NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

CITY OF ELLIOT LAKE, TOWN OF BLIND RIVER, TOWNSHIP OF THE NORTH SHORE AND TOWN OF SPANISH, ONTARIO

APM-REP-06144-0093

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PHASE 1 - GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

PROCESSING AND INTERPRETATION OF GEOPHYSICAL DATA

City of Elliot Lake, Town of Blind River, Township of The North Shore, Town of Spanish, Ontario

Prepared for

Golder Associates

and

Nuclear Waste Management Organization (NWMO)

by

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EXECUTIVE SUMMARY

In November and December of 2012, the City of Elliot Lake, the Town of Blind River, the Township of The North Shore, and the Town of Spanish 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 the area of the four 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 assessment are reported in an integrated report (NWMO, 2014a,b,c,d). The objective of the geoscientific desktop preliminary assessment is to determine whether the City of Elliot Lake, the Town of Blind River, the Township of The North Shore, the Town of Spanish and their periphery, referred to as the "area of the four communities", contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

This report presents the findings of a geophysical data interpretation assessment completed as part of the geoscientific desktop preliminary assessment of the area of the four communities (Golder, 2014). The purpose of this assessment was to perform a detailed interpretation of all available geophysical data (e.g., magnetic, electromagnetic, gravity and radiometric) for the area of the four communities. The aim is to identify additional information that can be extracted from the data, in particular that relating to the coincidence of geophysical features with mapped lithology and structural features in the area of the four communities.

The geophysical data covering the area of the four communities show variability in resolution. Low-resolution geophysical data, particularly the magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC), cover the entire area of the four communities. Two magnetic/electromagnetic surveys obtained from the Ontario Geological Survey (OGS) and one GSC magnetic survey provided higher resolution coverage over approximately 5% of the area of the four communities. The first two surveys focused on exploration in the greenstone belts, and the third covered the East Bull Lake intrusion and Parisien Lake syenite. Due to the lack of high-resolution data, the assessment files were reviewed and airborne geophysical images extracted from eight reports to amplify the coverage.

The coincidence between the geophysical data and the mapped lithology and structural features was interpreted using all available geophysical data sets (e.g., magnetic, electromagnetic, gravity and radiometric). In general the coincidence between the interpretation of aeromagnetic data and the published geological maps is not in good agreement. Four dyke swarms of varying strike, density and intensity are evident from the magnetic data, obscuring some of the responses from the host lithologies. Nevertheless, the magnetic data are useful in locating contacts on the boundaries of and within the Ramsey-Algoma granitoid complex, as well as identifying inhomogeneities. The gravity and radiometric data further characterize the rocks within the

Ramsey-Algoma granitoid complex, and indicate a greater degree of complexity than evident from the published geological mapping.

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1 INTRODUCTION

In November and December of 2012, the City of Elliot Lake, the Town of Blind River, the Township of The North Shore, and the Town of Spanish 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 the area of the four communities for safely hosting a deep geological repository (Step 3). The preliminary assessment is a multidisciplinary assessment 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,b,c,d).

This report presents the findings of a geophysical data interpretation assessment completed as part of the geoscientific desktop preliminary assessment of the area of the four communities (Golder, 2014). The objective of the geoscientific desktop preliminary assessment is to determine whether the area of the four communities contains general areas that have the potential to meet NWMO's geoscientific site evaluation factors. The assessment focused on the City of Elliot Lake, the Town of Blind River, the Township of The North Shore, the Town of Spanish, Ontario and their periphery, referred to as "the area of the four communities".

1.1 Objective

Geophysical data forms an important component of assessing a region for its potential suitability to host a deep geological repository, and to assist in the identification of general potentially suitable areas.

The purpose of this assessment was to perform a review of available geophysical data for the area of the four communities, followed by a detailed interpretation of all available geophysical data (e.g., magnetic, electromagnetic, gravity and radiometric) to identify additional information that could be extracted from the data, in particular regarding the coincidence of geophysical features with mapped lithology and structural features in the area of the four communities.

The role of the geophysical interpretation is to extrapolate our current understanding of the mapped lithology and extent of overburden cover to assess how the distribution of rock units may change at depth. Drill holes, wells and other underground information may be available at individual points to supplement geological data acquired on surface. However, where these individual data points are limited (or non-existent), the critical advantage of airborne geophysical data is that it provides a basis for interpreting the subsurface physical properties across the area. This is particularly important in areas where bedrock exposure is limited by surface water bodies and/or overburden cover such as glacial sediments. A secondary role of geophysics is that it often elucidates certain characteristics of geological formations and structures that may not be easily discerned from surface mapping and analysis. Thirdly, it highlights tectonic and regional-scale features that may not be easily extracted from studies of a particular area on a more detailed scale.

1.2 Communities of Elliot Lake, Blind River, The North Shore and Spanish and Surrounding Area

The area of the four communities incorporates the Communities of Elliot Lake, Blind River, The North Shore and Spanish and surrounding areas (as shown on Figure 1). They are situated in the Algoma District along the north shore of Lake Huron. The four communities and the surrounding area measure approximately 114 km by 126 km in size, encompassing an area of about 14,450 km^2. Highway 17 (Trans-Canada Highway) crosses through the communities and connects to Sudbury (100 km to the east) and Sault Ste. Marie (145 km to the west).

1.3 Qualifications of the Geophysical Interpretation Team

The team responsible for the geophysical review, processing and interpretation investigation component of the Phase 1geoscientific desktop preliminary assessment for the area of the four communities consisted of qualified experts from Paterson, Grant & Watson Limited (PGW). The personnel assigned to this assessment were as follows:

Stephen Reford, B.A.Sc., P.Eng. – project management, geophysical interpretation, report preparation

Mr. Reford is a senior consulting geophysicist and Vice-President of PGW. Mr. Reford has 32 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.

Dr. Hernan Ugalde, Ph.D., P.Geo. – geophysical interpretation

Dr. Ugalde is a senior consulting geophysicist for PGW. Dr. Ugalde has 19 years of experience in project management, acquisition, modelling and interpretation of airborne magnetic, electromagnetic, radiometric, gravity and digital terrain data for clients throughout Canada and around the world. For PGW, he has worked 7 years full-time and 8 years part-time (while earning his Ph.D., conducting post-doctoral research and lecturing). Projects include a lead role in interpretation and training for a nationwide program in Nigeria and exploration for precious and base metals throughout Latin America.

Winnie Pun, M.Sc. – data processing and map preparation

Ms. Pun will soon complete her second 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.

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

Ms. Mueller-Markham is a senior consulting geophysicist for PGW. She has 19 years of experience in project management, acquisition, processing and modelling of airborne magnetic, electromagnetic, radiometric, gravity and digital terrain data throughout 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.

Nikolay Paskalev, M.Sc. – GIS preparation

Mr. Paskalev has been the Manager, 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.

Dr. D. James Misener, Ph.D., P.Eng. – geophysical reviewer

Dr. Misener is President of PGW and a senior geophysicist with 38 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.

2 PHYSICAL GEOGRAPHY AND GEOLOGY

A detailed discussion of the geological setting of the area of the four communities is provided in Golder (2014). The following sections on physical geography, geological and structural history, Quaternary geology, and land use, present information from Golder (2014) and JDMA (2014a), where applicable, in order to provide the necessary context for discussion of the results of this geophysical interpretation (Section 5.0). The regional and local bedrock geology of the Nipigon area is shown on Figures 2 and 3, respectively.

2.1 Physical Geography

A detailed discussion of the physical geography of the area of the four communities is provided in a separate terrain analysis report (JDMA, 2014a) and the following is a summary of that information. The area of the four communities exhibits topographic and drainage features that are characteristic of the Canadian Shield. The topography in this area is largely bedrock-controlled, with bedrock hills and ridges, and structurally controlled valleys acting as the main landscape elements. As a result, topography can reveal much about the bedrock structure and distribution of overburden deposits.

Overall, the northern part of the area of the four communities is a highland and the southern part is a lowland. The narrow lowland along this part of the north shore of Lake Huron is characterized by wave-washed bedrock knolls interspersed with local pockets of glaciolacustrine sediments. The elevation gradient from north to south is from 612 to 176 m, with this elevation drop occurring over a distance of approximate 90 km. The highest point in the area of the four communities is within the highlands north of the Aubinadong River, in the northwest corner of the area. The lowest point is defined by the surface of Lake Huron, which has a chart datum of 176.0 m.

The areas mapped as bedrock within the area of the four communities amount to 76% of the area not covered by Lake Huron (Figure 4). Within these areas, drift deposits are thinnest on the bedrock hills and ridges scattered throughout the landscape, and local drift deposits too small to map explicitly at the scale of 1:100,000 exist within depressions. JDMA (2014a) mapped bedrock outcrop using Landsat MSS imagery, and found a greater amount of exposed bedrock in the southern part of the area of the four communities, particularly in the area between Highway 546 and Highway 108. Some of the outcrops within the lowland along the north shore of Lake Huron are expected to represent areas where the overburden deposits were eroded by wave erosion during glacial and postglacial high stands of the Lake Huron basin, leaving the bedrock exposed. The total extent of bedrock outcrops suggested by the Landsat MSS interpretation is about 8% of the portion of the area of the four communities not covered by Lake Huron.

The area of the four communities contains a large number of lakes of various sizes, twenty-four of which are larger than 10 km2 and ten of which are larger than 20 km2, with 21% (3,049 km2) of the area occupied by water bodies, 11% of which is represented by Lake Huron (JDMA, 2014a). Waterbodies cover 11.5% of the portion of the area of the four communities not covered by Lake Huron. The large lakes are sufficiently large to conceal geological structures up to about 5 km in length, and clusters of small lakes can conceal structures, especially when the lakes are located in areas covered by overburden.

2.2 Bedrock Geology

The area of the four communities is underlain by bedrock of the Canadian Shield, a stable craton created from a collage of ancient plates and accreted juvenile arc terranes that were progressively amalgamated over a period of more than 2 billion years. The Canadian Shield forms the stable core of the North American continent, and is composed of several geological provinces of Archean age, which in the area of the four communities, is bordered by the younger Proterozoic-aged Southern Province.

The Superior Province covers an area of approximately 1,500,000 km^2 stretching from the Ungava region of northern Québec through the northern part of Ontario and the eastern portion of Manitoba, and extending south into Minnesota and the northeastern part of South Dakota. The Superior Province is divided into subprovinces, medium- to large-scale regions that are characterized by their similar rock-types, structural style, age, metamorphic grade and mineralization.

The area of the four communities, situated on the north shore of Lake Huron, is underlain by early Proterozoic rocks of the Southern Province and Archean rocks of the westernmost portion of the Abitibi Subprovince of the Superior Province of the Canadian Shield. The Abitibi Subprovince is bounded to the west by the Kapuskasing structural zone (KSZ) and Wawa Subprovince and to the north by the Opatica Subprovince. The southern boundary of the Abitibi Subprovince is overlain by metasedimentary and metavolcanic rocks of the Huronian Supergroup of the Southern Province. The Southern Province is bounded to the southeast by the Proterozoic Grenville Province. Numerous mafic dyke swarms and mapped faults transect the bedrock in the area of the four communities. Figures 2 and 3 show the regional and local-scale geology for the area of the four communities and the surrounding area.

The Abitibi Subprovince is exposed in the northern half and much of the eastern side of the area of the four communities (Figures 2 and 3). The Abitibi Subprovince is a granite-greenstone-gneiss terrane that was developed between 2.8 and 2.6 billion years ago (Thurston, 1991). It is composed of low metamorphic grade volcanic rocks and granitoid plutonic and gneiss-dominated domains, the latter of which are predominant in the area of the four communities and are represented by the Ramsey-Algoma granitoid complex (e.g., Jackson and Fyon, 1991). The Ramsey-Algoma granitoid complex is a large heterogeneous group of granitic bodies that intruded the older metavolcanic and subordinate metasedimentary rocks of the Whiskey Lake and Benny Lake greenstone belts. Several smaller intrusive bodies are distributed throughout the area of the four communities, including the Cutler pluton, the Seabrook Lake intrusion, the Parisien Lake syenite, and the East Bull Lake intrusive suite, among others (Figure 3).

The Huronian Supergroup underlies the southern portion of the area of the four communities (Figure 2 and 3) and consists of a group of metasedimentary rocks (stratigraphically youngest) and lesser (stratigraphically oldest) metavolcanic rocks ranging in age from 2.5 to 2.2 billion years old. The Southern Province also includes the Sudbury Igneous Complex (ca. 1.85 billion years old) located to the east of the area of the four communities, and the metasedimentary and metavolcanic rocks of the Animikie and Sibley Groups that are exposed further to the west, beyond the assessment area, towards Thunder Bay.

Approximately two-thirds of the area of the four communities is underlain by the Ramsey-Algoma granitoid complex, which extends beyond this area to the east, west, and north (Figure 2). The bedrock in the southern third of this area is dominated by metasedimentary rocks and subordinated metavolcanic rocks of the Huronian Supergroup, and an inlier of the Ramsey-Algoma granitoid complex. Rocks of the Huronian Supergroup extend beyond this area to the east and west. Less areally extensive lithologies include thin slivers of greenstone belt affinity (Whiskey Lake and Benny Lake greenstone belts) distributed within the gneissic portion of the granitoid complex. In addition, mafic to ultramafic units of the East Bull Lake intrusive suite, the Parisien Lake syenite, and the Cutler pluton, among other small geological units, are present in the southern third of this area. As well, several generations of mafic dykes and brittle faults crosscut the area of the four communities with the former comprising a volumetrically significant portion of the total bedrock area. All mapped dykes post-date the older Archean rocks; however, as discussed further below, not all dykes post-date the metasedimentary rocks of the overlying Huronian Supergroup.

2.2.1 Whiskey Lake Greenstone Belt

The Whiskey Lake greenstone belt (Figure 3) consists of Archean metavolcanic and subordinated metasedimentary rocks that form an arcuate, easterly-striking, 10 km by 30 km, synclinal greenstone belt (Rogers, 1992). The greenstone belt has been subdivided into the Whiskey Lake greenstone belt for the portion south of the Folson Lake fault and a northern component named the Ompa greenstone belt (Easton, 2010) for the portion north of the Folson Lake fault. In the interest of simplicity and consistency with earlier nomenclature, the name Whiskey Lake refers to both components in this assessment. Radiometric (^{207}Pb/206^{Pb}) dating from greenstone rocks in the Joubin Township area, located 15 km west of the East Bull Lake intrusion, yielded ages of ca. 2.686 and 2.725 billion years, for upper and lower metavolcanic sequences (Easton, 2010; Easton and Heaman, 2011), while a similar age of 2.689 billion years was obtained from felsic metavolcanic rock of the northern portion of the greenstone belt (Easton, 2010). Drill holes in the Whiskey Lake greenstone belt in the vicinity of Folson Lake (AFRI # 41J08NW0001) indicate a thickness of at least 400 m for the greenstone rocks.

The Whiskey Lake greenstone belt is mostly composed of metavolcanic rocks in its eastern half. Metasedimentary rocks are more abundant in the western part of the greenstone belt. Although the greenstone belt is partly overlain by rocks of the Huronian Supergroup, there are large exposures of Archean greenstone rocks southeast and northwest of the easternmost portion of the Huronian Supergroup located in the vicinity of the City of Elliot Lake (Roscoe, 1969).

The eastern half of the Whiskey Lake greenstone belt consists of inter-layered tholeiitic and calc-alkalic metavolcanic rocks and rare, narrow horizons of bedded chert (Rogers, 1992). The tholeiitic rocks consist of massive and pillow basalt flows usually about 15 m thick. Mafic to felsic pyroclastic rocks, composing the calc-alkalic suite, occur as generally thin, less than 100 m thick, units of fine-grained tuff, exhibiting penetrative schistosity parallel to bedding (Rogers, 1992). These rocks are intruded by Archean gabbro dykes, sills, and stocks across the southern portion of the greenstone belt.

The mafic to intermediate metavolcanic portions of the greenstone belt are well-defined by discrete magnetic highs with a roughly east-west orientation; although, the widespread dyke activity makes it difficult to differentiate the more subtle responses of any felsic metavolcanic and metasedimentary rocks from adjacent rocks of the Ramsey-Algoma granitoid complex or the Huronian Supergroup. A slight gravity high is associated with the greenstone belt, which has a low radiometric response.

2.2.2 Benny Lake Greenstone Belt

The Benny Lake greenstone belt (Figure 3) consists of Archean metavolcanic and metasedimentary rocks that form an east-striking 40 km long by 5 km wide greenstone belt that extends from the Geneva Lake area to the Mink Lake area, some 70 km northeast of the City of Elliot Lake. The greenstone belt extends approximately 10 km into the area of the four communities to its mapped termination south of Mink Lake. Card and Innes (1981) described the central part of the belt as consisting of intercalated mafic flows and pyroclastic rocks with intermediate tuffs and tuff-breccia with some volcanogenic metasedimentary rocks including tuffaceous greywake and siltstone, chert, and iron formation. The stratigraphic sequence in this part of the belt comprises cyclic repetitions of mafic, intermediate, and felsic metavolcanics, plus sulphide-bearing tuffs and tuffaceous metasedimentary rocks that commonly lie along contact zones between the metavolcanic units. Outliers of the Huronian Supergroup have also been mapped in the area south of the greenstone belt.

Felsic plutonic rocks are noted to surround and intrude the greenstone rocks. Card and Innes (1981) subdivided these rocks into an older gneissic, granodioritic complex that occurs mainly to the north of the greenstone belt and a younger, relatively massive, homogeneous quartz monzonite that forms most of the terrain to the south, based on mapping carried out in 1973-74. Quartz monzonite, as used in 1973-74, may overlap with a number of fields in the currently used International Union of Geological Sciences (IUGS) classification. Although there is no published information on the age of this greenstone belt, Easton (2010) noted that the ages obtained for the Whiskey Lake greenstone belt mentioned above were consistent with 2.690 to 2.685 billion year old volcanism in the southern part of the Abitibi Subprovince, including the Benny Lake greenstone belt and other greenstone belts in the subprovince.

The greenstone sequence dips steeply to the south with a schistosity subparallel to the primary stratification. Movements on major northwest and north-northwest trending faults such as those along the Spanish River have resulted in progressive northward displacement of the Benny Lake belt from east to west.

The Benny Lake greenstone belt exhibits a similar aeromagnetic response to that of the Whiskey Lake greenstone belt, with the mafic to intermediate metavolcanic portions of the greenstone belt defined by magnetic highs with a roughly east-west orientation. A slight gravity high is associated with the Benny Lake greenstone belt.

2.2.3 Ramsey-Algoma Granitoid Complex

The Ramsey-Algoma granitoid complex is a large complex of granitoid and gneissic rocks divided in three large domains: Chapleau gneiss domain, Ramsey gneiss domain and Algoma plutonic domain (Jackson and Fyon, 1991). In the area of the four communities, the granitoid complex is dominated by the Algoma plutonic domain. Although some portions of the Algoma plutonic domain have been mapped in detail (e.g., Robertson, 1965a,b,c; Robertson and Johnson, 1965; Giblin, 1976; Giblin et al., 1977), the Algoma plutonic domain is generally not well studied. The Ramsey-Algoma granitoid complex is generally described in the literature as largely consisting of a massive to foliated granite-granodiorite suite intruding a tonalite-granodiorite suite. In addition, several narrow slivers of metavolcanic rock are mapped within the gneissic tonalite portion of the Ramsey-Algoma granitoid complex in the north part of the area of the four communities.

The Algoma plutonic domain consists of granitic and granodioritic rocks and granitic gneisses with numerous greenstone enclaves and massive to foliated granite, granodiorite, and syenite intrusions (Card, 1979); although, a variety of facies have been observed throughout the granitoid complex in the area of the four communities. For example, in the area of Rawhide Lake, about 15 km north of Elliot Lake, the Algoma plutonic domain consists generally of uniform, massive, medium to coarse-grained, equigranular granite (Ford, 1993). About 45 km northwest of Elliot Lake, in the area of Kirkpatrick Lake, the plutonic complex is reported to be predominantly composed of massive to foliated biotite-bearing to hornblende-bearing granitic rock with up to 30% amphibole. Minor, more leucocratic phases are typically quartz monzonite to granodiorite and trondhjemite. Further westward in the Wakomata Lake area, outcrops of pink to grey, equigranular, fine- to coarse-grained trondhjemite, quartz monzonite and granodiorite have been reported, of which grey, medium- to coarse-grained, leucocratic trondhjemite predominates (Siemiatkowska, 1977). Sage (1988) described granitic rock in the Seabrook Lake area as massive, medium- to coarse-grained, red to red-brown, leucocratic, granodiorite to quartz monzonite. In the area of East Bull Lake, Easton et al. (2004) reported mixtures of strongly foliated granitic gneiss and migmatitic facies enclosing mafic gneiss, whereas McCrank et al. (1989) described that area as comprising weakly to moderately foliated granodiorite and porphyroblastic granite. Lastly, Gordon (2012) noted massive, homogeneous syenogranite as the main plutonic phase in Otter Township, located just west of the area of the four communities.

Geochronology for the Algoma plutonic domain includes an age of 2.716 billion years old in the Batchawana area, about 60 km west of the area of the four communities (Corfu and Grunsky, 1987), and 2.662 billion years for the area south of Ramsey, about 20 km northeast of the area of the four communities (van Breemen et al., 2006). Heather et al. (1995) reported a preliminary age of ca. 2.727 billion years for biotite tonalite from immediately south of the Swayze greenstone belt to the northeast of the area of the four communities. More recently, Easton (2010) obtained preliminary dates of 2.675 and 2.651 billion years for two samples of granite and granodiorite near Elliot Lake. The wide range of dates suggests that the Algoma-Ramsey granitoid complex contains distinct plutonic and gneissic lithologies emplaced over a period of 75 million years and possibly longer. This interpretation is supported by van Breemen et al. (2006) who subdivided granitic rocks in the Swayze area, around 120 km north of Elliot Lake, into the following five broad categories:

- Synvolcanic diorite and hornblende tonalite intrusions ranging in age from ca. 2.740 to 2.696 billion years old;
- A transitional suite of tonalite and quartz monzonite intrusions ranging from ca. 2.695 to 2.686 billion years old;
- Syntectonic hornblende granodiorite intrusions ranging from ca. 2.685 to 2.686 billion years old;
- A younger transitional suite of tonalite and quartz monzonite intrusions ranging from ca. 2.680 to 2.665 billion years old; and
- Non-foliated ca. 2.665 billion year old post-tectonic granite intrusions occurring within areas of synvolcanic and syntectonic intrusions.

Although the Swayze area is located further north, it shares a similar tectonic setting to the northern part of the area of the four communities. Van Breeman et al. (2006) may therefore offer an interpretative framework for the largely unmapped Ramsey-Algoma granitoid complex within the northern part of the area of the four communities. Heather et al. (1995) also described a large body of massive Algoma biotite granite in the area southwest of Ramsey that extends into the area of the four communities.

There is only limited data on the thickness of the Ramsey-Algoma granitoid complex in the area of the four communities. Cruden (2006) used gravity and seismic measurements to estimate the regional thickness of late Archean granites to be on the order of 1 to 3 km thick, with the lower value assuming wedge-shaped plutons and the higher value corresponding to a tabular morphology.

2.2.4 Seabrook Lake Intrusion

The Seabrook Lake carbonatite intrusion is located within the northwest part of the area of the four communities some 80 km northwest of the City of Elliot Lake. Sage (1988) described the carbonatite as tadpole-shaped in plan-view, tapering to the south, and occupying an area of approximately 1.5 km^2. The northern portion is dominated by sovite and silicocarbonatite, while rocks of the ijolite suite dominate to the south. The intrusion occurs at the intersection of several regional lineaments, and Sage (1988) speculated that it may represent the southern limit of alkalic magmatism associated with faulting in the Kapuskasing structural zone which lies further to the north.

The carbonatite and ijolite are enclosed within an envelope of brecciated and fenitized granitic rock, which grades outward to an unbrecciated halo of fenitized granitic rocks up to 300 m wide. The granitic rocks are mapped as part of the Ramsey-Algoma granitoid complex and are described at this location (Sage, 1988) as typical of the late Archean granite diapirs found throughout the Canadian Shield. Texturally, the granite is massive, medium- to coarse-grained, red to red-brown, leucocratic, granodiorite to quartz monzonite with modal composition estimated as 35% quartz, 40 to 50% plagioclase, trace to 25% potassium feldspar, and up to 5% biotite. No petrographic evidence of recrystallization and/or metamorphism was noted by Sage (1988).

The granitic rocks enclosing the Seabrook Lake intrusion are crosscut by northwesterly-trending diabase dykes (Matachewan and Sudbury) but these dykes do not crosscut the carbonatite. The intrusion has been dated by K-Ar isotopic techniques at 1.109 and 1.107 billion years old (Gittins et al., 1967).

This intrusion is characterized by a central, east-northeast-striking, magnetic high and spotty magnetic highs beyond its mapped margin.

2.2.5 Parisien Lake Syenite

The Parisien Lake syenite is a late Archean, 2.665 billion year old (Krogh et al., 1984), elliptical intrusive stock located about 15 km east of the City of Elliot Lake, adjacent to the East Bull Lake intrusion. It measures approximately 13.5 km east-west and 3.3 km at its widest point north-south. The intrusion is composed of medium- to coarse-grained, pink, equigranular monzodiorite, monzonite and syenite (Rogers, 1992). Predominant minerals are K-feldspar phenocrysts, with interstitial amphibole, biotite, sphene, and magnetite, with a distinctive, locally developed K-feldspar alignment (McCrank et al., 1989). The Parisien Lake syenite is shown on Figure 3 as a diorite-monzonite-granodiorite suite. There is no readily available information on the thickness of this intrusion.

The Parisien Lake syenite, with its strong magnetic response, is clearly differentiated from the weakly magnetic East Bull Lake intrusion immediately to the north.

2.2.6 East Bull Lake Intrusive Suite

The East Bull Lake intrusive suite is located east of the City of Elliot Lake. It consists of a series of east-northeast-trending, elongated gabbro-anorthosite intrusions that were emplaced into Archean metavolcanic and metaplutonic rocks of the Superior Province during the early Proterozoic ca. 2.490 to 2.470 billion years ago (Easton et al., 2004). These intrusions are shown as mafic and ultramafic intrusive rocks on Figure 3. The East Bull Lake intrusive suite comprises three intrusions: 1) the East Bull Lake intrusion, which includes the East Bull Lake pluton and the intrusions to the north of the pluton; 2) the Agnew Lake intrusion; and 3) the May Township intrusion, located near Highway 17 east of the Town of Spanish, which is a thin sheet-like intrusion near the contact between Archean granitic rocks and the Huronian Supergroup.

