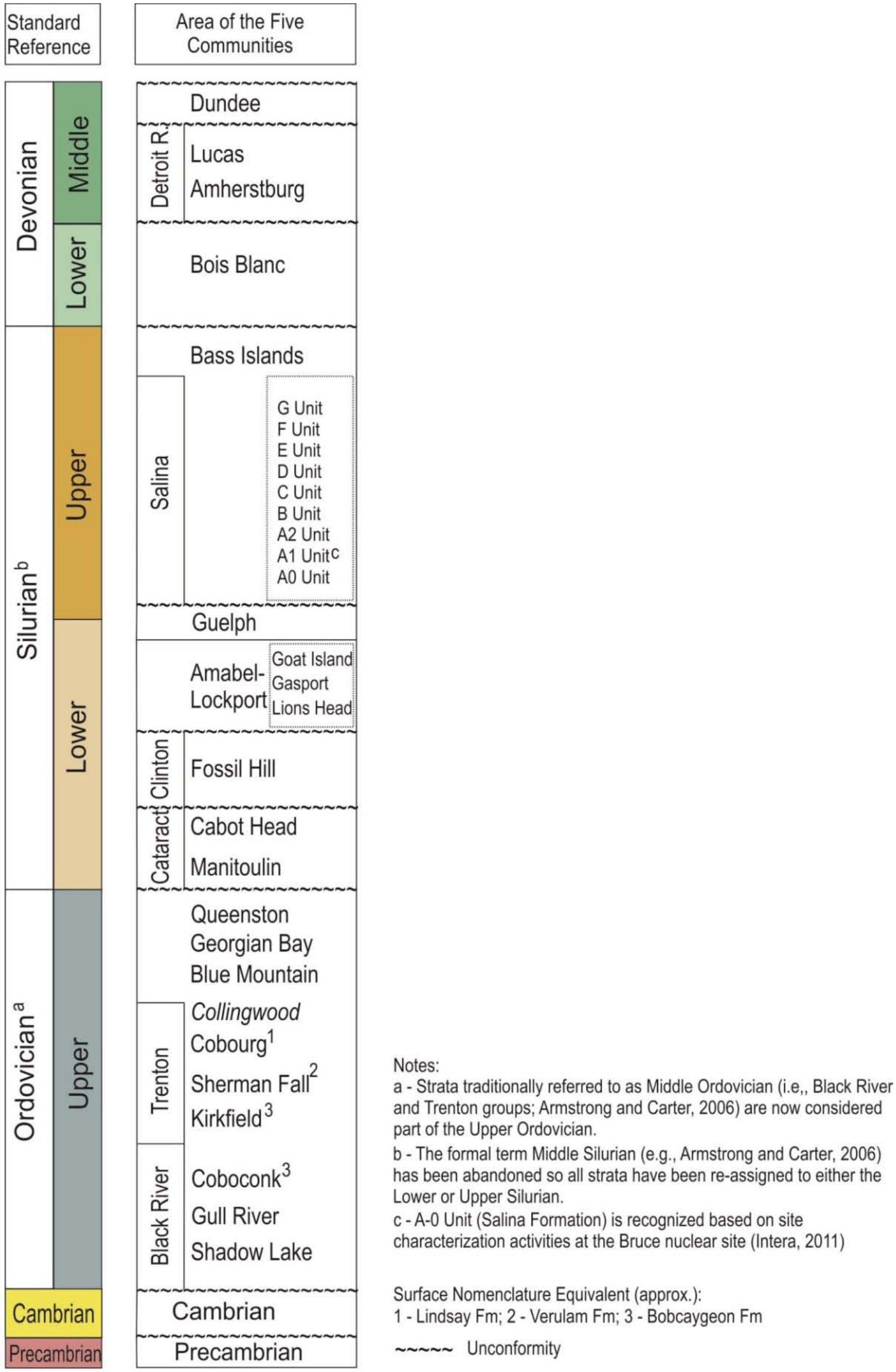
Based on aeromagnetic data and borehole samples, the Precambrian basement below the sedimentary rock cover has been subdivided into several lithotectonic domains and boundary zones similar in scale and form to those found where the Precambrian bedrock of the Grenville Province is exposed (Carter and Easton, 1990). Much of southern Ontario, including the Area of the Five Communities, is underlain by Precambrian crystalline basement of the Central Gneiss Belt and consists mainly of quartzofeldspathic gneissic rocks which have generally been metamorphosed to upper amphibolite facies, and locally to granulite facies. Most of these gneisses are believed to be plutonic in origin, with subordinate amounts of metasedimentary gneiss.

The Huron Domain is a lithotectonic domain within the Central Gneiss Belt, and underlies most of the Area of the Five Communities. The Huron Domain acted as single crustal block during the Paleozoic. It is defined by Carter and Easton (1990), Easton and Carter (1995) and Carter et al. (1996) based on lithologic data from boreholes and published aeromagnetic maps.

2.2.4 Paleozoic Stratigraphy

Table 2 illustrates the Paleozoic bedrock stratigraphy for the Area of the Five Communities as presented by Geofirma Engineering Ltd. (2014a). The Paleozoic stratigraphic nomenclature has evolved over time and a recent compilation by Armstrong and Carter (2010) provides the current standard for usage. Two key stratigraphic designations have recently been revised. Firstly, strata traditionally referred to as Middle Ordovician, i.e., Black River and Trenton groups (from Armstrong and Carter, 2006), are now

Table 2. Stratigraphy of Area of the Five Communities (after Armstrong and Carter, 2010)



considered part of the Upper Ordovician. Secondly, the formal term Middle Silurian (from Armstrong and Carter, 2006) has been abandoned so all strata have been re-assigned to either the Lower or Upper Silurian.

In addition, the stratigraphic nomenclature in Table 2 and Figure 3 adopts the subsurface nomenclature of Armstrong and Carter (2010), while geological mapping as shown in Figures 2 and 4 uses an outcrop nomenclature. This distinction primarily applies to the Trenton and Black River groups, where the Bobcaygeon Formation (outcrop) is equivalent to the Coboconk and Kirkfield formations (subsurface), and the Verulam and Lindsay formations (outcrop) are approximately equivalent to the Sherman Fall and Cobourg formations (subsurface), respectively.

The Paleozoic stratigraphy includes shale, carbonate and evaporite units formed predominantly from marine sediments that were deposited when this portion of eastern North America was located at tropical latitudes and intermittently covered by shallow seas (Johnson et al., 1992; Armstrong and Carter, 2010).

2.2.4.1 Cambrian

The Cambrian bedrock geology in southern Ontario is dominated by white to grey quartzose sandstone with regional lithological variations that include fine to medium crystalline dolostone, sandy dolostone, and argillaceous dolostone to fine to coarse quartzose sandstone (Hamblin, 1999). Cambrian sedimentary rocks unconformably overlie the Precambrian basement. These sedimentary rocks are generally characterized as a succession of clastic and carbonate rocks resulting from transgressive Cambrian seas that flooded across the broad platform of the Algonquin Arch and into the subsiding Michigan and Appalachian basins (Hamblin, 1999). The Cambrian units are largely absent over the Algonquin Arch as the result of a pre-Ordovician regional-scale unconformity (Bailey Geological Services Ltd. and Cochrane, 1984a). The Cambrian unit is interpreted to pinch out eastwards, near the western boundaries of the municipalities of Arran-Elderslie, Brockton and South Bruce (Bailey Geological Services Ltd. and Cochrane, 1984a), and thus is expected to be absent beneath the eastern and central parts of the Area of the Five Communities. There are no surface exposures of the Cambrian unit in southern Ontario.

2.2.4.2 Upper Ordovician

Unconformably overlying the Cambrian unit is a thick sequence of Upper Ordovician sedimentary units with a distinctly bimodal composition: a carbonate-rich lower unit and a shale-rich upper unit. The lower unit was deposited during a major marine transgression (Coniglio et al., 1990) prior to the westward inundation of the carbonate platform by the upper shale-dominated sediments (Hamblin, 1999). The Upper Ordovician carbonates subcrop in the northeastern part of southern Ontario around the Lake Ontario and Lake Simcoe regions, and the Upper Ordovician shales subcrop east of the Niagara Escarpment between Owen Sound and Niagara Falls (Figure 2).

The lower carbonate unit of the Upper Ordovician succession is a thick sequence of predominantly limestone formations (carbonate and argillaceous carbonate sedimentary rocks), which include, from bottom to top: the Shadow Lake, Gull River and Coboconk formations of the Black River Group; and the Kirkfield, Sherman Fall, and Cobourg (including the Collingwood Member) formations of the Trenton Group (Table 2). These rocks range in character from coarse-grained bioclastic carbonates to carbonate mudstone with interbedded calcareous and non-calcareous shales. The Shadow Lake Formation, at the base of the Black River Group, is characterized by poorly sorted, red and green sandy shales, argillaceous and arkosic sandstones, minor sandy argillaceous dolostones and rare basal arkosic conglomerate. The lower part of the overlying Gull River Formation consists mainly of light grey to dark brown limestones and the upper part of the formation is very fine grained with thin shale beds and partings. The Coboconk Formation, at the top of the Black River Group, is composed of light grey-tan to brown-grey, medium to very thick bedded, fine to medium grained bioclastic limestones (Armstrong and Carter, 2010).

The Kirkfield Formation, at the base of the Trenton Group, is characterized by fossiliferous limestones with shaley partings and locally significant thin shale interbeds. The overlying Sherman Fall Formation ranges in lithology from dark grey argillaceous limestones interbedded with calcareous shales, found lower in the formation, to grey to tan bioclastic, fossiliferous limestones that characterize the upper portions of the formation. The overlying Cobourg Formation is described regionally as a grey, fine-grained limestone to argillaceous limestone with coarse-grained fossiliferous beds and a nodular texture. The Cobourg Formation is also subdivided to include an upper Collingwood Member that consists of dark grey to black, calcareous shales with increased organic content and distinctive fossiliferous limestone interbeds (Hamblin, 2003; Armstrong and Carter, 2010).

The upper unit of the Upper Ordovician succession is characterized by a thick sequence of predominantly shale sedimentary rocks, which comprise from base to top: the Blue Mountain, Georgian Bay and Queenston formations. The Blue Mountain Formation is characterized by uniform soft and laminated grey non-calcareous shale with minor siltstone and minor impure carbonate (Johnson et al., 1992; Hamblin, 1999). In the lower part of the Blue Mountain Formation there is downward gradation from grey to greenish-grey shales to a very dark grey to black shale (Armstrong and Carter, 2010). This lower part of the Blue Mountain Formation was historically named the Rouge River Member (Russell and Telford, 1983). The overlying Georgian Bay Formation is composed of blue-grey shale with intermittent centimetre-scale siltstone and limestone interbeds. The Queenston Formation is characterized by maroon, with lesser green, shale and siltstone with varying amounts of carbonate. The top of the Queenston Formation is marked by a regional erosional unconformity (Table 2; Armstrong and Carter, 2010).

2.2.4.3 Lower Silurian

The Lower Silurian units, including the Cataract and Clinton groups and the Amabel-Lockport and Guelph formations, unconformably overlie the Upper Ordovician shales (Table 2). A major marine transgression at the top of the Clinton Group marks the transition to deposition of the extensive carbonate-dominated Amabel and Guelph formations. These Lower Silurian units form the cap-rock of the Niagara Escarpment in outcrop. The Lower to Upper Silurian boundary occurs within the Guelph Formation (Table 2; Brunton and Dodge, 2008).

The Cataract Group unconformably overlies the Upper Ordovician Queenston Formation and includes a lower unit of grey argillaceous dolostone and minor grey-green shale, and an upper clastic unit which consists of grey to green to maroon noncalcareous shales with minor sandstone and carbonate interbeds. The Clinton Group is composed of thin- to medium-bedded, very fine- to coarse-grained fossiliferous dolostone.

The Amabel-Lockport Formation includes a lower unit of light grey to grey-brown, finely crystalline, thin- to medium-bedded, sparingly fossiliferous dolostone with minor chert nodules. It also includes an upper unit of blue-grey, fine- to coarse-grained, thick bedded to massive dolostone, which locally contains minor dolomitic limestone.

The Guelph Formation lithology varies from reefal to inter-reefal dolostones and dolo-mudstones (Armstrong and Goodman, 1990). Reefal facies represent pinnacle, patch and barrier reefs and their distribution defines the key aspects of the paleogeography during deposition. The widespread inter-reefal dolostones are typically sucrosic, dark brown to black dolo-mudstones with pebble-size fragments lithologically similar to the underlying Goat Island unit (Armstrong and Carter, 2006). Within the Area of the Five Communities, the Guelph Formation is characterized by facies deposited between the basinward pinnacle reef belt found along the eastern shore of Lake Huron, the patch reefs found in the central parts of the Area of the Five Communities, and the basin margin reef complex typically located in the eastern part of the Area of Five Communities (Johnson et al., 1992).

2.2.4.4 Upper Silurian

The Upper Silurian units include the evaporite and evaporite-related sedimentary rocks of the Salina Group, and overlying dolostones and minor evaporites of the Bass Islands Formation (Table 2). The Upper Silurian units subcrop in a northwest trending belt that extends from south of Niagara Falls to west of Owen Sound (Figure 4). The Salina Group is characterized by repeated, cyclical deposition of carbonate, evaporite and argillaceous sedimentary rocks, comprising Units A through G. Parts of the Silurian salt beds (i.e., B, D, E and F Unit salts) have been dissolved resulting in the collapse structure within the overlying uppermost Silurian and Devonian strata (Sanford, 1993; 1976).

A change to less-restricted depositional conditions was responsible for deposition of the Bass Islands Formation, which is a microcrystalline, commonly bituminous dolostone containing evaporite mineral clasts. The contact with the overlying Devonian carbonates marks a major unconformity characterized by subaerial exposure (Uyeno et al., 1982).

2.2.4.5 Lower and Middle Devonian

The Lower and Middle Devonian units unconformably overlie the Upper Silurian Bass Islands Formation and are dominated by carbonate sedimentary rocks of the Bois Blanc Formation, the Detroit River Group consisting of the Amherstburg and Lucas formations. The Bois Blanc Formation consists of cherty, fossiliferous limestones and argillaceous dolostones that unconformably overlie Silurian strata. The Lucas Formation is fine-crystalline, fossiliferous dolostone and limestone. The Amherstburg Formation is a bituminous bioclastic fossiliferous limestone and dolostone (Table 2). The Dundee Formation, which does not subcrop within the Communities, comprises sparsely fossiliferous limestones and minor dolostones that unconformably overly the Detroit River Group.

The Detroit River Group rocks represent the subcropping bedrock within western and central parts of the municipalities of Brockton and South Bruce and all of the Township of Huron-Kinloss (Figure 4). Devonian rocks are not present beneath the Municipality of Arran-Elderslie (Figure 4). The Devonian carbonates are found southwest of the Municipality and crop out along the shoreline of Lake Huron and north shoreline of Lake Erie.

2.2.5 Faulting of the Paleozoic Strata

Figures 2 and 4 show basement-seated faults that displace the Paleozoic strata in southern Ontario and the Area of the Five Communities, respectively. These faults were compiled from several sources by the Ontario Geological Survey (Armstrong and Carter, 2010) and given relative ages based on the youngest geological unit that is offset: i) Shadow Lake/Precambrian, ii) Trenton Group and iii) Rochester Formation (Silurian-aged). These faults are interpreted based on vertical displacements of key unit-top surfaces in the Paleozoic strata, based on earlier compilation and assessment work completed by

Brigham (1971) and Bailey Geological Services Ltd. and Cochrane (1984a; 1984b). Vertical displacement of unit top surfaces was identified based primarily on hand contouring and interpretation of formation top data in the Petroleum Wells Subsurface Database (OGSRL, 2013). Where these data are numerous, such as in the southwestern corner of southern Ontario, the faults are identified with a high degree of confidence, and are often named (e.g., Dawn Fault and Electric Fault). In areas where oil and gas exploration wells are widely spaced, such as in the Area of the Five Communities, faults are identified with a low degree of confidence.

2.3 Quaternary Geology

Information on Quaternary geology in the Area of the Five Communities is described in detail in the Terrain and Remote Sensing Study Report (JDMA, 2014) and a summary of that information is provided here.

Quaternary glaciations have played a major role in shaping and creating the landscape of southern Ontario (Barnett, 1992). Glacial landforms and associated sediments within the Area of the Five Communities were deposited by the Huron and Georgian Bay lobes of the Laurentide Ice Sheet during the Late Wisconsinan 23,000 to 10,000 years ago. Exposures of older deposits are rare as they are mostly buried beneath the Late Wisconsinan sediments and can only be seen in such places as riverbank exposures, lake bluffs or man-made exposures in quarries and pits (Barnett, 1992). The surficial deposits of the Area of the Five Communities have been mapped at the scale of 1:50,000 by Cowan (1977), Cowan et al. (1986), Cowan and Pinch (1986), Feenstra (1994), Karrow (1993), Sharpe and Broster (1977), Sharpe and Edwards (1979) and Sharpe and Jamieson (1982). The overburden can exceed 100 m in this area with values in the range of 30 to 60 m (Karrow, 1989).

Overburden thickness in the areas Area of the Five Communities ranges from zero up to about 104 m. The thickest overburden in the area appears to be associated with buried bedrock valleys. One of the regional buried valleys extends from Wellesley, through Milverton to Wingham. Another extends from Drayton to Mount Forest. There appears to be a complex of valleys east and west of Walkerton in the Area of the Five Communities. Overburden thickness exceeds 60 m within these structures. Table 3 lists the statistics on overburden thickness within each of the Communities and within the Area of the Five Communities based on the data release of Gao et al. (2006) that involved quality assurance checking to remove erroneous water well information from the MOE Water Well Information System.

Table 3. Summary of overburden thickness within the Communities

Community	***Overburden Thickness (m)***		
	Minimum	***Maximum***	***Mean***
Municipality of Arran-Elderslie	0	89	37
Municipality of Brockton	0	104	33
Municipality of South Bruce	0	73	20
Township of Huron-Kinloss	9	91	39
Town of Saugeen Shores	2	86	50
Area of the Five Communities	0	104	30

Figure 5 shows the surficial Quaternary geology of the Area of the Five Communities. Glacial deposits composed of till are exposed at the surface over 45.6 % of the Area of the Five Communities, and are found as drumlinized and undrumlinized till plains, bevelled till plains and till moraines. The Elma Till is the most abundant till in the Area of the Five Communities, mapped over 23 % of the area. The St. Joseph and Dunkeld/Rannoch tills are the next most common till formations mapped in the Area of the Five Communities, covering 20 % and 1 % of the area, respectively.

Glaciofluvial deposits primarily of sand or sand and gravel are exposed over 21.2 % of the Area of the Five Communities. These deposits are associated with kame moraines, spillways and eskers. Glaciolacustrine deposits of primarily clay, silt and sand are exposed over 23.7 % of the Area of the Five Communities, with about 58 % of these deposits mapped as foreshore to basinal deposits and the remaining 42 % as littoral to foreshore deposits. The largest glaciolacustrine deposit mapped in the Area of the Five Communities is represented by the Saugeen clay plain. Fluvial deposits are represented by the modern and abandoned floodplains of the major rivers and creeks in the Area of the Five Communities. These deposits are primarily composed of silt, sand and gravel. Lacustrine deposits of sand and gravel consisting of beaches, bars and spits have been mapped along the shores of Lake Huron and Georgian Bay, covering only 0.2 % of the Area of the Five Communities. Organic deposits of peat and muck have been mapped over 4.4 % of the Area of the Five Communities, with many of the deposits located within spillways, within topographic lows within till plains or on rocky plains of the Bruce Peninsula.

2.4 Land Use

Land use within the Area of the Five Communities consists mostly of agricultural lands, wetlands, forested areas, and developed/built-up areas with residential, commercial and industrial land uses. Wetlands and forested areas represent 14.3 % and 25.2 % respectively of the Area of the Five Communities.

3 GEOPHYSICAL DATA SOURCES AND QUALITY

Geophysical data were obtained from available public-domain sources, including the Geological Survey of Canada (GSC), and two proprietary sources. To provide a regional context to the assessment, geophysical data were collected for the Area of the Five Communities and its surrounding region. The interpretation of the data focused on the Area of the Five Communities only.

The types of geophysical data obtained included aeromagnetic, gravity, and radiometric. The flight path of the aeromagnetic surveys is shown in Figure 6. The gravity station locations are shown in Figure 7.

The quality of the available data was assessed to determine which data sets are suitable for inclusion in this study. The geophysical surveys covering the Area of the Five Communities show variability in data set resolution, which is a function of the flight line or station spacing, the sensor height (airborne surveys), and equipment sensitivity. In particular, where more than one data set overlaps, the available data were assembled using the highest quality coverage. Various geophysical data processing techniques were applied to enhance components of the data most applicable to the current interpretation. The integrity of the higher quality data was maintained throughout.

3.1 Data Sources

The geophysical data obtained from the Geological Survey of Canada (GSC) provide complete coverage of magnetic and gravity data for the entire Area of the Five Communities. Higher resolution aeromagnetic data from a proprietary survey was obtained and incorporated into this assessment for the Strathroy area. In addition to the regional GSC gravity data, higher resolution ground gravity data was obtained covering 90 percent of the Area of the Five Communities. Very low frequency electromagnetic data exists in the area, covering a very small area near Douglas Point. Radiometric data from the GSC covers only the land portion of the Area of the Five Communities. Ontario Geological Survey (OGS) geophysical data does not exist within the Area of the Five Communities. The geophysical data sets are summarized in Table 4, and the characteristics of each of the data sources are discussed in detail below.

3.1.1 Magnetic Data

Magnetic data over the Area of the Five Communities were collected as part of various surveys illustrated in Figure 6 and by using different survey parameters outlined in Table 4. Magnetic data shows the distribution of magnetic and nonmagnetic geological bodies within the subsurface, particularly useful for delineating spatial geometry of bodies of rock, and the presence of structural features.

The resolution of the retrieved magnetic datasets varies greatly within the Area of the Five Communities. Surveys were flown over a period of 50 years, over which time the quality and precision of the equipment as well as the quality of the processing has improved. Low-resolution magnetic data from the GSC provides complete coverage of the entire Area of the Five Communities, comprising four individual survey data sources (Table 4). Ontario #28 covers a small portion of the assessment area in the northeast and was flown at a terrain clearance of 305 m and flight line spacing of 805 m, providing it with relatively low spatial resolution. The Waterloo survey covers the largest portion of the onshore assessment area and also provides a relatively high resolution compared to the other surveys in the assessment area, flown at a terrain clearance of 305 m and flight line spacing of 926 m. Both the Lake Huron and Georgian Bay surveys provide the lowest spatial resolution in the assessment area, and cover the waterbody portion, and in parts onlap onto the onshore portion of the assessment area. The Lake Huron survey was flown at a terrain clearance of 303 m and flight line spacing of 1,900 m and the

Table 4. Summary of the characteristics for the geophysical data sources in the Area of the Five Communities

Product	*Source*	*Type*	*Line Spacing/ Sensor Height*	*Line Direction*	*Location*	*Date*	*Additional Comments*
Waterloo	GSC	Fixed wing magnetic	926m/305m	0°	Central	1986	Large overlap with newer survey to the south.
Lake Huron	GSC	Fixed wing magnetic	1,900 m/303 m	90°	West	1986	Low resolution survey over Lake Huron
Georgian Bay	GSC	Fixed wing magnetic	1,200 m/298 m	0°	Northeast	1985	Low resolution survey over Georgian Bay
Ontario #28	GSC	Fixed wing magnetic	805 m/305 m	135°	East central	1950	Southwest superseded by newer survey.
Strathroy	Randsburg International Gold Corp.	Fixed wing magnetic	700 m x 700 m grid/450m above sea level	0° x 90°	Coast along west shore	1999	Higher resolution than GSC surveys. Terrain clearance varies from 130m to 275m.
GSC Gravity Coverage	GSC	Ground gravity measurements	6 km (onshore), 1.6 km x 18 km (offshore)/ surface		Entire Area of the Five Communities	1945-2007	Station spacing variable.
PGW Gravity Coverage	PGW	Ground gravity measurements	0.4 km x 2 km/ surface		Onshore west and south	1980s -90s	Much higher resolution than GSC coverage. Station spacing variable.
South Ontario Radon Survey – Block 2	GSC	Fixed wing radiometric and magnetic	1,000 m/150 m	90°	Southern half of area	2008	Recent survey providing radiometric coverage of the southern half of the area. Survey includes unlevelled magnetic data.
South Central Ontario – Collingwood-Hamilton	GSC	Fixed wing radiometric	1,000 m/150 m	90°	Northern half of area	2009	Recent survey providing radiometric coverage of the northern half of the area.
Douglas Point	GSC	Fixed wing magnetic, radiometric and VLF-EM	1,000 m/120 m	135°	Local survey extending offshore	1982	Magnetic and radiometric data superseded by more recent survey.

GSC – Geological Survey of Canada (2013)
PGW – Paterson, Grant & Watson Limited

Georgian Bay survey was flown at a terrain clearance of 305 m and flight line spacing of 1,200 m, providing both surveys with relatively low spatial resolution.

In addition to the low resolution magnetic data collected by the GSC, the Strathroy survey was acquired through a data license agreement with Randsburg International Gold Corporation which covers a good portion of the west side of the Area of the Five Communities along the north trending shoreline. This survey is medium-resolution and was flown on a 700 m x 700 m grid pattern at a survey elevation of 450 m above sea level (Spector, 1999). Because the survey was flown at a constant elevation the survey terrain clearance varied from approximately 130 m to 275 m above ground surface.

3.1.2 Gravity Data

Gravity data within the Area of the Five Communities were acquired from two sources, comprising relatively sparse coverage from the GSC gravity database, and a dense network of gravity stations derived from a proprietary dataset from numerous ground surveys conducted in Southwest Ontario for oil and gas exploration. The acquired GSC gravity data consists of an irregular distribution of 237 station measurements providing coverage of the entire Area of the Five Communities. On land, the data consists of 149 station measurements comprising roughly a station every 3 to 6 km. Offshore the data consists of 88 station measurements comprising roughly a station every 1.6 to 18 km, predominantly along profile lines recorded by boat.

The proprietary dataset includes a dense network of gravity stations (roughly 45 times the density of the GSC coverage) providing approximately 90 % coverage of the Area of the Five Communities. The gravity measurements were acquired mainly along local roads, with an average station separation of approximately 400 m. In addition to providing sufficient coverage to the Area of the Five Communities, the dataset extends for several kilometers south of the Communities, into the surrounding region.

3.1.3 Radiometric Data

Radiometric data collected by various GSC surveys using different survey parameters provides complete coverage of the onshore portion of the Area of the Five Communities, consisting of three separate survey datasets (Table 4). The South Ontario Radon Survey – Block 2 was flown in 2008 and the South Central Ontario – Collingwood-Hamilton survey was flown in 2009. Both surveys had a flight line spacing of 1,000 m, a nominal terrain clearance of 150 m. The line direction of the South Ontario Radon Survey – Block 2 was north-south, whereas the line direction for South Central Ontario – Collingwood-Hamilton survey was east-west. The Douglas Point survey is a relatively small survey acquired in 1982 over the nuclear generating station (Bruce Power). This survey was flown with flight line spacing of 1,000 m, a terrain clearance of 120 m and a flight line direction of 135^{o}, covering only 177 km^2. Due to the more recent radiometric data sets superseding this survey data, and the relatively small area of extent, the Douglas Point radiometric data was not incorporated into this assessment.

3.1.4 VLF-EM Data

A single VLF-EM dataset was flown within the Area of the Five Communities, included as part of the Douglas Point survey discussed in Section 3.1.3. The Douglas Point survey is a relatively small survey covering only 177 km^2, acquired in 1982 over the nuclear generating station (Bruce Power). This survey was flown with flight line spacing of 1,000 m, a terrain clearance of 120 m and a flight line direction of 135^{o}. However, due to its limited extent in the Area of the Five Communities, this data set has not been incorporated into this assessment.

3.1.5 Formation Top and Overburden Data

To support the interpretation of gravity data in the Area of the Five Communities an updated database of the depth to several key formation tops was used to construct depth contour maps. Geofirma Engineering Ltd. (2014b) provides details on the approach and methodology used to update borehole data from the Oil, Gas and Salt Resources Library (OGSRL, 2013) through the re-interpretation of key formation tops using borehole geophysical data.

In total, 334 boreholes were obtained from the OGSRL database for the Area of the Five Communities and its surrounding region, providing information on depth to formation tops. Gamma ray and neutron logs available from 111 of these boreholes were used to re-interpret the depth to eight key formation tops. Within the Area of the Five Communities there are a total of 60 boreholes, 37 of which also have borehole geophysical data available for the re-interpretation of key formation tops.

The top of bedrock surface was contoured using data from the MNDM's Miscellaneous Release Data 207 Bedrock Topography and Overburden Thickness Mapping, Southern Ontario (Gao et al., 2006). The source for the ground surface dataset used to construct depth contour maps was the topographic model created from Shuttle Radar Topographic Mission (SRTM) data provided by the National Aeronautical and Space Administration (NASA, 2006).

3.2 Data Limitations

The magnetic surveys that cover the Area of the Five Communities, with the exception of the Strathroy proprietary aeromagnetic survey, consist of older regional low resolution coverage. Nevertheless, the magnetic data reflect quite coherent responses that identify subsurface geology. A cursory review of the magnetic data for the area indicates that the sedimentary section within the Area of the Five Communities is magnetically transparent. There is an extensive array of basement responses that shows variable lithologies, and ductile structures. The magnetic data is critical for mapping the basement and linking with the other datasets to determine which structures control and/or penetrate the overlying sedimentary section.

The two data types considered, magnetic and gravity, contribute to the interpretation of bedrock geology. Due to its limited extent of the VLF-EM data in the Area of the Five Communities, this data set has not been incorporated into this assessment. The usefulness of the radiometric data is limited for interpreting the bedrock geology; however, this dataset provides sufficient information to assess the coincidence with the distribution of mapped overburden deposits in the Area of the Five Communities. The limitation in applying these data types to the Area of the Five Communities is governed mainly by the following factors:

- Coverage and quality of data – types available, density of the coverage, vintage and specifications of the instrumentation; and
- Overburden – areal extent, thickness and physical properties

The user of the geophysical information must bear in mind that each method relies on characterizing a certain physical property of the rocks. The degree to which these properties can be used to translate the geophysical responses to geological information depends mainly on the amount of contrast and variability in that property within a geological unit and between adjacent geological units. The usability of each data set also depends on its quality, especially resolution.

The main limitation associated with the borehole data used to construct depth contour maps is the sparse spatial distribution of the boreholes in the Area of the Five Communities and surrounding region. It is common for any two boreholes within Area of the Five Communities to be 5 to 10 km apart on average, and no well control exists beneath Lake Huron. Furthermore, very few boreholes extend through the entire sequence of Paleozoic bedrock; therefore vertical control is limited on some of the deeper bedrock formations (Geofirma Engineering Ltd., 2014b).

4 GEOPHYSICAL DATA PROCESSING AND WORKFLOW

All data were processed and gridded using the Geosoft Oasis montaj software package (Geosoft, 2012). Several magnetic data grids were prepared using the Encom PA software package (Pitney Bowes, 2012). Gravity data and formation tops were incorporated into ModelVision Pro 11 (Pitney Bowes, 2011) to support the interpretation of gravity data in the Area of the Five Communities. The grids that resulted from the various processing steps were loaded in ArcMAP 10 (ESRI, 2012).

4.1 Magnetic

All magnetic surveys in the Area of the Five Communities were projected to the UTM17N/NAD83 coordinate system. Total magnetic intensity grid data from the surveys were upward or downward continued (if necessary) to a common flying height of 305 m, and re-gridded to a common grid cell size of 100 m. The GSC surveys were all flown at or close to 305 m mean terrain clearance. The Strathroy survey was flown at a constant barometric altitude of 450 m above sea level. This ranges approximately between 130 and 275 m above the terrain. Using Oasis montaj (Geosoft, 2012) this magnetic grid was upward continued to a mean terrain clearance of 305 m.

Microlevelling was required for all magnetic surveys, with the exception of the Strathroy survey in the Area of the Five Communities in order to remove the apparent flight line noise from the total magnetic intensity grid data. This procedure removes the residual flight line noise that remains after conventional control line levelling, and is increasingly important as the resolution of aeromagnetic surveys has improved and the requirement of interpreting subtle geophysical anomalies has increased. The separation of noise from signal in the profile data is done by determining the wavelength and amplitude of the noise and applying filters to remove it. The wavelength and amplitude used in microlevelling is summarized in Table 5.

Table 5. Parameters used for microlevelling process applied to magnetic survey data

Survey	*Amplitude Limit*	*Naudy Filter Wavelength*
Waterloo	5 nT	2,000 m
Georgian Bay	20 nT	5,000 m
Lake Huron	10 nT	5,000 m
GSC #28	5 nT	3,000 m
GSC #29	5 nT	6,000 m
Strathroy	No microlevelling required	

The surveys were merged together using Oasis montaj (Geosoft, 2012), where the suture path between the grids was chosen along the edge of the grid with the original higher resolution grid cell size so that the most detailed data was retained in the final product. The merging of data sets, in particular along the boundary with the Strathroy survey, produced a linear artifact in the data along the data set boundary. The resultant grid was the residual magnetic intensity grid (i.e. total magnetic field after IGRF (International Geomagnetic Reference Field) correction) and the basis for preparing the enhanced magnetic grids.

Several data processing steps were completed on the residual magnetic intensity grid data including:

- Reduction to the Pole (RTP)

- First Vertical Derivative of the Pole Reduced Field (1VD)
- Second Vertical Derivative of the Pole Reduced Field (2D)
- Tilt Angle of the Pole Reduced Field
- Analytic Signal Amplitude
- Total Horizontal Gradient of the Pole Reduced Field

Each of these processing steps is further discussed below.

Reduction to the Pole (RTP)

The direction (inclination and declination) of the geomagnetic field varies over the Earth and influences the shape of the magnetic responses over geological sources. At the North Magnetic Pole the inducing magnetic field is vertical (i.e. inclination of 90° and declination of 0°), which results in the magnetic response being a symmetric positive magnetic peak over a source, in the absence of dip and magnetic remanence. Transforming the measured magnetic field to a pole reduced magnetic field simplifies the interpretation, particularly to determine the location and geometry of the sources (Baranov, 1957). For the Area of the Five Communities, the residual magnetic intensity grid was reduced to the pole using a magnetic inclination of 72° N and magnetic declination of 9° W (Figure 8) based upon an IGRF (International Geomagnetic Reference Field) model, dated June 1, 1999. This date is the middle of the year 1999, the year of the Strathroy survey was flown, which is the highest resolution survey in the Area of the Five Communities.

The RTP filter, L, is applied to the residual magnetic field after it is transformed to the Fourier domain, and is defined as follows:

$$L(\theta) = \frac{[\sin(I) - i \cdot \cos(I) \cdot \cos(D-\theta)]^2}{[sin^2(I_a) + cos^2(I_a) \cdot cos^2(D-\theta)] \cdot [sin^2(I) + cos^2(I) \cdot cos^2(D-\theta)]}$$

if $(|\mathrm{I_a}| < |\mathrm{I}|), \mathrm{I_a} = \mathrm{I}$ (eq. 4.1)

Where:

θ = wavenumber
I = geomagnetic inclination
I_a = inclination for amplitude correction (never less than I).
D = geomagnetic declination
i = imaginary number in the Fourier domain.

First Vertical Derivative of the Pole Reduced Field (1VD)

The vertical derivative is commonly applied to the RTP magnetic field data in the Fourier domain to enhance shallower geologic sources in the data (Figure 9). This is particularly useful for lithologic mapping (e.g. the anomaly texture is revealed), locating contacts and mapping structure (Telford et al., 1990). It is expressed as:

$$1\mathrm{VD} = {}^{\mathrm{dRTP}}/_{\mathrm{dZ}} \qquad \text{(eq. 4.2)}$$

where Z is the vertical offset.

Second Vertical Derivative of the Pole Reduced Field (2VD)

The second vertical derivative is commonly applied to the RTP magnetic field data in the Fourier domain to further enhance shallower geologic sources in the data (Figure 10). This is particularly useful for lithologic mapping (e.g. the anomaly texture is revealed), locating contacts and mapping structure close to surface (Telford et al., 1990). It is expressed as:

$$2\mathrm{VD} = {\mathrm{d}^2\mathrm{RTP}}/{\mathrm{dZ}^2} \qquad \text{(eq. 4.3)}$$

where Z is the vertical offset.

To reduce noise that resulted from aliasing during the minimum curvature gridding process, an 8th-order 200 m low-pass Butterworth filter was also applied. The Butterworth filter is a type of signal processing filter designed to have as flat a frequency response as possible in the pass band.

Tilt Angle of the Pole Reduced Field

The tilt angle (Miller and Singh, 1994) has been applied to the RTP magnetic field data to preferentially enhance the weaker magnetic signals (Figure 11). This is particularly useful for mapping texture, structure, and edge contacts of weakly magnetic sources. It is expressed as:

$$\mathrm{TILT} = \tan^{-1}\left\{\frac{\frac{\mathrm{dRTP}}{\mathrm{dZ}}}{\sqrt{\left([\frac{\mathrm{dRTP}}{\mathrm{dX}}]^2+[\frac{\mathrm{dRTP}}{\mathrm{dY}}]^2\right)}}\right\} \qquad \text{(eq. 4.4)}$$

where *X* and *Y* are the horizontal offsets in the east and north directions. The first vertical derivative is computed in the Fourier domain whereas the horizontal derivatives in X and Y are computed in the space domain.