The elliptical East Bull Lake pluton, about 15 km east of the City of Elliot Lake, has surface dimensions of at least 13.5 km east to west, and a maximum north-south extent of 3.5 km (Figure 3). It is about 780 m thick in its central part (McCrank et al., 1989). The East Bull Lake pluton has a U-Pb isotopic age of 2.480 billion years old (Krogh et al., 1984), and it is divided into several large composite rock units distinguishable by variations in mineral composition, texture, and style of internal layering (McCrank et al., 1982; James et al., 1985; Ejeckam et al., 1985). Within the composite units, mineralogical grading produced layers that grade from gabbro to leucogabbro, rhythmic layers that grade upwards from clinopyroxenite and gabbro, to anorthosite layers and thin, centimetre-sized laminations of clinopyroxenite within gabbroic rock (McCrank et al., 1989).

The main mass of the Agnew Lake intrusion is located about 35 km east of the City of Elliot Lake. It is similar in age and size to the East Bull Lake intrusion, with an estimated U-Pb isotopic age of approximately 2.491 billion years old (Krogh et al., 1984), a thickness of 1 to 2.1 km, and an area of 50 km^2 (Vogel et al., 1998). The primary axis of the Agnew Lake intrusion is east-west, similar to the East Bull Lake intrusion, and is thought to reflect the orientation of the rift structure that permitted magma intrusion (Easton et al., 2004), and would have shaped the Agnew Lake and the East Bull Lake intrusions originally into funnel-like bodies (Vogel et al., 1998). The Agnew Lake intrusion is linked to the East Bull Lake intrusive suite on its northwest side by the Streich dyke, a 200 to 300 m wide gabbronoritic body with a strike length of approximately 10 km (not shown on Figure 3). The Agnew Lake intrusion is a product of four major magma pulses that produced an internal layered distribution of gabbronorite, olivine gabbronorite and leucogabbronorite in the intrusive body, each ranging in thickness from a few tens of metres to hundreds of metres. The Camp Eleven fault bisects the intrusion and exhibits 600 m of dextral displacement of this internal layering (Vogel et al., 1998). The Agnew Lake intrusion was wholly emplaced in granitoid rocks of the Algoma plutonic domain, while the top of this intrusion corresponds to a major disconformity separating the Agnew Lake intrusion from the Huronian Supergroup (Vogel et al., 1998). Also, potentially related to the East Bull Lake suite is the Tennyson sill (Prevec, 1993), an approximately 650 m thick body of medium-grained gabbro north of Massey. The Tennyson sill intruded Archean granodiorite, but is crosscut by

Matachewan dykes. Easton (2010) interpreted the Tennyson sill to be a primitive phase of the East Bull Lake intrusive suite.

2.2.7 Cutler Pluton

The Cutler pluton is located south of the City of Elliot Lake (Figure 3) and extends west into Lake Huron (Giblin and Leahy, 1979). The pluton is an elongated muscovite-biotite granitic body with dimensions of approximately 3 km by 28 km. The pluton intrudes both metamorphosed rocks of the Huronian Supergroup and Nipissing intrusive rocks south of the Murray fault (Robertson, 1970; Card, 1978) along the axis of the doubly plunging Spanish anticline (Robertson, 1970). The pluton consists of different intrusive phases, medium- to coarse-grained, foliated quartz monzonite, granodiorite and tonalite. The Cutler pluton was emplaced approximately 1.75 billion years ago after the Penokean Orogeny (Wetherill et al., 1960). There is no readily available information on the thickness of this intrusion.

2.2.8 Huronian Supergroup

The Huronian Supergroup (Figures 2 and 3) is a stratigraphic sequence that extends for about 450 km from the east shore of Lake Superior to northwest Quebec, with varying thickness of up to 12 km southwest of Sudbury, thinning northward against rocks of the Ramsey-Algoma granitoid complex (Bennett et al., 1991). The Huronian Supergroup surrounds the City of Elliot Lake and overlies rocks of both the Whiskey Lake greenstone belt and the Ramsey-Algoma granitoid complex over large areas. Deposition of the thick Huronian stratigraphic package in a rift setting started approximately 2.497 billion years ago (Rainbird et al., 2006), influenced by Archean tectonic activity and possibly an early Proterozoic extension event, and was later succeeded by a passive-margin setting (Bennett et al., 1991; Young et al., 2001). Deposition ceased sometime before 2.219 billion years ago (Corfu and Andrews, 1986).

The Huronian Supergroup consists of a succession of four lithostratigraphic groups: the Elliot Lake Group is at the base and is overlain, in ascending order, by the Hough Lake, Quirke Lake and Cobalt groups. The Elliot Lake Group forms an eastward-thinning volcano-sedimentary package of uranium-bearing conglomerate beds and sandstone sequences associated with the extensional rifting events (Bennett et al., 1991). The other three groups represent three sedimentary cycles deposited in a continental passive-margin setting, intercalated by periods of Neoproterozoic glaciations (Bennett et al., 1991; Young et al., 2001). Each metasedimentary cycle typically consists of conglomerate, overlain by either mudstone, siltstone or carbonate, and is capped by coarse, cross-bedded sandstone (Roscoe, 1969).

The Huronian Supergroup sequence underwent subgreenschist facies metamorphism that resulted in highly indurated, non-porous quartzite and arkose-greywacke strata. The sequence was gently folded through north–south compression prior to the emplacement of Nipissing diabase intrusions (2.2 to 2.1 billion years ago). The Huronian Supergroup is also intruded by the Cutler pluton (Bennett et al., 1991) and several groups of mafic dykes such as Nipissing, Sudbury and unclassified dykes (Lewis, 2013) described in the section below.

The Huronian Supergroup strata are generally magnetically transparent. The southern part of the Huronian Supergroup shows a slightly higher magnetic response than the northern part, corresponding to the shallower and deeper underlying basement reflected by the Chiblow anticline and the east-west Quirke Lake syncline axes respectively (Johns et al., 2003). Two prominent, broadly north-west trending magnetic highs are observed east of Elliot Lake. The larger of the two anomalies is referred to as the Pecors magnetic anomaly, known to exhibit resource potential. The north-west orientation of these anomalies tends to be broadly coincident with the strike of the Matachewan dyke swarm through the area. Magnetic inversion modelling suggests that the source of the magnetic anomaly is located within the Archean bedrock underlying the Huronian Supergroup units (Hawke, 2011). The east-southeast oriented gravity high, previously described, occurs near the center of the Huronian Supergroup and is aligned with the Quirke Lake syncline. The Huronian Supergroup strata show a mixture of radiometric responses, with higher responses in the Quirke Lake syncline, particularly north and east of Elliot Lake.

2.2.9 Mafic Dykes

Mafic dykes and intrusions of diabase and gabbroic composition are widespread in and around the area of the four communities (Figure 3). Although the similar composition and texture of these intrusions has hampered the determination of their age and character, most of the studies carried out in the area of the four communities have historically assigned the mafic intrusions and dykes either to the Matachewan or Nipissing suites. More recent studies (Osmani, 1991; Phinney and Halls, 2001) indicate the presence of at least four distinct generations of mafic dyke emplacement: Matachewan swarm, Nipissing intrusions, Biscotasing swarm, Sudbury swarm, North Channel swarm, and younger unclassified dykes (in addition to the local occurrence of highly deformed unclassified mafic dykes of Archean age). The determination of age relationships is further hampered by the widespread occurrence of composite dykes, resulting from multiple injections of magma into the same fracture system (Easton, 2009). Finally, Easton (2010) noted that south of approximately 46°42′N, the Matachewan swarm diabase dykes lose their magnetic character, making their identification based on aeromagnetic response problematic.

The main generations of mafic dykes in the area of the four communities are described in the following subsections.

Matachewan dykes

Matachewan diabase dykes are early Proterozoic intrusions ca. 2.473 billion years old (Buchan and Ernst, 2004). These dykes form the oldest and most extensive dyke swarm, cutting the Archean Superior Province rocks, and are characterized by a north-northwest orientation and the display of large phenocrysts of plagioclase in an epidote-rich matrix (Robertson, 1977). Variations can be found in particular areas; for example, in the area of Albanel Township, located approximately 35 km northwest of Elliot Lake, these dykes are equigranular, fine- to medium-grained, composed predominantly of hornblende and plagioclase, and vary in width from 2 to 20 m (Lewis, 2013). In the Pecors-Whiskey Lake area, Easton (2010) noted dyke widths of up to 150 m and identified two compositional groups: non-phyric and plagioclase-phyric with phenocrysts up to 3 mm in size. The majority of the mafic dykes cutting the Archean terrane beneath the northern half of the area of the four communities and south and east of the

Quirke Lake syncline are considered to be Matachewan dykes, which have also been related to the East Bull Lake intrusive event and may be related to the basal Thessalon Formation basaltic flow deposits (Vogel et al., 1998; Easton, 2009). The Matachewan dykes in the East Bull Lake area trend northwestward through the Archean terrain of the northern half of the assessment area (Figure 3). Easton (2010) noted that in the area south of Elliot Lake, Matachewan dykes constitute roughly 60 to 75% of the mafic dykes exposed in outcrop with this percentage rising to approximately 90% in the Whiskey Lake area. The Matachewan dykes predate the deposition of the sedimentary rocks of the Huronian Supergroup, but they may have served as feeders for the volcanic rocks of the Huronian Supergroup (Buchan and Ernst, 2004), given their similar age and geochemical affinity (Vogel et al., 1998).

Nipissing intrusions

The Nipissing intrusions consist of early Proterozoic mafic bodies of irregular sill-like and dyke-like geometry, approximately 2.21 billion years old (Corfu and Andrews, 1986; Palmer et al., 2007). These intrusions post-date the Matachewan dykes and cut both the Archean basement and the folded Huronian Supergroup. In the area of the four communities, mapped Nipissing intrusions are confined to the Huronian Supergroup and adjacent crystalline rocks of the Ramsey-Algoma granitoid complex. These undulating sill-like intrusions are up to around 460 m thick, and roughly parallel the regional east-west structural-stratigraphic trends (Lovell and Caine, 1970; Card and Pattison, 1973; Card, 1976), predominating over much less frequent dyke-like intrusions of tens of metres wide, and other intrusive bodies interpreted as cone sheets (Palmer et al., 2007).

Most of the Nipissing intrusions consist of uniform, undifferentiated quartz diabase; nevertheless, more differentiation exists in the area of the four communities, as quartz diabase and two-pyroxene gabbro appear to be the most common Nipissing intrusive rock type (Lightfoot et al., 1993). Other varieties of Nipissing intrusive rocks consist of olivine gabbro, hornblende gabbro, feldspathic pyroxenite, leucogabbro, granophyric gabbro and granophyre (Card and Pattison, 1973). In the Iron Bridge area (at the intersection of Highway 17 and Highway 546), steeply dipping, metagabbro bodies are dominant (Bennett et al., 1991). The gabbros are massive, but commonly display weak foliations near their contacts with other rocks. Some sills are altered mainly by hydrous fluids produced by the elevated temperature and pressure of regional metamorphism (Card, 1964).

The Nipissing intrusions seem to have been emplaced during at least two magmatic pulses from approximately 2.209 to 2.218 billion years ago (Buchan et al. 1989; Palmer et al., 2007). No major tectonic event has been identified to be the source of the Nipissing intrusive rocks (Bennett et al., 1991), but subduction of oceanic crust with some continental crustal contribution could possibly account for their emplacement (Lightfoot et al., 1993), or a second extensional event (Jackson, 2001). More recently, however, Palmer et al. (2007) suggested that coeval Seneterre dykes acted as feeders for the Nipissing intrusions, mostly based on measurements of anisotropy of magnetic susceptibility and age correlation, but apparently also supported by geochemical affinities.

Biscotasing dykes

Biscotasing dykes are prominent, regional northeasterly-trending vertical features that have been identified within the northern half of the assessment area, where they cut rocks of the Archean basement, and further south where they transect the Huronian Supergroup. At the regional scale these dykes extend from the Flack Lake syncline northeast several hundred kilometres to the Lake Abitibi area. The dykes have been dated at 2.167 billion year old (Buchan et al., 1993). These dykes, also formerly referred to as the Preissac dykes, are quartz tholeiitic features usually 50 to 100 m in width, with fine-grained chilled margins and medium- to coarse-grained interiors (Buchan et al., 1993; Halls et al., 2008), which were emplaced along fault structures that possibly pre-date the dykes. Compositionally, the Biscotasing dykes are composed of approximately 50% plagioclase, 30% pyroxene, up to 10% quartz, and several percent magnetite–ilmenite intergrowths. Alteration of the dykes is highly variable from one dyke to another and within individual dykes (Buchan et al., 1993).

Sudbury dykes

Archean rocks in the area of the four communities in the vicinity of East Bull Lake intrusive suite are themselves intruded by Proterozoic, post-Nipissing mafic dykes that correlated with the 1.238 to 1.235 billion years old Sudbury dyke swarm (Krogh et al., 1987). These younger dykes typically range in composition from olivine diabase, amphibole diabase, diabase, magnetite-bearing diabase to lamprophyre diabase. All have in common a narrow width, generally less than 10 m, and a west-northwest orientation; they appear to have filled the space of older northwest-trending faults (Easton, 2009). Dykes of this age and composition are scarce or absent within a prism-shaped area of approximately 150 km^2 centered on Elliot Lake (Robertson, 1968; Easton, 2009).

North Channel dykes

A suite of west-northwest striking mafic dykes occurs along the southern portion of the area of the four communities. Previously mapped as part of the Nipissing dyke swarm, these dykes are now considered to represent a separate phase of intrusion and they are mapped separately in the most recent seamless geology coverage of Ontario (OGS, 2011) which gives an age range from 1.6 to 2.5 billion years old.

Younger dykes

Archean rocks in the area of the four communities are also intruded by younger post-Sudbury dykes including olivine lamprophyres (Siemiatkowska, 1977). These late intrusions were mapped crosscutting the Seabrook carbonatite intrusion (Sage, 1988) suggesting an emplacement age that post-dates ca. 1.1 billion years ago. Easton (2010) also recognized several intrusions in the area of the four communities that could not be confidently assigned to the extensive Nipissing intrusions, one of which seem to correlate with that observed more recently by Lewis (2013) in the Albanel Township area.

2.2.10 Faults

Mapped structures in the area of the four communities include large-scale folds, several mafic dyke swarms of different age and orientation, and a mosaic of brittle faults (Figures 2 and 3). Their complex present day geometrical arrangement is attributed to the protracted history of tectonic events that has overprinted the area, as described in Section 2.3. At the broader regional scale, additional prominent structures include the Sudbury Igneous Complex, the Kapuskasing structural zone and the Grenville Front tectonic zone (Figure 2). The following paragraphs provide additional details on these structural features.

During the Penokean Orogeny and earlier deformational periods, both the Archean basement and Huronian Supergroup were affected by different degrees of folding, deformation and faulting. The synformal structure of the Whiskey Lake greenstone belt and its belt-parallel foliation is evidence of early structural overprinting related to the Archean amalgamation of the Superior Province. The development of the Quirke Lake syncline, Chiblow anticline and Flack Lake syncline (Figure 3) occurred between approximately 2.219 and 1.8 billion years ago in response to northward compression that included tectonic events attributed to the Penokean Orogeny (e.g., Zolnai et al., 1984; Easton, 2013). The regional scale folding is also evident in the map pattern of the gneissic tonalite suite of the Ramsey-Algoma granitoid complex wrapping around a massive granodioritic to granitic core (e.g., Figure 3).

Several distinct mafic dyke swarms form some of the most prominent geological features within the area of the four communities and surrounding region (Figures 2 and 3). These include the northwesterly trending intrusions corresponding to the ca. 2.473 billion year old Matachewan dyke swarm (Buchan and Ernst, 2004). Volumetrically, these are the most prominent dyke swarms in the region and their mapped spacing of about 1 to 3 km may not be indicative of their detailed distribution, as suggested by detailed mapping studies undertaken elsewhere (e.g., Halls, 1982). The Matachewan dykes are orthogonally crosscut by the approximately east-west trending ca. 2.22 billion year old Nipissing intrusions (Corfu and Andrews, 1986); the younger, less frequent, northeasterly trending ca. 2.167 billion year old Biscotasing dykes (Buchan et al., 1993); and the east-northeast trending 2.1 billion year old Kapuskasing/Marathon dykes (not mapped within the area of the four communities). Later emplacement of the ca. 1.238 billion year old Sudbury dyke swarm (Krogh et al., 1987), and a suite of mafic dykes of uncertain affinity and unknown age (ca. 2.5 to 1.6 billion years old) referred to as the North Channel dyke swarm (OGS, 2011), provide evidence of the long and complicated crustal deformation that has occurred in the area of the four communities.

The various mafic dyke swarms are associated with, and overprinted by, regional and local scale brittle fractures or fault systems that are also evident throughout the area of the four communities. The faults include northwest-trending strike-slip faults (e.g., the Spanish American, Pecors Lake and Horne Lake faults) that cut the Huronian Supergroup, and the parallel Nook Lake fault within the Archean basement directly north of the Quirke Lake syncline (Robertson, 1968). These faults locally offset diabase dyke intrusions across some fault traces (Spanish American and Horne Lake faults), and offset diabase sills across others (Pecors Lake fault). Thrust faults also occur in the sedimentary sequence parallel to the axis of the syncline and over-thrusting toward the north such as the Quirke Lake fault (Robertson, 1968).

The regional scale arcuate east-trending Flack Lake fault (Figure 3) extends for about 150 km and transects both the Huronian Supergroup rocks and the Ramsey-Algoma granitoid complex. The Flack Lake fault is interpreted as a north-directed listric thrust that reactivated an earlier normal fault. Its movement history may be related to post-Nipissing and Penokean events (Bennett et al., 1991).

The Murray fault (referred to in the literature by some as the Murray fault zone) is a major east-trending structure that can be traced a few hundred kilometres from Sault Ste. Marie to Sudbury (Robertson, 1967). Within the area of the four communities, the Murray fault parallels the shoreline of Lake Huron (Figure 3) where it is a steeply south-dipping fault zone with approximately 15 to 20 km of reverse sense offset (Zolnai et al., 1984). It records both dextral (Bennett et al., 1991), and sinistral (Abraham, 1953) movement. The Murray fault appears to have been initiated prior to deposition of the Huronian Supergroup, but periodic reactivation occurred synchronous with and after sediment deposition (Reid, 2003; Dyer, 2010). As discussed in Section 2.3, the most recent movement of the Murray fault was during the Grenville Orogeny (Robertson, 1970; Card, 1978; McCrank et al., 1989; Piercy, 2006). North of the fault, the Huronian Supergroup deposits are largely fluvial and accumulated to depths of about 5 km, while south of the fault the deposits are dominated by turbidites that accumulated to depths of 15 to 20 km as reflected by their higher metamorphic grade (Bennett et al., 1991). North of the Murray fault, the Huronian Supergroup is considered largely unmetamorphosed, ranging from sub-greenschist to lower greenschist (Bennett et al., 1991). South of the Murray fault, metamorphism increases to middle greenschist and upward to amphibolite facies (Bennett et al., 1991; Jackson, 2001).

Detailed mapping at the East Bull Lake pluton (Ejeckam et al., 1985) highlights the northwest-trending Folson Lake and East Bull Lake faults, and the east-trending Parisien Lake deformation zone. The Folson Lake fault offsets the East Bull Lake intrusion with approximately 3 km of dextral movement and the fault lineament is traceable for approximately 45 km trending northwest (McCrank et al., 1989). Cataclastic zones up to 10 m wide associated with various episodes of movement and dyke injection were identified and drilling difficulties were experienced where these zones were intersected at depth (McCrank et al., 1989). Some evidence gained from dyke-fault relationships suggests that the Folson Lake fault may have been active prior to the injection of the East Bull Lake intrusion while potassium feldspar (adularia) from a hydrothermal vein suggests reactivation ca. 940 million years ago during a later stage of the Grenville Orogeny. Additional fractures and minor faults occur in several preferred orientations, the most common being subparallel to the Folson Lake fault, to mafic dykes and to topographic lineaments (McCrank et al., 1989). The contact between the East Bull Lake pluton and the Huronian Supergroup seems to be faulted, but this has not been confirmed (Easton et al., 2004). In the Whiskey Lake area, at least some of these faults have been inactive since the Archean Eon as shear zones are cut by Archean granitoid rocks that do not appear to be affected by subsequent deformation (Easton, 2010).

Proximal to the area of the four communities, there are several tectonic features of importance. The north-northeast-trending KSZ is an approximately 150 km wide by 500 km long fault-bounded block, located to the northwest of the area of the four communities, which subdivides the Superior Province into eastern and western halves (Percival and West, 1994). The KSZ consists of Archean granulite facies metasedimentary rocks derived from a lower crustal environment (high pressure and temperature) that was brought to higher levels in the crust along the major westward dipping thrust fault and shear zones during the Penokean Orogeny (Percival and West, 1994). The maximum uplift along the fault zone is in the order of 30 to 40 km based on the granulite metamorphic facies of the zone being brought into juxtaposition with greenshist facies rock. Continued tectonic activity in proximity to the KSZ is evidenced by the emplacement of alkalic complexes as recently as ca. 1.1 billion years ago (Sage, 1991). The ca. 1.85 billion year old Sudbury Igneous Complex, located east of the area of the four communities, is generally considered to represent the scar of a meteorite impact event that occurred during the Penokean Orogeny (Young et al., 2001). The Grenville Front tectonic zone, located to the southeast of the area of the four communities represents the mapped northwestern boundary of rocks affected by the Grenville Orogeny. While acknowledging their existence, it is unclear what effect the development of these regional structures had on the local structural complexity of the area of the four communities.

2.2.11 Metamorphism

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in several publications, including Fraser and Heywood (1978), Kraus and Menard (1997), Menard and Gordon (1997), Berman et al. (2000), Easton (2000a,b), Holm et al. (2001) and Berman et al. (2005). The thermochronologic record for major parts of the Canadian Shield is given in a number of studies such as those by Berman et al. (2005), Bleeker and Hall (2007), Corrigan et al. (2007), and Pease et al. (2008). Overall, most of the Canadian Shield, outside of unmetamorphosed late tectonic plutons, contains a complex episodic history of tectonometamorphism largely of Neoarchean age with broad tectonothermal overprints extending from the Paleoproterozoic to the end of the Grenville Orogeny approximately 0.95 billion years ago.

The Superior Province largely preserves low pressure – low to high temperature Neoarchean metamorphism from ca. 2.710 to 2.640 billion years ago, but there is a widespread tectonothermal overprint of the Archean crust by Paleoproterozoic deformation and typically amphibolite facies metamorphism across the Churchill Province through northernmost Ontario under the northern Hudson Bay Lowland, western Manitoba, northern Saskatchewan and Nunavut (e.g., Skulski et al., 2002; Berman et al., 2005).

In the Archean Superior Province, the relative timing and grade of regional metamorphism corresponds to the lithologic composition of the subprovinces (Easton, 2000a; Percival et al., 2006). Granite-greenstone subprovinces contain the oldest metamorphism of lower greenschist to amphibolite facies in volcano-sedimentary assemblages and synvolcanic to syntectonic plutons. Both metasedimentary and associated migmatite-dominated subprovinces, such as the English River and Quetico subprovinces, and dominantly plutonic and orthogneissic subprovinces, such as the Winnipeg River Subprovince, display younger, syntectonic middle amphibolite to granulite facies metamorphism (Breaks and Bond, 1993; Corfu et al., 1995).

Subgreenschist facies metamorphism in the Superior Province is restricted to limited areas, notably within the central Abitibi greenstone belt (e.g., Jolly, 1978; Powell et al., 1993) and locally within the Uchi Subprovince (Thurston and Paktunc, 1985). Most late orogenic shear zones in the Superior Province experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through $^{40}Ar/^{39}Ar$ dating to ca. 2.50 billion years ago (Powell et al., 1995). The distribution of contrasting grades of metamorphism is a consequence of relative uplift, block rotation and erosion from Neoarchean orogenesis and subsequent local Proterozoic orogenic events and broader epeirogeny during Proterozoic and Phanerozoic eons.

Metamorphic grade in the area of the four communities is largely of subgreenschist facies north of the Murray fault, east and north of Blind River. South of the fault (Piercey, 2006), metamorphism increases to localized lower amphibolite facies extending eastward between Blind River, Sudbury and the Grenville Front (Riller et al., 1999). Most authors (e.g., Zolnai et al., 1984) have considered the medium grade metamorphism reached south of the Murray fault to be a product of tectonothermal burial. However, Jackson (2001) pointed out that the high temperature-low pressure metamorphism reached could not be solely the result of burial, and he advanced the alternative of a second period of crustal extension in the area of the four communities. This hypothesis would not only account for the required heat for medium grade metamorphism but would also explain the emplacement of Nipissing intrusions. Holm et al. (2001) suggested that peak Penokean Orogeny metamorphism occurred ca. 1.835 billion years ago, based on monazite ages. More recently, Piercey (2006) pointed out that the Penokean Orogeny was only the first of several accretionary events that impinged on the southern Laurentide margin and presented evidence of a younger and more significant, ca. 1.7 billion year old, metamorphic event possibly related to the Yavapai tectonothermal pulse. This event may have affected the metamorphic conditions in the area of the four communities and possibly increased the metamorphic overprint to greenschist facies, at least in the area proximal to the Cutler pluton, on the north side of the Murray fault. Also north of the Murray fault, Fedo et al. (1997) pointed out that a ca. 1.7 to 1.75 billion years ago metasomatic event is evident in potassic and sodic alterations of the Huronian Supergroup. This event is probably what replaces most metamorphic minerals in the Huronian Supergroup with white mica and is presumably related to fluid-flow driven by post-orogenic uplift of the Penokean Orogeny. Minor contact metamorphism exists in the metavolcanic rocks of the greenstone belt near some of the large Proterozoic mafic intrusions (Rogers, 1992).

2.3 Geological and Structural History

The geological and structural history of the area of the four communities spans almost 3 billion years and includes both Archean and Proterozoic orogenic events, periods of intense felsic and mafic intrusive activity, and complex brittle deformation. The geological history is moderately well understood in the south where the Huronian Supergroup is exposed, but is less well constrained for the underlying Archean Ramsey-Algoma granitoid complex further to the north and east. The geologic and structural history is discussed below and summarized in Table 1. The discussion integrates the results from studies undertaken mainly within and proximal to the Huronian Supergroup, augmented by studies within the Swayze area (van Breemen et al., 2006), approximately 120 km north of Elliot Lake, to present an integrated geological and structural history for the area of the four communities.

The oldest rocks in the area of the four communities include the isolated greenstone belt slivers of the ca. 2.725 to 2.686 billion year old Whiskey Lake and Benny Lake greenstone belts, which are themselves intruded by and deformed with the Ramsey-Algoma granitoid complex. Geochronology for the Ramsey-Algoma granitoid complex spans the period between ca. 2.716 and ca. 2.651 billion years (Corfu and Grunsky, 1987; Easton, 2010), indicating that these rocks were emplaced and deformed during the same cratonization event that is characteristic of the regional scale deformation history of the Superior Province.

At the beginning of the Proterozoic Eon, approximately 2.5 billion years ago, an Archean supercontinent (Williams et al., 1991) began fragmentation into several continental masses, including the Superior craton, caused by a widespread and voluminous magmatic event that took place in the Lake Superior region (Heaman, 1997). This magmatic event is associated with rifting and intracratonic development of basins in many areas across the Lake Superior region. Major regional-scale faults such as the Murray and Flack Lake faults were likely formed during the rifting event or represent pre-existing structures reactivated during rifting.