Analytic Signal Amplitude

The amplitude of the analytic signal (AS) (Figure 12) is the square root of the sum of the squares of the derivatives in the horizontal (X and Y) and vertical (Z) directions (i.e. the Fourier domain first vertical derivative and the space domain horizontal derivatives in X and Y), computed from the total magnetic field (Nabighian, 1972):

$$\mathrm{AS} = \sqrt{\left([\frac{\mathrm{dT}}{\mathrm{dX}}]^2 + [\frac{\mathrm{dT}}{\mathrm{dY}}]^2 + [\frac{\mathrm{dT}}{\mathrm{dZ}}]^2\right)} \qquad \text{(eq. 4.5)}$$

The analytic signal is useful in locating the edges of magnetic source bodies, particularly where remanence complicates interpretation. It is particularly useful to interpret the contacts of intrusions.

Total Horizontal Gradient of the Pole Reduced Field

The total horizontal gradient is the square root of the sum of the squares of the derivatives in the horizontal (X and Y) directions (i.e. the space domain horizontal derivatives in X and Y), computed from the pole reduced magnetic field:

$$\text{THG} = \sqrt{\left([\frac{\text{dRTP}}{\text{dX}}]^2 + [\frac{\text{dRTP}}{\text{dY}}]^2\right)} \qquad \text{(eq. 4.6)}$$

The total horizontal gradient is useful in locating the edges (contacts) of magnetic source bodies.

4.2 Gravity

The GSC gravity data were gridded with a 2 km grid cell size and the proprietary gravity data were gridded with a 100 m grid cell size, both using a minimum curvature gridding algorithm. The GSC Bouguer gravity data were re-gridded to a 100 m grid cell size prior to being merged with the proprietary gravity data. The suture path between the grids was along the edge of the grid with the original higher resolution grid cell size so that the most detailed data was retained in the final product. The high resolution proprietary Bouguer gravity data was not tied to the national gravity network. Thus, when it was merged with the GSC gravity data, a shift was applied to the GSC data by determining the average difference in the Bouguer gravity values in the area of overlap between the GSC and proprietary data. The merging of data sets results in a linear feature along the data set boundary.

Both the GSC data and the proprietary data have been reduced using standard gravity methods to compute the Bouguer gravity fields (Telford et al., 1990), using a density of 2.67 g/cm^3 which is the average density of crustal bedrock typically used for the Canadian Shield. Although the data was reduced using this value, the bulk rock density of the Precambrian basement derived from borehole measurements in the Area of the Five Communities was measured as 2.54 g/cm^3 (Intera Engineering Ltd., 2011). Despite this value being slightly lower in density, it may simply reflect a bedrock unit of lesser density or alteration and weathering of the Precambrian bedrock surface.

As the data for the Area of the Five Communities were collected as far back as 1945, the older survey's station elevations were likely determined using barometric altimeters (much less accurate than GPS) and terrain corrections were not applied.

Gravity Model Development

In order to facilitate the interpretation of gravity data in the Area of the Five Communities, the key formation tops and overburden data were used to define key formation packages to be incorporated into a gravity model to determine the expected gravity effect. Elevations of the key formation tops were gridded using Oasis Montaj minimum curvature gridding algorithm with a grid cell size of 500 meters (Geosoft, 2012), with the exception of the Cobourg and Precambrian surfaces. The Cobourg and Precambrian surfaces were computed with a grid cell size of 1,000 m. This larger cell size for these surfaces is based on a fewer number of boreholes which intersects these two surfaces. Surfaces were generated using a minimum curvature gridding tolerance of 0.001 and percent-pass tolerance of 99.99 % with a blanking distance between 20 and 40 km. In some cases the depths of adjacent gridded surfaces overlapped resulting in a negative thickness. In such cases, the overlap area was examined and the surface with valid data was used in both surfaces, resulting in a thickness of zero for that part of the model.

The key formation top grids were used to define the thickness of seven key formation packages over the extent of the Area of Five Communities. The thickness of each formation package was determined by the difference in elevation between the overlying and underlying gridded surfaces.

To determine the weighted bulk density to be assigned to each formation package, the volume of each formation within the package was calculated and a weighted average of the density for each formation was determined (Table 6). The gravity effect of each model layer has been computed from its thickness, depth and density using ModelVision Pro 11 (Pitney Bowes, 2011). The thickness distribution coupled with the volume weighted bulk density of the key formation packages provide key input to determine the modeled gravity effect, which is used to remove the influence of the formation package responses from the observed Bouguer gravity (e.g., Hammer, 1963). Because of the sparse distribution of well data and the limited information on the key formation packages extending into Lake Huron, the modeled gravity effect was not calculated under Lake Huron. The resulting stripped Bouguer gravity is only determined for the land portion of the Area of the Five Communities.

Table 6. The upper and lower boundary formation tops that define the individual formation packages, and their weighted densities (density values adapted from Intera Engineering Ltd., 2011).

	Upper Bound	***Lower Bound***	***Weighted Density (g/cm^3)***
1	Surface	Top of Bedrock	2.00
2	Top of Bedrock	Bass Island	2.70
3	Bass Island	Salina G Unit	2.76
4	Salina G Unit	Cabot Head	2.66
5	Cabot Head	Queenston	2.62
6	Queenston	Cobourg-Collingwood	2.64
7	Cobourg-Collingwood	Precambrian	2.67
	Precambrian	---	2.54

4.3 Radiometric

The following seven radiometric grids (radioelement concentrations and ratios) were downloaded for the Area of the Five Communities and are gridded with a 250 m cell size:

- Potassium (K %)
- Thorium (eTh ppm)
- Uranium (eU ppm)
- Total air absorbed dose rate (nGy/h)
- Thorium over potassium ratio (eTh/K)
- Uranium over potassium ratio (eU/K)
- Uranium over thorium ratio (eU/eTh).

The grids were previously merged by the GSC. The determination of the radioelement concentrations, dose rate and ratios followed the methods and standards published by the International Atomic Energy Agency (IAEA, 2010), many of which were developed at the GSC. All grids were re-projected to the Area of the Five Communities local coordinate system, UTM17N/NAD83. The dose rate is a calibrated version of the measured total count, and reflects the total radioactivity from natural and man-made sources.

5 GEOPHYSICAL INTERPRETATION

5.1 Methodology

The geophysical data within the Area of the Five Communities was assessed in order to understand the responses from the various geological features associated with the Paleozoic sedimentary units and the underlying crystalline rocks of the Precambrian basement. The available magnetic data, and to a lesser extent gravity data, were used to assess the lithological variations within the Precambrian basement, and to identify broad lithological domains. This assessment relied most heavily on the pole reduced magnetic field and its first and second vertical derivatives for mapping the domain boundaries and providing discussion on any basement heterogeneity. The first and second vertical derivatives were used to outline similar magnetic anomaly patterns reflecting potential variability in the basement rock ductile features. These ductile features are interpreted as being associated with the internal fabric of the crystalline basement and likely include tectonic foliation or gneissosity. Interpretations derived from the magnetic data are then compared to results from available literature on basement lithology of the Grenville Province in southern Ontario (e.g. O'Hara and Hinze, 1980; Turek and Robinson, 1982; Carter and Easton, 1990; Easton and Carter, 1995; Carr et al, 2000; Boyce and Morris, 2002), as well as on the Precambrian basement rocks exposed further to the northeast of the Area of the Five Communities (Easton, 1992).

The use of both the observed and the modeled Bouguer gravity data in the Area of the Five Communities focused on identifying features within the Precambrian basement as well as the overlying Paleozoic sedimentary sequence. The observed gravity data were stripped using the modeled Bouguer gravity to determine the influence of the Paleozoic sedimentary sequence and the overburden deposits on the overall gravity response. Because of the sparse distribution of well data and the limited information on the key formation packages extending into Lake Huron, the modeled gravity effect was not calculated under Lake Huron and the resulting stripped Bouguer gravity is only determined for the land portion of the Area of the Five Communities. Where possible, the observed and stripped gravity data were used to identify coincidence with known features located in the Paleozoic formations, such as pinnacle reefs and variations in the thickness of salt units, both of which are known to occur within the Area of the Five Communities. In an effort to confirm the usefulness of this gravity data to identify these features, the gravity data were compared to the location of known pinnacle reefs (OGSRL, 2013) and to the known extent of salt units (Sanford, 1976).

Within the Area of the Five Communities, where bedrock is mostly covered by overburden, the radiometric data have been used in an attempt to confirm the distribution of the mapped Quaternary deposits, and also provide some discussion on the radon risk within the Area of the Five Communities. Due to the very limited extent of the VLF-EM data over the Douglas Point survey area within the Area of the Five Communities, and its poor quality, this data set has not be assessed within this report.

The following sections present the results and interpretations of each geophysical data set in the Area of the Five Communities. This discussion will focus on features that are identifiable in the geophysical data that cover the entire Area of the Five Communities. This discussion will be followed by detailed interpretations of the geophysical responses within each of the communities.

5.2 Magnetic Results

The magnetic data over the Area of the Five Communities exhibits mainly broad magnetic responses, which are presumably associated with geological features of the Precambrian basement rocks, underlying the Paleozoic sedimentary units. In general, it is understood that magnetic anomalies that are caused by sedimentary units are much weaker than those generated from igneous and metamorphic rock. In the case of the Area of the Five Communities, it is assumed that the majority of the observable magnetic response is generated from the in Precambrian basement rocks, and the overlying sedimentary units are considered magnetically transparent. This is consistent with the interpretation of magnetic data over Lake Huron by O'Hara and Hinze (1980).

Based on the distribution of magnetic responses observed in the reduced to pole magnetic field data (Figure 8), and their character observed in the first and second vertical derivatives, tilt angle and analytic signal maps (Figures 9 to 12), several lithological domains have been interpreted in the Area of the Five Communities (Figure 13). These interpretations are based on variability in the intensity and curvilinear pattern development in the magnetic data, most particularly observed in the first and second vertical derivative grids. Magnetic data covering a portion of Lake Huron shows the most pronounced magnetic high within the area and has a strong northeast trend (Figure 13, Domain A). This complex anomaly has previously been interpreted as having a strong magnetic intensity which parallels the Grenville Front Tectonic Zone, which is the boundary between the Grenville and Superior provinces of the Canadian Shield (O'Hara and Hinze, 1980; Boyce and Morris, 2002).

The remaining portion of the Area of the Five Communities has been defined as the Huron Domain of the Grenville Province based on borehole data from wells that intersect the basement rocks (Carter and Easton, 1990). Lithologically, the Huron domain is described as predominantly containing variable amounts of granitic, monzonitic and tonalitic rocks that are strongly gneissic, which in general corresponds to a lower magnetic intensity (Figure 8). The interpretation of magnetic data as part of this assessment further divides the Huron Domain based on subtle variability in the character and pattern of the magnetic data sets.

In the northern portion of the Area of the Five Communities, Domain B is identified consisting of magnetic features that trend for a short distance in a northwesterly direction immediately adjacent to the Grenville Front Tectonic Zone (Domain A). These anomalies have moderate magnetic intensity on the pole reduced magnetic field map (Figure 8), and are best represented on the first vertical derivative and tilt angle maps (Figures 9 and 11). Where similar rock units are exposed north of the Area of the Five Communities, several mapped domains similarly show northwest-trending fold structures (Easton 1992), and are observable in the regional magnetic data for southern Ontario (Gupta, 1991).

In the central portion of the Area of the Five Communities the magnetic response follows a similar northeastern trend as the response over Lake Huron, although it tends to be significantly weaker in magnitude (Figure 8). This unique unit is outlined as Domain C (Figure 13). Due to the weaker magnetic response, the vertical derivatives and the tilt angle maps were used to emphasize the subtle magnetic response. The resulting magnetic features appear as distinct wavy curvilinear to elliptical magnetic anomalies which are interpreted to reflect large areas of complex ductile shearing and folding that is preserved in the Precambrian basement rocks. These anomalies where also identified by Boyce and Morris (2002) in this region of southern Ontario. Easton and Carter (1995) suggest these elliptical magnetic features may represent metamorphosed plutons, where the trend variability corresponds to the structure of the Precambrian basement, which may include gneissosity, foliation, folds and shear zones near the Grenville Front Tectonic Zone. This observation is consistent with features preserved in the same rock types exposed further north of the Area of the Five Communities (Easton, 1992).

The eastern portion of the Area of the Five Communities is divided into Domains D and E. Despite the Paleozoic sedimentary units being thinnest at this location, Domain D is characterized by relatively amorphous and curvilinear anomalies with weak magnetic responses in the reduced to pole magnetic field, and weakest responses in the vertical derivative maps (Figure 9 and 10). Although the responses are similar in magnitude to Domain C, the observed curvilinear features reflect distinctly different patterns compared to the other domains. This may provide some indication of slight variability in lithologies or metamorphic grade in the underlying Precambrian basement in this location. Similar variability between adjacent domains in the exposed Precambrian bedrock is certainly documented (Easton 1992), and is similarly reflected in magnetic data (Gupta, 1991).

The southeastern portion of the Area of the Five Communities has been identified as Domain E. The magnetic data within this domain is similarly characterized by curvilinear anomalies with slightly stronger magnetic responses compared to Domains C and D, shown in the reduced to pole magnetic field and the first vertical derivative and tilt angle data sets (Figures 8, 9 and 11). Although the curvilinear features are similar, the domain is mainly based on the slightly higher total magnetic field response, which may reflect differing lithology with higher magnetic mineral content of the Precambrian basement rocks compared to the adjacent Domains C and D.

In addition to magnetic response derived from the Precambrian basement source rocks, magnetic response may also occur from the presence of salt deposits within the sedimentary sequence in the Area of the Five Communities. Results from other studies have shown the potential for deposits of pure halite, gypsum, or anhydrite to result in low magnitude responses (Gunn, 1997). In addition, a few salt deposits have resulted in magnetic high responses that have been attributed to banding of diamagnetic magnetite within these units (Smith and Whitehead, 1989). Although, this has been observed in other salt units, the magnetic data in the Area of the Five Communities does not provide any supporting evidence that the salt units, based on subsurface mapping by Sanford (1976), results in a response in the magnetic data. Instead, as described above, the interpreted magnetic responses tend to be attributed to patterns that reflect the Precambrian basement, and show no spatial association to the mapped salt deposits.

5.3 Gravity Results

5.3.1 Observed Bouguer Gravity

The observed Bouguer gravity data over the Area of the Five Communities exhibits mainly broad responses that can be attributed to spatial variability in rock density as well as changes in formation thickness in the Paleozoic sedimentary sequence and the deeper Precambrian basement rocks. Variability in the observed Bouguer gravity response is shown in Figure 14, and its first vertical derivative is shown in Figure 15.

The gravity data display a significant gravity high on the northwestern portion of the Area of Five Communities, which broadly trends in the northeastern direction and corresponds fairly well to the outline of Domain A, identified based on the magnetic data. This gravity high has been suggested to indicate a significant thickening of the Precambrian basement rocks associated with the Grenville Front Tectonic Zone (Easton, 1992). This basement feature extends for a significant distance north and south of the Area of the Five Communities. Although the magnetic anomaly shows some amplitude variability, the corresponding gravity anomaly tends to be broad and does not display much variability, which is likely attributed to the lower resolution gravity data collected over Lake Huron. The gravity data in the central portion of the Area of the Five Communities shows a significantly lower gravity response. Although speculative, this broad lower gravity response may reflect a thinning of the Precambrian basement in this portion of the area.

In the case of the broad gravity responses, it is assumed they are primarily associated with variations in rock density due to changes in lithology and geometry of the Precambrian basement rocks. Similar assumptions have been made elsewhere in southern Ontario where the gravity responses are attributed to the Precambrian basement (O'Hara and Hinze, 1980). The first vertical derivative of the Bouguer gravity shows clear wavy to curvilinear features that display similar trends and texture as the magnetic data. Again, these features are interpreted to correspond to deformation patterns of the Precambrian basement rocks. Some of the higher magnitude features in this data are likely to reflect changes in rock density and lithology of the basement. The fact that the gravity data is dominated from basement responses is likely due to the Paleozoic sedimentary units being predominantly uniform and homogeneous across the area. However, lateral variations in rock density within Paleozoic sedimentary sequence may also produce localized Bouguer gravity responses associated with lateral changes in depositional environments, such as pinnacle reefs and salt units.

Known pinnacle reefs and salt deposits in the Area of the Five Communities were compared to the observed Bouguer gravity (Figure 14) and its first vertical derivative data (Figure 15) to identify coincidence. The first vertical derivative effectively emphasized the weaker localized gravity responses in order to attempt to identify features in the Paleozoic sedimentary sequence. Although gravity data has been used throughout southwestern Ontario to locate pinnacle reefs for exploration programs (Pohly, 1966), the gravity data within the Area of the Five Communities do not provide any evidence of reef type anomalies within the Paleozoic sedimentary sequence. This lack of anomaly may result from a negligible density contrast between the reef and the surrounding rock, or an insufficient amount of gravity measurements collected.

The known salt units located in the southwestern portion of the Area of the Five Communities were also compared to the observed gravity data. This comparison shows a broad higher gravity response that loosely corresponds to the outline of the salt occurrence. Although a subtle correlation exists, the gravity high response is more likely related to the regional high anomaly associated with the Grenville Front Tectonic Zone. Gravity data over Lake Huron similarly shows this extension of the Grenville Front Tectonic Zone gravity anomaly into the Area of the Five Communities (O'Hara and Hinze, 1980).

The Bouguer gravity data within the Area of the Five Communities also appears to be sensitive to variability in thickness and densities of the overburden material. In particular, the observed Bouguer gravity data shows some evidence of surficial features, such as the Saugeen River Valley, through the central portion of the area. These features tend to be lesser in magnitude and wavelength, and are largely overprinted by the broad high magnitude responses from the Precambrian basement rocks. Through modeling much of this surficial artifact can be removed using overburden thickness information derived from the available water well database (e.g. Gao et al., 2006).

5.3.2 Bouguer Gravity Effect from Modeling

The cumulative results of the modeled Bouguer gravity response from each of the Paleozoic key formation packages and the overburden deposits show a range of approximately 6 mGal across the Area of the Five Communities (Figure 16). These results display a general increase in the modeled gravity effect toward the southwest, with subtle low-amplitude variability throughout. As expected, the modeled gravity effect shows an increased contribution towards the southwest as a result of the Paleozoic sequence becoming thicker within the sedimentary basin. This contribution may also reflect the presence of Devonian sedimentary rocks that are present in the southern portion of the Area of the Five Communities and which comprise a higher rock density input into the model (Figure 4). The majority of the lower amplitude variability observed in the modelled gravity effect results from the models sensitivity to the higher quality dataset for the overburden deposit thickness, in particular, to its strong density contrast with the underlying Paleozoic bedrock. As expected, areas of thick overburden such as along the Walkerton Trough (see JDMA, 2014) tend to correlate well with large-scale, low-amplitude responses shown in the modeled gravity effects (Figure 16).

The stripped Bouguer gravity data show a range of approximately 20 mGal, which is derived by subtracting the modeled gravity effect from the observed Bouguer gravity results (Figure 17). In general, the response distributions of the stripped Bouguer gravity data are similar to the observed Bouguer gravity data within the Area of the Five Communities. The more broad-scale features still display the same general appearance, which provides further support for the source being mainly from the basement rocks. It appears as though the removal of the modeled gravity effect accounted for the influence of overburden units on the gravity data. However, the removal of the general thickening of the Paleozoic sequence from the gravity data did not significantly change the appearance of the gravity response.

In addition, the stripped Bouguer gravity data does not appear to be useful in highlighting the locations of the known pinnacle reef structures or salt units within the Area of the Five Communities. Similar to the observed Bouguer gravity, it is assumed that although a small amount of this resulting response may be attributed to the Paleozoic layers, the majority of the signal is derived from the lithological variability within the Precambrian basement rocks.

5.4 Radiometric Results

The radiometric data in the Area of the Five Communities shows a strong correlation with the distribution of the mapped Quaternary deposits, as well as impacts from varying amounts of vegetation cover, soil moisture, and surface water (Figure 18). In particular, the distributions of mapped morainal deposits are associated with a strong radiometric dose rate response, and are elevated in concentrations of both equivalent thorium and potassium. Portions of the Area of the Five Communities that have a lower dose rate tend to correlate with locations of mapped glaciofluvial deposits. Weaker responses in much of the eastern and south-central portions of the Area of the Five Communities correspond to areas with a higher number of wetlands and forested area (JDMA, 2014).

For the GSC radiometric compilation within the Area of the Five Communities, the radioelement responses are summarized in Table 7.

Table 7. Radioelement response statistics

Radioelement	***Minimum****	***Maximum***	***Mean***
Potassium (%)	-0.44	4.29	1.35
Equivalent uranium (ppm)	-1.76	4.67	0.75
Equivalent thorium (ppm)	-3.06	10.74	4.32
Natural air absorbed dose rate (nGy/h)	-13.66	90.90	32.66

*Negative values are not unusual due to the statistical nature of gamma-ray spectrometer data and grid interpolation effects.

The low uranium levels suggest low radon risk (Ford et al, 2001). However, radon risk is also quite dependent on soil permeability and should be verified by soil gas measurements (IAEA, 2010). The highest uranium response in the area is located within the Area of the Five Communities.

5.5 Geophysical Characteristics for Each of the Five Communities

The following section provides more detailed interpretations of all geophysical datasets within each of the Five Communities; the Town of Saugeen Shores, Municipality of Arran-Elderslie, Municipality of Brockton, Municipality of South Bruce, and the Township of Huron-Kinloss.

5.5.1 Town of Saugeen Shores

The geophysical responses from the magnetic and gravity data in the Town of Saugeen Shores consists of anomalies that are associated with variability in magnetic susceptibility and bulk rock density of the Precambrian basement rocks. The magnetic data in the Town of Saugeen Shores reflect wavy curvilinear to elliptical magnetic features which are interpreted to reflect large areas of complex ductile shearing and folding that is preserved in the Precambrian basement rocks (Figure 8). These magnetic patterns define the boundary of Domain C which underlies the entire Town of Saugeen Shores, and extends to underlie much of the Area of the Five Communities.

The gravity data in the Town of Saugeen Shores similarly reflects very curvilinear to elliptical features that are interpreted as variations in lithology and deformation patterns preserved in the Precambrian basement rocks. These patterns are predominantly exposed in the first vertical derivative of the Bouguer gravity (Figure 15). Both the observed Bouguer gravity (Figure 14) and the stripped Bouguer gravity (Figure 17) data within the Town of Saugeen Shores present a distinct low gravity response, which may reflect the thinning of the Precambrian basement rocks in that area.

Although two known pinnacle reefs are located within the Town of Saugeen Shores, neither the observed or the stripped gravity data provide any evidence of reef type anomalies within the Paleozoic sedimentary sequence (Figures 14 and 16). This lack of anomaly in this area may result from a negligible density contrast between the reef and the surrounding rock, or an insufficient amount of gravity measurements collected.

The radiometric data in the Town of Saugeen Shores displays a moderate dose rate over the majority of the area (Figure 18), which decreases quickly towards Lake Huron. The distributions of radiometric responses tend to correspond reasonably well to distribution of mapped surficial geology features.

5.5.2 Municipality of Arran-Elderslie

The geophysical responses from the magnetic and gravity data in the Municipality of Arran-Elderslie comprise anomalies that are predominantly associated with changes in magnetic and rock density properties of the Precambrian basement rocks. The magnetic data in the Municipality of Arran-Elderslie reflect wavy curvilinear magnetic features interpreted as zones of complex ductile shearing and folding of the Precambrian basement rocks (Figure 9). These magnetic patterns mainly define the boundary of Domain C which underlies the much of the Municipality of Arran-Elderslie, as well as a small portion of Domain D to the east.

The gravity data in the Municipality of Arran-Elderslie similarly reflects curvilinear features that are interpreted as variations in basement lithology and deformation patterns preserved in the Precambrian rocks. Both the observed Bouguer gravity (Figure 14) and the stripped Bouguer gravity (Figure 17) data within the Municipality of Arran-Elderslie show a moderate magnitude response that generally decreases towards Lake Huron. The more subtle patterns are primarily evident in the first vertical derivative of the Bouguer gravity (Figure 15). Throughout the Municipality of Arran-Elderslie the first vertical derivative of the Bouguer gravity data (Figure 15) shows several discrete high magnitude curvilinear-type features. Considering that the trend of these features is consistent with the overall trend in the Area of the Five Communities, these features most likely reflect the continuity of higher density units in the Precambrian basement rock. Although, it is possible that these features may be associated with variations in density of the surficial geology units, there does not appear to be a coincidence with either the mapped surficial features or overburden thickness. In addition, the stripped Bouguer gravity data still shows consistent curvilinear anomaly features, which suggests that variations in overburden thickness are not responsible for these anomalies (Figure 17). Within the Municipality of Arran-Elderslie there are no known pinnacle reef structures. In addition, the gravity data does not provide any evidence of potential pinnacle reef structures in the area.

The radiometric data in the Municipality of Arran-Elderslie predominantly shows a higher dose rate over the entire area (Figure 18). These radiometric responses tend to be attributed to distributions in glacial morainal and lacustrine units, with minor amounts of glaciofluvial material. The locations of mapped glaciofluvial units tend to have a much lower radiometric dose rate. The lowest radiometric responses in the Municipality of Arran-Elderslie are attributed to the location of larger water bodies and small wetlands.

5.5.3 Municipality of Brockton

Magnetic and gravity data in the Municipality of Brockton show anomalies that are interpreted to reflect changes in magnetic and rock density properties of the Precambrian basement rocks. The magnetic data in the Municipality of Brockton consist of a broad, northeast trending low magnitude response that extends through most of the Area of the Five Communities. The first vertical derivative of the magnetic data shows a significant amount of curvilinear magnetic features interpreted as zones of complex ductile shearing and folding of the Precambrian basement rocks (Figure 9). These magnetic patterns mainly define the boundary of Domain C which underlies the most of the Municipality of Brockton, as well as a small portion of Domain D along the eastern boundary.

Similar to the magnetic data, the gravity data in the Municipality of Brockton reflects curvilinear features that are interpreted as changes in basement lithology and deformation patterns preserved in the Precambrian rocks. Within the Municipality of Brockton, both the observed Bouguer gravity (Figure 14) and the stripped Bouguer gravity (Figure 17) show a moderate magnitude response that generally decreases towards Lake Huron. Throughout the Municipality of Brockton the first vertical derivative of the Bouguer gravity data (Figure 15) shows several discrete curvilinear-type features, both high and low magnitude. The dominant low-magnitude feature tends to bisect the more regional curvilinear pattern in the area with a general north directed strike. This gravity feature is predominantly influenced by surficial geology units associated with the location of the Saugeen River Valley, and does not correspond to any subsurface feature in the Paleozoic or Precambrian bedrock. Within the Municipality of Brockton there are no known pinnacle reef structures. In addition, the gravity data does not provide any evidence of potential pinnacle reef structures in the area.

The radiometric data in the Municipality of Brockton shows a random distribution of high and low dose rate over the area (Figure 18). Within the Municipality, these radiometric responses are attributed to the location of glacial lacustrine units, with lesser amounts of glaciofluvial and morainal units. Although the locations glaciolacustrine units mainly show a higher radiometric dose rate, the large unit in the western portion of the Municipality of Brockton is covered by a significant wetland, and the resulting radiometric response is negligible.

5.5.4 Municipality of South Bruce

Magnetic and gravity data in the Municipality of South Bruce show anomalies that are interpreted to reflect changes in the Precambrian basement rocks associated with lithological variability and magnetic and rock density properties. The magnetic data in the Municipality of South Bruce predominantly show a high magnitude response over the majority of the Municipality that extends further to the east within the Area of the Five Communities. The first vertical derivative of the magnetic data shows broad curvilinear magnetic features interpreted as zones of complex ductile shearing and folding of the Precambrian basement rocks (Figure 9). These magnetic patterns mainly define the boundary of Domain E which underlies the eastern most portion of the Municipality of South Bruce, as well as a small portion of Domain C along the western boundary of the Municipality.

Within the Municipality of South Bruce, both the observed Bouguer gravity (Figure 14) and the stripped Bouguer gravity (Figure 17) show a distribution of high responses along the south and eastern boundary, which decrease towards the northwest. The first vertical derivative of the gravity data (Figure 15) shows distinct curvilinear features that are interpreted as changes in basement lithology and deformation patterns preserved in the Precambrian rocks. Within the lower resolution gravity data on the eastern margin of the Municipality the broad gravity response is represented by several individual features in the higher resolution data. Within the Municipality of South Bruce there are no known pinnacle reef structures. In addition, the gravity data does not provide any evidence of potential pinnacle reef structures in the area.

The radiometric data in the Municipality of South Bruce displays strong variability in the distribution of dose rate over the area (Figure 18). The higher radiometric responses are predominantly coincident with the location of localized glacial morainal and sporadic glaciolacustrine units. The lower radiometric response in the eastern portion of the Municipality results from a high amount of wetland coverage.

5.5.5 Township of Huron-Kinloss

The magnetic and gravity data display broad anomalies which present variability in the distribution of magnetic and rock density properties associated with the Precambrian basement rocks underlying the Township of Huron-Kinloss. The magnetic data is dominated by weak magnitude responses over the Township (Figure 8), whereas the first vertical derivative tends to emphasize the variability of the curvilinear magnetic features (Figure 9). These features are interpreted to reflect the presence of ductile characteristic associated with the Precambrian basement rocks. These curvilinear magnetic patterns comprise a portion of Domain C within the Area of the Five Communities, in which the magnetic features generally trend in a northeast direction.

Within the Township of Huron-Kinloss, both the observed Bouguer gravity (Figure 14) and the stripped Bouguer gravity (Figure 17) show a similar distribution of high responses along the eastern portion of the Township, and a sharp decrease towards the northwest. This gravity high represents a small portion of an anomaly that extends east from the Grenville Front Tectonic Zone, which has been suggested to reflect a regional-scale thickening of the Precambrian basement rocks in the vicinity of the Grenville Front Tectonic Zone (O'Hara and Hinze, 1980). The first vertical derivative of the gravity data (Figure 15) shows a clear wavy to curvilinear pattern that trend in a general northwest to western direction across the Township of Huron-Kinloss. These patterns are interpreted to reflect the subtle changes in Precambrian basement lithology.

Although three pinnacle reefs are known to exist within the Township of Huron-Kinloss, neither the observed or stripped gravity data provide any evidence of reef type anomalies within the Paleozoic sedimentary sequence (Figures 14 and 17). The lack of observed anomaly in this area may result from a negligible density contrast between the reef and the surrounding rock, or an insufficient amount of gravity measurements collected.

The radiometric data in the Township of Huron-Kinloss is dominated by high radiometric responses over the central and western portion of the Township (Figure 18). These high radiometric responses are strongly coincident with the mapped distribution of glacial morainal units deposited through the area. In addition, internal northeast trending lower responses nicely coincide with the elongated distribution of glaciolacustrine deposits. In the eastern part of the Township of Huron-Kinloss the radiometric responses tend to be weaker and are associated with mainly glacial fluvial deposits.

Respectfully Submitted,

PATERSON, GRANT & WATSON LIMITED

D. James Misener, Ph.D., P.Eng.
President

Edna Mueller-Markham, M.Sc., P.Geo.
Senior Geophysicist

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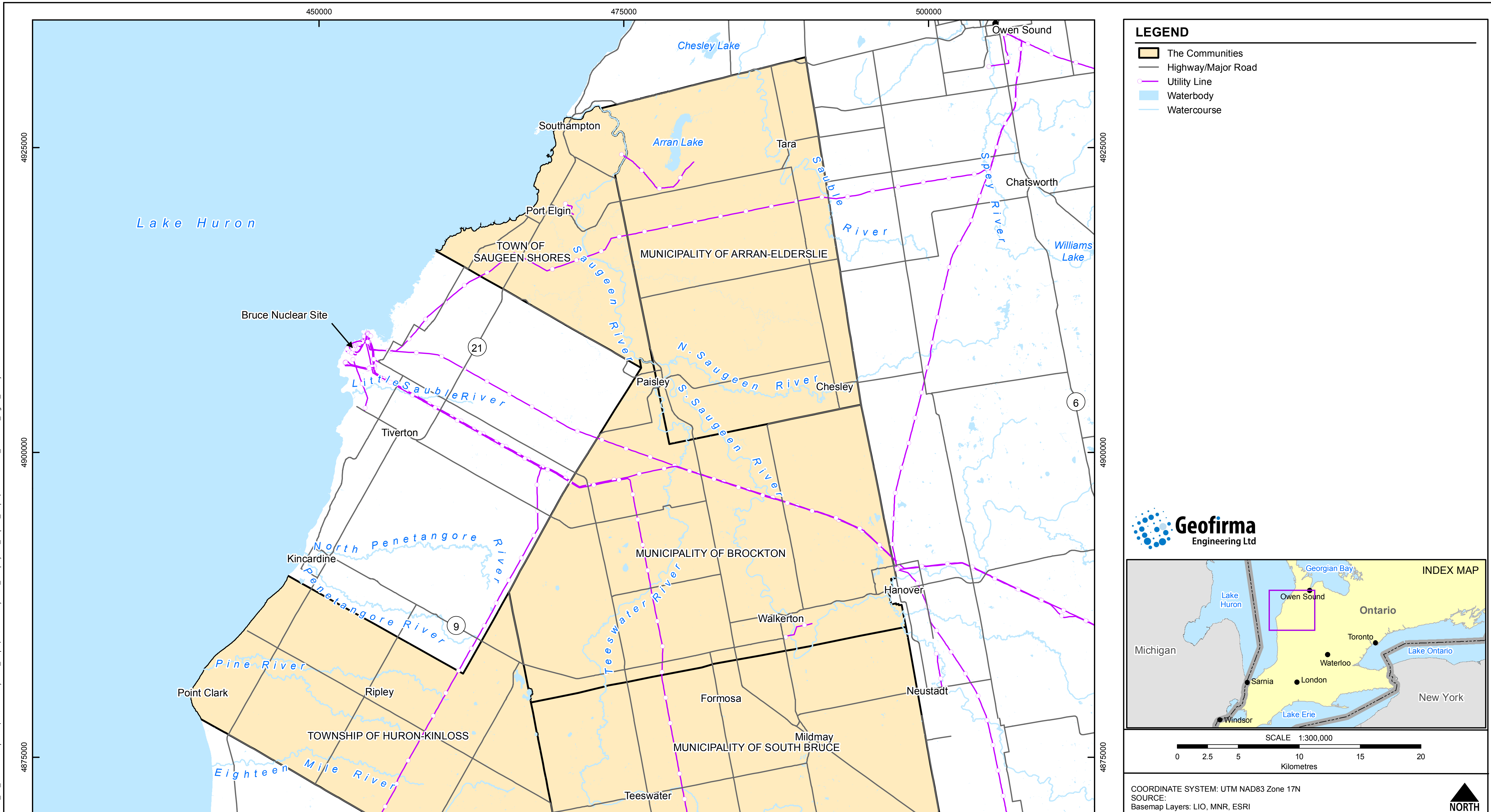
FIGURES



COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI

PROJECT No. 10-214-7.40
Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE
The Area of the Five Communities