Continental extension at the southern margin of the Superior craton, particularly in the Lake Huron area, allowed intrusion of coeval and comagmatic, mafic-ultramafic geological units such as the ca. 2.49 to 2.47 billion year old Agnew Lake and East Bull Lake intrusions, and contemporaneous to slightly younger (ca. 2.473 billion year old) Matachewan dyke swarm (Vogel et al., 1998; Buchan and Ernst, 2004; Easton, 2009). The timing of intrusion of the mafic and ultramafic units is also approximately contemporaneous with deposition of the basal volcanic rocks of the Huronian Supergroup (Rainbird et al., 2006) upon the Archean basement. The current areal extent of the intrusions likely represents the deformed and erosional remnants of one or more sill-like bodies that may originally have formed an extensive and interconnected mafic sheet (Vogel et al., 1998); similarly, the original extent of the volcanic rocks was much greater than that which is exposed today (Easton, 2010).

The area of the four communities was overprinted by a poorly understood tectonic event, the Blezardian Orogeny, during deposition of the metavolcanic and overlying metasedimentary rocks of the basal portion of the Huronian Supergroup from source regions to the east and northeast (Rainbird et al., 2006). The Blezardian event is interpreted to represent a short-lived orogenic pulse within a larger extensional tectonic setting (Schneider and Holm, 2005). The Blezardian Orogeny is interpreted to have been underway between ca. 2.47 and 2.4 billion years ago (Riller et al., 1999), and ended before ca. 2.30 billion years ago (Raharimahefa et al., 2011; Hoffman, 2013). It was characterized by the development of rifted and structurally-controlled depressions that themselves controlled the deposition of the basal portion of the Huronian Supergroup (Riller et al., 1999; Young et al., 2001). The Blezardian Orogeny is also thought to have initiated the map-scale thick-skinned folding of the Archean basement and rocks within the basal portion of the Huronian Supergroup (Riller et al., 1999).

The rift setting ultimately evolved into a passive margin setting, reflective of a more advanced stage of ocean-opening conditions of a Wilson cycle (Young et al., 2001; Bekker et al., 2005) during deposition of the remainder of the Huronian Supergroup. Deposition continued until between ca. 2.22 and 2.10 billion years ago (Corfu and Andrews, 1986) when rocks of the Archean basement and the Huronian Supergroup were pervasively intruded by the ca. 2.2 to 2.1

billion year old Nipissing intrusions (Lightfoot et al., 1993). The area of the four communities was subsequently overprinted by the Penokean Orogeny that occurred ca. 1.89 to 1.84 billion years ago (Sims et al., 1989). At the regional scale, the Penokean Orogeny is marked first by the beginning of ocean closure and development of the Pembina-Wasau volcanic arc terrane ca. 1.889 to 1.860 billion years ago (Sims et al., 1989), which was later accreted to the southern margin of the Superior craton in the Lake Superior area (ca. 1.860 billion years ago). This was followed by indentation of the Marshfield terrane ca. 1.840 billion years ago in what is today part of Wisconsin and Illinois (Sims et al., 1989; Schulz and Cannon, 2007). Whether either the Pembina-Wasau terrane or the Marshfield terrane extended to the Lake Huron area, or whether in this latter area the oceanic crust was subducted, remains unknown (Riller et al., 1999). In the Lake Huron area, the Penokean Orogeny involved the reactivation of pre-existing listric normal faults, such as the Murray and Flack Lake faults, enhancement of the pre-existing (Blezardian) folds in the basement and cover rocks, and the northward thrust of rocks of the Huronian Supergroup. Together, these deformation events produced burial depths of up to 15 km for the basal rocks of the Huronian Supergroup (Zolnai et al., 1984). An associated metamorphic overprint was insignificant to the north of the Murray fault, where sub-greenschist facies assemblages are preserved. Amphibolite facies were reached southward of the Murray fault (Piercey, 2006), but seem to be associated with younger tectonothermal pulses such as the Yavapai Orogeny, which occurred ca. 1.75 billion years ago (Piercey, 2006).

In addition, there may be structural overprinting along the eastern part of the area of the four communities resulting from the ca. 1.85 billion year old emplacement of the Sudbury Igneous Complex. The Sudbury Igneous Complex is generally considered to represent the scar of a meteorite impact event that occurred during the Penokean Orogeny (Young et al., 2001). Breccias within metamorphosed argillites of the Huronian Supergroup are known from the Whitefish Falls area approximately 70 km southwest of Sudbury and slightly to the southeast of the area of the four communities. These are attributed (Parmenter et al., 2002) to the Sudbury impact event and their distance suggests a diameter in excess of 200 km for the entire impact ring structure. Similar estimates are given by Thompson and Spray (1996) who inferred an original diameter of as much as 250 km for the Sudbury structure based on the distribution of pseudotachylyte. This distance encompasses the eastern third of the area of the four communities and structures related to the Sudbury impact may therefore be present within the area.

Around 1.238 to 1.235 billion years ago, a swarm of dykes intruded the bedrock in the area of the four communities. These are the Sudbury swarm mafic dykes which crosscut all bedrock units in the area of the four communities. The effects of later orogenic events, such as the Grenville Orogeny (ca. 1.250 to 0.980 billion years ago), remain unknown in the area of the four communities; although, towards the Grenville Front (the northwesternmost boundary of the area defining the Grenville Orogeny), the pre-existing mafic dykes are deformed and disrupted from their through-going nature further away from this young orogenic belt.

Around ca. 1.1 billion years ago, a continental-scale rifting event in the Lake Superior area produced the Midcontinent Rift structure (Van Schmus, 1992) that extends southward via an eastern branch down through Minnesota, and via a western branch from Sault Ste. Marie to central Michigan. The rifting event included deposition of large volumes of volcanic rocks and voluminous emplacement of mafic intrusions (Heaman et al., 2007).

Uplift and erosion of bedrock occurred over a protracted period following the rifting event such that at the end of the Precambrian Eon (ca. 540 million years ago), the folded and faulted terrain of the area of the four communities had been eroded to a peneplain roughly approximating the bedrock surface seen today over much of the area. Resistant strata of the Huronian Supergroup formed topographic ridges that persist to the present time, such as the La Cloche Mountains near Espanola. During the Paleozoic Era, commencing in the late Cambrian to early Ordovician Periods, most, perhaps all, of the area of the four communities was submerged beneath shallow seas and overlain by flat-lying carbonate and shale formations. Subsequent uplift and erosion during the late Paleozoic/Mesozoic eras stripped the Paleozoic cover from the area of the four communities. Weathering and erosion of the re-exposed Precambrian surface continued throughout the Cenozoic Era.

The area of the four communities was glaciated during the Pliocene-Pleistocene ice ages when a series of continental ice sheets moved southward across the area (Barnett et al., 1991; Reid, 2003). The advance of the ice sheets and subsequent outwash of meltwaters during glacial retreat scoured the bedrock surface, removing residual soil and weathered rock, and exposing fresh polished bedrock surfaces. Glacial erosion may have enhanced the numerous geological linear features that characterize the area of the four communities where deeper residual soils and weathered rock occurred in association with faults, dykes and formational contacts (e.g., greenstone/granite contacts) of contrasting hardness. This erosion established drainage patterns and lakes which tend to follow the various structural lineaments.

Table 1. Summary of the geological and structural history of the communities of Elliot Lake, Blind River, The North Shore and Spanish, and surrounding area.

Approximate Time Period (billion years ago)	Geological Event
2.72 to 2.651	Kenoran Orogeny: • Emplacement and deformation of the ca. 2.72 to 2.68 billion year old Whiskey Lake and Benny Lake greenstone belts and ca. 2.716 to 2.651 billion year old Ramsey-Algoma granitoid complex. Intrusion of the ca. 2.665 billion year old Parisien Lake syenite. • Development of folds and east-trending foliation in the greenstone belts (ca. 2.72 to 2.70 billion years ago). [D_1]
<2.651 to 2.5	• Early (re)activation of NE-, ENE-, WNW- and NW-striking faults (e.g., Murray and Flack Lake faults) [D_2]
2.497 to 2.47	Onset of continental break-up [D_3]; rifting in many areas across Lake Superior. • Deposition of volcanic rocks and basal sedimentary rocks of the Huronian Supergroup. • Reactivation, or continued activity, of WNW- to NW- and E-striking faults. Widespread mafic magmatism, and emplacement of: • Agnew Lake intrusion and East Bull Lake intrusion 2.49 to 2.47 billion years; ca. 2.473 billion years Matachewan dyke swarm.
2.47 to > 2.3	Blezardian Orogeny. [D_4] • Thick-skinned folding of Archean basement and basal rocks of the Huronian Supergroup. Initiation of Quirke Lake syncline and Chiblow anticline.

Approximate Time Period (billion years ago)	Geological Event
< 2.3 and > 2.1	Transition to passive margin setting; • Continued deposition of sedimentary rocks of Huronian Supergroup. • Emplacement of ca. 2.2 to 2.1 billion year old Nipissing diabase intrusions and ca. 2.17 to 2.15 billion year old Biscotasing dyke swarm.
2.10 to 1.89	Denudation of bedrock and formation of peneplain.
1.89 to 1.84	Penokean Orogeny. [D_5] • Crustal shortening and development of thrust-and-fold belt in rocks of the Huronian Supergroup, buckling and faulting of Archean basement. • Subgreenschist and amphibolite grade metamorphic overprint to north and south of Murray fault, respectively. • Emplacement of the Sudbury Igneous Complex ca. 1.85 billion years ago.
1.75 to 1.7	Emplacement of ca. 1.7 billion years Cutler pluton and metamorphic overprint south of Murray fault. Ca. 1.75 to 1.7 billion years ago, a metasomatic event of the Huronian Supergroup (Fedo et.al., 1997).
1.238 to 1.235	Emplacement age of Sudbury dyke swarm and related intrusions of unclassified olivine diabase dykes.
1.25 to 0.98	Grenville Orogeny (overprint in area of the four communities is unclear) • Development of Midcontinent Rift (ca. 1.1. billion years ago) (D_6)
< 1.1 to present	ca. 1.1 to 0.54 billion years ago: denudation of bedrock, formation of peneplain (continuation of D_6). Post-0.54 billion years ago: sedimentation, erosion, ingression and regression of sea water, shallow sea, glaciations. Exhumation of peneplain.

The structural history in the area of the four communities is complex. Recent geologic investigations within the area of the four communities and its vicinity conclude that the region has undergone complicated polyphase deformation (e.g., Card et al., 1972; Young, 1983; Riller et al., 1999; Jackson, 2001; Easton, 2005). The most comprehensive studies on the structural geology of the area of the four communities and its vicinity have been carried out by Zolnai et al. (1984), Riller et al. (1999) and Jackson (2001). These and other investigations documenting the structural geology of particular portions of the area of the four communities (e.g. Easton, 2005) support the existence of two main deformation events which have overprinted all bedrock lithologies. These have been assigned to the aforementioned Blezardian and Penokean orogenies. It should be noted, however, that the occurrence of the Penokean Orogeny in the area of the four communities remains controversial with some authors (e.g. Davidson et al., 1992; Piercey et al. 2003).

It is understood that there are potential problems in applying a regional deformation numbering (Dx) system into a local geological history. Nonetheless, the following summary offers an initial interpretation for the area of the four communities, which may be modified in future if site-specific information is collected.

The earliest deformation phase (D_1) is associated with ca. 2.72 to 2.7 billion year old penetrative deformation of rocks of the Whiskey Lake greenstone belt. According to Jensen (1994), this penetrative deformation is represented by foliation closely paralleling the strike and dip of the metavolcanic and metasedimentary strata composing the greenstone belt. The foliation was likely developed concurrent with folding which is expressed by a west-northwest-trending, isoclinal syncline that strikes about 110°E and dips approximately 70°NE. Recently, Easton (2010) reported the existence of an east-trending shear zone apparently overprinting only the greenstone rocks. Later truncation of the foliation by plutonic material indicates that much of this deformation occurred prior to at least the youngest phase of emplacement of the ca. 2.716 to 2.651 billion year old Ramsey-Algoma granitoid complex (Jensen, 1994).

Subsequent to emplacement of the Ramsey-Algoma granitoid complex, a series of northeast-striking sinistral strike-slip faults and later subvertical, east-northeast-striking faults exhibiting sinistral-oblique movement were formed along the margins of the greenstone belts. The earliest activation along regional east-trending faults, such as the Murray and Flack Lake faults, is attributed to this deformation. This early faulting episode, defined herein as the D_2 event, is poorly constrained to have occurred between ca. 2.651 and 2.5 billion years ago.

Subsequently, a large-scale rifting event (D_3) overprinted the area of the four communities in association with the ca. 2.497 to 2.47 billion year old break-up of the Superior Craton (Williams et al., 1991). This deformation event also involved continued activation along regional faults, including the Murray and Flack Lake faults, and overlapped in time with the deposition of the basal volcano-sedimentary rocks of the Huronian Supergroup (Jensen, 1994). These faulting episodes also involved dextral, west-northwest- to northwest-striking fault reactivation crosscutting the earlier formed structures throughout the Huronian Supergroup (Jackson, 2001). These younger faults also cut the Archean basement and the Murray fault (Jackson, 2001). Alternatively, Jensen (1994) and Jackson (2001) suggested that some of the faults in the area of the four communities may have initiated as Archean structures that subsequently experienced a long history of reactivation during and post-dating the Penokean Orogeny.

D_3 also overlaps in time with the widespread emplacement of mafic intrusions such as the Agnew Lake intrusion and the East Bull Lake intrusive suite (Vogel et al., 1998; Easton, 2009), as well as the pervasive Matachewan dyke swarm. Numerous, narrow, discontinuous shear zones that range from east-northeast to east-southeast in strike, cut the volcanic rocks of the Huronian Supergroup suggesting that east-trending faulting continued during the period of volcanism (Jensen, 1994). As well, the Flack Lake fault and the Murray fault continued as down-to-the-south syn-sedimentary growth faults during the formation of the Huronian Supergroup (Zolnai et al., 1984) while the Neoarchean dextral, west-northwest to northwest faults were reactivated.

The Blezardian Orogeny is assigned as the fourth deformation event, D_4, in the area of the four communities. The Blezardian Orogeny produced steeply south-dipping reverse faults and upright, kilometre-scale folds (Zolnai et al., 1984). Riller et al. (1999) interpreted the initial development of the Quirke Lake syncline and the Chiblow anticline to be attributed to the Blezardian event. As mentioned, the timing of the Blezardian Orogeny is poorly constrained. It is thought to have occurred between ca. 2.4 (possibly as early as 2.47 billion years ago), and 2.3 billion years ago (Riller et al., 1999; Raharimahefa et al., 2011).

The ca. 1.89 to 1.84 billion year old Penokean Orogeny represents a fifth deformation event, D_5. Riller et al. (1999) contended that the Penokean Orogeny in the area of the four communities involved dextral shearing and horizontal shortening. Jensen (1994) also noted that east-northeast faults in the Archean basement and Huronian Supergroup near the Whiskey Lake greenstone belt were reactivated at this time. Crustal shortening and fault reactivation enhanced the previously buckled (Blezardian) structure of the Archean basement and further compressed, folded and faulted rocks of the Huronian Supergroup, so that overlapping thrusted blocks stacked up to possibly 15 km in burial thickness (Zolnai et al., 1984). Penetrative deformation features, included cleavage, stretching lineation and rotation of tectonic fabric to a near-vertical orientation, and development of medium to high grade metamorphic assemblages (south of the Murray fault) were developed at this time (Zolnai et al., 1984). Northwest-trending strike-slip faults such as the Spanish American, Pecors Lake and Horne Lake faults that cut the Huronian Supergroup sequence and the parallel Nook Lake fault within the Archean basement directly north of the Quirke Lake syncline (Robertson, 1968), may have been formed during the Penokean Orogeny, or they may be reactivated Archean faults as suggested by Jackson (2001). The effect that the syn-Penokean meteorite impact, which produced the Sudbury Igneous Complex, had on the geological and structural evolution of the area of the four communities is unclear.

Deformation associated with the Grenville Orogeny, ca. 1.250 to 0.98 billion years ago, is considered the next major deformation episode, D_6, in the area of the four communities. In spite of the scarcity of evidence and problems of deformation overprinting and fault reactivation, it seems that the Murray fault remained active or was reactivated during this orogeny (Robertson, 1970; Card, 1978; McCrank et al., 1989; Piercey, 2006). The Midcontinent Rift (ca. 1.1 to 1.0 billion years ago) was developed contemporaneously with the long-lived Grenville Orogeny and is also included as part of D_6, although its effect on the area of the four communities is not known. There is poor control on any subsequent fault reactivation in the area of the four communities. Therefore all possible post-Grenville fault reactivation is included as part of a protracted D6 event.

2.4 Quaternary Geology

Information on Quaternary geology in the area of the four communities is described in detail in the terrain report (JDMA, 2014a) and is summarized here. The Quaternary geology of the area of the four communities is dominated at surface by different types of glacial deposits that accumulated with the progressive retreat of the ice sheet during the end of the Wisconsinan glaciation. This period of glaciation began approximately 115,000 years ago and peaked about 21,000 years ago, at which time the glacial ice front extended south of Ontario into what is now Ohio and Indiana (Barnett, 1992).

The area of the four communities is dominated by exposed bedrock or bedrock having only a thin mantle of unconsolidated sediments. Quaternary deposits are predominantly located in bedrock-controlled valleys. Figure 4 illustrates the extent and type of Quaternary deposits in the area of the four communities. Overburden deposits within the area were also mapped as part of the Northern Ontario Engineering Terrain Study (NOEGTS), a program undertaken between 1977 and 1981 (Gartner, 1978a,b,c; 1980 a,b; Roed and Hallet, 1979a,b,c,d; 1980a,b; VanDine, 1979a,b,c,d; 1980a,b,c,d; Gartner et al., 1981). These studies divided the landscape into a set of distinct terrain units within which the engineering characteristics are broadly predictable. Major landforms mapped by the NOEGTS program are shown on Figure 4.

Data on ice flow direction compiled from the literature (Karrow, 1987) reveal that glacial ice flowed in a generally southwesterly direction across the area of the four communities from the Hudson Bay basin. Ford (1993) recognized two dominant orientations in glacial striations, lunate fractures, drumlinoid features, and till flutings in the Rawhide Lake area to the north of the City of Elliot Lake. These are recorded as 175° (165° to 180°) and 195° (190° to 210°). At three sites, older 100° to 120° striations were found intersecting either the 175° or 195° sets.

The most widely occurring and oldest known stratigraphic unit in the area is a silty sand to sandy silt till found overlying bedrock in low relief areas and along the flanks of topographic lows. It is typically thin and discontinuous and is coarse-textured, unsorted, and boulder-rich, although there are some areas of compact, massive to fissile and gravelly to silty and sandy till (Barnett et al., 1991). Glaciolacustrine sediments have more limited distribution and are limited to only very small mappable surficial units (Ford, 1993) largely along river valleys. These units, typically composed of laminated silt and fine sand and silt-clay rhythmites, may be related to the series of postglacial lakes of the Lake Huron basin.

Deposits of glaciofluvial outwash and ice-contact stratified drift are commonly encountered along valleys in the area of the four communities. Ice contact deposits are composed of variable quantities of sand, gravel, and boulders, locally with minor silt and/or till in the form of small moraines. Glaciofluvial outwash is common in low-lying areas and occasionally in esker ridges with the local formation of terraces related to changing lake levels in the Lake Huron basin. Thick deposits of alluvial sand and gravel are found along many of the rivers in the region. Recent swamp, lake, and stream deposits are also common throughout the area.

The northward retreat of the ice sheet in the area of the four communities started approximately 12,000 years ago between the Onaway Advance (11,800 years ago) and the Marquette Advance (10,000 years ago). Ice retreat took place as Lake Algonquin spread northward, leaving a series of shorelines during isostatic uplift and opening of the sequence of outlets near North Bay, Ontario. The high water level associated with Lake Algonquin has been mapped between 309 and 312 m above present day sea level (Cowan, 1976; 1985). Lower strand sequences are interpreted as recessional strands representing falling Lake Algonquin water levels as the retreating Laurentide ice sheet exposed a series of outlets south of North Bay. These recessional beaches are believed to have formed between about 10,400 and 10,000 years ago, and some strands may actually represent single storm events (Cowan and Bennett, 1998). After the opening of a very low-level outlet at North Bay after 10,000 years ago, water levels in the Huron-Michigan basin dropped to more than 100 m below present levels, creating two smaller water bodies: Lake Stanley in the main Huron basin and Lake Hough in Georgian Bay (Eschman and Karrow, 1985).

Over time, isostatic uplift continued to raise the North Bay outlet, and by about 7,500 years ago, the Huron-Michigan and Superior basins became confluent again. The St. Marys River thus became the St. Marys Strait connecting the three upper Great Lakes. Ongoing uplift closed the North Bay outlet around 5,500 years ago, restoring high-level outlets at Chicago and Port Huron and initiating the Nipissing phase in the upper Great Lakes. The Nipissing transgression is marked by buried wood and peat 7,300 to 5,900 years old and by the development of a prominent shoreline above the present lake level.

Information on the thickness of Quaternary deposits in the area of the four communities was largely derived from a small number of water well records for rural residential properties, a small number of water well records along the highways, and from diamond drill holes. A more detailed accounting of recorded depths to bedrock in the area of the four communities is provided by JDMA (2014a). Diamond drill hole records and water well records in the area show overburden thickness to be between 0 and 137 m.

2.5 Land Use

The main land use within the area of the four communities is forestry. Other land use activities include agriculture, commercial fishing, trapping and recreation. There are a number of linear infrastructure corridors present within the area, including roads, railways, pipelines and electrical transmission lines. These features do not negatively impact the interpretation of bedrock lineaments. There are numerous active gravel pits in the area, as well as an active building stone quarry. There are currently no active mines in the area of the four communities.

3 GEOPHYSICAL DATA SOURCES AND QUALITY

For the area of the four communities, geophysical data were obtained from available public-domain sources, particularly the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC). To supplement these data, geophysical surveys performed in the area of the four communities by the mining industry were reviewed, as available from assessment files.

The quality of the available data was assessed to determine which data sets are suitable for inclusion in this assessment. The geophysical surveys covering the area of the four communities show variability in data set resolution, which is a function of the flight line spacing, the sensor height 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 (discussed in Section 4) were applied to enhance components of the data most applicable to the current assessment. The integrity of the higher quality data was maintained throughout.

3.1 Data Sources

The geophysical data covering the area of the four communities show variability in dataset resolution. Low to moderate resolution geophysical data, particularly the magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC), cover the entire area of the four communities (excluding radiometric coverage over Lake HuronHuron). Two additional magnetic/electromagnetic surveys obtained from the Ontario Geological Survey (OGS) provided higher resolution coverage over small parts area of the four communities, over the Benny Lake greenstone belt across the eastern boundary and a small part of the Huronian Supergroup and Whiskey Lake greenstone belt in the south central part of the area (Figure 5). A high-resolution magnetic and VLF survey flown by the GSC over AECL’s RA-7 radioactive waste research site covered the East Bull Lake intrusion and Parisien Lake syenite. The geophysical data sets are summarized in Table 2 and the characteristics of each of the data sources are discussed in detail below.

Due to the lack of high-resolution data over most of the area of the four communities, the OGS Assessment File Research Imaging Database (AFRI) was searched through the OGS Earth application, and numerous reports covering large areas were downloaded and reviewed. Of these, eight files provided images of magnetic data, as well as radiometric (four files), time-domain electromagnetic (two files), frequency-domain electromagnetic (one file) and VLF (four files). These files were chosen due to the quality of the images and scatter of locations across the area of the four communities. Although they focused on areas of mineral exploration interest, they provide additional information on various lithologies and more precisely map lineaments (e.g. dykes, faults). Where applicable, geophysics data from the assessment files were incorporated into this report in the form of raster maps that were extracted from the reports and georeferenced. Table 3 summarizes the assessment files incorporated in the geophysical interpretation.

3.1.1 Magnetic Data

Magnetic data over the area of the four communities were collected by various surveys using different survey parameters outlined in Tables 2 and 3. Magnetic surveys help in the understanding of geological and structural variations caused by different rock types associated with their content of magnetic minerals, such as magnetite and pyrrhotite. Magnetic maps show the distribution of magnetic and non-magnetic geologic bodies within the subsurface, and are particularly useful for delineating spatial geometry of bodies of rock, and the presence of faults and folds.

The resolution of the retrieved magnetic datasets varies greatly within the area of the four communities. Surveys were flown over a period of 52 years, over which time the quality and precision of the equipment as well as the quality of the processing has improved. Variability in the quality of the survey coverage also influenced the ability of the magnetic data to identify geological structures of interest relevant to this assessment.

Low-resolution magnetic data from four GSC aeromagnetic surveys provide complete coverage of the entire area of the four communities (GSC, 2013). Magnetic data from these surveys form part of the GSC Regional Magnetic Compilation data. Three of the surveys (Ontario #13, #16, #17) were flown at a terrain clearance of 305 m and flight line spacing of 805 m, providing it with a relatively low spatial resolution. The fourth survey (Ontario #04) was flown at a terrain clearance of 305 m and flight line spacing of 402 m, providing improved spatial resolution. The GSC flew one high-resolution survey in the area of the four communities (East Bull Lake (RA-7)), flown at a lower terrain clearance (150 m) compared to the older GSC surveys, and with tighter flight line spacing (300 m), providing these surveys with a relatively high spatial resolution. Additional, high resolution surveys from the OGS (Benny Survey (OGS, 2003) and Elliot Lake-River aux Sables Survey (OGS, 2011b)) were flown at a lower terrain clearance (30 – 67 m) compared to the GSC surveys, and with tighter flight line spacing (200 m and 100/50 m). These surveys focused primarily on exploration in the greenstone belts and to characterize the intrusions in the East Bull Lake area. The high resolution coverage amounts to approximately 5 percent of the area of the four communities.

Eight assessment files containing magnetic data were reviewed and their raster data were incorporated into this report (Table 3).)Data from these surveys mainly focused on exploration for uranium or nickel-platinum group elements in the Area of the Four Communities. These surveys had line spacing between 100 m and 200 m, and a magnetic sensor terrain clearance between 30 m and 73 m. The most useful images to augment the geophysical and lineament interpretations were extracted from the reports and georeferenced. The coverage of these surveys is provided in Figure 5 and a magnetic image selected from each assessment report shown in Figure 6.

3.1.2 Gravity Data

Gravity data provides complete coverage of the area of the four communities (GSC, 2013), consisting of an irregular distribution of 911 station measurements within the area of the four communities, comprising roughly a station every 5 to 15 km, with denser concentrations to the south and east, as well as over the Seabrook Lake and East Bull Lake intrusions. Spacing between gravity stations over the East Bull Lake intrusion range from 25 m to 200 m near its centre, expanding to 1 km around the margins.