FIGURE 1

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 8/6/2014

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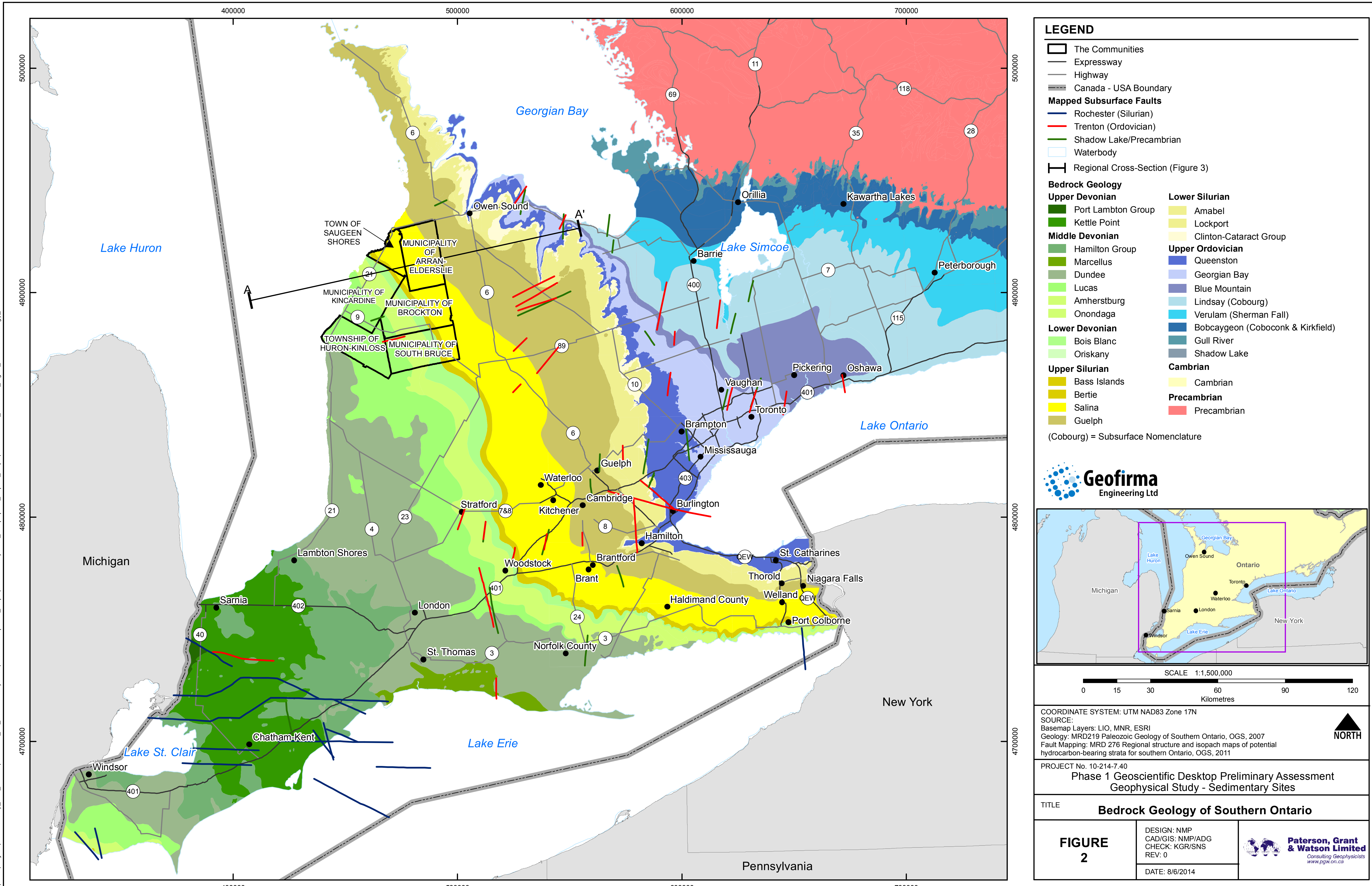
LEGEND
The Communities
Expressway
Highway
Canada - USA Boundary
Mapped Subsurface Faults
Rochester (Silurian)
Trenton (Ordovician)
Shadow Lake/Precambrian
Waterbody
Regional Cross-Section (Figure 3)
Bedrock Geology
Upper Devonian
Port Lambton Group
Kettle Point
Middle Devonian
Hamilton Group
Marcellus
Dundee
Lucas
Amherstburg
Onondaga
Lower Devonian
Bois Blanc
Oriskany
Upper Silurian
Bass Islands
Bertie
Salina
Guelph
Lower Silurian
Amabel
Lockport
Clinton-Cataract Group
Upper Ordovician
Queenston
Georgian Bay
Blue Mountain
Lindsay (Cobourg)
Verulam (Sherman Fall)
Bobcaygeon (Coboconk & Kirkfield)
Gull River
Shadow Lake
Cambrian
Cambrian
Precambrian
Precambrian
(Cobourg) = Subsurface Nomenclature
Geofirma Engineering Ltd
Lake Huron
Georgian Bay
Lake Simcoe
Lake Ontario
Lake Erie
Lake St. Clair
Michigan
New York
Pennsylvania
TOWN OF SAUGEEN SHORES
MUNICIPALITY OF ARRAN-ELDERSLIE
MUNICIPALITY OF KINCARDINE
MUNICIPALITY OF BROCKTON
TOWNSHIP OF HURON-KINLOSS
MUNICIPALITY OF SOUTH BRUCE
A
A'
Owen Sound
Orillia
Kawartha Lakes
Barrie
Peterborough
Pickering
Oshawa
Vaughan
Toronto
Brampton
Mississauga
Guelph
Waterloo
Kitchener
Cambridge
Burlington
Stratford
Hamilton
St. Catharines
Woodstock
Brantford
Brant
Thorold
Niagara Falls
Welland
Haldimand County
Port Colborne
Lambton Shores
Sarnia
London
St. Thomas
Norfolk County
Chatham-Kent
Windsor
400000
500000
600000
700000
5000000
4900000
4800000
4700000
Ontario
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Kilometres
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Geology: MRD219 Paleozoic Geology of Southern Ontario, OGS, 2007
Fault Mapping: MRD 276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
NORTH
PROJECT No. 10-214-7.40
Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites
TITLE
Bedrock Geology of Southern Ontario
FIGURE 2
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 8/6/2014
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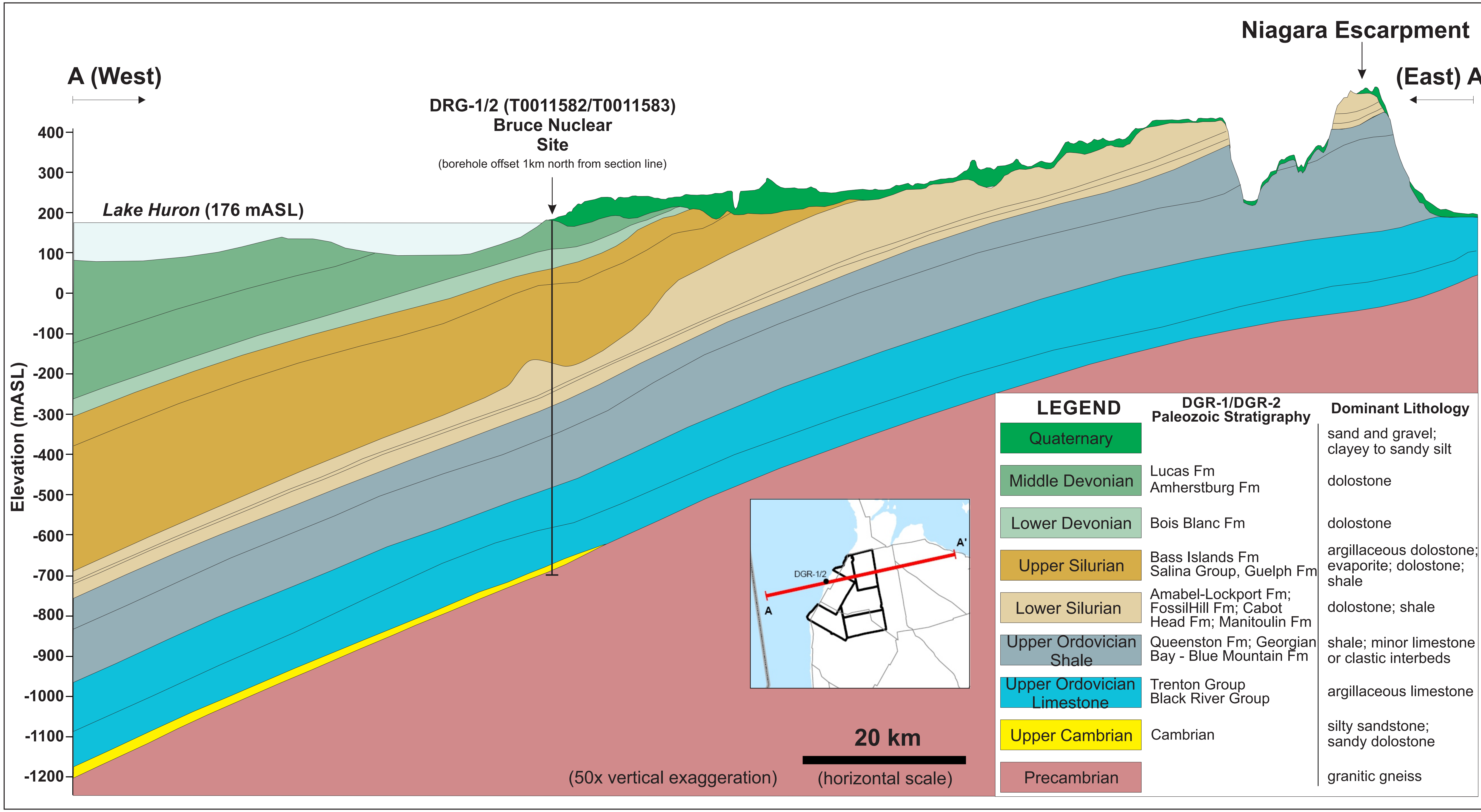

Data Source: NWMO, 2011

FIGURE 3 - Regional Geological Cross-Section of the Eastern Flank of the Michigan Basin

PROJECT No: 10-214-7.40

Phase 1 Geoscientific Desktop Preliminary Assessment, Geophysical Study - Sedimentary Sites

Prepared by: NMP/ADG
Reviewed by: KGR/SNS
Date: 03/06/2014

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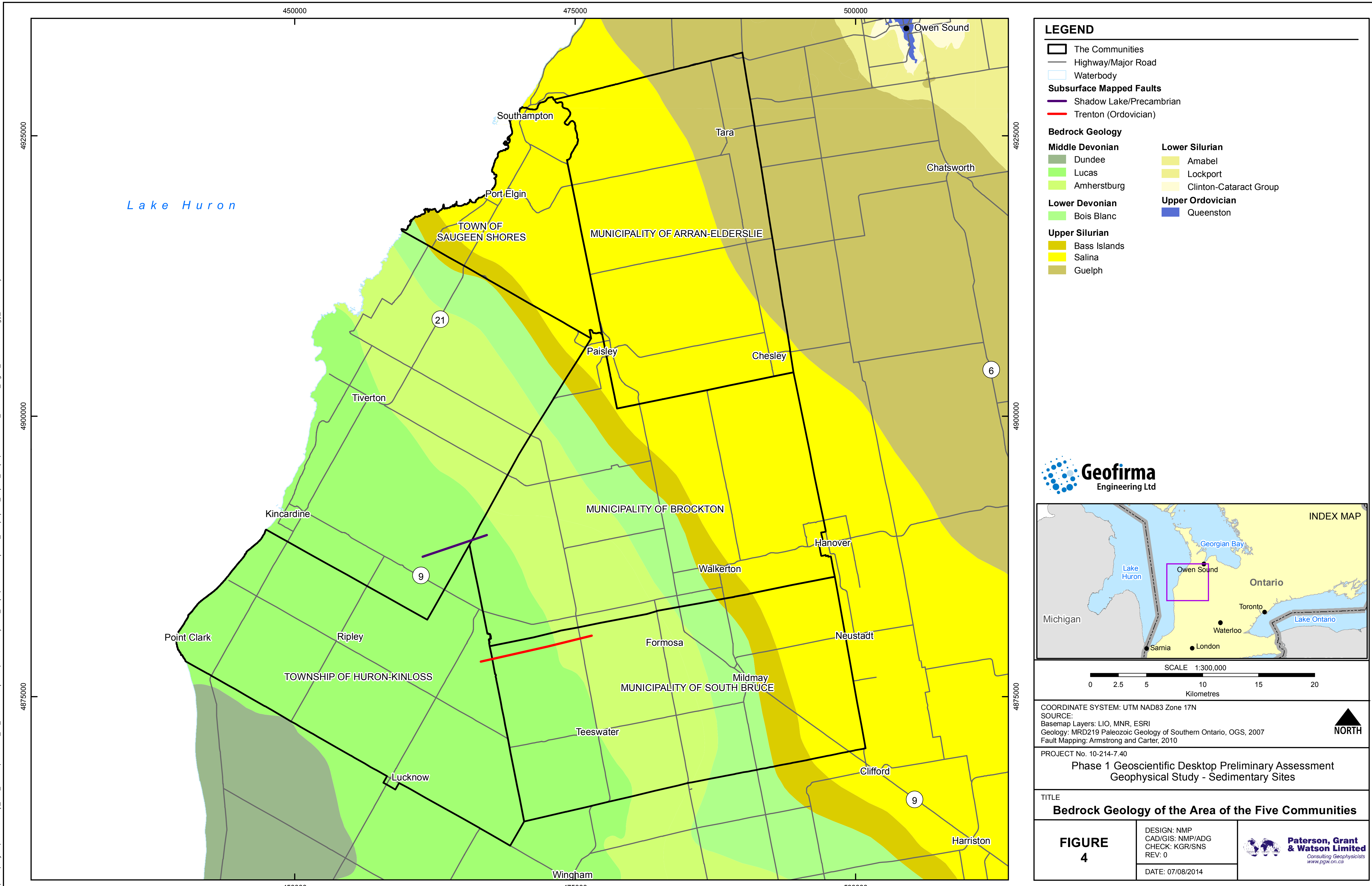

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475000
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Owen Sound
Southampton
Tara
Chatsworth
Port Elgin
Lake Huron
TOWN OF SAUGEEN SHORES
MUNICIPALITY OF ARRAN-ELDERSLIE
21
Paisley
Chesley
6
Tiverton
MUNICIPALITY OF BROCKTON
Kincardine
Hanover
9
Walkerton
Point Clark
Ripley
Formosa
Neustadt
TOWNSHIP OF HURON-KINLOSS
Mildmay
MUNICIPALITY OF SOUTH BRUCE
Teeswater
Lucknow
Clifford
Harriston
Wingham
LEGEND
The Communities
Highway/Major Road
Waterbody
Subsurface Mapped Faults
Shadow Lake/Precambrian
Trenton (Ordovician)
Bedrock Geology
Middle Devonian
Dundee
Lucas
Amherstburg
Lower Devonian
Bois Blanc
Upper Silurian
Bass Islands
Salina
Guelph
Lower Silurian
Amabel
Lockport
Clinton-Cataract Group
Upper Ordovician
Queenston
Geofirma Engineering Ltd
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Toronto
Michigan
Waterloo
Lake Ontario
Sarnia
London
SCALE 1:300,000
0 2.5 5 10 15 20
Kilometres
COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: MRD219 Paleozoic Geology of Southern Ontario, OGS, 2007
Fault Mapping: Armstrong and Carter, 2010
NORTH
PROJECT No. 10-214-7.40
Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites
TITLE
Bedrock Geology of the Area of the Five Communities
FIGURE 4
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 07/08/2014
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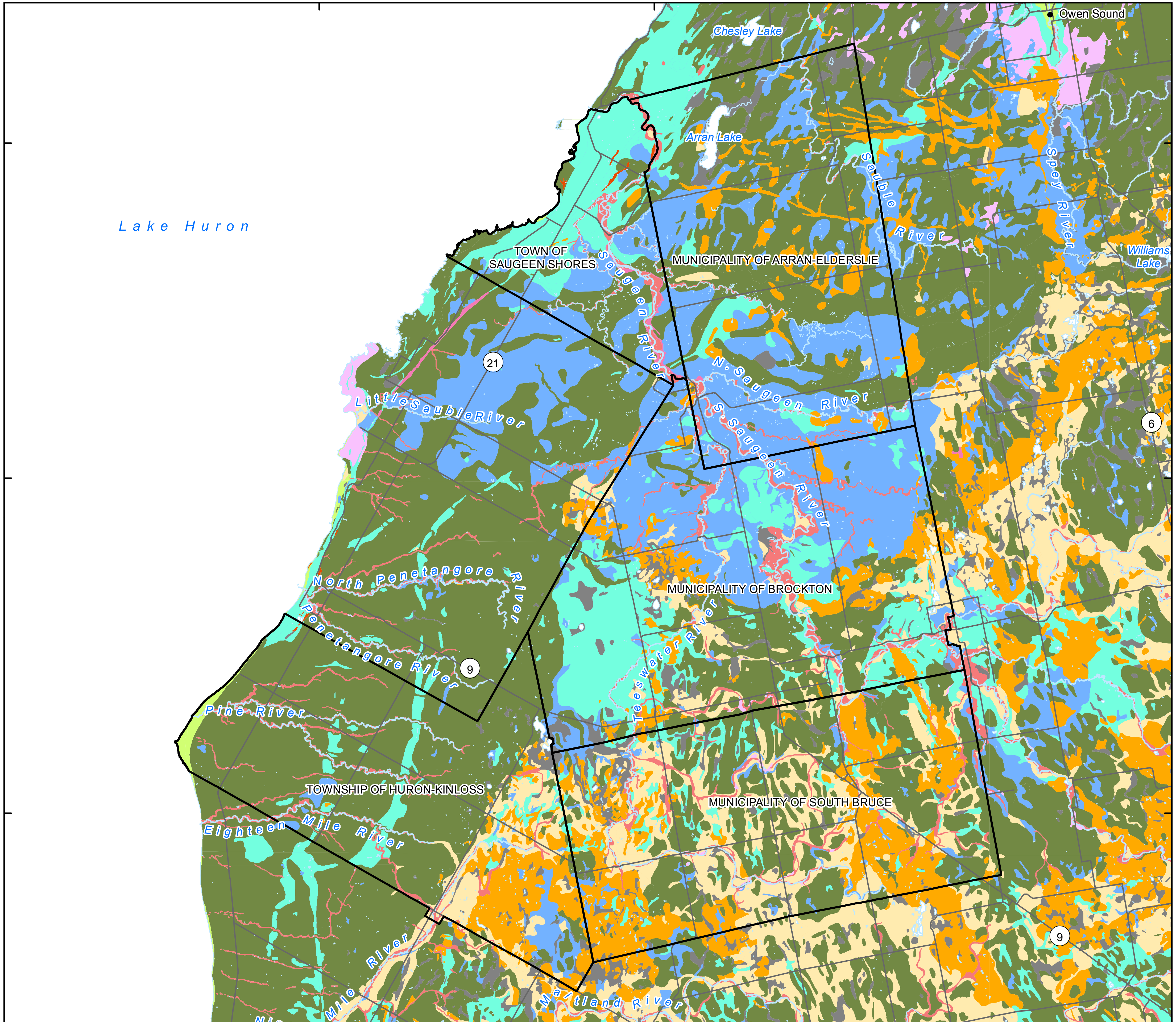

LEGEND

- The Communities
- Highway/Major Road
- Waterbody
- Watercourse

Surficial Geology

- Wetland
- Colluvial
- Lacustrine
- Fluvial
- Aeolian
- Glaciolacustrine (coarse)
- Glaciolacustrine (fine)
- Glaciofluvial (ice-contact)
- Glaciofluvial (outwash)
- Glacial (morainal)
- Bedrock-drift Complex

Geofirma Engineering Ltd

INDEX MAP

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Geology: OGS MRD128 Surficial Geology of Southern Ontario,1:50,000, 2010

NORTH

PROJECT No. 10-214-7.40

Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE

Surficial Geology of the Area of the Five Communities

FIGURE 5

DESIGN: NMP
CAD/GIS: NMP
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DATE: 8/6/2014