The gravity measurements were retrieved as Bouguer corrected data. The Bouguer correction is applied to compensate for the gravity effect of the material between the measurement station and the datum elevation. However, the contribution to the measurement of the gravity effects of the surrounding topographic features (i.e. terrain correction) was not applied by the GSC.

Despite the fact that data are of good quality, the sparseness of the measurement locations in the area of the four communities is such that it can only be used to provide information about large-scale geologic features.

3.1.3 Radiometric Data

The GSC radiometric data provide complete coverage of the area of the four communities (GSC, 2013), with the exception of Lake Huron where there would be no radiometric responses. The acquired data show the distribution of natural radioactive elements at surface: uranium (eU), thorium (eTh) and potassium (K), which can be interpreted to reflect the distribution of mineralogical and geochemical information in the area. The GSC radiometric data were flown at 5,000 m line spacing at a terrain clearance of 120 m above the surface over most of the area of the four communities. Along the eastern boundary, the resolution improves where the line spacing is 1,000 m (Table 2). In the Elliot Lake area, higher resolution coverage at 500 m line spacing (and 123 m line spacing over a smaller block) improves the resolution further.

Retrieved radiometric data consisted of measurements of four variables:

- Potassium, K (%);
- Equivalent uranium, eU (ppm);
- Equivalent thorium, eTh (ppm); and
- Total Air Absorbed Dose Rate (nGy/h).

Radiometric images from five high-resolution surveys conducted by industry and filed as assessment reports with the OGS were reviewed and further assessed for inclusion in this report (see Table 3 for list of Assessment files). The files included a series of radiometric images including colour/contour maps of dose rate, potassium, equivalent thorium and equivalent uranium, reduced to elemental concentrations.

3.1.4 Electromagnetic Data

Two electromagnetic surveys available from the OGS provide a small amount of coverage in the east central and south central parts of the area of the four communities. The outline of these surveys focused on exploration within the greenstone belts.

One frequency-domain electromagnetic (FDEM) survey carried out by the OGS was retrieved from the Benny survey (GDS1017, OGS, 2003) (Figure 5). This survey acquired FDEM data using an Aerodat system to measure the inphase and quadrature components of four different frequencies (two coaxial and two coplanar coil pairs) towed below a helicopter with the sensor at a nominal terrain clearance of 30 m. The survey was flown at 200 m flight line spacing providing a relatively high spatial resolution.

One time-domain electromagnetic (TDEM) survey carried out for industry and later acquired by the OGS was retrieved from the Elliot Lake-River aux Sables survey (GDS1236, OGS2011b) (Figure 5). The TDEM system was designed to locate moderate to highly conductive ore deposits with a reduced sensitivity to conductive overburden, and can penetrate to depths of several hundred metres, depending on transmitter power and geology. The TDEM system used for the Elliot Lake-River aux Sables survey was a VTEM system to measure the off-time (7,203 μs period, 24 channels) Z component response. The transmitter and receiver were mounted on a bird flown at a nominal height of 47 m above terrain and towed beneath a helicopter. The survey was flown at 200 m flight line spacing providing relatively high spatial resolution.

As indicated in Table 2, the East Bull Lake (RA-7), Benny and Sudbury surveys also incorporated VLF data. The Benny survey recorded the VLF total field and quadrature channels for two transmitters: line - NSS (Annapolis, Maryland; 21.4 kHz) and orthogonal - NLK (Jim Creek, Washington; 24.8 kHz). The VLF receiver was located in a towed bird 12 m below the helicopter and had a nominal altitude of 48 m above terrain. For the East Bull Lake (RA-7) survey, the VLF total field and quadrature channels were recorded from an orthogonal transmitter but additional details are not available. For the Sudbury survey, the VLF total field and quadrature channels were recorded from one transmitter but additional details are not available. The VLF surveys (Sudbury and East Bull Lake (RA-7)) are not particularly useful. The orientation of the VLF transmitter for the Sudbury survey results in linear anomalies oriented between east-northeast an east-southeast, almost perpendicular to the topographic grain. This makes it difficult to screen topographic effects from bedrock responses. The data from East Bull Lake (RA-7) is very noisy. For the Benny survey, the FDEM data provided superior resolution of bedrock sources to the VLF data and were relied upon for the interpretation.

Table 2. Summary of the characteristics for the geophysical data sources in the Communities of Elliot Lake, Blind River, The North Shore and Spanish and Surrounding Area

Product	Source	Type	Line Spacing/ Sensor Height	Line Direction	Coverage	Date	Additional Comments
East Bull Lake (RA-7)	GSC, 2013	Fixed wing vertical gradiometer magnetic, VLF	300 m/150 m	0°	East central over the East Bull Lake and nearby intrusions	1981	Higher resolution
Ontario #4	GSC, 2013	Fixed wing magnetic	402 m/305 m	0°	West central	1956	Moderate resolution dataset
Ontario #13	GSC, 2013	Fixed wing magnetic	805 m/305 m	0°	Northeast	1960	Lowest resolution dataset
Ontario #16	GSC, 2013	Fixed wing magnetic	805 m/305 m	0°	East	1959	Lowest resolution dataset
Ontario #17	GSC, 2013	Fixed wing magnetic	805 m/305 m	0°	Most of area of the four communities	1963	Lowest resolution dataset
GDS1017 Benny	OGS, 2003	Helicopter magnetic, FDEM, VLF	200 m/30 m	0°	East central over Benny greenstone belt	1990	4-frequency Aerodat system, radar navigation, higher resolution
GDS1236 Elliot Lake-River aux Sables	OGS, 2011b	Helicopter magnetic, TDEM	100 m (east), 50 m (west)/ 67 m (mag), 47 m (TDEM)	0°	South central over Whiskey Lake greenstone belt	2008	VTEM system, higher resolution
Sudbury	GSC, 2013	Fixed wing magnetic, radiometric, VLF	1000 m/120 m	0°	East	1989	Utilized for its radiometric and VLF coverage only
Elliot Lake	GSC, 2013	Fixed wing radiometric	500 m/124 m	0°	South central over Huronian Supergroup	1970	Higher resolution
Elliot Lake (detail)	GSC, 2013	Fixed wing radiometric	123 m/115 m	0°	South central over Huronian Supergroup	1977	Higher resolution over Huronian Supergroup
GSC Gravity Coverage	GSC, 2013	Ground gravity measurements	5-15 km, 25 m to 1 km locally		Entire area of the four communities	1945-1989	Station spacing somewhat variable overall with more detailed data over the East Bull Lake and Seabrook Lake intrusions

GSC – Geological Survey of Canada
OGS – Ontario Geological Survey

Table 3. Summary of the characteristics for the airborne geophysical assessment file reports in the Communities of Elliot Lake, Blind River, The North Shore and Spanish and Surrounding Area

AFRI No.	Source	Type	Line Spacing/ Sensor Height	Line Direction	Coverage	Date	Additional Comments
20000850	North American Gem	Fixed wing horizontal gradiometer magnetic, radiometric, VLF	100 m/70 m	0°	Northwest	2008	
20003244	Canada Enerco	Fixed wing magnetic, TDEM	200 m/73 m	55°	North of Elliott Lake	2007	MEGATEM system
20004445	Delta Uranium	Fixed wing horizontal gradiometer magnetic, radiometric, VLF	100 m/70 m	0°	North central	2006	
200005757-1 to -3	Carina Energy	Helicopter magnetic, TDEM	100 m/47 m	0°	West central over the Huronian Supergroup	2007	AeroTEM II system
20005762	Carina Energy	Helicopter magnetic, radiometric	150 m/30 m	0°	West central over the Huronian Supergroup	2007	
20006243	North American Gem	Fixed wing horizontal gradiometer magnetic, radiometric, VLF	100 m/70 m	0°	Northwest	2008	
20006734	Hawk Uranium	Helicopter magnetic, radiometric, VLF	100 m/30 m	0°	North central	2007	
41I12SW2002	Mustang Minerals	Helicopter vertical gradiometer magnetic, FDEM	100 m/45 m	0°	Southeast over the East Bull Lake and nearby intrusions	2000	Dighem V system

AFRI – Assessment File Research Imaging Database
OGS – Ontario Geological Survey

As discussed in Section 3.1.1, the results from seven high-resolution electromagnetic surveys conducted by industry and filed for assessment were incorporated in the geophysical interpretation (Table 3). Four surveys incorporated VLF data, two surveys incorporated TDEM data (Megatem and Aerotem II) and one survey incorporated FDEM data (Dighem V).

3.2 Data Limitations

There is a fairly stark contrast between the high resolution of the magnetic surveys that partially cover the greenstone belts and the older regional low resolution coverage elsewhere in the area of the four communities. Nevertheless, the magnetic data reflect quite coherent responses that elucidate the mapped geology, particularly in areas of limited bedrock exposure. The smaller intrusions, dyke swarms and main structural regimes are clearly delineated by the magnetic data, regardless of resolution, but at different levels of detail.

All four data types considered, magnetic, gravity, radiometric and electromagnetic, contribute to the interpretation. The limitation in applying these data types to the area of the four 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;
- Overburden – areal extent, thickness and physical properties; and
- Bedrock lithologies – physical properties and homogeneity (e.g. batholith contacts can be easily mapped but batholiths themselves are sometimes quite homogeneous, making geophysical characterization of internal structure difficult).

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 overall interpretation of the geophysical data is limited by a lack of physical rock properties available for the rocks in this area. The usability of each data set also depends on its quality, especially resolution.

4 GEOPHYSICAL DATA PROCESSING

All data were processed and imaged using the Oasis montaj software package (Geosoft, 2013). Three additional magnetic grids were prepared using the Encom PA software package (Pitney Bowes, 2013). The grids that resulted from the various processing steps were also loaded in ArcMAP 10 (ESRI, 2013) using a Geosoft plug-in.

4.1 Magnetic

All surveys in the area of the four communities where projected to the UTM17N/NAD83 coordinate system. Magnetic data from the surveys were gridded at a cell size of ¼ the line spacing. The resultant grids were examined for level noise along the survey lines and as a result, microlevelling was applied to the GSC surveys Ontario #04, #13, #16, #17 and East Bull Lake (RA-7). The resultant grids were regridded to a common grid cell size of 40 m.

The surveys were knitted together using Oasis montaj (Geosoft, 2013), where 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 resultant grid was the residual magnetic intensity grid (i.e. total magnetic field after IGRF correction) and the basis for preparing the enhanced magnetic grids.

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 four communities, the residual magnetic intensity grid was reduced to the pole using a magnetic inclination of 76.1° N and magnetic declination of 6.2° W (Figure 7).

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

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

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

Where:
$L(\theta)$ = pole-reduced magnetic field for wavenumber θ
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 locating contacts (e.g. the anomaly texture is revealed) and mapping structure (Telford et al., 1990). It is expressed as:

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

where Z is the vertical offset.

To reduce noise that resulted from aliasing during the minimum curvature gridding process, an 8^{th}-order 300 m low pass Butterworth filter was also applied.

Directional Filters

The magnetic responses in the area of the four communities are significantly influenced by the Matachewan and Sudbury dyke swarms due to their widespread prevalence across the area and the amplitude of their magnetic anomalies compared to the relatively subdued responses over most of the bedrock. As a result, directional filters were applied along the approximate strike direction of each swarm to better image the bedrock responses (e.g., Fuller, 1967; Pilkington and Roest, 1997). Grids of the pole-reduced magnetic field and its first vertical derivative were prepared by removing the signal for a median strike direction of 127° (Sudbury swarm), of 150° (Matachewan). The result with both swarms removed is presented for the pole-reduced magnetic field (Figure 8) and its first vertical derivative (Figure 10). The directional filter, applied in the Fourier domain, is defined as follows:

$$L(\theta) = \left|\cos\left(\alpha - \theta + \frac{\pi}{2}\right)\right| \qquad \text{(eq. 4.3)}$$

Where:
L(θ) = magnetic field for wavenumber θ
α = direction to be filtered

Upward continued grids of the pole-reduced magnetic field to levels 500 m, 1,000 m and 2,000 m above the observation surface were also prepared, to reduce the influence of the dyke responses and gain a better understanding of the broader geophysical units.

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 11). This is particularly useful for locating contacts (e.g. the anomaly texture is revealed) and mapping structure close to surface (Telford et al., 1990). It is expressed as:

$$2VD = {d^2RTP}/{dZ^2} \qquad \text{(eq. 4.4)}$$

Where:
Z = vertical distance upwards
One limitation of this filter is that the higher order derivatives tend to also enhance high frequency noise in the data set. To reduce noise that resulted from aliasing during the minimum curvature gridding process, an 8^{th}-order 600 m low-pass Butterworth filter was also applied.

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 12). This is particularly useful for mapping texture, structure, and edge contacts of weakly magnetic sources. It is expressed as:

$$TILT = \tan^{-1}\left\{\frac{\frac{dRTP}{dZ}}{\sqrt{\left([\frac{dRTP}{dX}]^2+[\frac{dRTP}{dY}]^2\right)}}\right\} \qquad \text{(eq. 4.5)}$$

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.

<u>Analytic Signal Amplitude</u>

The amplitude of the analytic signal (AS) (Figure 13) 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):

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

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.

<u>Depth to Magnetic Sources Using Source Parameter Imaging (SPI™)</u>

The SPI method locates the depths of edges in the gridded magnetic data (Thurston and Smith, 1997). It assumes a 2D sloping contact or 2D dipping thin sheet model. The SPI solutions extracted from the pole reduced magnetic field grid are stored in a database. The SPI values calculated are depths between the magnetic source and the instrument height. If the survey was flown at a constant terrain clearance, then the drape height could be subtracted from the SPI value to result in a depth below surface. For the GSC surveys, only the average flying height was known. For the remaining surveys (Benny and Elliot Lake-River aux Sables), the radar altimeter data were included in the survey database and were consequently used to more accurately determine the distance between the magnetic sensor and the computed depth to the magnetic source. The radar altimeter channel was gridded at the original grid cell size and sampled back to the SPI database. If the value of the depth to source is < 0, i.e. above ground, it is set to a value of zero. Thus, the SPI depth with respect to the ground surface is calculated as:

- SPI_depth = SPI_value – average flying height, if no radar data is available, or
- SPI_depth = SPI_value – radar value, if available.

The SPI depths were calculated for each individual data set in the area of the four communities, taking into account that the elevation of the magnetic sensor (Figure 14). Low resolution grids are biased with deeper basement depths due to the lack of high frequency content. Thus, where a high resolution survey overlaps with a low resolution regional survey, the SPI depths from the low resolution grid were excluded. The final SPI depth grid was calculated with a grid cell size of 200 m.

Encom Magnetic Grids

A series of grids were created to highlight the edges of both shallow and deep sources and to categorize anomalous zones into different areas (Shi and Butt, 2004). These grids are:

- rtpzsedge – gradient filters applied to the pole reduced magnetic field to emphasize edges
- rtpzsedgezone – gradient filters and amplitude equalization filters applied to the pole reduced magnetic field to emphasize edges
- rtpzsplateau – gradient filters and amplitude equalization filters applied to the pole reduced magnetic field to emphasize homogeneous blocks bounded by edges.

Magnetic Peaks, Troughs and Edges

The semi-automated extraction of magnetic anomaly peaks, troughs and edges is useful for delineating structure, foliation, texture and contacts. Anomaly peaks typically trace the center of a source or the more magnetic horizons within a larger source. Anomaly troughs often complement the peaks, indicating a less magnetic horizon. They also may map a remanent (i.e. reversely) magnetized source, or magnetite depletions (e.g. along a fault) which are a less magnetic source in a more magnetic host rock. Anomaly edges mark geological contacts or the boundaries of horizons within a geological unit. Offsets and orientation changes in the peaks, troughs and edges are useful for mapping faults and shears. Detection for peaks, troughs and edges was performed based on the CET (Centre for Exploration Targeting) Grid Analysis package in Oasis montaj (Geosoft, 2013).

The phase symmetry method, a frequency-domain approach based on axes of symmetry, is used to identify arbitrarily oriented line features. The 2D image is analyzed with 1D profiles in multiple orientations and varying scales. A line feature exhibits strong symmetry responses from profiles in all orientations not parallel to the line itself. Symmetry is closely related to periodicity: the symmetry point in the spatial domain corresponds to either a minimum or maximum of its local Fourier components. Thus the detection is carried out by frequency analysis.

The frequency analysis is performed by wavelet transform, which estimates local frequency using complex valued log-Gabor filters. The filters are comprised of an even symmetric (cosine) wavelet and an odd symmetric (sine) wavelet, each modulated by a Gaussian. These filters at different scales respond to particular bands of frequencies. The local frequency information is obtained from the convolution of the wavelet filters with the 2D data. An array of filter response vectors are generated for each point in the signal for each scale. Localized frequency representation is produced from these vectors. The frequency component is represented as a complex number; its real and imaginary parts are the outputs from the even and odd symmetry filter responses, respectively. At the point of symmetry, frequency components are at their amplitude extrema. This corresponds to where the absolute values of the outputs are high from even symmetry filter and low from odd symmetry filter, for all frequencies. This 1D analysis is performed in multiple orientations to extend to 2D analysis (Holden et al., 2008).

An amplitude threshold is then applied to the output symmetry grid, to distinguish cells that contain signal of interest from the background. A lower threshold value leads to the detection of more features, but may also introduce noise in the data. The resulting grid is binary: 1 for regions of interest and dummies for background. The grid is then skeletonized to trendlines. This process also sets the minimum valid line length.

The smallest filter wavelength used in this analysis for the area of the four communities was five cells (equivalent to 200 m), over four scales. The filter sizes were therefore 200 m, 400 m, 800 m, and 1,600 m. All orientations were considered in the search for symmetry. A threshold value of 0.15 was applied, and a minimum line length of 3 cells (120 m) was set.

Edges were enhanced by computing the balanced horizontal gradient magnitude (TDX) (Cooper and Cowan, 2006) from the RTP grid, as modified by Fairhead and Williams (2006):

$$TDX = \tan^{-1}\left\{\frac{\sqrt{\left([\frac{dRTP}{dX}]^2+[\frac{dRTP}{dY}]^2\right)}}{\frac{dRTP}{dZ}}\right\} \qquad \text{(eq. 4.7)}$$

The first vertical derivative is computed in the Fourier domain whereas the horizontal derivatives in X and Y are computed in the space domain.

The TDX of the pole-reduced magnetic field is a more accurate locator of source edges and less susceptible to noise in the data than other forms of edge detectors. Pilkington and Keating (2009) confirmed that TDX and its analog, "theta mapping", produce identical results and are the most robust of the edge detection techniques applicable to potential field data.

The positive peak values are extracted by applying an amplitude threshold to the TDX grid to identify cells of interest. The resulting grid is binary and is skeletonized to locate the source edges. In this project, a threshold value of 0.92 was used.

The peaks, troughs and edges generated using the CET methods were not submitted directly for further lineament analysis. The ENCOM grids and TDX images are not presented in this report. However, all of these maps and images were used as guides during the manual interpretation process. The accuracy and reliability of these products were greatly influenced by the resolution of the original magnetic data.

4.2 Gravity

The following four gravity grids and their gravity station locations (911 gravity measurements) were downloaded for the area of the four communities from the GSC gravity compilation (GSC, 2013) at 2,000 m grid cell size:

- Bouguer gravity field (Figure 15);
- First vertical derivative of the Bouguer gravity field (Figure 16);
- Total horizontal gradient of the Bouguer gravity field; and
- Isostatic residual gravity field.

All grids were reprojected to a UTM17N/NAD83 coordinate system. The first vertical derivative was computed by the GSC using the same methodology applied to the pole reduced magnetic field, as described in Section 2.1. The total horizontal gradient of the Bouguer gravity provided similar results as the first vertical derivative, and therefore was not presented in this report. The isostatic residual compensates for mass deficiencies at depth predicted from topography, preserving the shorter wavelength components of the field due to nearer surface sources. In the area of the four communities, the isostatic residual field closely resembles the Bouguer gravity field due to the relatively gentle topography, and therefore was not presented in this report. The GSC applied standard gravity reduction methods to compute the free air and Bouguer gravity fields. A Bouguer correction density of 2.67 g/cm^3 was applied, the typical value for the Canadian Shield. As the regional data for the area of the four communities were collected in 1965 and earlier, station elevations were likely determined using barometric altimeters (much less accurate than GPS) and terrain corrections were not applied. The detailed surveys at East Bull Lake used more accurate methods to measure station elevation.

Due to the presence of some higher resolution coverage in the area of the four communities, new grids of the Bouguer gravity field (Figure 15) and its first vertical derivative (Figure 16) were prepared at a 500 m grid cell size.

4.3 Radiometric

The following seven radiometric grids (radioelement concentrations and ratios) were downloaded for the area of the four communities from the GSC radiometric compilation (GSC, 2013) at 250 m grid 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 already a merge of high and low resolution data prepared by the GSC. However, the two higher resolution surveys in the Elliott Lake area were not incorporated in the GSC grids. Thus, they were gridded at 100 m resolution and merged together with the regional grids at that cell size.

The determination of the radioelement concentrations, dose rate and ratios followed the methods and standards published by the International Atomic Energy Agency (IAEA, 2003), many of which were developed at the GSC. All grids were reprojected to a UTM17N/NAD83 coordinate system. The dose rate is a calibrated version of the measured “total count”, and reflects the total radioactivity from natural and man-made sources. The radiometric data are presented in Figure 17 as a ternary RGB image of the three radioelements, with the intensity of potassium (%) displayed in red, equivalent thorium (ppm) in green and equivalent uranium (ppm) in blue. Areas of highest intensity in all three radioelements show light colours and trend towards white. Areas of lowest intensity of all three radioelements are dark colours and trend towards black.

4.4 Electromagnetic

Theelectromagnetic surveys flown by the Ontario Geological Survey (e.g. OGS, 2003) were invariably at 200 m line spacing, which provides good resolution for mapping (some industry surveys distributed by OGS (e.g. OGS, 2011b) are at closer line spacing). Older surveys were typically helicopter FDEM (e.g. OGS, 2003) or fixed wing TDEM; newer surveys are typically fixed wing or helicopter TDEM.

These surveys typically focus on the greenstone belts, extending into the edges of neighbouring granites and sometimes encompassing smaller plutons where the greenstones wrap around them (Figure 18). Certain intrusions that have known mineral potential have also been flown (e.g. in the Abitibi Subprovince). Helicopter surveys generally have better signal/noise than fixed wing surveys due to closer proximity of the EM transmitter, EM receiver and magnetometer to the ground.

FDEM surveys typically include a grid of apparent resistivity (conductivity is simply the inverse). Newer surveys have an apparent resistivity for three frequencies reflecting shallower (highest frequency) to deeper (lowest frequency) responses – this helps in discriminating between overburden and bedrock responses. Coplanar coils are more responsive to mapping subhorizontal structures, whereas coaxial coils are better suited to map subvertical structures.

TDEM surveys typically include a grid of decay constant, which is used to discriminate bedrock conductors, and a grid of conductance or conductivity, which is oriented towards mapping conductive horizons. Newer systems measure three components: Z-component that best couples with subhorizontal conductors, X-component with subvertical conductors and sometimes Y-component with lateral (offline) conductors.

All surveys are delivered with an EM anomaly database, where individual anomalies have been picked along flightlines and then classified as bedrock source, surficial source (e.g. overburden) or cultural (e.g. hydro line). Bedrock anomalies usually incorporate a vertical plate or similar model to provide an estimate of depth-to-top and conductivity. The depth values give an indication of overburden thickness, assuming the conductor subcrops.

The analysis of the EM data herein consisted mainly of plotting the EM anomalies over the gridded images provided by OGS and joining bedrock anomalies into quasi-linear conductors, where the character of the EM response remained consistent along strike. Typically, these conductors follow the stratigraphy evident in the mapped geology and magnetic data.

5 GEOPHYSICAL INTERPRETATION

5.1 Methodology

The coincidence of geophysical units with mapped lithology and structural featureswas identified and interpreted for the area of the four communities using all available geophysical data sets. In particular, the pole reduced magnetic field and its first vertical derivative were the most reliable for mapping variations in geological contacts, identifying heterogeneity, and delineation and classification of structural lineaments (faults, dykes). The results from the structural lineament interpretations are presented in the lineament report for the area of the four communities (JDMA, 2014b). The first and second vertical derivatives were used to trace quasilinear magnetic anomaly peaks to emphasize the ductile features. These ductile features are interpreted as being associated with the internal fabric to the rock units and may include in places sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation. Enhanced grids of the magnetic field data were used to assist in the interpretation:

- Pole-reduced magnetic field – magnetic units (Figures 7 and 8);
- Pole-reduced first and second vertical derivatives – lineaments, boundaries, texture, foliation (Figures 9, 10 and 11);
- Tilt angle – subtle magnetic responses (Figure 12); and
- Analytic signal – anomaly character, texture, boundaries (Figure 13).

Gravity data were of insufficient resolution to be used for interpretation of geological units and boundaries. However, some general characterizations of the regional scale units were possible (Figures 15 and 16). Similar comments apply to the radiometric data (Figure 17), except where the higher resolution data and images were available. The electromagnetic data (Figure 18) were not used for interpreting lithologies as the magnetic data proved greatly superior from a mapping perspective in the area of the four communities. However, certain geological features were evident in the electromagnetic data and are discussed below in the results.

The coincidence of the lithological units with the geophysical data was mainly recognized in the magnetic images from their anomaly amplitude, texture, width, and orientation characteristics. The automated peaks, troughs and edges generated from the magnetic data assisted in more accurate location of contacts. The magnetic anomaly characteristics and geophysical contacts were compared to the current bedrock geologic map in order to identify similarities and/or changes in the lithological contact locations. In some cases, difference in the boundaries determined from the magnetic data and the mapped boundaries may reflect a subsurface response which may not match the mapped surface contacts (e.g. dipping unit) and/or a contact extended through locations with limited outcrop exposure (e.g. under overburden and drainage cover). The coincidence between the geophysical interpretation and the bedrock geologic map is presented in Figure 19. The geophysical data were initially evaluated against the following published geological maps:

- OGS 1:250 000 scale bedrock geology of Ontario, Miscellaneous Release Data 126-Revision 1 (OGS, 2011a) (Figure 2 and 3)
- OGS Map 2315 Precambrian Geology – Lewis and Shedden Townships and Parts of Indian Reserves No. 5 and No. 7 (OGS, 1977)
- OGS Map 2419 Bedrock Geology Compilation Map – Sault Ste. Marie-Elliot Lake Sheet (Giblin and Leahy, 1979)
- OGS Map P.3596 Precambrian Geology – Geological Compilation, East Bull Lake and Agnew Intrusions (Easton et al., 2011)
- OGS Map 2670 Bedrock Geology Compilation Map – Sault Ste. Marie-Blind River Sheet (Johns et al., 2003).

Additional maps were used to supplement the evaluation of geophysical data against the bedrock geology over the area of the four communities, consisting of variable scales of mapping. A detailed discussion of all available bedrock mapping is provided in Golder (2014).

5.2 Results

The following section presents a regional-scale description and interpretation of each geophysical data set in the area of the four communities, followed by detailed interpretations of geophysical responses within the Ramsey-Algoma granitoid complex (gneissic tonalite and massive granodiorite to granite) in the area of the four communities (Figure 3). Using the published regional bedrock geology maps as a starting point, the geophysical results discuss the relationship between the interpreted geophysical units and the mapped bedrock lithology for the area of the four communities. Outlines of geophysical units are presented in Figure 19. In many cases, the geophysical units referred to in this section generally match those of the published regional bedrock geology (OGS, 2011a).

5.2.1 Magnetic

The magnetic data over the area of the four communities exhibits strong variability in its magnetic response associated with the mapped distribution of intrusive rock units of the Ramsey-Algoma granitoid complex in the Superior Province, and Huronian Supergroup units and bedrock underlying the North Channel associated with the Southern Province. Strong regional magnetic highs located to the northwest and northeast are associated with portions of the mapped massive granodiorite to granite unit of the Superior Province (Figures 7 and 8). Regional magnetic lows are located throughout the central and southwestern portion of the area associated with Southern Province metasedimentary units of the Huronian Supergroup, and further south underlying the North Channel. Smaller discrete magnetic highs are located throughout the area, and correspond to the mapped distribution of intrusions of different ages and lithologies, as well as the Benny Lake and Whiskey Lake greenstone belts and smaller greenstone fragments. The boundaries of these units are not always well-defined, largely due to the low resolution data, and the resulting relatively subdued texture exhibited in the magnetic image.

In addition to the Ramsey-Algoma granitoid complex in the Superior Province, magnetic character of several smaller felsic to intermediate intrusions were assessed, in particular where higher resolution geophysical data exist. The East Bull Lake intrusion shows a relatively low magnetic response compared to the surrounding bedrock units, with some areas of higher intensity extending towards its west end, reflecting some internal inhomogeneity. The northern two lobes mapped for this intrusion do not show a distinct magnetic contrast with the host rock, and have not been separated in the interpretation. Magnetic character of the Parisien Lake syenite tends to be clearly differentiated from the East Bull Lake intrusion immediately to the north by its strong magnetic response. Similar to the East Bull Lake intrusion, the Agnew Lake intrusion shows a magnetic response that cannot be differentiated from the surrounding massive granodiorite to granite, with a local magnetic high in its southeast corner. In the northwest corner of the four communities’ area, the Seabrook Lake intrusion is characterized by a high magnetic response at its center, striking east-northeast and spotty magnetic highs beyond its mapped margin.

Bedrock units of the Huronian Supergroup located north and south of the Murray fault tend to be magnetically transparent. Magnetic anomalies in the reduced to pole magnetic data, and its derivative grids, tend to be lower frequency and predominantly reflect magnetic sources from greater depths (Figure 14). The Cutler pluton has been mapped within the Huronian Supergroup bedrock as a large felsic granitic intrusion located immediately south of the Township of The North Shore. Presumably due to a lack of magnetic susceptibility contrast, this intrusion cannot be distinguished magnetically from the adjacent bedrock. Two prominent, broadly north-west trending magnetic highs are observed east of Elliot Lake. The larger of the two anomalies is referred to as the Pecors magnetic anomaly, known to exhibit resource potential. The north-west orientation of these anomalies tends to be broadly coincident with the strike of the Matachewan dyke swarm through the area. Magnetic inversion modeling by L.E. Reed Geophysical Consultant suggests that the source of the magnetic anomaly is located within the Archean bedrock underlying the Huronian Supergroup units (Hawke, 2011).

In the southeastern part of the Huronian Supergroup bedrock, the Cobalt Group units correlate well with several curvilinear magnetic horizons which show an easterly trend in the magnetic data. These are the only metasedimentaryary rocks in the four communities area that show such distinct magnetic patterns. The Croker Bay pluton lies mainly beneath the surface of the North Channel but it is well-defined by a strong magnetic response of roughly 10 km diameter, with quasi-circular foliation patterns.

The mafic to intermediate metavolcanic portions of the Benny Lake greenstone belt, the Whiskey Lake greenstone belt and the greenstone near the western boundary of the four communities area are generally well-defined by discrete magnetic highs with a roughly east-west orientation. The widespread dyke activity makes it difficult to differentiate the more subtle responses of any felsic metavolcanics and metasediments from adjacent rocks of the Ramsey-Algoma granitoid complex (or Huronian Supergroup on the north side of the Whiskey Lake greenstone belt).

Four dominant dyke orientations were observed from the magnetic data and incorporated in the lineament analysis (JDMA, 2014b). Their identification depended mainly on strike direction and cross-cutting relationships, and to a lesser extent anomaly amplitude. Matachewan dykes have a consistent northwest to north-northwest strike and are mainly located in the north half of the area. Spray et al. (2004) noted areduction in the number of Matachewan dykes identified in magnetic data in the southern portion of the area, which they attributed to demagnetization of the rock due to shock from the nearby Sudbury Impact Structure (western margin located 25 km outside of the area of the four communities to the east). In places, the strike directions of the Matachewan and Sudbury dykes are within a few degrees of each other and can be difficult to differentiate from the magnetic data. To a lesser extent, the same issue applies to the Biscotasing and the North Channel dykes in the central part of the area, where both swarms exhibit an easterly strike direction. In general, the Matachewan dykes exhibit a more northerly orientation compared to the other dykes. Biscotasing dykes are present in the area to a lesser extent and are characterized by their higher amplitude response, and northeast to east-northeast strike.

Numerous dykes, particularly the North Channel and Sudbury swarms, are evident in the area covered by the Huronian Supergroup. The Huronian Supergroup rocks appear to be magnetically transparent, whereby the high-frequency magnetic responses in that area tend to reflect the presence of dykes within the Huronian Supergroup, and the lower amplitude and low-frequency responses are correspond to the underlying granitic rocks. The Sudbury dykes post-date the deposition of the Huronian metasediments, as do a portion of the North Channel swarm, since they appear shallow in the magnetic data relative to the magnetic sources that underlie the Huronian Supergroup. There are also linear and broader magnetic responses due to Nipissing diabase intrusions into the Huronian Supergroup in the Elliot Lake and southwest parts of the area of the four communities. It is difficult to determine whether the volcanic rocks at the base of the Huronian Supergroup have a magnetic signature. The southern part of the Huronian Supergroup shows a slightly higher magnetic response than the northern part, corresponding to the deeper and shallower underlying basement, steered respectively by the Quirke Lake syncline and Chiblow anticline with east-west axial surface traces (Johns et al., 2003).

The Nipissing dykes were not interpreted separately from the other four swarms, and it is possible that some were incorporated with them, most likely the North Channel and/or Biscotasing swarms towards the south. The Nipissing rocks that were interpreted form sills and other small intrusions. Many follow linear patterns (e.g. along the north edge of the Murray fault) but do not show the continuity of the four dyke swarms.

Foliation and ductile lineaments were not completed due to the overwhelming masking response from the dykes, as well as limited magnetic horizons in the small greenstone belts present in the area. The low resolution of the magnetic data played a role in limiting the recognition of these lineaments as well.

5.2.2 Gravity

The Bouguer gravity data and gravity station locations across the area of the four communities are presented in Figure 15, and its first vertical derivative in Figure 16. A large arcuate gravity high anomaly, measuring approximately 10 mGal from peak to trough, follows a northeast direction through the central portion of the Ramsey-Algoma granitoid complex. This gravity anomaly is roughly coincident with the trend of the mapped gneissic tonalite suite, although gravity stations are sparse in this area. The arcuate nature of the gravity anomaly extending through the Ramsey-Algoma complex, and into the Huronian Supergroup rocks appears to spatially correlate to a large scale fold structure with east-west trending axial surface traces in the area of the four communities.

The discrete gravity high underlying much of the Huronian Supergroup reflects the highest values in the area of the four communities, measuring 25 mGal from peak to trough, and shows a strong spatial relationship with the location of the Quirke Lake syncline and Chiblow anticline. It is speculated that this high near the center of the four communities area reflects the distribution and increased thickness of high density metasedimentary and metavolcanic rocks within the core of a regional fold (i.e. Quirke Lake syncline), and/or may reflect the presence of a discrete intrusion at depth within the sub-Huronian Archean basement rocks. The Chiblow anticline to the southwest is reflected by a gravity low, which suggests that the exposed Huronian sedimentary units and/or the underlying basement rocks (Giblin and Leahy, 1979) are lighter than the volume of metasedimentary and metavolcanic rocks that infill the Quirke Lake syncline.

In the north-central portion of the Ramsey-Algoma granitoid complex there is broad correlation between a gravity low and the mapped distribution of massive granodiorite to granite. A similar low gravity response occurs in the northwestern corner of the area of the four communities, which is also broadly correlative with a massive granodiorite to granite unit.

A high gravity anomaly located in the southeast part of the area of the four communities is coincident with the mapped distribution of the Elliot Lake Group metasedimentary rocks exposed to the north of the Murray fault, near the North Channel. Card et al. (1984) describe the high gravity responses along the Murray fault, correlating with the boundary between the Superior and Southern Provinces, as being part of a regional anomaly that extends 350 km to the east and due to a mafic-ultramafic body at depth. Hearst and Morris (2001) interpret the positive gravity anomaly to reflect an uplifted block of Huronian Supergroup volcanic rocks.

Gravity measurements locally show a higher density of sampling over some of the smaller intrusions and greenstone belts in the area of the four communities, including the Benny Lake greenstone belt, Whiskey Lake greenstone belt, East Bull Lake intrusion, Agnew Lake intrusion and Seabrook Lake intrusion. These units are predominantly characterized by anomalies with relatively high gravity values and may reflect rock units that are higher density than the surrounding bedrock. Although the gravity data is still relatively sparse, the last two intrusions appearmore extensive in the gravity data compared to their response in the magnetic data and the bedrock geology map.

5.2.3 Radiometric

The radiometric data across the area of the four communities is presented in Figure 17. These data display broad trends in radioelement distributions at a regional scale; however, they were of insufficient resolution to be used for interpretation of geological units and boundaries. Although bedrock exposure is extensive in the area of the four communities, in areas where the overburden material is locally derived from the underlying bedrock, it may serve as a proxy for the underlying bedrock when interpreting the radiometric data. Nevertheless, some smearing of the signal or anomalous patterns along drainage channels may be anticipated due to glacial and fluvial transport in the area of higher resolution data.

In the Ramsey-Algoma granitoid complex, the mapped massive granodiorite to granite correlates quite well with the trend of a broad regional radiometric response that is relatively high in all three radioelements, although radiometric data is relatively low resolution in this area. This radiometric anomaly trend is also consistent with a broad gravity anomaly through the Ramsey-Algoma granitoid complex. The adjacent gneissic tonalites also tend to be relatively high in potassium, but lower in uranium and thorium.

The Huronian Supergroup metasedimentary units show a mixture of responses, with higher values north and east of Elliot Lake, despite the low resolution data. Radiometric data over the Benny Lake greenstone belt shows low concentrations of all three radioelements, typical of metavolcanic rocks (IAEA, 2003). The Whiskey Lake greenstone belt also appears to show subdued radioelement responses, although the interpretation is hampered by the lower resolution data acquired over this greenstone belt. The intrusions that show well-defined responses include the Agnew Lake intrusion (low in all three radioelements) and the Cutler pluton (high in all three radioelements).

For the GSC radiometric compilation within the area of the four communities, the radioelement responses are summarized in Table 4.

Table 4. Radioelement response statistics

Radioelement	Minimum*	Maximum	Mean
Potassium (%)	0.05	4.75	1.52
Equivalent uranium (ppm)	-0.25	23.2	1.35
Equivalent thorium (ppm)	-0.42	7.85	4.85
Natural air absorbed dose rate (nGy/h)	0.89	257.63	46.84

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

These levels are atypical of most of the Canadian Shield due to the higher values of uranium and dose rate associated with the Huronian Supergroup metasedimentary units. The responses elsewhere are typical of those found in granite-greenstone terrane (IAEA, 2003).

The highest uranium response in the area is located in the Huronian Supergroup metasedimentary units in the northern part of the Quirke Lake syncline, where the uranium response exceeds 4 ppm over an area measuring roughly 18 km by 16 km. The generally low uranium levels elsewhere suggest low radon risk. However, radon risk is also quite dependent on soil permeability and should be verified by soil gas measurements (IAEA, 2003). The broader regional anomaly over the massive granodiorite to granite is in the 2.0 to 3.5 ppm range for uranium.

5.2.4 Electromagnetic

The two electromagnetic surveys in the area of the four communities focused on the Benny Lake and Whiskey Lake greenstone belts (Figure 18). The results from these electromagnetic surveys correspond to a mixture of sources, including cultural (e.g. power lines), surficial (e.g. clays and lake-bottom sediments) and bedrock (e.g. conductive horizons, sulphide minerals). The interpretation in this report focused on delineating bedrock sources into conductors that traverse a few to several flight lines (i.e. 200 m to 1,000 m or more). In addition, Figure 18 shows the several electromagnetic grid images from assessment files in the area of the four communities.

The apparent conductivity results (4,175 Hz coplanar) from the Benny survey (GDS1017, OGS, 2003) show several conductive responses (Figure 18) that are typical of drainage-related sediments in northern Ontario. Some responses are fairly narrow and linear but do follow drainage controlled by faults. There are relatively few EM responses interpreted as having bedrock sources in this western part of the Benny Lake greenstone belt. They tend to occur along the edges of magnetic anomalies that may reflect mafic metavolcanic horizons.

The decay constant (Z-component) grid from the Elliot Lake-River aux Sables (GDS1236, OGS, 2011b) survey, and the results from the OGS electromagnetic anomaly database suggest that the identified conductors predominantly correspond to horizons within the metavolcanic-metasedimentary rocks, which follow the structural trends in the Whiskey Lake greenstone belt (Figure 18). Bedrock conductors of 500 m to 2,000 m in length strike east-northeast to east-southeast and most are coincident with or trace the margins of linear magnetic anomalies that likely reflect lithological horizons. There is also a prominent power line response in this survey.

TDEM results from assessment file 20003244 (Figure 18) show conductive EM responses that correlate with lake-bottom sediments (mainly Quirke Lake) or cultural sources, but no bedrock conductors. From assessment files 200005757-1 to -3, three bedrock conductors are evident, all located within the Huronian Supergroup sedimentary rocks. The most prominent is located at the east end of the survey area, with a 1 km strike length and east-southeast orientation. The other two conductors are 100 m long.

The VLF surveys (Sudbury and East Bull Lake (RA-7)) are not particularly useful. The orientation of the VLF transmitter for the Sudbury survey (Figure 18) results in linear anomalies oriented between east-northeast and east-southeast, almost perpendicular to the topographic trend. This makes it difficult to screen topographic effects from bedrock responses. The data from East Bull Lake (RA-7) is very noisy (base level shifts between flights and between individual flightlines), and conductive responses are not recognizable.

VLF-EM data from assessment file 20000850 show several orientations of VLF conductors: east-northeast to northeast, east, west-southwest to southwest (northwest oriented conductor in the southwest is due to a power line). Some have direct correlation with topography but others appear to reflect bedrock sources (e.g. faults) and are shown on Figure 18. VLF-EM data from assessment file 20004445 show two sets of VLF conductors oriented east-northeast and west-northwest. A few are associated with ridges but most follow troughs, particularly the latter set, and may incorporate bedrock responses (likely faults) as shown on Figure 18.

Overall, the EM coverage over the geological formations of interest in the area of the four communities is very limited, and the EM data has not proven to be particularly useful as a geological mapping tool. The data has predominantly shown overburden responses associated with drainage patterns in the area around the Benny Lake greenstone belt, and weak bedrock conductors as well as cultural noise near the Whiskey Lake greenstone belt. Where the data overlies the metavolcanics and metasediments, the EM conductors typically reflect lithological horizons which are also evident in the magnetic data.

5.3 Geophysical Interpretation of the Ramsey-Algoma Granitoid Complex

The following section provides more detailed geophysical interpretations of the Ramsey-Algoma granitoid complex in the area of the four communities. The interpretations include a description of the geophysical characteristics of the massive granodiorite to granite and the gneissic tonalite units, and other associated intrusions, with a focus on identifying internal heterogeneity associated with lithology contrasts, if present. These interpreted units are presented alongside the current bedrock geology mapping on Figure 19, noting that the interpretations are preliminary and based on predominantly low resolution geophysical data and require future geologic validation. As a result of the Huronian Supergroup bedrock units generally being magnetically unresponsive, the outline as determined by geological mapping was used to show the distribution of these units in Figure 19.

5.3.1 Massive Granodiorite to Granite

The geological mapping shows two large blocks of massive granodiorite to granite covering roughly half the area of the four communities, divided by a block of gneissic tonalite (Figure 3 and Figure 19). The geophysical interpretation has identified variations in the magnitude and character of the magnetic data, shown in the reduced to pole magnetic field (Figure 7), the vertical derivatives (Figure 9 and Figure 11), as well as the directional filtered magnetic data (Figure 8 and Figure 10). This interpretation has highlighted five geophysical units (A to E)overlying the massive granodiorite to granite, and three additional units (F to H) that extend from the massive granodiorite to granite and overlap into the gneissic tonalite rocks (Figure 19). Units A, B and C outline the strongest magnetic responses in the Ramsey-Algoma granitoid complex, which extend well to the east beyond the area of the four communities. These three units have the appearance of discrete intrusions within the larger Ramsey-Algoma granitoid complex (e.g. Figure 7), and whose higher magnetic susceptibility may indicate a more dioritic phase (Clark, 1997). Linear magnetic highs cross through all of these units and are interpreted as dykes, originating from various dyke swarms in the area. The dykes within unit C show a northwest orientation, and show a more northerly change in orientation in units A and B. Unit D shows a similar high magnetic response in the northwest corner of the area with a broad east-west orientation. The orientation of this anomaly tends to correlate well with the trend of the mapped massive granite to granodiorite unit, which extends further to the west beyond the extent of the area of the four communities. The magnetic character of unit E shows a more subdued magnetic response compared to the previous geophysical units, comprising much more local variation in the magnetic field reflecting more localized units of high magnetic response.

The variability in the magnetic data overlying the massive granite to granodiorite may reflect regional-scale heterogeneity associated with subtle changes in lithology. Although a majority of the magnetic character is somewhat controlled by the dominance of dykes in the area reflecting near-surface magnetic sources, the broader magnetic high anomalies are likely to reflect magnetic sources from greater depths, and reflect lithologies with a higher abundance of magnetic minerals. Although the interpretation relied predominantly on low resolution magnetic data, the outline of some of the geophysical units have changed position in the geophysical interpretation relative to where they have been mapped, especially between the massive granodiorite to granite and the gneissic tonalite. The interpreted outlines between geophysical units are hindered by the presence of numerous dyke swarms and are generally gradational in character, and therefore their exact positions are uncertain. The geophysical unit outlines around the greenstone belts are typically better defined between the intrusive units and the mafic metavolcanics in the Benny Lake and Whiskey Lake belts, and reflects the presence of higher resolution magnetic data in these areas. The Agnew Lake intrusion appears quite small in the magnetic interpretation (unit R) but its gravity response conforms quite well to its mapped extent.

Throughout much of the Ramsey-Algoma granitoid complex the gravity and radiometric data project a somewhat different picture from the magnetic data. The massive granodiorite to granite units generally show a low gravity response and a radiometric response that is high in all three radioelements. Although both the gravity and radiometric data sets are fairly low resolution, these geophysical trends tend to be broadly consistent with the mapped distribution of massive granodiorite to granite. These contrasts between the magnetic, gravity and radiometric responses suggest inhomogeneities within the massive granodiorite to granite, and possibly a more complex intermingling of this granitic rock with the gneissic tonalite, both laterally and vertically, than indicated by the geological mapping.

5.3.2 Gneissic Tonalite

The geological mapping shows gneissic tonalite completely encircling the Huronian Supergroup except at the south end at Blind River, as well as an east-northeast trending block in the northern part of the area of the four communities (Figure 3 and Figure 19). This interpretation has highlighted several geophysical units (F to H) that are overlying portions of the massive granodiorite to granite and gneissic tonalite rocks (Figure 19). Unit H shows a broad magnetic unit consisting of the weakest magnetic response within the Ramsey-Algoma granitoid complex. The outline for this geophysical unit predominantly overlies the massive granodiorite to granite, however, extends further south and overlies the mapped portion of the gneissic tonalite suite adjacent to the Huronian Supergroup rocks. This geophysical unit is punctuated by linear anomalies associated with dykes that tend to have a weaker magnitude compared to the dykes in the surrounding units. Unit F tends to have a slightly elevated magnetic response, and resulted in this unit being separated from adjacent unit H; although this separation may only reflect a subtle variation in lithological composition. Unit G shows a lower magnetic response trending in a northeasterly direction in the northern portion of the Ramsey-Algoma granitoid complex. This geophysical unit has a similar character as unit H, and is particularly evident in the reduced to pole magnetic field with a directional filter applied to remove the influence of dykes.

Geophysical units I and J reflect areas of weak magnetic response where the gneissic tonalite surrounds the Huronian Supergroup rocks. Unit I shows a weak magnetic response associated with the mapped gneissic tonalite suite rocks located between the Huronian Supergroup rocks and the Murray fault, within the Chiblow anticline. This unit tends to produce fairly uniform magnetic character, with minimal interference by linear dyke traces. This uniformity may reflect a lesser degree of lithological heterogeneity, or may suggest that the dykes, which are prevalent through much of the area of the four communities, are in fact reduced within the geophysical unit. Spray et al. (2004) noted a similar reduction of dykes in the southern portion of the area, which they attributed to demagnetization of the rock due to shock from the nearby Sudbury Impact Structure. In spite of this character, local magnetic highs exist within unit I that are likely to reflect the distribution of Nipissing intrusive rocks, some of which are mapped.

Units L and M on the north edge of the area of the four communities are located within mapped gneissic tonalite, on either side of greenstone interpreted as felsic metavolcanics and metasediments. These units are characterized by a distinct magnetic low, relatively low radiometric responses (especially potassium) and a weak gravity low. These responses conflict with those over the gneissic tonalite elsewhere and are interpreted to reflect a granitic and migmatitic rock with areas of pegmatite, all of which were mapped by Parker (2008).

The most notable gravity response in the area of the four communities consists of a large arcuate gravity high anomaly that underlies much of the Huronian Supergroup units in an east-southeast direction, and continues in a northeast direction through the central portion of the Ramsey-

Algoma granitoid complex. This gravity anomaly appears to spatially relate to a large-scale fold structure with east-west trending axial surface traces in the area of the four communities. The highest magnitude portion of the anomaly tends to show a strong spatial relationship with the location of the Quirke Lake syncline and Chiblow anticline with east-west axial surface traces. Where the anomaly extends into the Ramsey-Algoma granitoid complex it creates a broad gravity high that is roughly coincident with the trend of the mapped gneissic tonalite suite, although gravity stations are sparse in this area. This gravity high is also generally consistent with unit K interpreted from the magnetic data, as well as a broad anomaly seen in the radiometric data. In the radiometric data, this anomaly tends to be potassium and thorium rich, and locally depleted in uranium. This radiometric response is clearly distinguishable from the elevated radioelements over the massive granodiorite to granite units.

5.3.3 Other Intrusions and Metasedimentary Units

Unit O delineates a Huronian Supergroup metasedimentary unit south of the Murray fault. It covers Cobalt Group metasediments with magnetic horizons that trace fold structures. The remaining Huronian Supergroup metasedimentary formations south of the fault are weakly to non-magnetic. The Cutler pluton has a magnetic signature which is indistinguishable from them. The Huronian Supergroup metasedimentary units north of the Murray fault were not subdivided. They are essentially magnetically transparent, with magnetic responses reflecting the underlying Ramsey-Algoma granitoid complex and discrete magnetic anomalies associated with metavolcanics, Huronian Supergroup volcanics and Nipissing diabase intrusions.

Units P to T delineate the magnetic portions of known intrusions, including the southern part of the East Bull Lake intrusion (unit P), the Parisien Lake syenite (unit Q), the Agnew Lake intrusion (unit R), the Seabrook Lake carbonatite (unit S) and the Croker Bay pluton (unit T). The two northern lobes of the East Bull Lake intrusion show no magnetic contrast with their host rock in the low-resolution data. The Agnew Lake intrusion (unit R) is more extensive and better delineated by its gravity response.

6 SUMMARY OF RESULTS

The purpose of this assessment was to identify and obtain the available geophysical data for the Communities of Elliot Lake, Blind River, The North Shore and Spanish, Ontario, followed by a detailed interpretation of all available geophysical data (e.g., magnetic, electromagnetic, gravity and radiometric) to identify additional information that could be extracted from the data, in particular regarding the coincidence of geophysical features with mapped lithology and structural features in the area of the four communities.

The geophysical data covering the area of the four communities show variability in data set resolution. Low-resolution geophysical data, particularly the magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC), cover the entire area of the four communities. One additional GSC magnetic survey and two additional magnetic/electromagnetic surveys obtained from the Ontario Geological Survey (OGS, 2003; 2011b) provided higher resolution coverage over approximately 5 percent in the area of the four communities, over the

East Bull Lake intrusion, Benny Lake and Whiskey Lake greenstone belts. The latter two surveys focused primarily on mineral exploration in the greenstone belts. The data were supplemented by geophysical images extracted from eight assessment file reports. These proved extremely useful in understanding the dyke architecture of the area.

The coincidence between the geophysical data and the mapped lithology, faults and other structure were interpreted using all available geophysical data sets (e.g., magnetic, electromagnetic, gravity and radiometric). In particular, the pole reduced magnetic field (RTP) and its first vertical derivative (1VD) were the most reliable for mapping variations in geological contacts and identifying heterogeneity. At a regional scale, the coincidence between the geophysical interpretations and the published geological maps is in good agreement. However, limited magnetic contrasts between the rock units within the Ramsey-Algoma granitoid complex made the geological unit boundaries difficult to differentiate. This resulted in new interpretation of the extent of some geological units, and some subdivision as well. The radiometric and gravity data provide a different perspective in the granitoid complex to regional magnetic data so the interpretation of the extent of contacts is tentative. Heterogeneity and intermixing of lithologies may occur laterally and vertically.

The delineation and subdivision of the Ramsey-Algoma granitoid complex relied on the magnetic data, primarily on regional-scale anomaly amplitude, supplemented in some cases by the predominant strike direction. Units A to C are the most magnetic of the massive granodiorite to granite, covering large parts of the northeast area of the four communities and extending beyond, with northwest to north orientations. Unit D and the northwest lobe of unit E are moderately magnetic with an easterly orientation. The southeast lobe of unit E is also moderately magnetic. Units F to H incorporate moderate to low magnetic responses, straddling the mapped massive granodiorite to granite and gneissic tonalite. The magnetic responses over units F and G more closely resemble the former and unit H the latter. Units I to K reflect a lower magnetic response and correlate with the gneissic tonalite, with units I and J surrounding the Huronian Supergroup. Units L and M are located in an area of mapped gneissic tonalite but the distinct magnetic low and field observations by Parker (2008) suggest that these units reflect a granitic and migmatitic rock. Unit N is also mapped mainly as gneissic tonalite, but the strong magnetic responses with a northwest orientation indicate that it forms the southeast extension to a diorite-monzodiorite-granodiorite suite mapped just beyond the area boundary.