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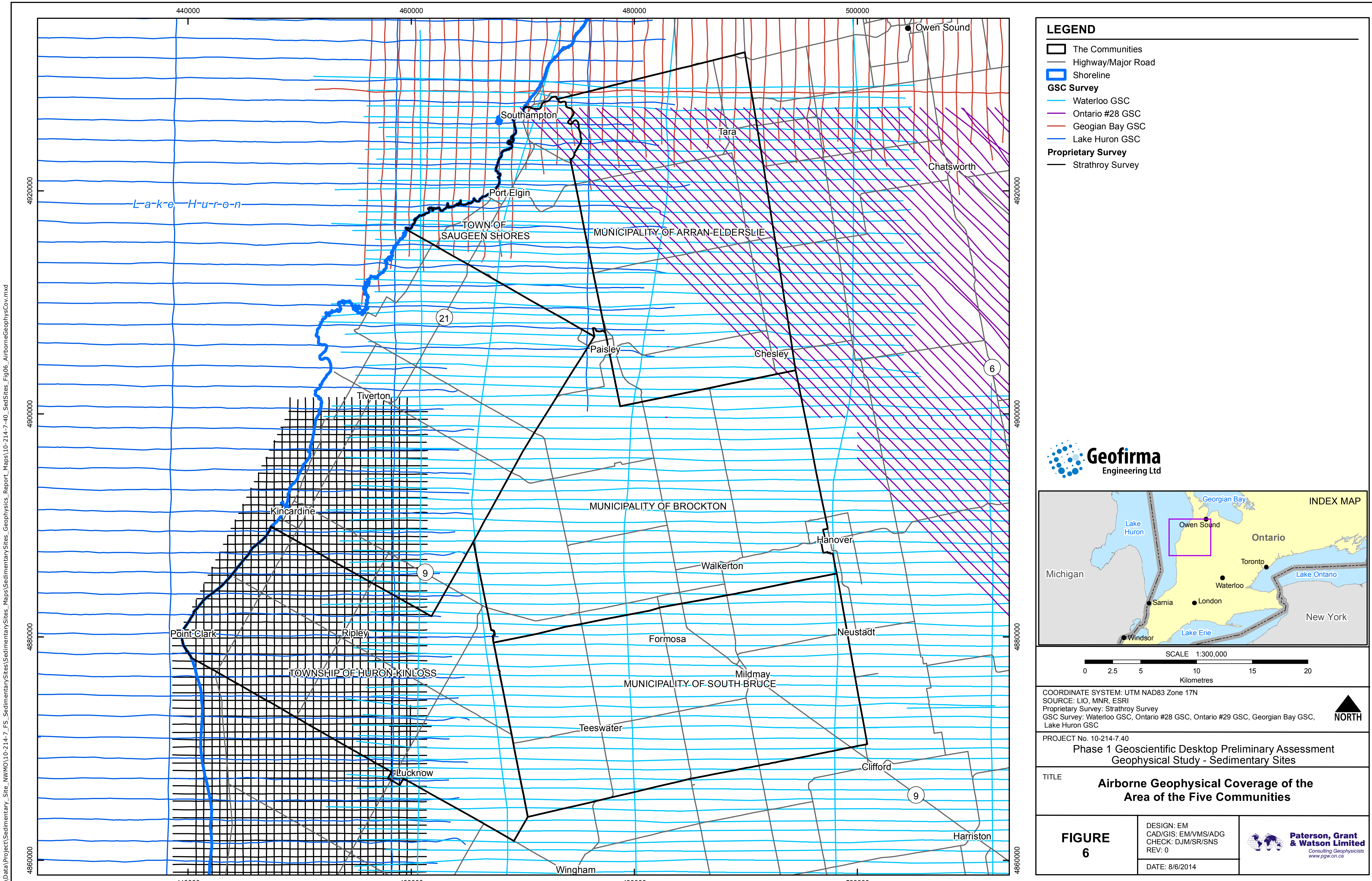
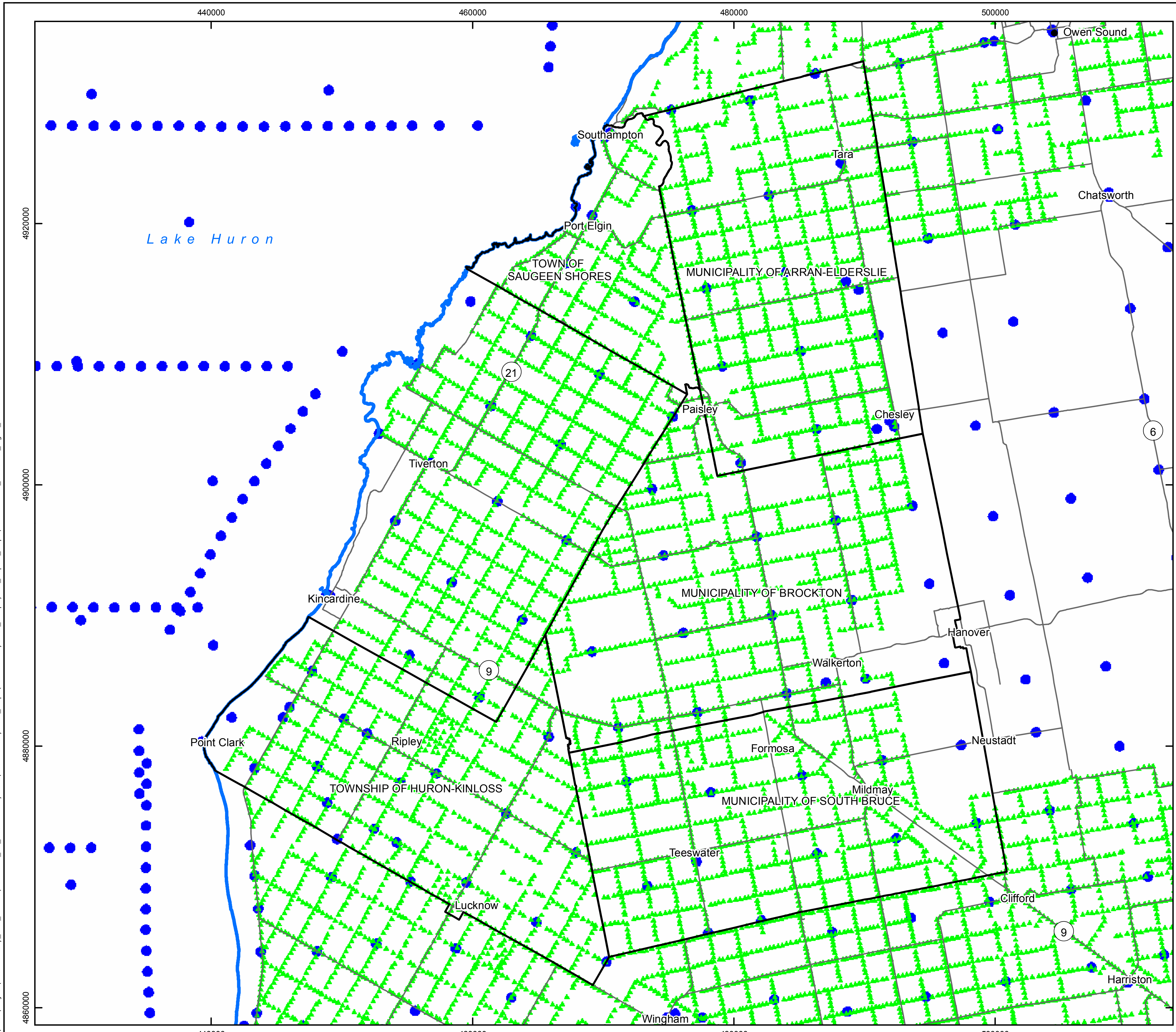


TITLE
Airborne Geophysical Coverage of the Area of the Five Communities

FIGURE 6



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LEGEND

- The Communities
- Highway/Major Road
- Shoreline
- GSC GGravity Station Location
- PGW Gravity Station Location

Geofirma Engineering Ltd

SCALE 1:300,000

0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Proprietary Survey: PGW Coverage
GSC Survey: GSC Coverage

NORTH

PROJECT No. 10-214-7.40

Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE

Ground Gravity Station Locations of the Area of the Five Communities

FIGURE 7

DESIGN: EM
CAD/GIS: EM/VMS
CHECK: JDJM/SR
REV: 0

DATE: 8/6/2014

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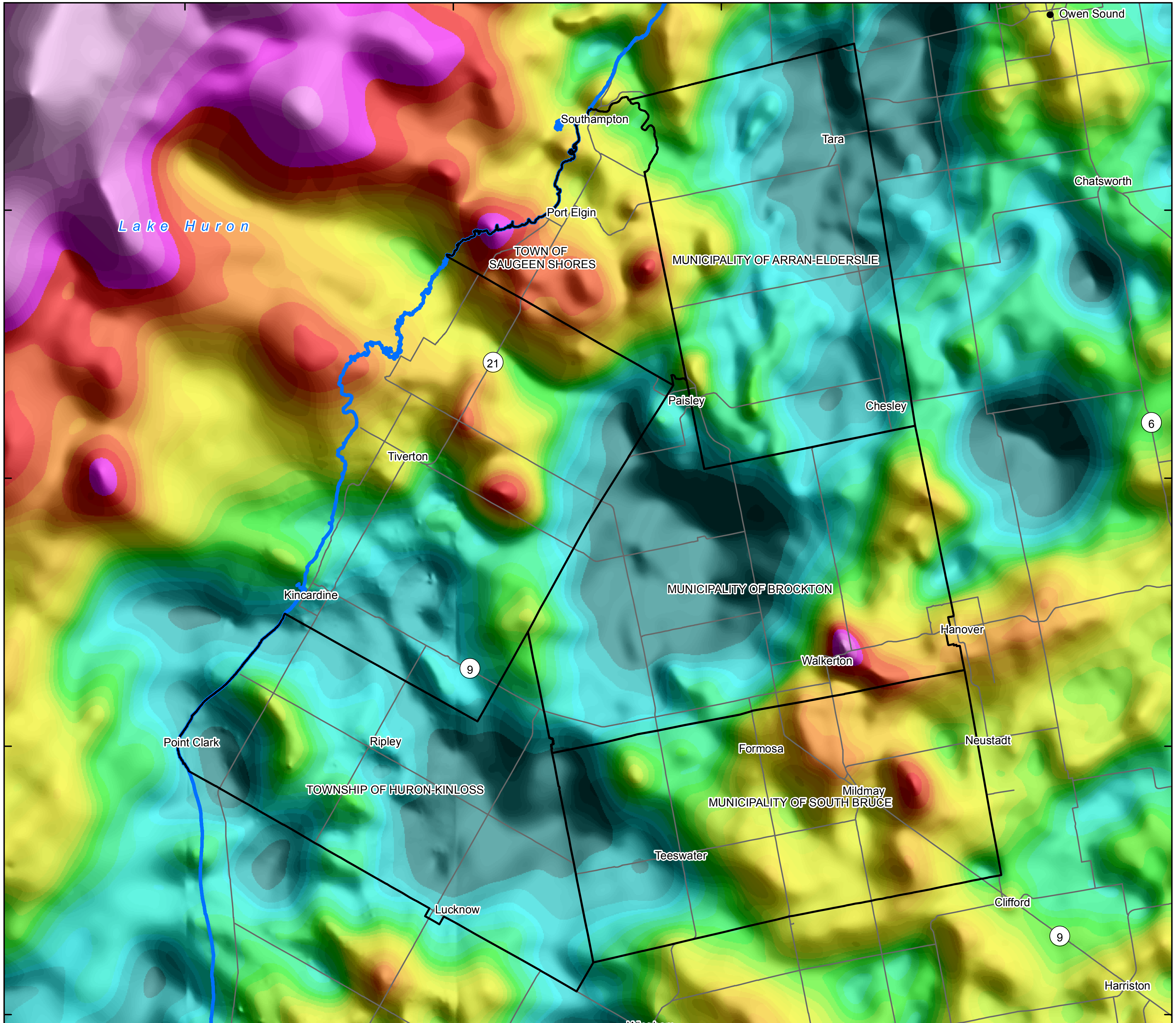

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LEGEND

- The Communities
- Highway/Major Road
- Shoreline

RTP (nT): 640, 330, 220, 150, 100, 60, 20, 0, -10, -20, -40, -50, -60, -70, -80, -90, -100, -110, -120, -130, -140, -150, -170, -180, -200, -210, -230, -260

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SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Proprietary Survey: Strathroy
GSC Survey: Waterloo, Lake Huron, Georgian Bay, Ontario #28, Ontario #29

NORTH

PROJECT No. 10-214-7.40

Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE

Residual Magnetic Field Reduced to Pole

FIGURE 8

DESIGN: EM
CAD/GIS: EM/VMS/ADG
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REV: 0

DATE: 8/6/2014

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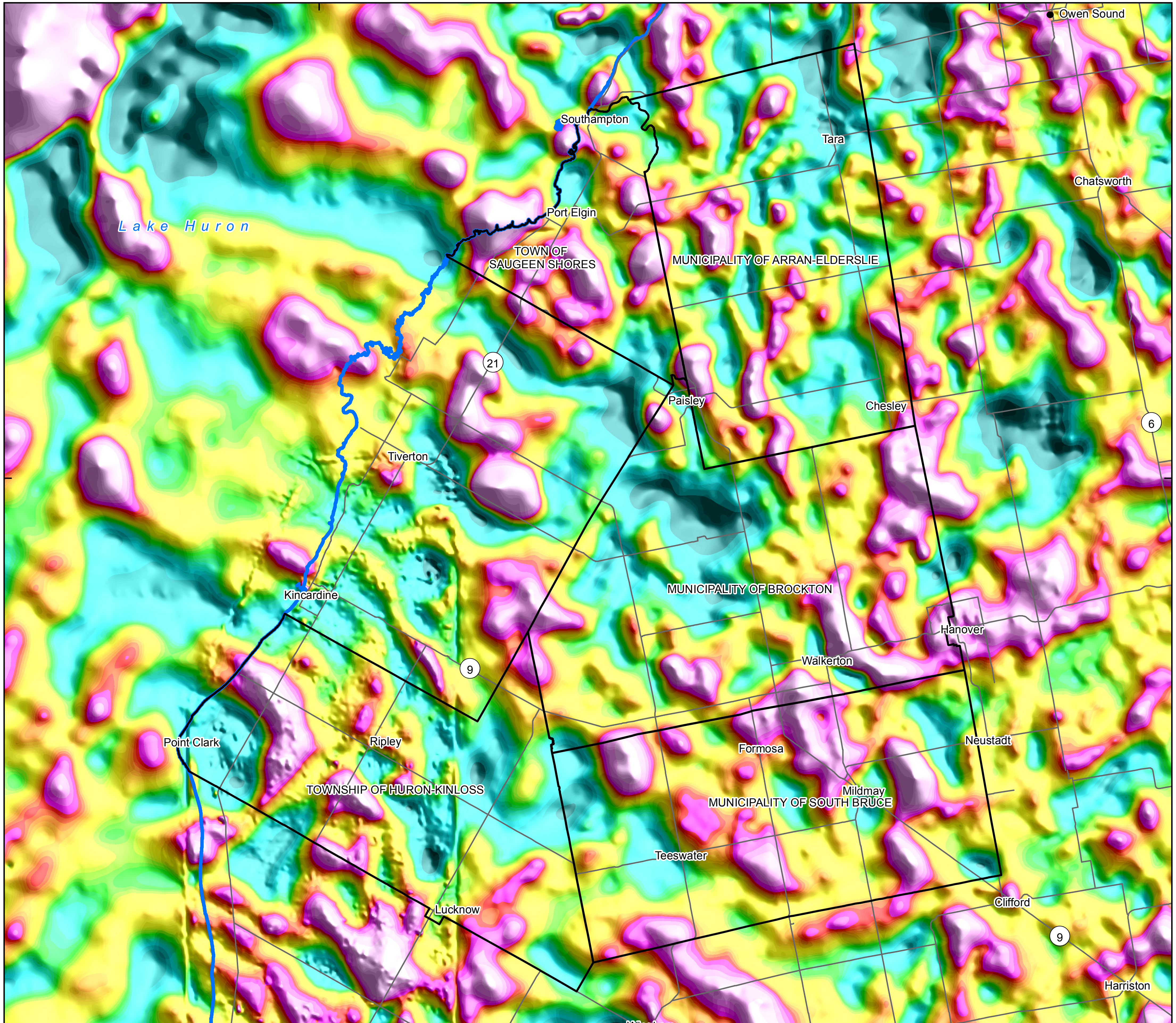

LEGEND

- The Communities
- Highway/Major Road
- Shoreline

First Vertical Derivative, Reduced to Pole, Magnetic Field

0.052
0.036
0.028
0.022
0.017
0.014
0.011
0.008
0.005
0.002
0.000
-0.002
-0.004
-0.006
-0.009
-0.011
-0.013
-0.015
-0.018
-0.020
-0.023
-0.026
-0.029
-0.033
-0.037
-0.043
-0.051
-0.065

nT/m

Geofirma Engineering Ltd

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Proprietary Survey: Strathroy
GSC Survey: Waterloo, Lake Huron, Georgian Bay, Ontario #28, Ontario #29

NORTH

PROJECT No. 10-214-7.40
Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE
First Vertical Derivative of the Pole Reduced Magnetic Field

FIGURE 9

DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DLM/SR/SNS
REV: 0

DATE: 8/6/2014

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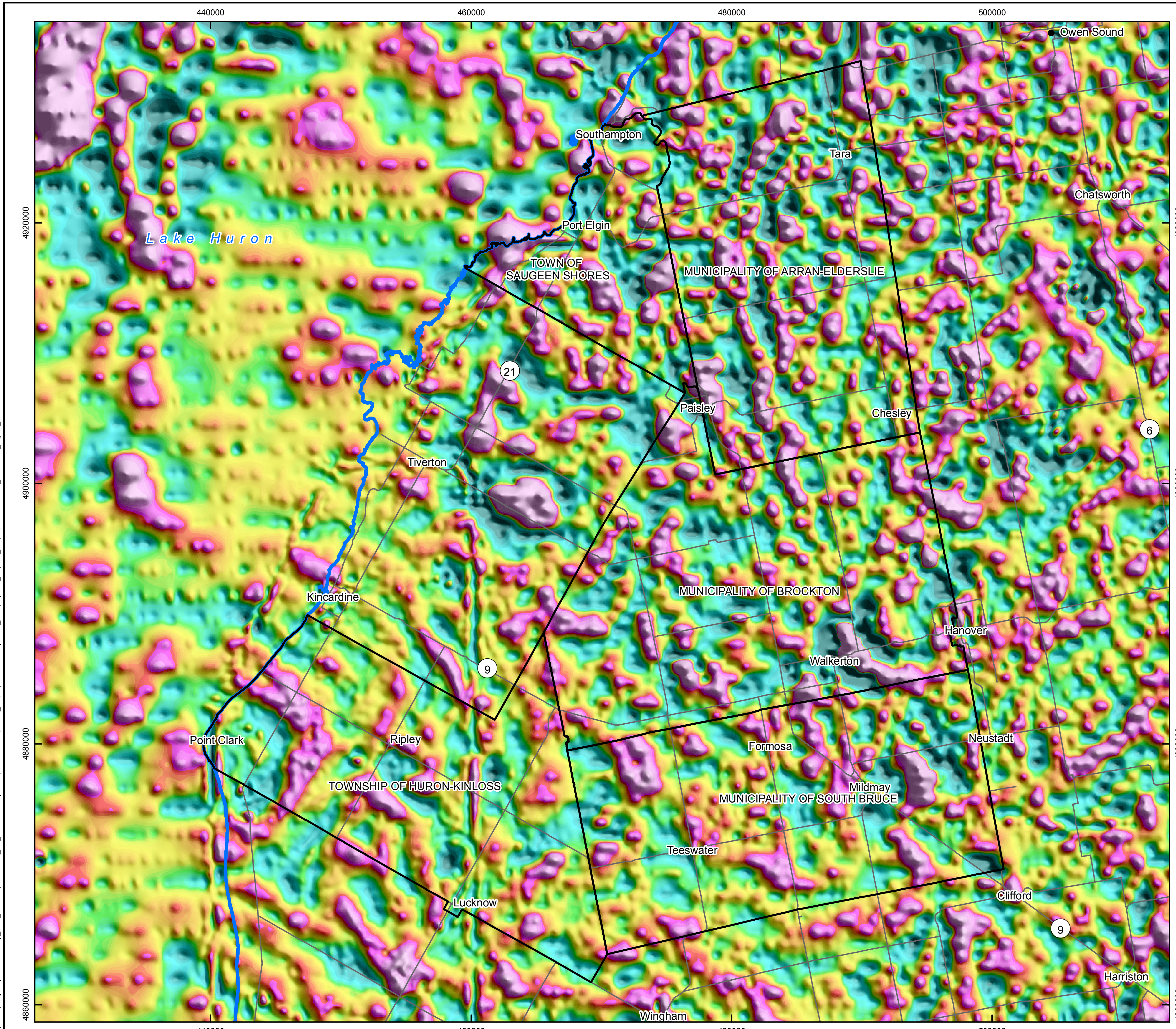

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LEGEND

- The Communities
- Highway/Major Road
- Shoreline

2VD of RTP (nT/m/m)
0.000075
0.000051
0.000040
0.000032
0.000026
0.000021
0.000017
0.000014
0.000011
0.000008
0.000006
0.000004
0.000002
-0.000000
-0.000002
-0.000005
-0.000007
-0.000009
-0.000011
-0.000014
-0.000016
-0.000019
-0.000023
-0.000027
-0.000032
-0.000039
-0.000049
-0.000068

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2VD of RTP
(nT/m/m)

SCALE 1:300,000
0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Proprietary Survey: Strathroy
GSC Survey: Waterloo, Lake Huron, Georgian Bay, Ontario #28, Ontario #29

NORTH

PROJECT No. 10-214-7.40
Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE
Second Vertical Derivative of the Pole Reduced Magnetic Field

FIGURE 10

DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DJM/SR/SNS
REV: 0

DATE: 8/6/2014

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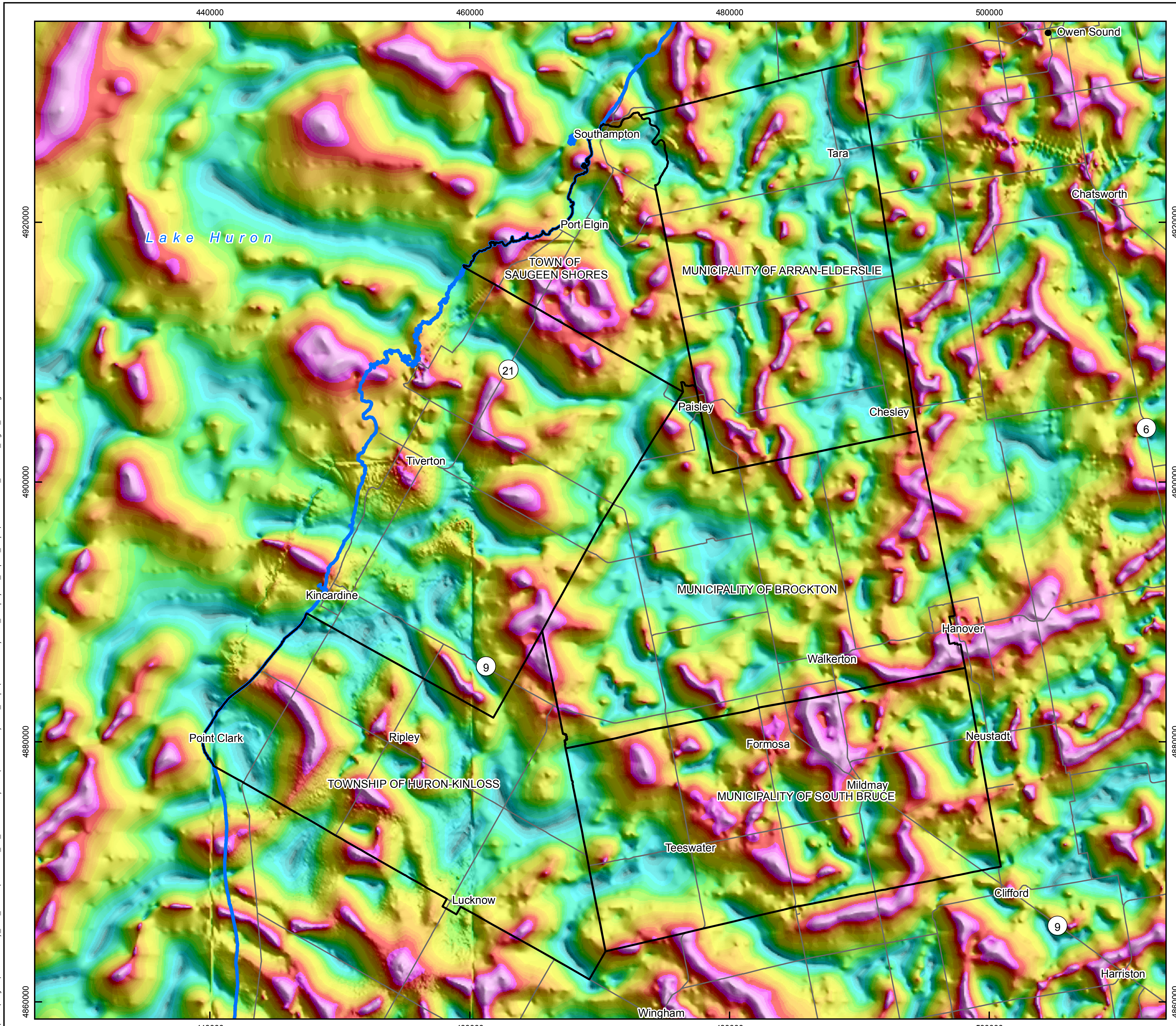

LEGEND

The Communities
Highway/Major Road
Shoreline

Tilt Angle (radians)

1.50
1.30
1.20
1.10
1.00
0.80
0.70
0.60
0.50
0.30
0.20
0.10
0.00
-0.20
-0.30
-0.40
-0.50
-0.70
-0.80
-0.90
-1.00
-1.20
-1.30
-1.40
-1.50

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SCALE 1:300,000
0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Proprietary Survey: Strathroy
GSC Survey: Waterloo, Lake Huron, Georgian Bay, Ontario #28, Ontario #29

NORTH

PROJECT No. 10-214-7.40

Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE

Tilt Angle of the Pole Reduced Magnetic Field

FIGURE 11

DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DJM/SR/SNS
REV: 0

DATE: 8/6/2014

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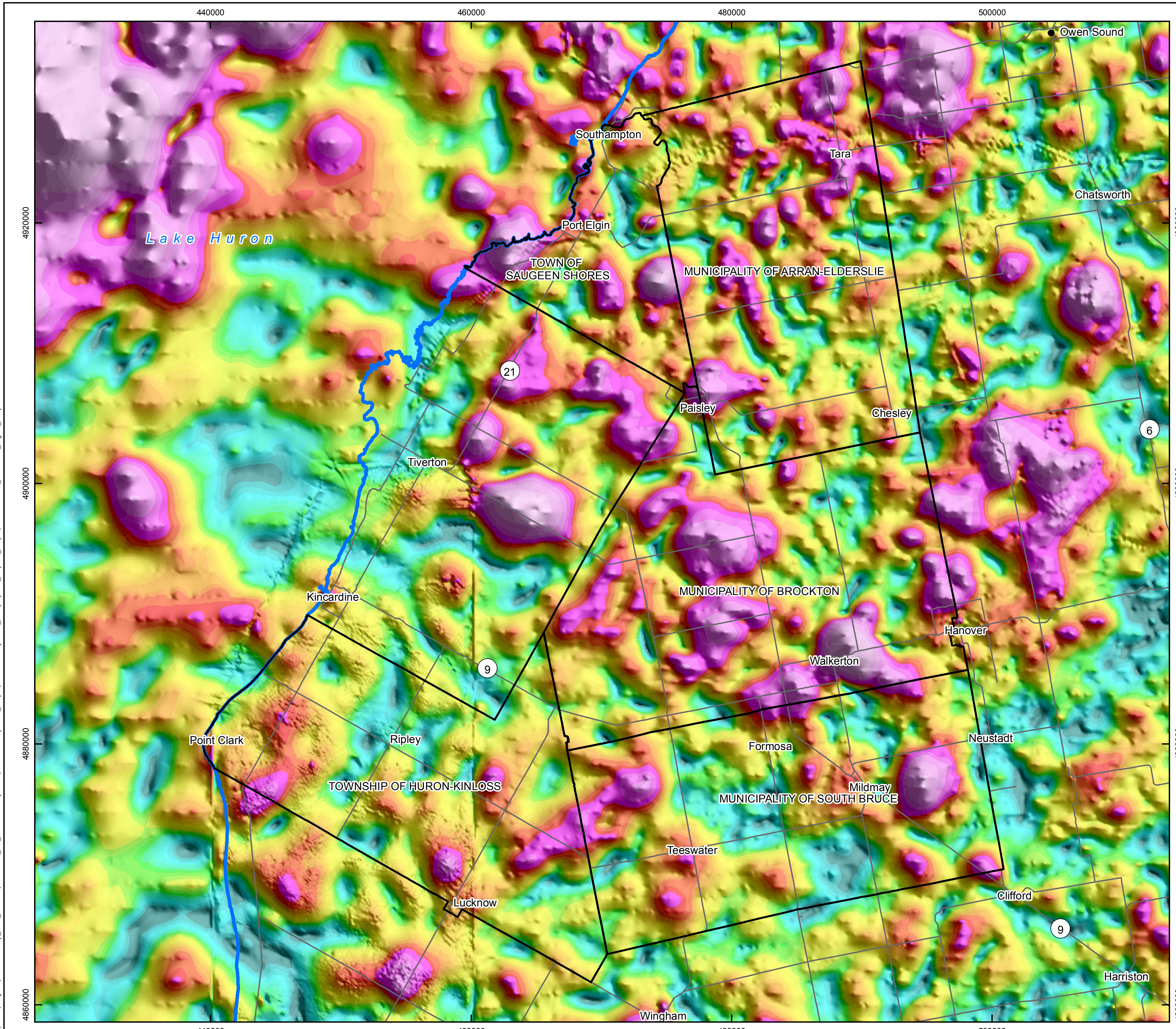

LEGEND

- The Communities
- Highway/Major Road
- Shoreline

Analytic Signal (nT/m)
0.150
0.104
0.080
0.068
0.058
0.054
0.048
0.046
0.042
0.040
0.038
0.036
0.034
0.032
0.030
0.028
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008

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Analytic Signal (nT/m)

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Proprietary Survey: Strathroy
GSC Survey: Waterloo, Lake Huron, Georgian Bay, Ontario #28, Ontario #29

NORTH

PROJECT No. 10-214-7.40

Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE

Analytic Signal Amplitude of the Total Magnetic Field

FIGURE 12

DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DJM/SR/SNS
REV: 0

DATE: 8/6/2014

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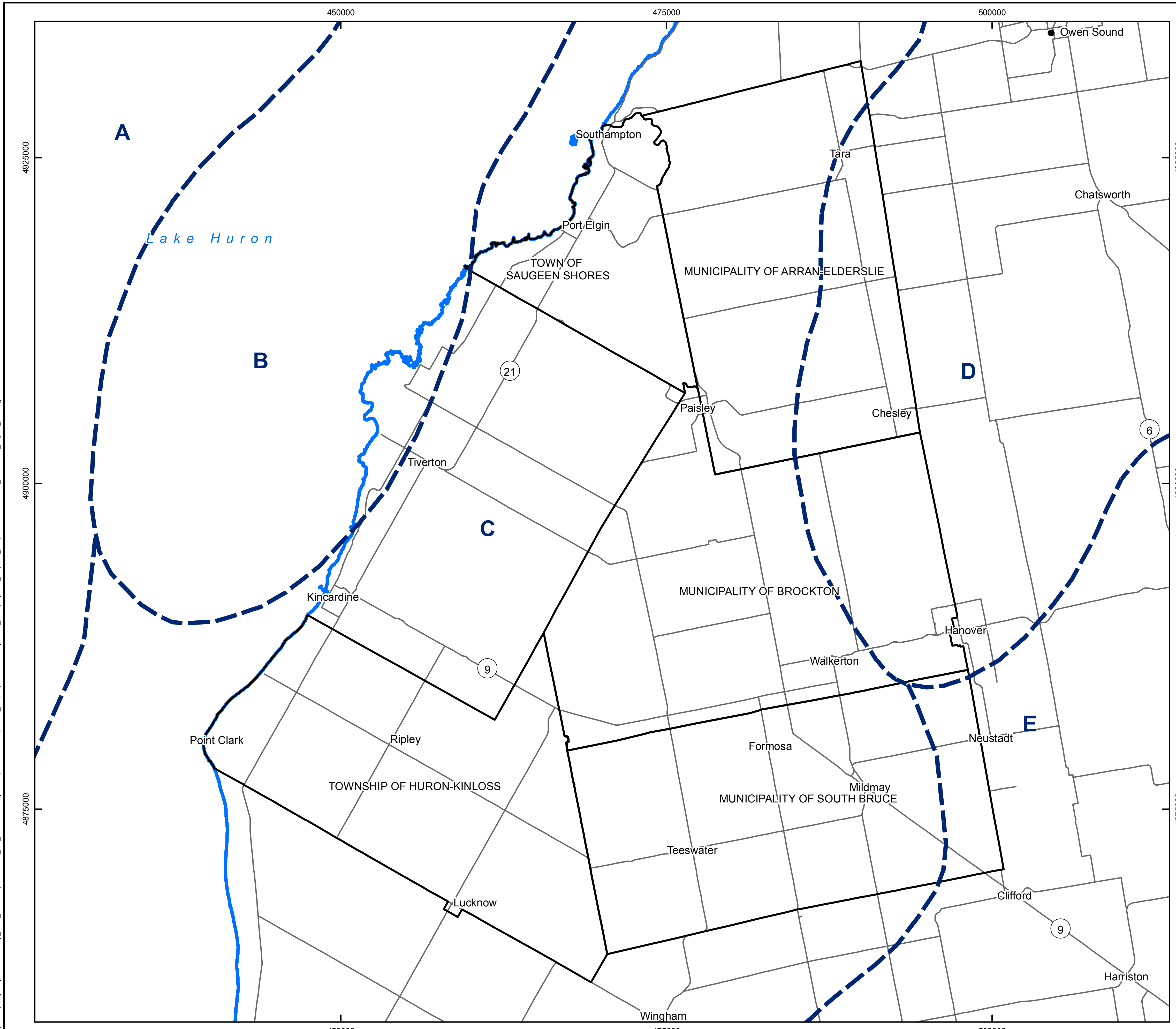

LEGEND

- The Communities
- Highway/Major Road
- Shoreline
- Interpreted Magnetic Domains

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SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Proprietary Survey: Strathroy Survey
GSC Survey: Waterloo GSC, Ontario #28 GSC, Ontario #29 GSC, Georgian Bay GSC, Lake Huron GSC

NORTH

PROJECT No. 10-214-7.40

Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE

Geophysical Interpretation of Magnetic Domains

FIGURE 13

DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DJM/SR/SNS
REV: 0

DATE: 8/6/2014

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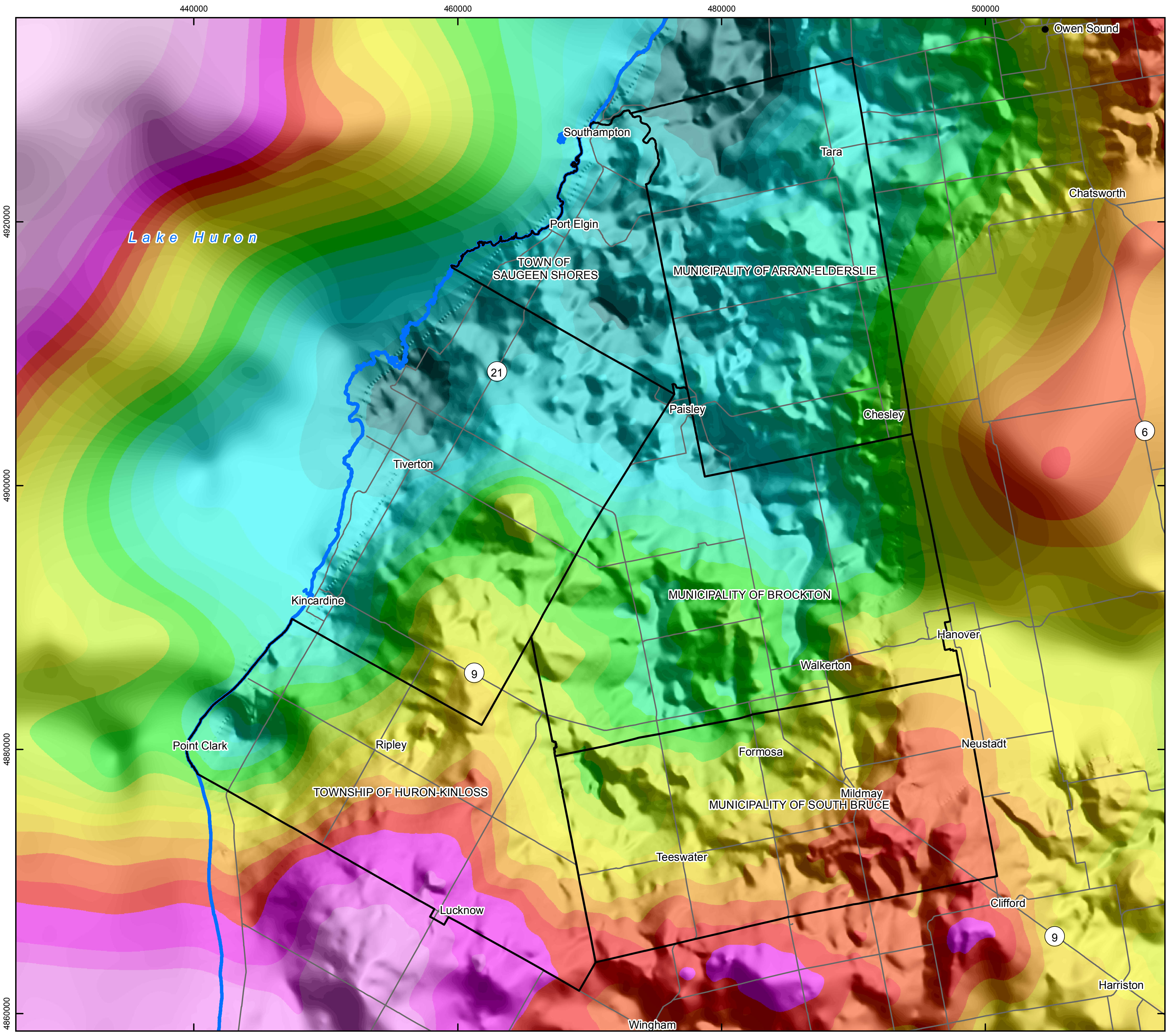

LEGEND

- The Communities
- Highway/Major Road
- Shoreline

67, 65, 62, 61, 59, 58, 57, 56, 55, 54, 53, 52, 51, 50, 49, 48, 47, 46, 45, 44

Bouguer Gravity
(mGal)

Geofirma Engineering Ltd

SCALE 1:300,000

0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Proprietary Survey: PGW Coverage
GSC Survey: GSC Coverage