Unit O delineates a Huronian Supergroup metasedimentary unit south of the Murray fault. Units P to T delineate the magnetic portions of known intrusions, including the southern part of the East Bull Lake intrusion (unit P), the Parisien Lake syenite (unit Q), the Agnew Lake intrusion (unit R), the Seabrook Lake carbonatite (unit S) and the Croker Bay pluton (unit T).

Four dyke swarms were interpreted from the magnetic data and incorporated in the lineament analysis (JDMA, 2014b). Their identification depended mainly on strike direction and cross-cutting relationships, and to a lesser extent anomaly amplitude. Matachewan dykes have a consistent northwest to north-northwest strike and are mainly located in the north half of the area. In places, the strike directions of the Matachewan and Sudbury dykes, and, are within a few degrees of each other and can be difficult to differentiate. To a lesser extent, the same issue applies to the Biscotasing and the North Channel dykes in the central part of the area, where both swarms exhibit an easterly strike direction. In general, the Matachewan dykes exhibit a more northerly orientation compared to the other dykes. Biscotasing dykes are present in the area to a lesser extent and are characterized by their higher amplitude response, and northeast to east-northeast strike.

The magnetic data proved useful for delineating the mafic metavolcanic portions of the Benny Lake and Whiskey Lake greenstone belts and a sliver mapped to the northwest, which possess strong, discrete magnetic responses. Any associated felsic metavolcanics and metasediments in these belts do not show a magnetic contrast with the surrounding rock. A felsic metavolcanic unit to the northeast is associated with a strong magnetic low.

Throughout much of the Ramsey-Algoma granitoid complex the gravity and radiometric data project a somewhat different picture from the magnetic data. The massive granodiorite to granite units generally show a low gravity response and a radiometric response that is high in all three radioelements. Although both the gravity and radiometric data sets are fairly low resolution, these geophysical trends tend to be broadly consistent with the mapped distribution of massive granodiorite to granite. These contrasts between the magnetic, gravity and radiometric responses suggest inhomogeneities within the massive granodiorite to granite, and possibly a more complex intermingling of this granitic rock with the gneissic tonalite, both laterally and vertically, than indicated by the geological mapping.

The most notable gravity response in the area of the four communities consists of a large arcuate gravity high anomaly that underlies much of the Huronian Supergroup units in an east-southeast direction, and continues in a northeast direction through the central portion of the Ramsey-Algoma granitoid complex. This gravity anomaly appears to spatially relate to a large-scale fold structure with east-west trending axial surface traces in the area of the four communities. The highest magnitude portion of the anomaly tends to show a strong spatial relationship with the location of the Quirke Lake syncline and Chiblow anticline with east-west axial surface traces.

Both the gravity and radiometric data differentiate the Quirke Lake syncline and the Chiblow anticline within the Huronian Supergroup near Elliot Lake. It is speculated that the gravity high associated with the syncline reflects the distribution and increased thickness of high density metasedimentary and metavolcanic rocks within the core of a regional fold, and/or may reflect the presence of a discrete intrusion at depth within the sub-Huronian Archean basement rocks. A separate gravity high associated with the Murray fault and extending 350 km eastwards is interpreted to reflect an uplifted block of volcanic rocks near the base of the Huronian Supergroup (Card et al., 1984). Many of the discrete intrusions exposed in the area of the four communities show distinct gravity and/or radiometric signatures.

Electromagnetic surveys show a mixture of sources, including cultural (e.g. power lines), surficial (e.g. clays and lake-bottom sediments) and bedrock (e.g. conductive horizons, sulphide minerals) over the greenstone belts. The FDEM survey over the Benny Lake greenstone belt mainly maps conductive sediments in drainage features at the west end of the belt. The TDEM survey over the Whiskey Lake greenstone belt traces a number of bedrock conductors that follow the peaks or edges of curvilinear magnetic horizons. The VLF data available in the area of the four communities is limited in coverage and did not couple well with the local orientation of the bedrock geology.

Respectfully Submitted,

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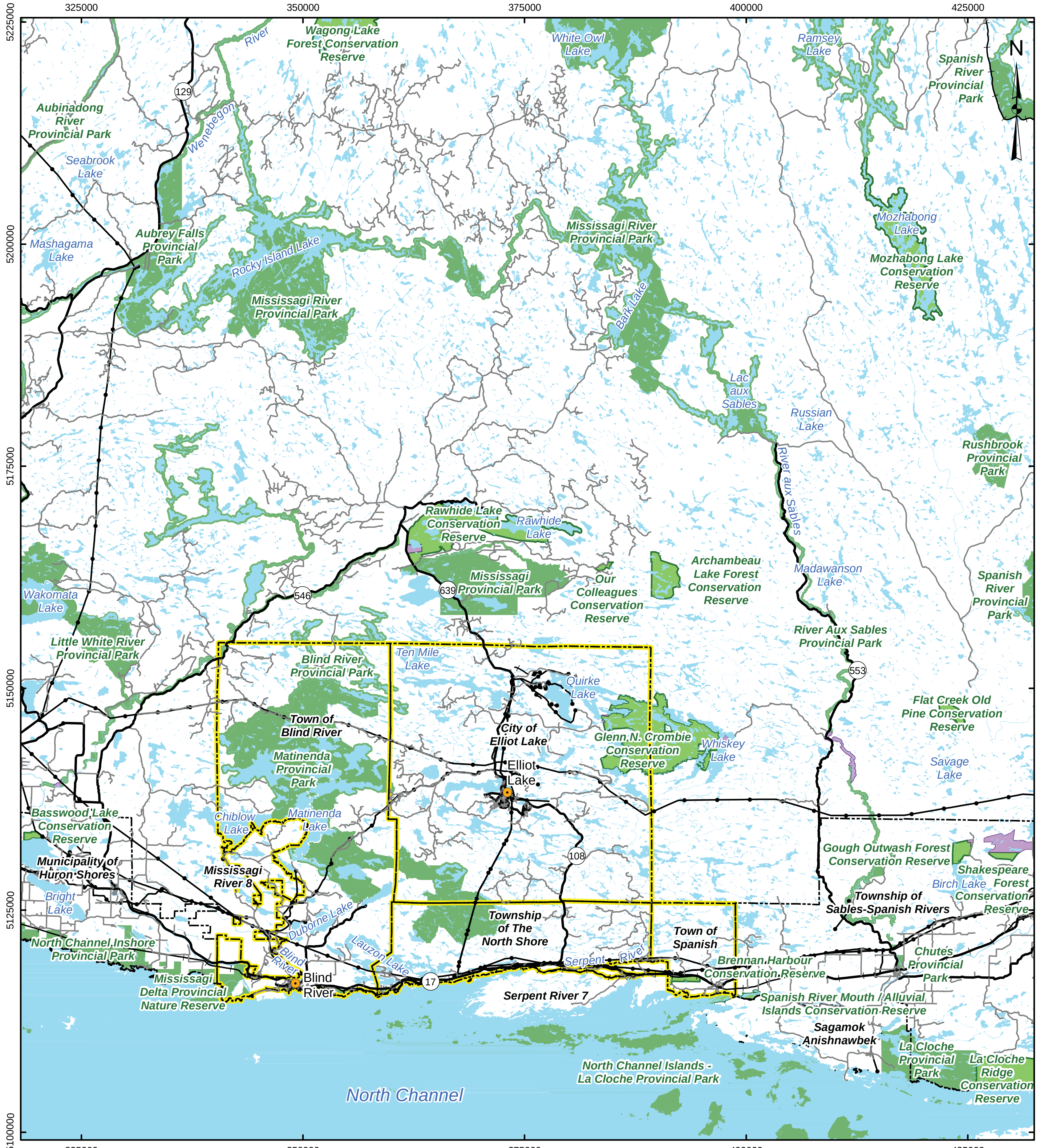

LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Utility Line
- Waterbody
- Forest Reserve
- Conservation Reserve
- Provincial Park

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REFERENCE

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10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Communities of Elliot Lake, Blind River, The North Shore, Spanish and Surrounding Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar. 2013		
GIS	PRM	17 Dec. 2013		
CHECK	PMcC	17 Dec. 2013		
REVIEW	SWR	18 Jun. 2014		

FIGURE 1

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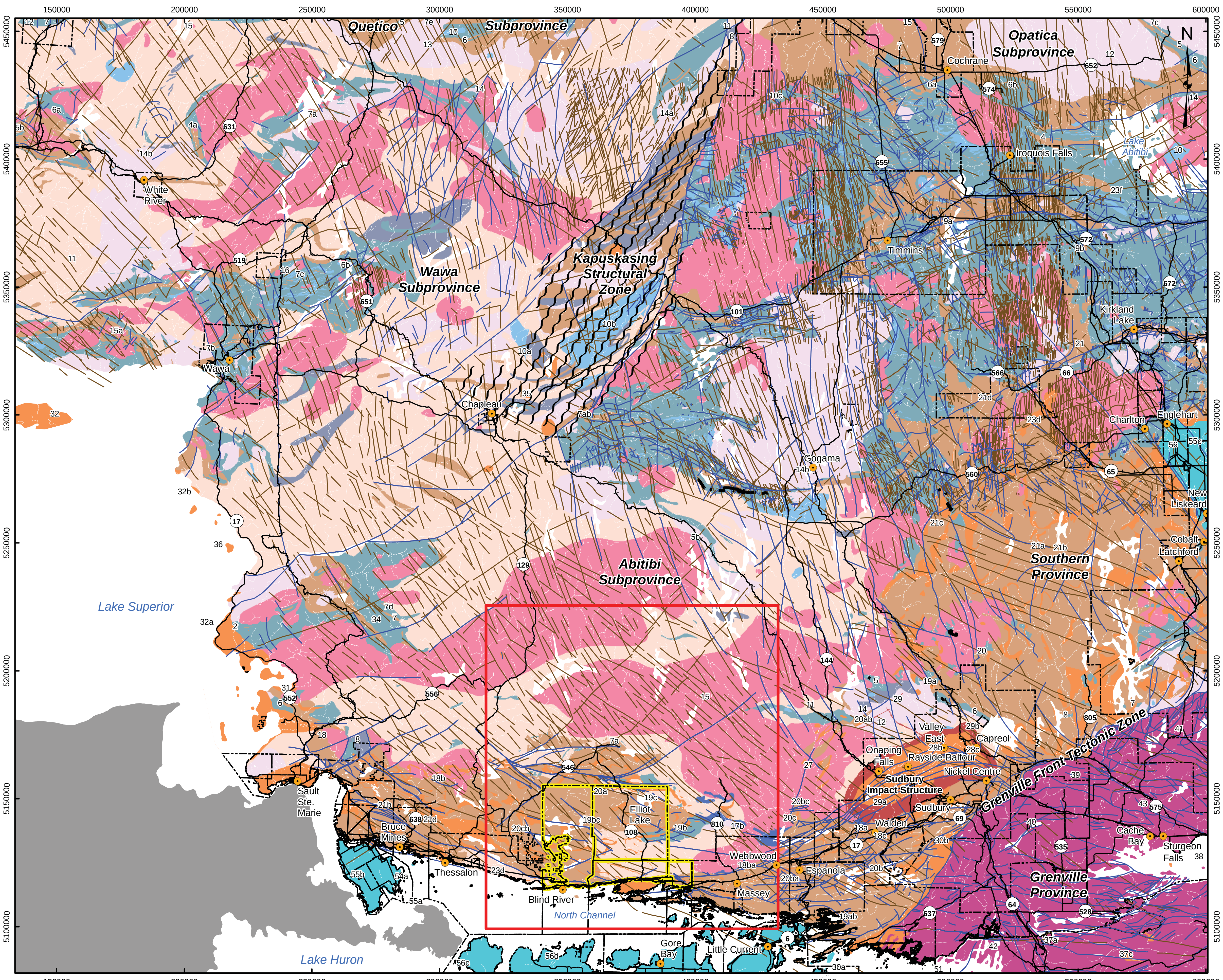

LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish Area
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Railway
- Waterbody/Watercourse
- Mapped Fault
- Mapped Dyke
- Kapuskasing Structural Zone
- Iron Formation

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (56, 55, 54)

Proterozoic

- Various rock units of the Grenville Province (51, 43, 42, 41, 40, 39)

Southern Province

- Various rock units of the Southern Province (38, 37, 36, 35, 34, 32, 31, 30, 28, 27, 23, 22)
- Sudbury Igneous Complex (29)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Archean granitoid suites (16, 14, 13, 12)
- Massive granodiorite to granite (15)
- Gneissic tonalite suite (11)
- Mafic and ultramafic rocks (10)
- Metasedimentary rocks (9, 7)
- Migmatized supracrustal rocks (8)
- Metavolcanic rocks (6, 5, 4, 2)

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REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

25 12.5 0 25 50 75

SCALE 1:1,500,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Regional bedrock geology of the Communities of Elliot Lake, Blind River, The North Shore and Spanish and Surrounding Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245		
DESIGN	PRM	13 Mar. 2013
GIS	PM/JB	19 Jun. 2014
CHECK	PMcC	25 Jun. 2014
REVIEW	SWR	25 Jun. 2014

SCALE AS SHOWN REV. 1.2

FIGURE 2

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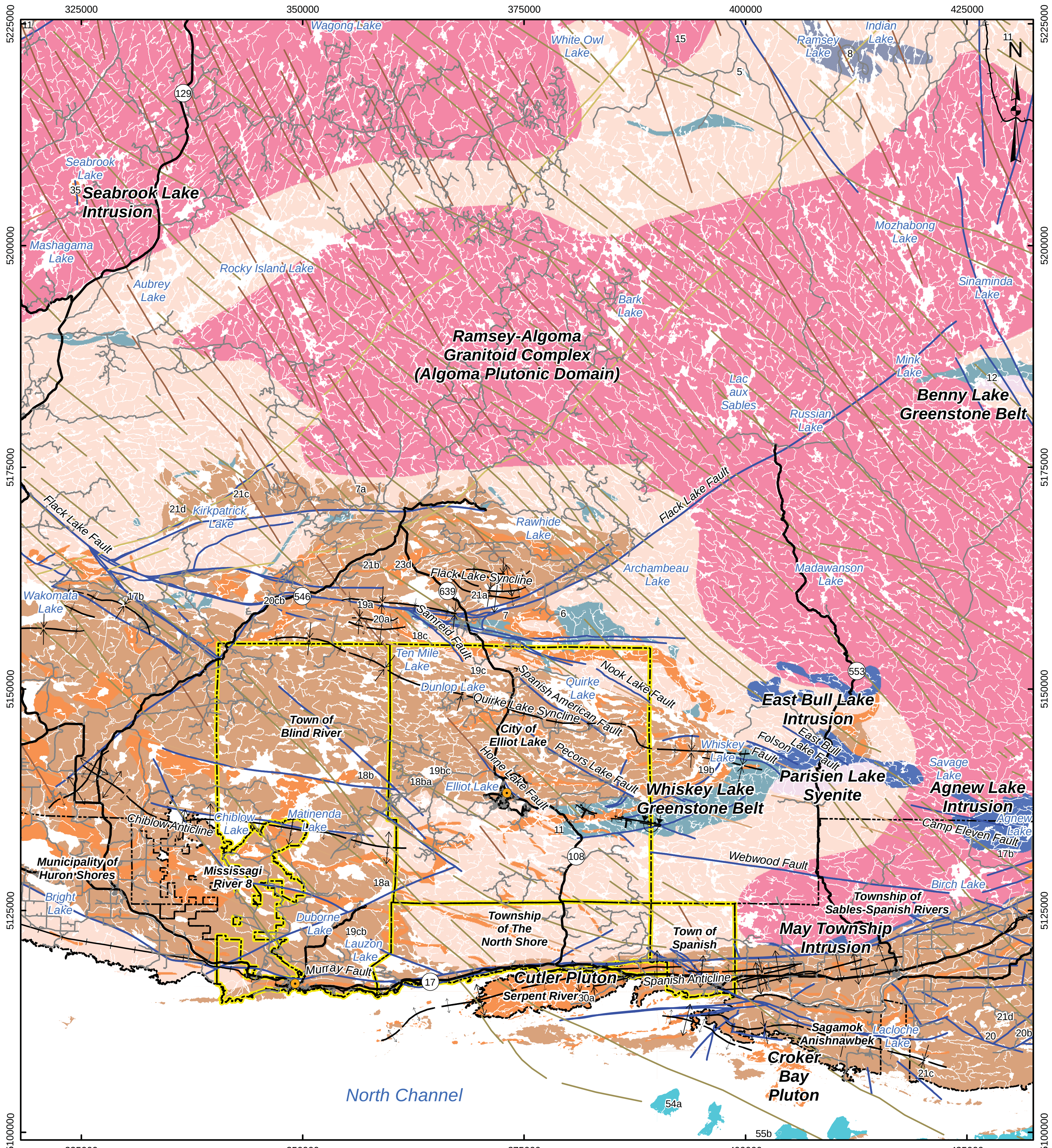

LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse
- Major Fold (syncline)
- Major Fold (anticline)
- Synform with inclined axial plane
- Mapped Fault

Mapped Dyke

- Biscotasing Mafic Dyke
- Matachewan Mafic Dyke
- North Channel Mafic Dyke
- Sudbury Mafic Dyke
- Unsubdivided Mafic Dyke

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

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REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011, Johns, G.W., et al. 2003.
Precambrian geology compilation map—Sault Ste. Marie–Blind River sheet; OGS, Map 2670.
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Local Bedrock Geology of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar. 2013	**FIGURE 3**	
GIS	PM/JB	19 Jun. 2014		
CHECK	PMcC	25 Jun. 2014		
REVIEW	SWR	25 Jun. 2014		

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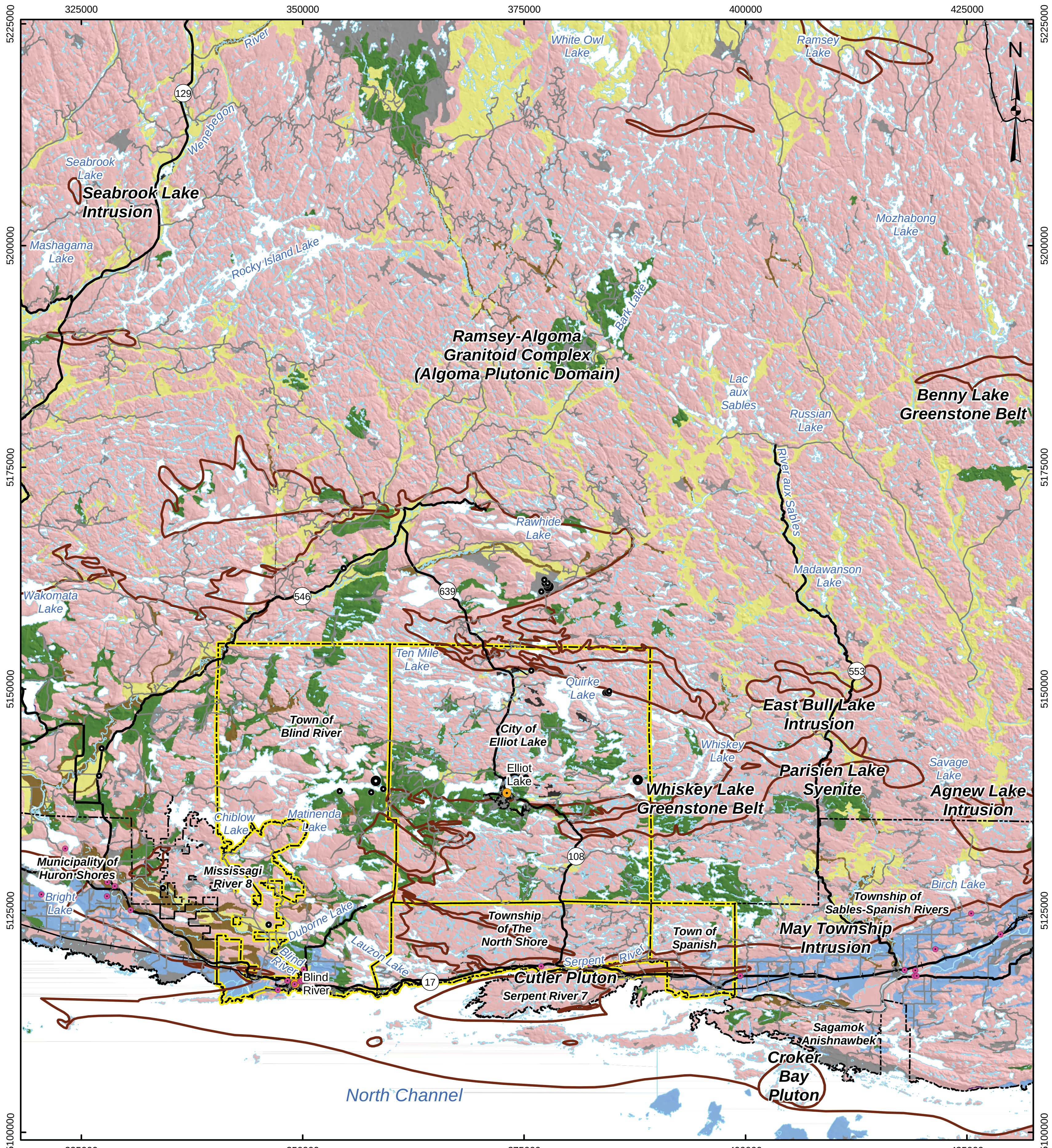

LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Major Geological Contact

Depth to bedrock

Drillhole

- 40 - 80 m
- > 80 m

Water well

- > 30 m

Landform

- Man Made
- End moraine
- Ground moraine
- Hummocky moraine
- Esker
- Kame
- Outwash plain
- Raised beach
- Glaciolacustrine delta
- Glaciolacustrine plain
- Alluvial
- Talus pile
- Organics
- Bedrock Terrain

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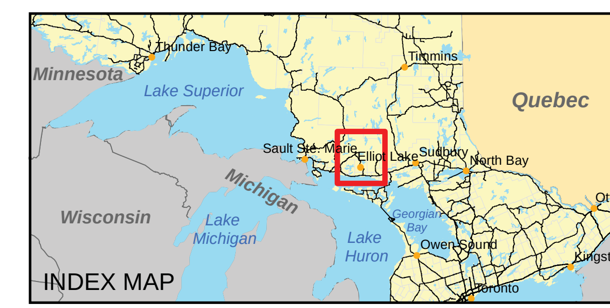

INDEX MAP

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Digital Elevation Model - CDED slope raster: Geobase.ca (1:50,000)
Landform- OGS, MND Mines, and Northeast Science and Information Section, MNR 2005
Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160.
Geology - MRD126-Bedrock Geology of Ontario, 2011
Drillhole - OGS Ontario Drillhole Database
Water Well - MOE Water Well Information System
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Surficial geology of the Communities of Elliot Lake, Blind River, The North Shore and Spanish and Surrounding Area

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar. 2013		
GIS	PRM	17 Dec. 2013		
CHECK	PMcC	20 June 2014		
REVIEW	SWR	20 June 2014		

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Mississauga, Ontario

FIGURE 4

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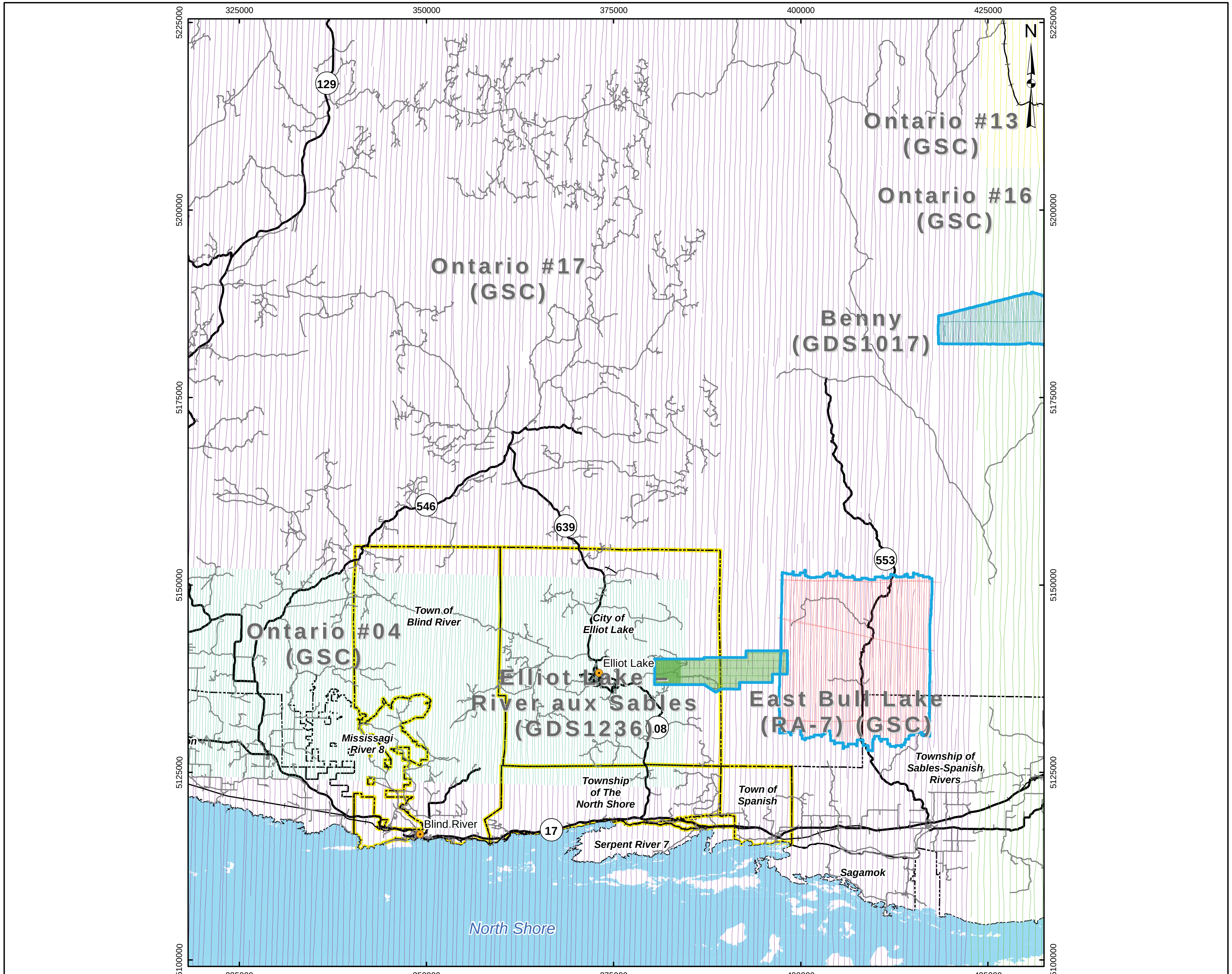

LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Waterbody
- High Resolution Geophysical Survey Outlines
- Flightpath OGS GDS 1017 Benny
- Flightpath OGS GDS 1236 Elliot Lake – River aux Sables
- Flightpath GSC East Bull Lake (RA-7)
- Flightpath GSC Ontario #04
- Flightpath GSC Ontario #13
- Flightpath GSC Ontario #16
- Flightpath GSC Ontario #17