NORTH

PROJECT No. 10-214-7.40

Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE

Bouguer Gravity Field

FIGURE 14

DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DJM/SR/SNS
REV: 0

DATE: 8/6/2014

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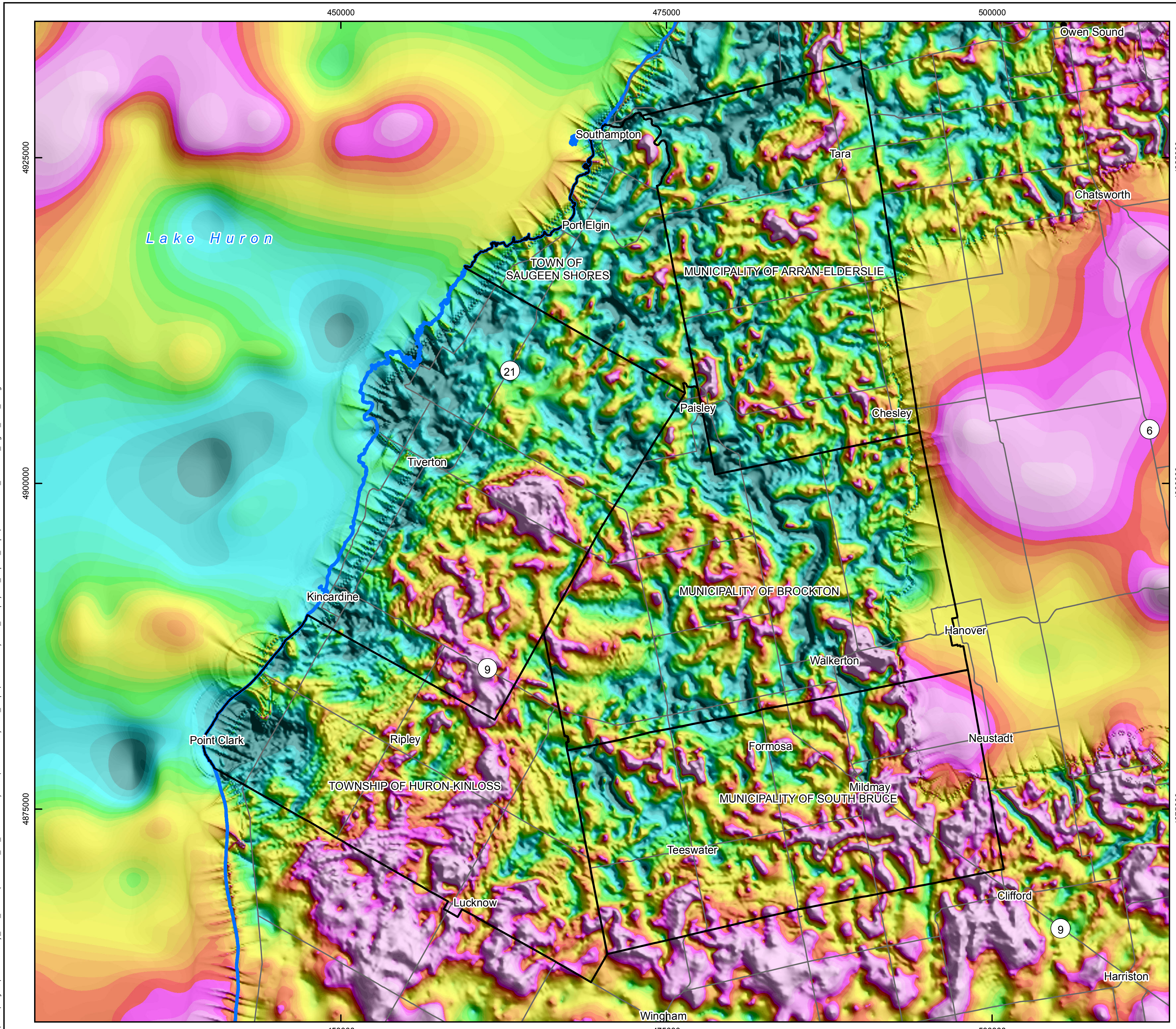

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LEGEND

- The Communities
- Highway/Major Road
- Shoreline

First Vertical Derivative of Bouguer Gravity

0.00085
0.00070
0.00055
0.00050
0.00040
0.00035
0.00025
0.00020
0.00010
0.00005
0.00000
-0.00005
-0.00015
-0.00020
-0.00025
-0.00030
-0.00040
-0.00045
-0.00055
-0.00060
-0.00070
-0.00075
-0.00085
-0.00090
-0.00100
-0.00115
-0.00140

mGal/m

Geofirma Engineering Ltd

SCALE 1:300,000

0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
Proprietary Survey: PGW Coverage
GSC Survey: GSC Coverage

NORTH

PROJECT No. 10-214-7.40
Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE
First Vertical Derivative of the Bouguer Gravity Field

FIGURE 15

DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DLM/SR/SNS
REV: 0

DATE: 07/08/2014

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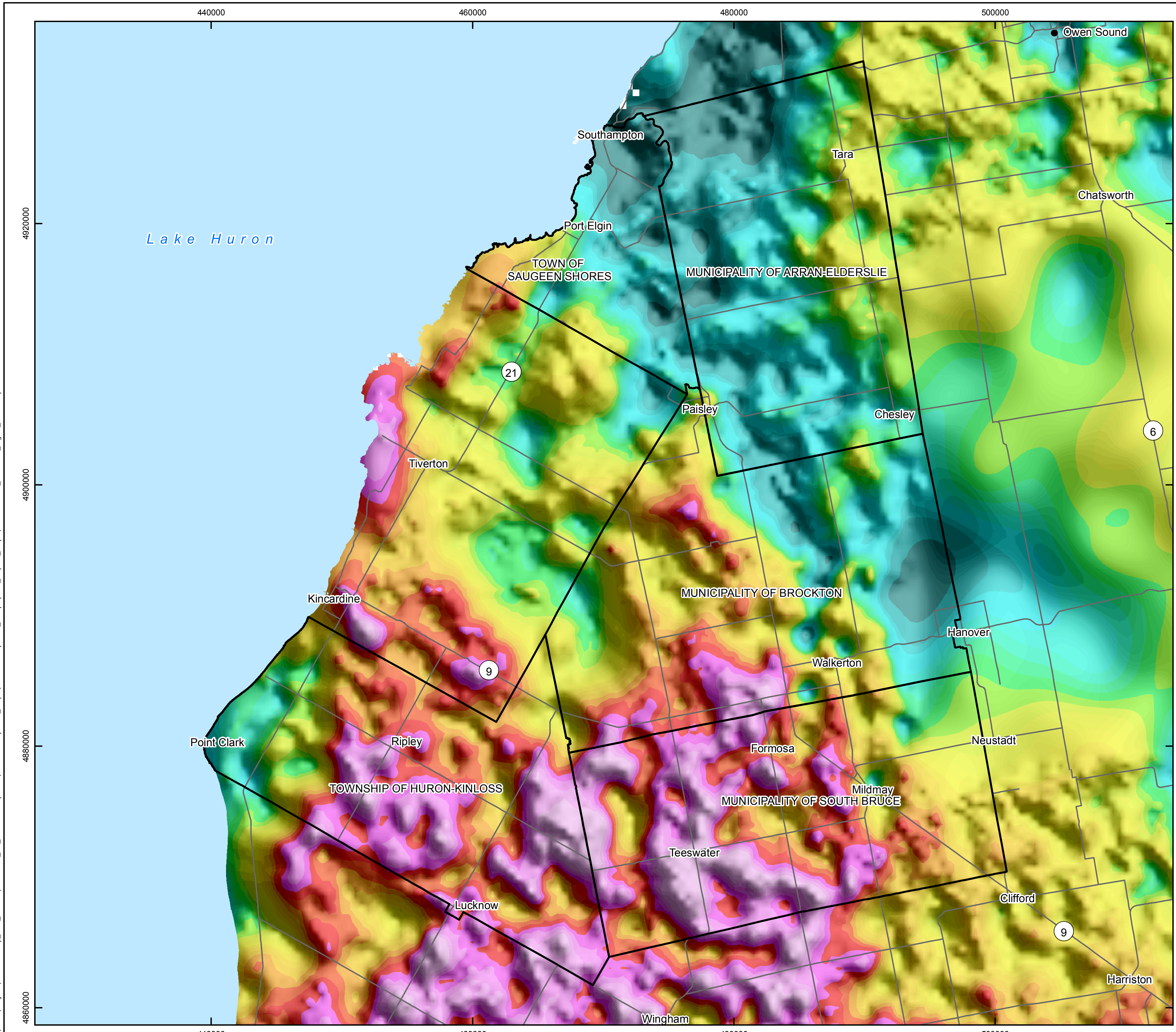

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LEGEND

- The Communities
- Highway/Major Road
- Waterbody

3.2, 3.1, 3.0, 2.9, 2.8, 2.7, 2.6, 2.5, 2.4, 2.3, 2.2, 2.1, 2.0, 1.9, 1.8, 1.7, 1.6, 1.5, 1.4, 1.2, 1.1, 0.8

Gravity (mGal)

Geofirma Engineering Ltd

SCALE 1:300,000

0 2.5 5 10 15 20

Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE: LIO, MNR, ESRI

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PROJECT No. 10-214-7.40

Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE **Modeled Bouguer Gravity from Overburden and Paleozoic Sedimentary Sequence**

FIGURE 16

DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DJM/SR/SNS
REV: 0

DATE: 8/6/2014

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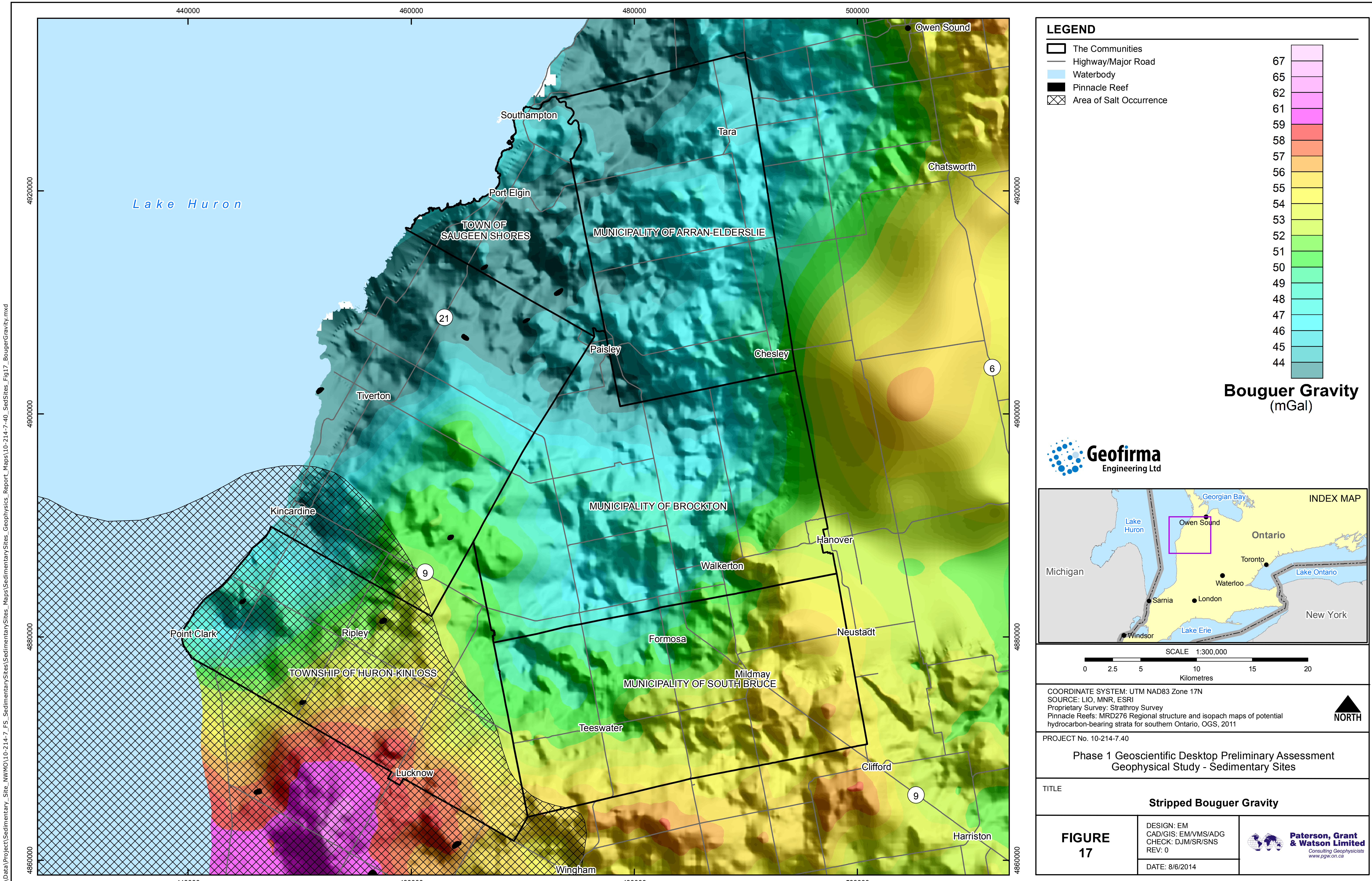

LEGEND
The Communities
Highway/Major Road
Waterbody
Pinnacle Reef
Area of Salt Occurrence
67
65
62
61
59
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
Bouguer Gravity
(mGal)
Geofirma
Engineering Ltd
INDEX MAP
Georgian Bay
Lake Huron
Owen Sound
Ontario
Michigan
Toronto
Lake Ontario
Waterloo
Sarnia
London
New York
Windsor
Lake Erie
SCALE 1:300,000
0
2.5
5
10
15
20
Kilometres
COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE: LIO, MNR, ESRI
Proprietary Survey: Strathroy Survey
Pinnacle Reefs: MRD276 Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario, OGS, 2011
NORTH
PROJECT No. 10-214-7.40
Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites
TITLE
Stripped Bouguer Gravity
FIGURE
17
DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DJM/SR/SNS
REV: 0
DATE: 8/6/2014
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440000
460000
480000
500000
4920000
4900000
4880000
4860000
Lake Huron
Owen Sound
Southampton
Tara
Chatsworth
Port Elgin
TOWN OF
SAUGEEN SHORES
MUNICIPALITY OF ARRAN-ELDERSLIE
21
Paisley
Chesley
6
Tiverton
MUNICIPALITY OF BROCKTON
Kincardine
Hanover
9
Walkerton
Point Clark
Ripley
Neustadt
Formosa
TOWNSHIP OF HURON-KINLOSS
Mildmay
MUNICIPALITY OF SOUTH BRUCE
Teeswater
Lucknow
Clifford
9
Harriston
Wingham
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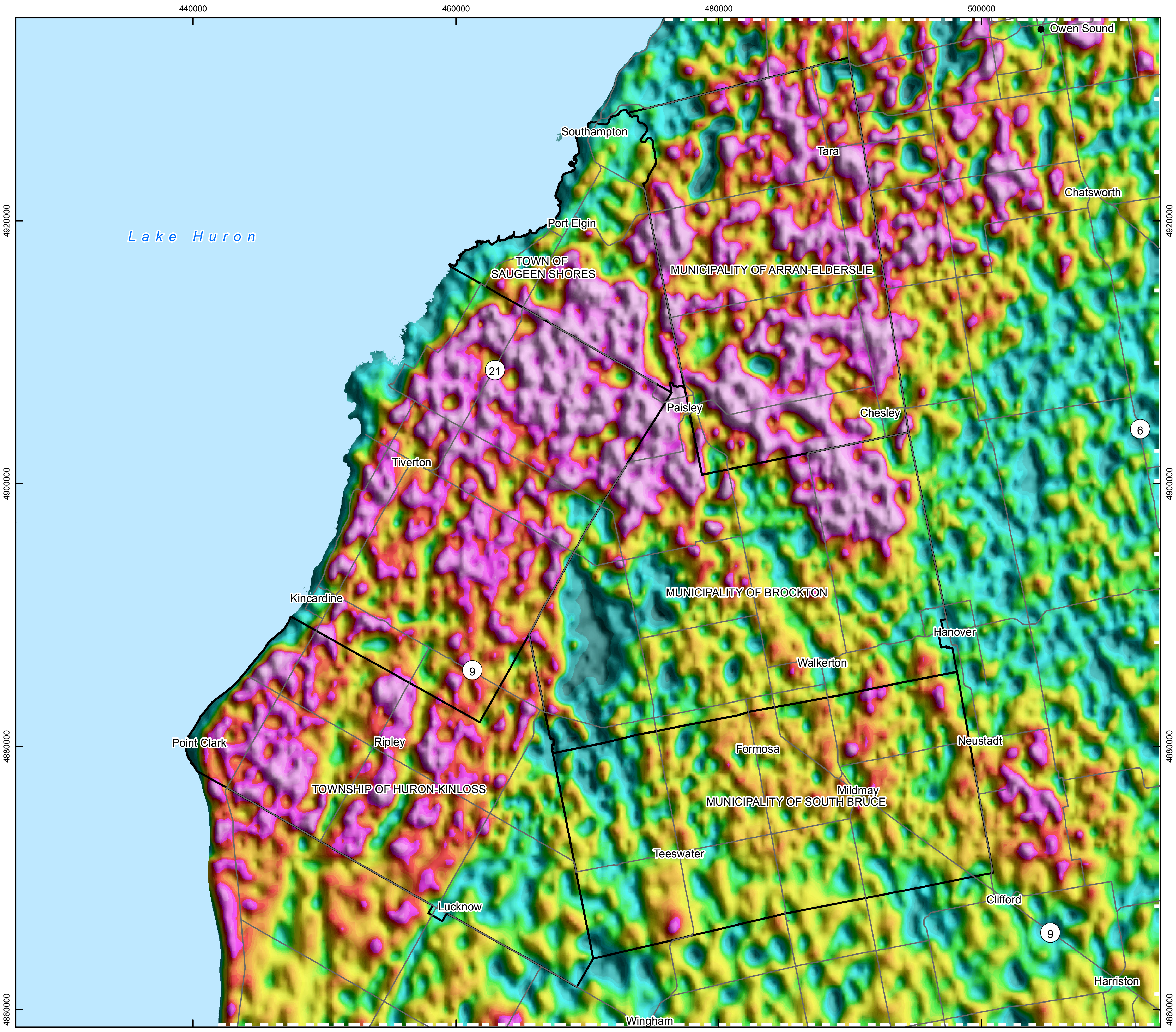

LEGEND

- The Communities
- Highway/Major Road
- Waterbody

51.0
48.0
46.5
45.0
43.5
42.5
41.0
40.0
39.0
38.0
37.0
36.0
35.0
34.0
33.0
32.0
31.0
30.5
29.5
28.5
27.5
26.0
25.0
23.5
21.5
19.5
15.5
5.0

Natural Air Absorbed Dose Rate
(nGy/h)

Geofirma Engineering Ltd

SCALE 1:300,000
0 2.5 5 10 15 20
Kilometres

COORDINATE SYSTEM: UTM NAD83 Zone 17N
SOURCE:
Basemap Layers: LIO, MNR, ESRI
GSC CSurvey: Douglas Point, S. Central Ontario-Collingwood-Hamilton, S. Ontario Block 2

NORTH

PROJECT No. 10-214-7

Phase 1 Geoscientific Desktop Preliminary Assessment
Geophysical Study - Sedimentary Sites

TITLE
Radiometric Dose Rate

FIGURE 18

DESIGN: EM
CAD/GIS: EM/VMS/ADG
CHECK: DJM/SR/SNS
REV: 0

DATE: 8/6/2014

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