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REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys:
Ontario #4, #13, #16, #17, East Bull Lake (RA-7)
Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Airborne geophysical coverage of the Communities of Elliot Lake, Blind River, The North Shore and Spanish and Surrounding Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013		
GIS	WP	2 May 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

FIGURE 5

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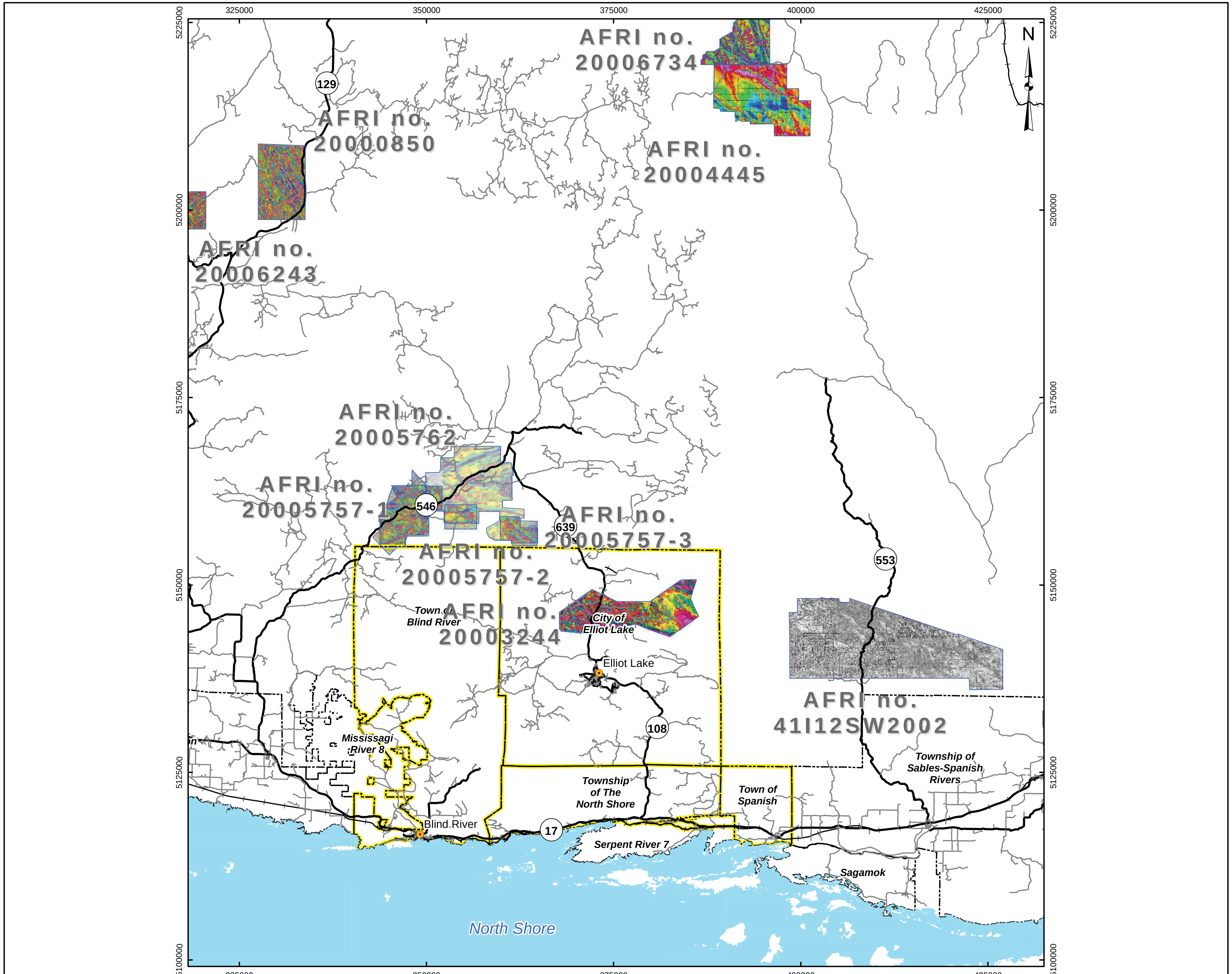

LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Waterbody
- Industry Geophysical Survey Outlines

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REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Ontario Geological Survey - Assessment File (AFRI) Database
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Assessment file magnetic images for the Communities of Elliot Lake, Blind River, The North Shore and Spanish and Surrounding Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013		
GIS	WP	2 May 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

FIGURE 6

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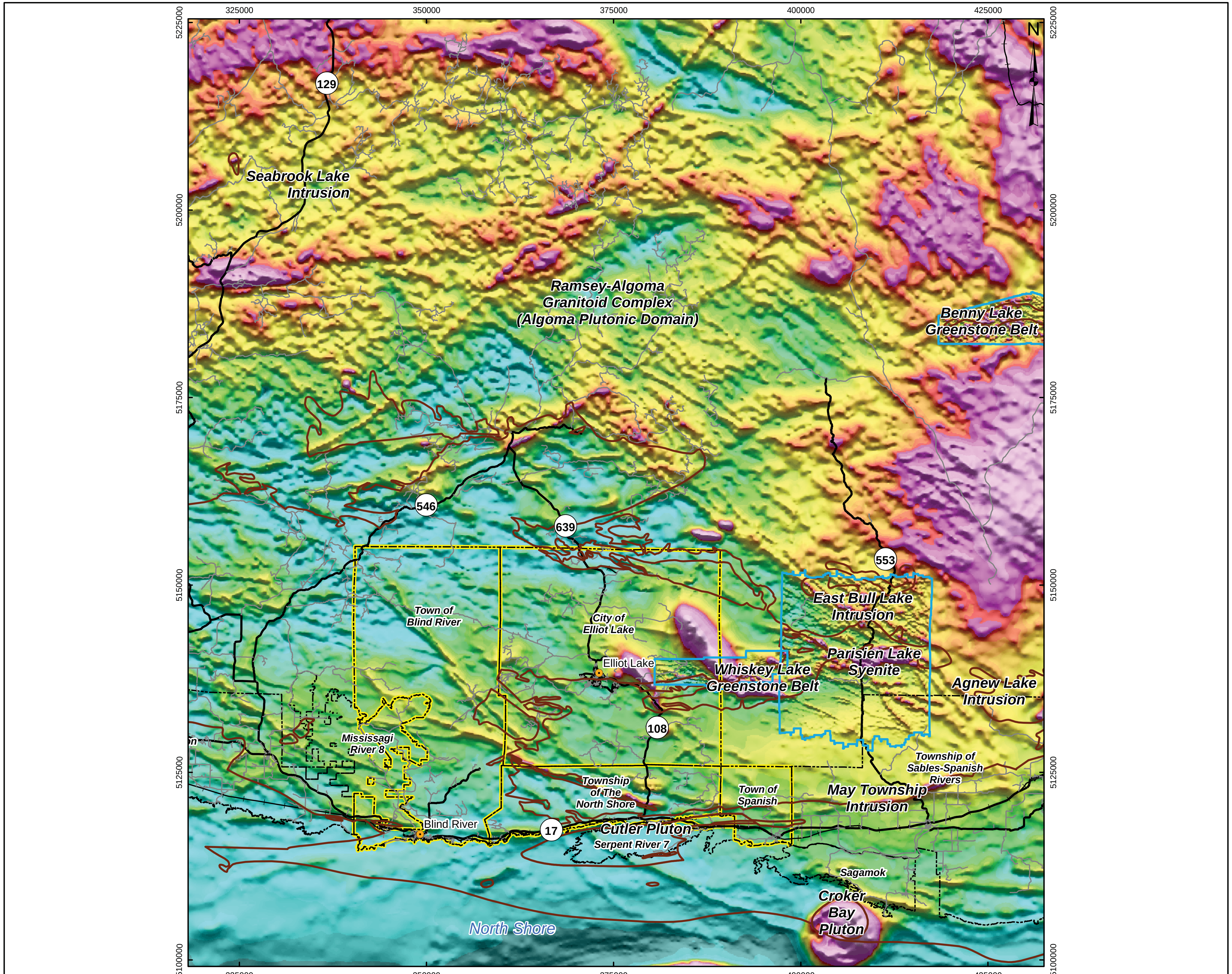

LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- High resolution geophysical survey outlines

Pole-reduced Magnetic Field (nT)

3009, 550, 370, 280, 230, 200, 180, 160, 140, 120, 110, 90, 80, 60, 40, 30, 10, 0, -20, -40, -60, -70, -90, -110, -130, -150, -180, -230, -300, -522

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REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys:
Ontario #4, #13, #16, #17, East Bull Lake (RA-7)
Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236
Geology - MRD126-Bedrock Geology of Ontario, 2011
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Residual magnetic field reduced to pole

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013	FIGURE 7	
GIS	WP	18 Apr 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

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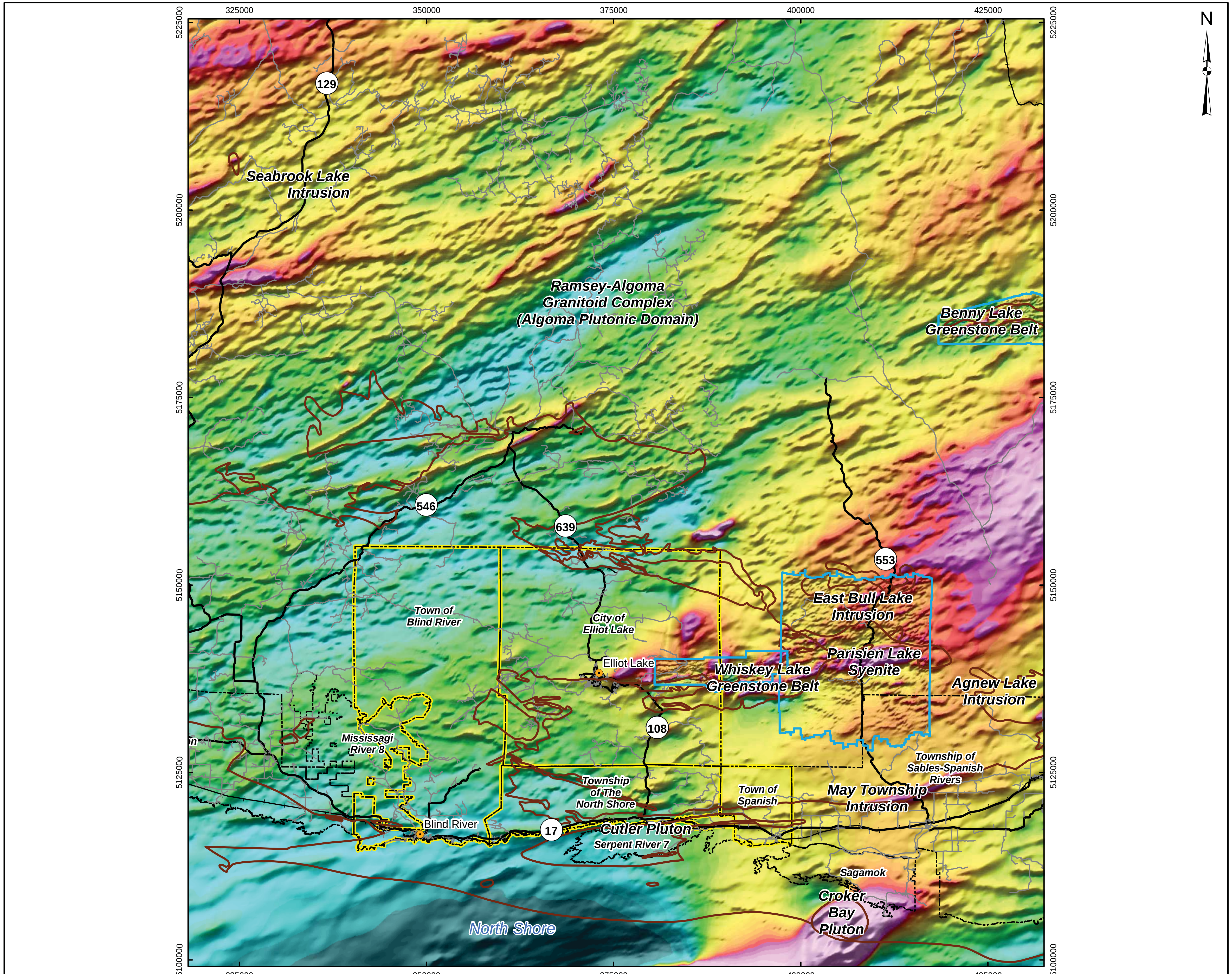

LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- High resolution geophysical survey outlines

Pole-reduced Magnetic Field (nT)

3009, 550, 370, 280, 230, 200, 180, 160, 140, 120, 110, 90, 80, 60, 40, 30, 10, 0, -20, -40, -60, -70, -90, -110, -130, -150, -180, -230, -300, -522

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Geophysics - Geological Survey of Canada - Aeromagnetic Surveys:
Ontario #4, #13, #16, #17, East Bull Lake (RA-7)
Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236
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10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Residual magnetic field reduced to pole with dyke responses removed

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013	FIGURE 8	
GIS	WP	2 May 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

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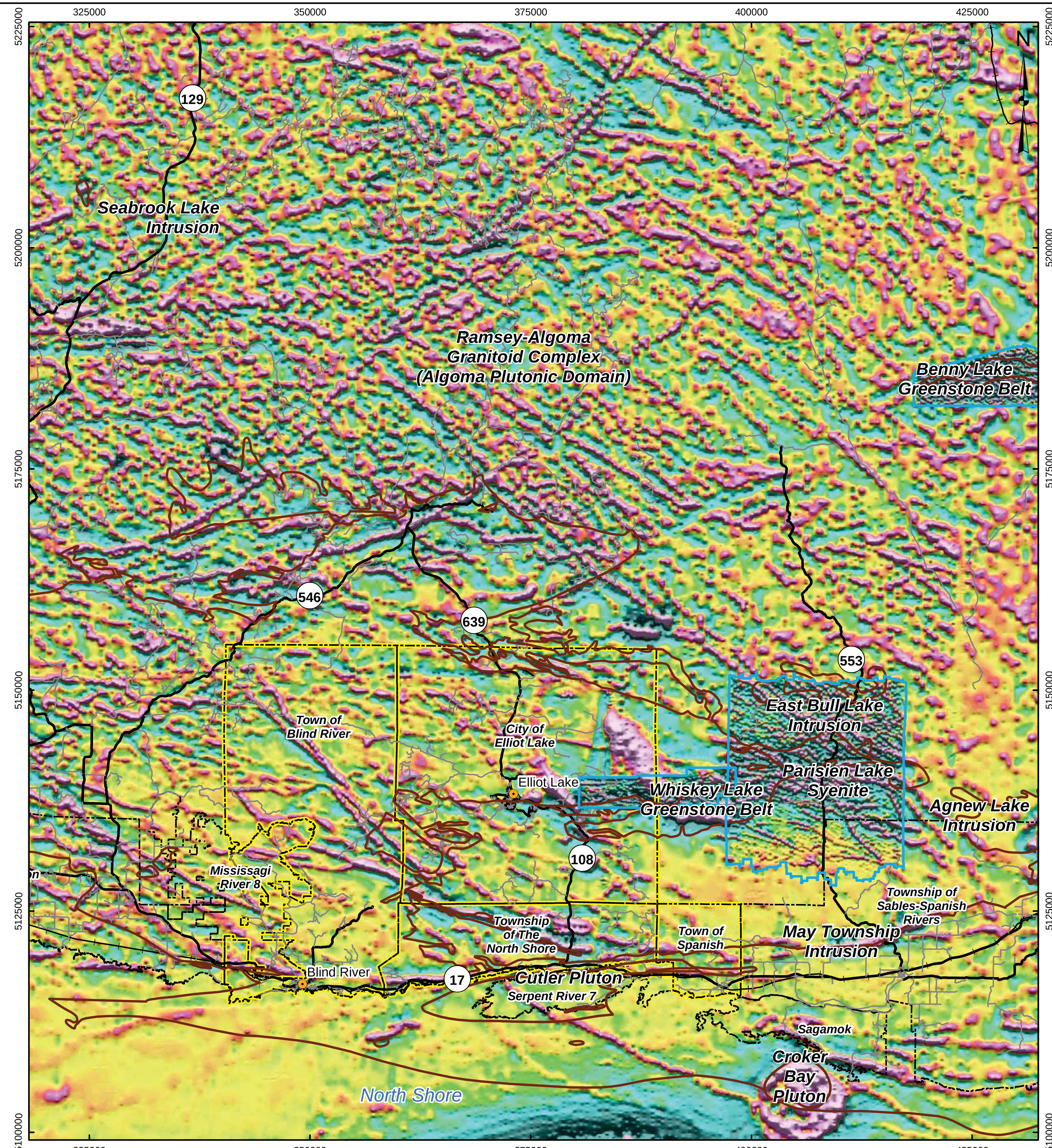

LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- High resolution geophysical survey outlines

First Vertical Derivative of the Pole-reduced Magnetic Field (nT/m)

20.483
0.220
0.145
0.105
0.080
0.065
0.050
0.040
0.030
0.020
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.050
-0.055
-0.065
-0.075
-0.090
-0.105
-0.130
-0.180
-7.102

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www.pgw.on.ca

REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys:
Ontario #4, #13, #16, #17, East Bull Lake (RA-7)
Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236
Geology - MRD126-Bedrock Geology of Ontario, 2011
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Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

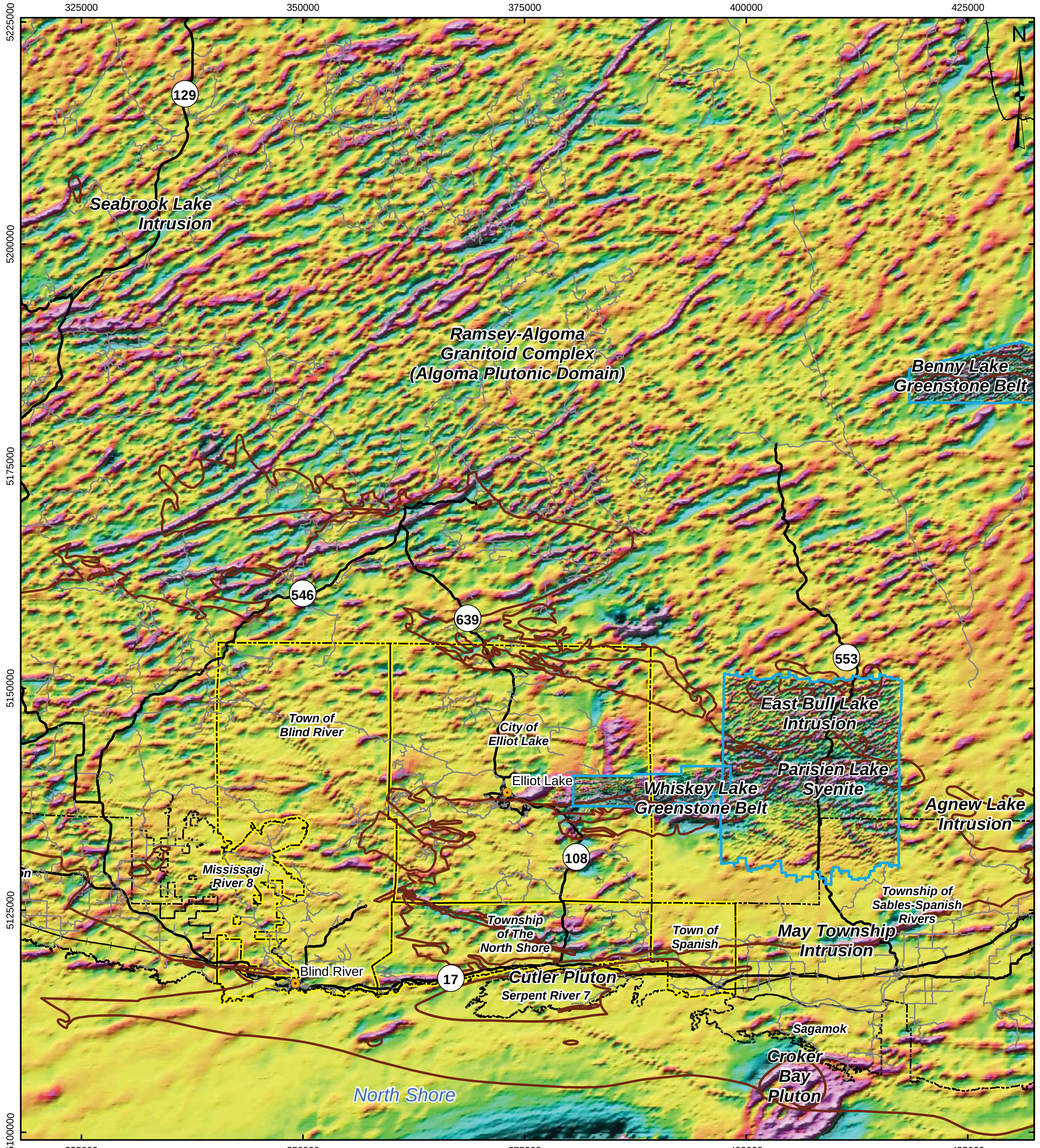
PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
First vertical derivative of the pole-reduced magnetic field

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013	**FIGURE 9**	
GIS	WP	18 Apr 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\ELNOS\Draft_Integrated_Report\TotalMagneticField\ELNOS.mxd



LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- High resolution geophysical survey outlines

First Vertical Derivative of the Pole-reduced Magnetic Field (nT/m)

20.483
0.220
0.145
0.105
0.080
0.065
0.050
0.040
0.030
0.020
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.050
-0.055
-0.065
-0.075
-0.090
-0.105
-0.130
-0.180
-7.102

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

REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys:
Ontario #4, #13, #16, #17, East Bull Lake (RA-7)
Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236
Geology - MRD126-Bedrock Geology of Ontario, 2011
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
First vertical derivative of the pole reduced magnetic field with dyke responses removed

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013	**FIGURE 10**	
GIS	WP	2 May 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

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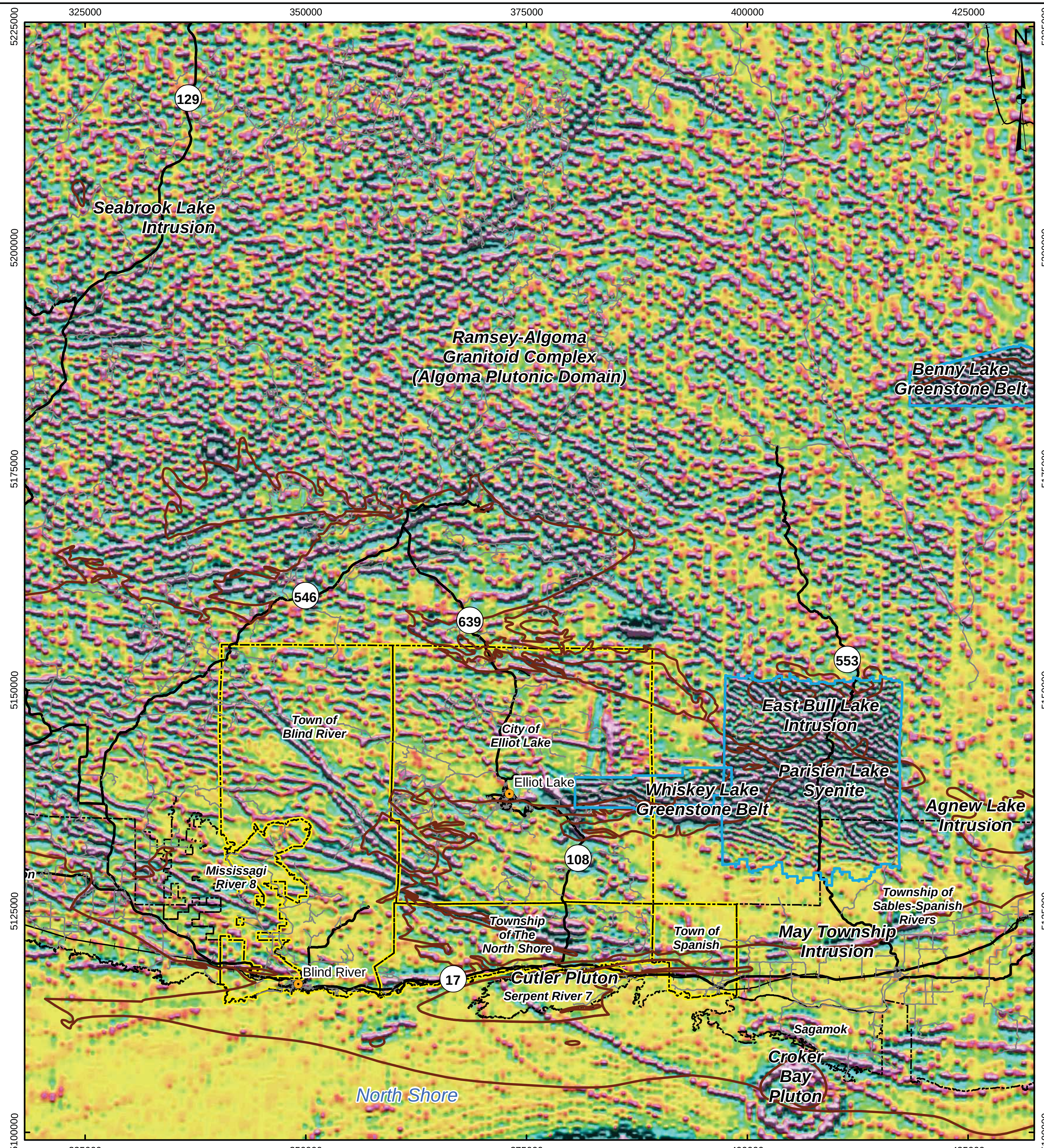
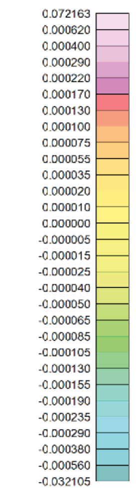


LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- High resolution geophysical survey outlines

Second Vertical Derivative of the Pole-reduced Magnetic Field (nT/m2)



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Consulting Geophysicists
www.pgw.on.ca

REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys:
Ontario #4, #13, #16, #17, East Bull Lake (RA-7)
Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236
Geology - MRD126-Bedrock Geology of Ontario, 2011
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

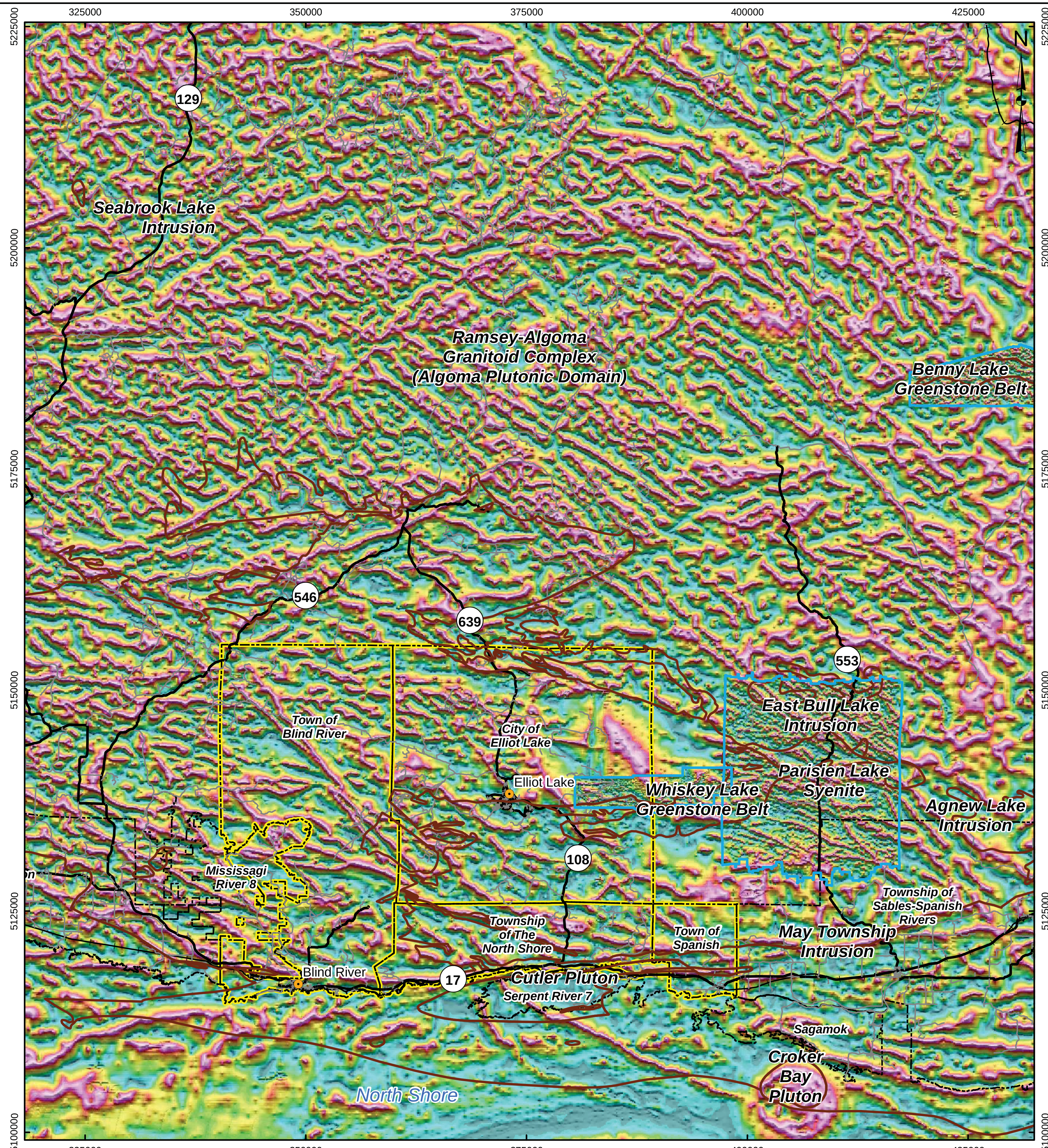
TITLE
Second vertical derivative of the pole-reduced magnetic field

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013		
GIS	WP	18 Apr 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

FIGURE 11

G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\ELNOS\Draft_Integrated_Report\TotalMagneticField\ELNOS.mxd



LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- High resolution geophysical survey outlines

Tilt Angle of the Pole-reduced Magnetic Field (radians)

1.57
1.25
1.10
1.00
0.85
0.75
0.65
0.55
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.55
-0.65
-0.75
-0.85
-0.90
-1.00
-1.05
-1.10
-1.20
-1.25
-1.35
-1.57

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

REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys:
Ontario #4, #13, #16, #17, East Bull Lake (RA-7)
Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236
Geology - MRD126-Bedrock Geology of Ontario, 2011
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Tilt angle of the pole-reduced magnetic field

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013	FIGURE 12	
GIS	WP	18 Apr 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

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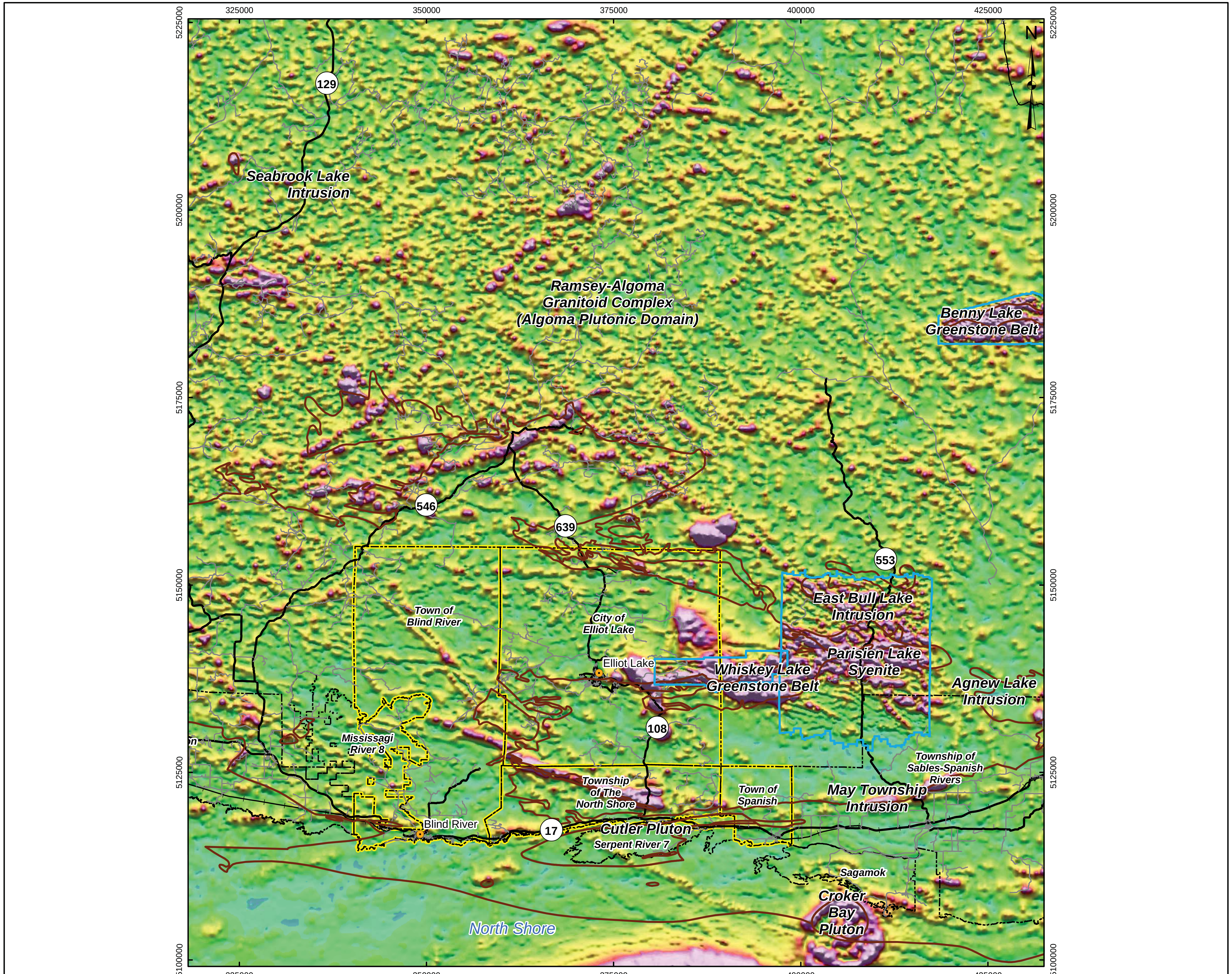

LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- High resolution geophysical survey outlines

Analytic Signal Amplitude of the Total Magnetic Field (nT/m)

9.467
0.385
0.335
0.300
0.275
0.260
0.240
0.220
0.205
0.190
0.175
0.165
0.150
0.135
0.125
0.110
0.100
0.085
0.075
0.060
0.045
0.030
0.015
0.005
0.000

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Consulting Geophysicists
www.pgw.on.ca

REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys:
Ontario #4, #13, #16, #17, East Bull Lake (RA-7)
Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236
Geology - MRD126-Bedrock Geology of Ontario, 2011
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Analytic signal amplitude of the total magnetic field

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013	**FIGURE 13**	
GIS	WP	18 Apr 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

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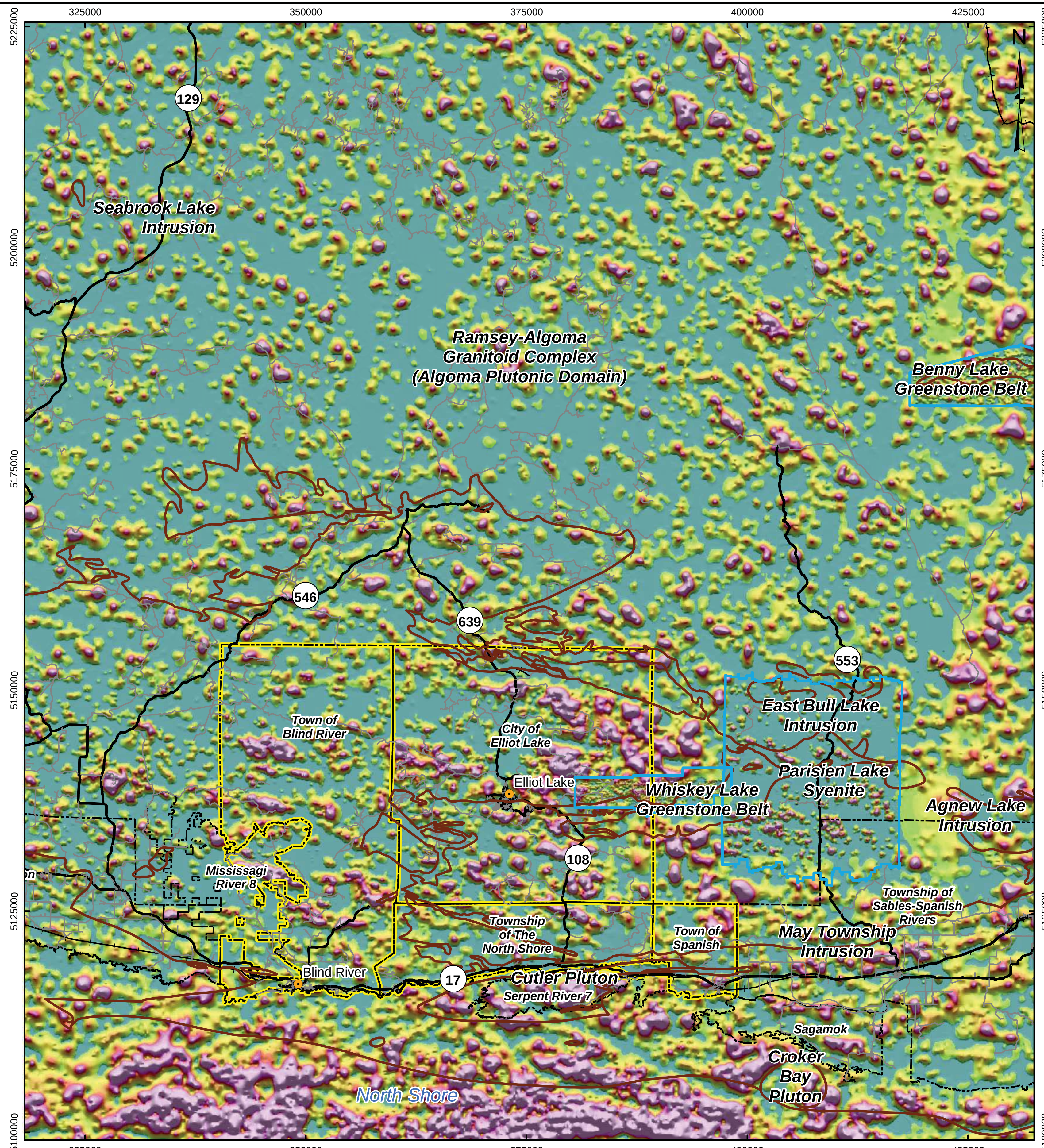

LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- High resolution geophysical survey outlines

Depth to Sources (m below surface)

10975, 800, 680, 600, 540, 500, 460, 400, 380, 340, 300, 260, 240, 200, 180, 140, 120, 80, 60, 20, 0

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

REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys:
Ontario #4, #13, #16, #17, East Bull Lake (RA-7)
Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Depth to magnetic sources from source parameter imaging

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013	**FIGURE 14**	
GIS	WP	18 Apr 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

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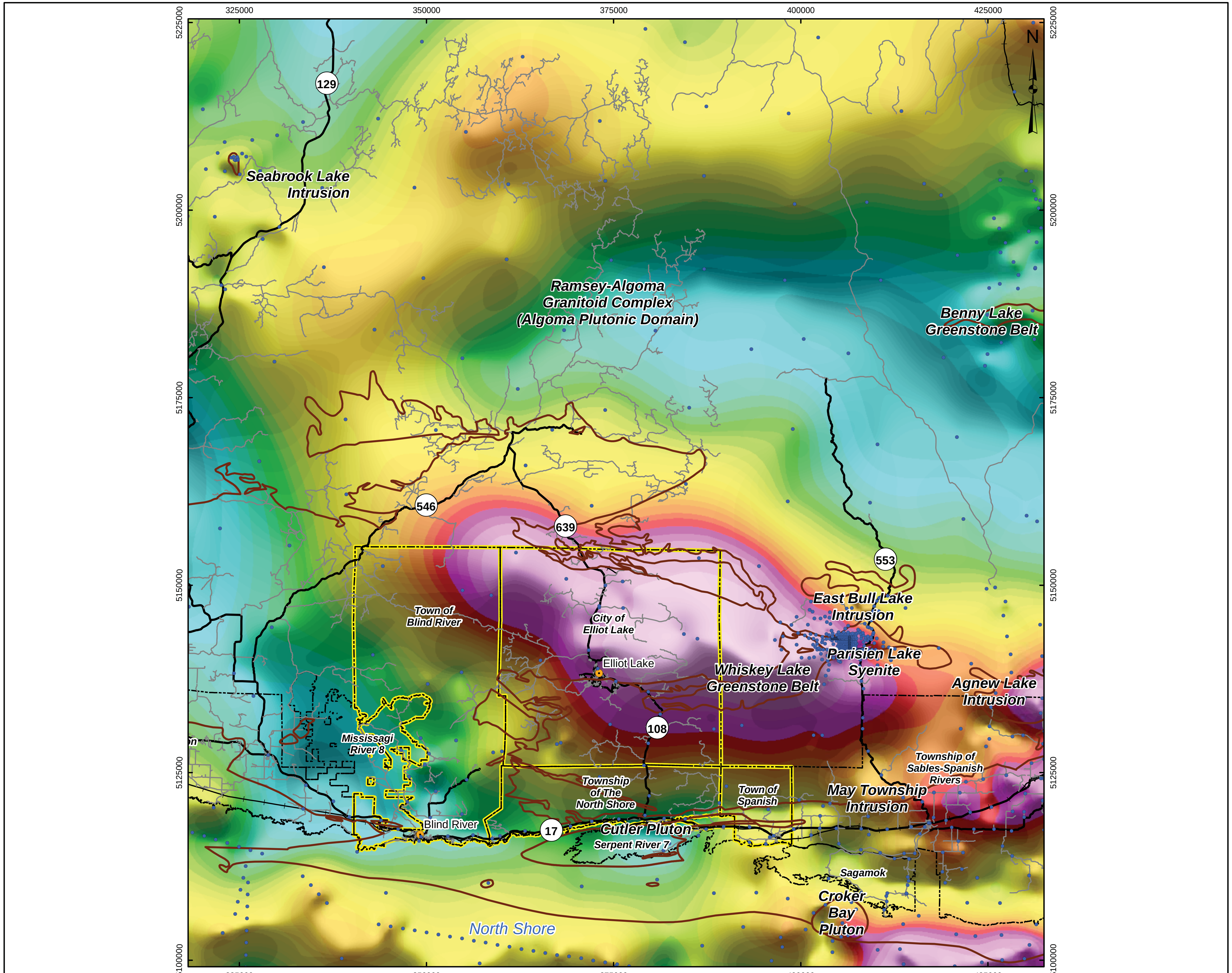
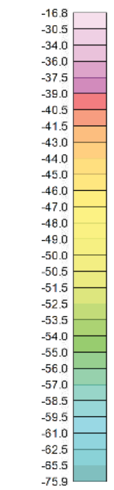


LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- Gravity Stations

Bouguer Gravity Field (mGal)



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

REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada Nationwide Gravity Compilation
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

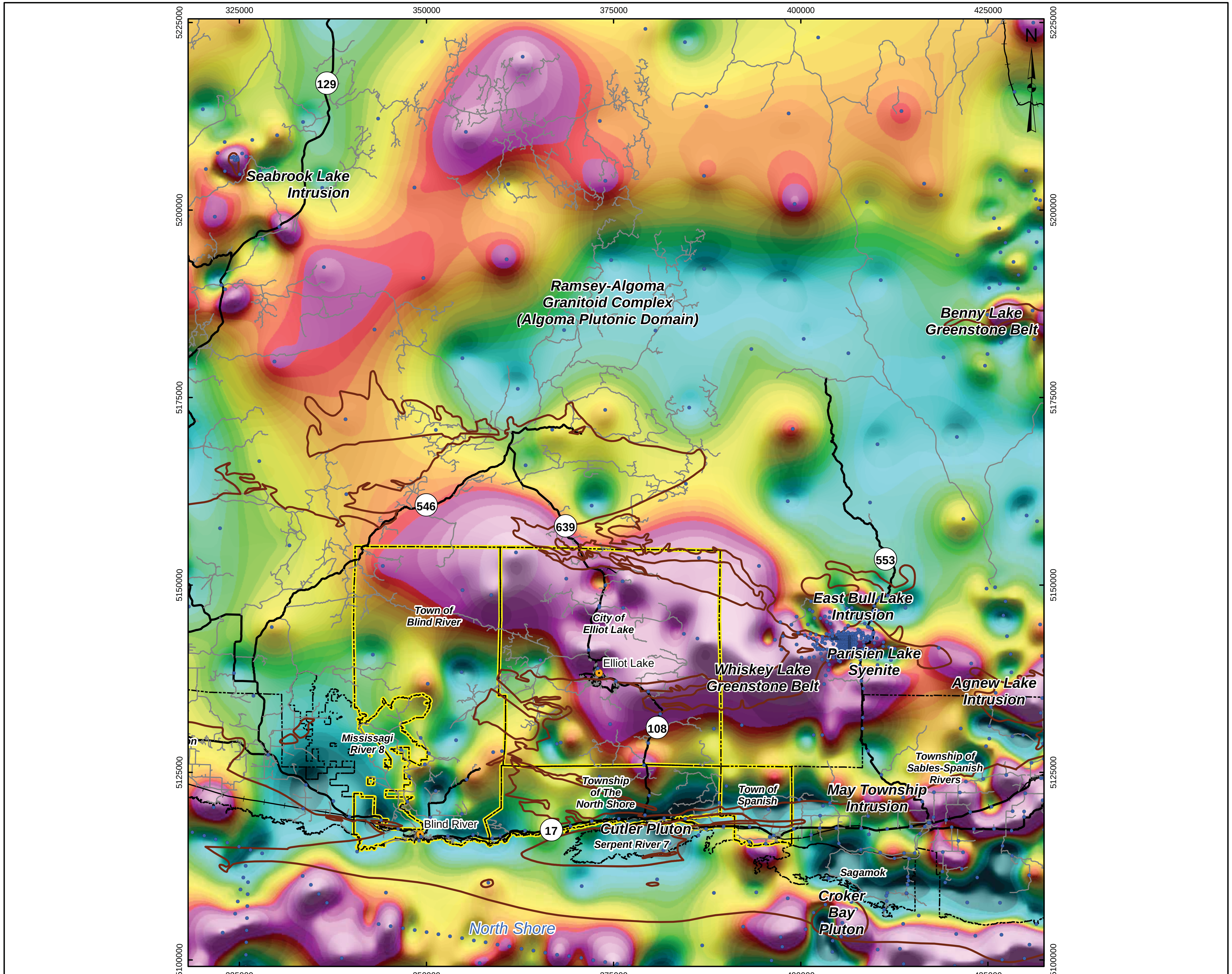
10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Bouguer gravity field with station locations

Golder Associates, Mississauga, Ontario	PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
	DESIGN	PRM	13 Mar 2013	**FIGURE 15**	
	GIS	WP	18 Apr 2013		
	CHECK	SWR	20 June 2014		
	REVIEW	GWS	20 June 2014		

G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\ELNOS\Draft_Integrated_Report\TotalMagneticField\ELNOS.mxd



LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- Gravity Stations

First Vertical Derivative of the Bouguer Gravity Field (mGal/m)

0.00775
0.00205
0.00145
0.00110
0.00090
0.00070
0.00060
0.00050
0.00040
0.00030
0.00025
0.00015
0.00010
0.00005
0.00000
-0.00005
-0.00015
-0.00020
-0.00030
-0.00035
-0.00045
-0.00050
-0.00060
-0.00070
-0.00080
-0.00095
-0.00110
-0.00130
-0.00170
-0.00648

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

REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada Nationwide Gravity Compilation
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
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10 5 0 10 20 30

SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

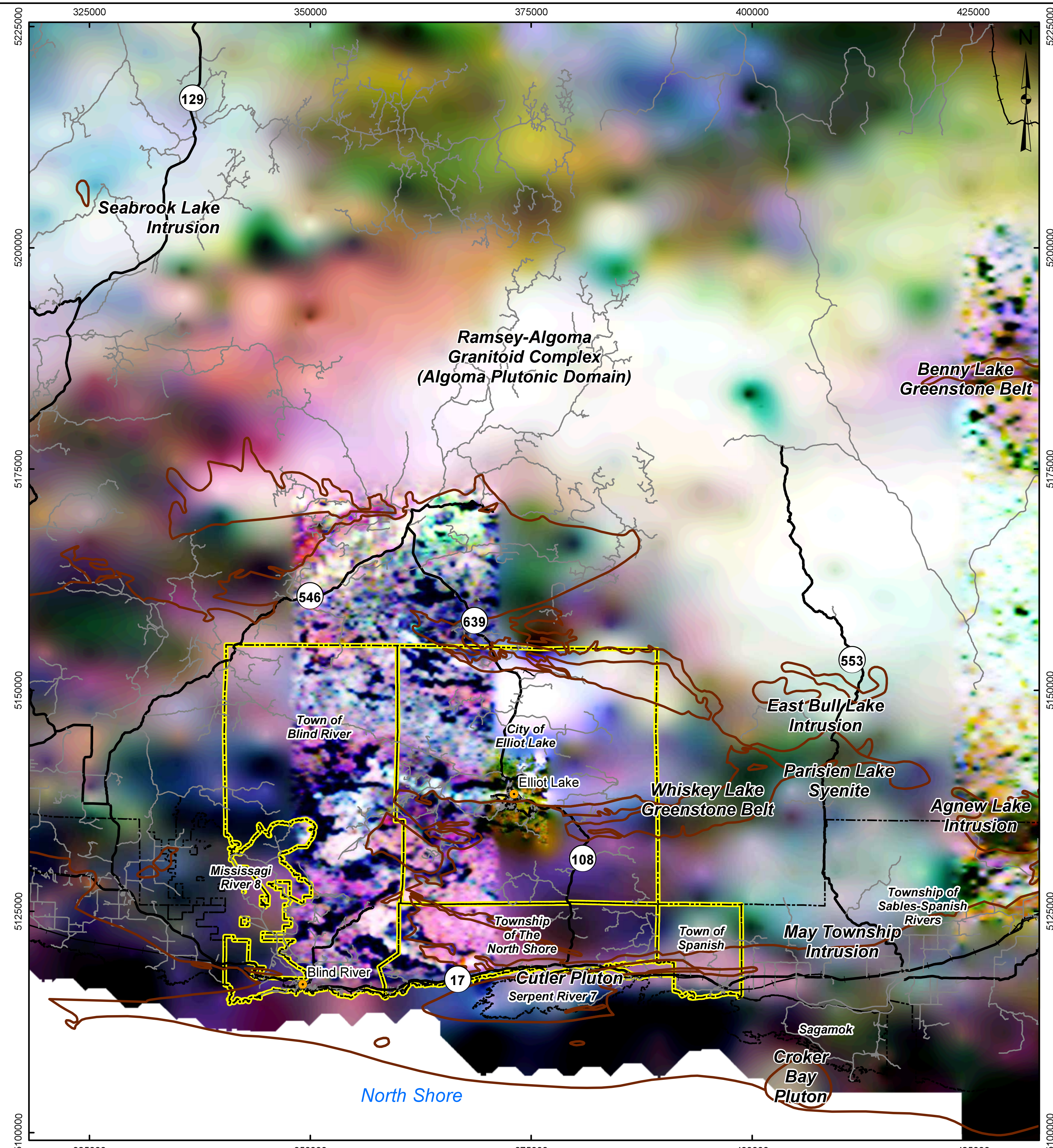
TITLE
First vertical derivative of the Bouguer gravity field

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013		
GIS	WP	18 Apr 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

FIGURE 16

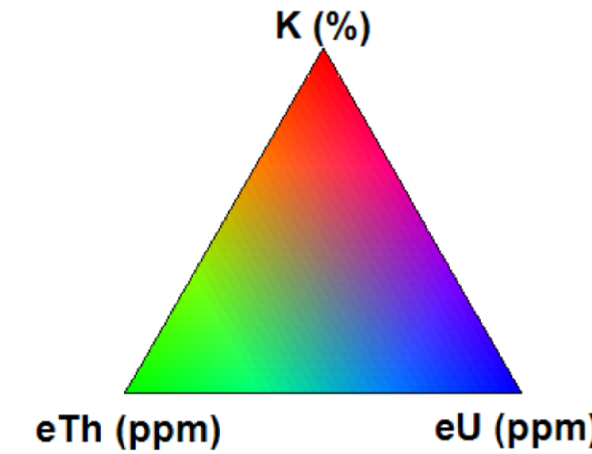
G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\ELNOS\Draft_Integrated_Report\TotalMagneticField\ELNOS.mxd



LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact

Radiometric Ternary Image
RGB = K-eTh-eU



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www.pgw.on.ca

REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Geological Survey of Canada Nationwide Radiometric Compilation
Geology - MRD126-Bedrock Geology of Ontario, 2011
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10 5 0 10 20 30
SCALE 1:525,000   KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Radiometric ternary image (RGB - K-eTh-eU)

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	13 Mar 2013	**FIGURE 17**	
GIS	WP	18 Apr 2013		
CHECK	SWR	2 Dec 2014		
REVIEW	GWS	3 Dec 2014		

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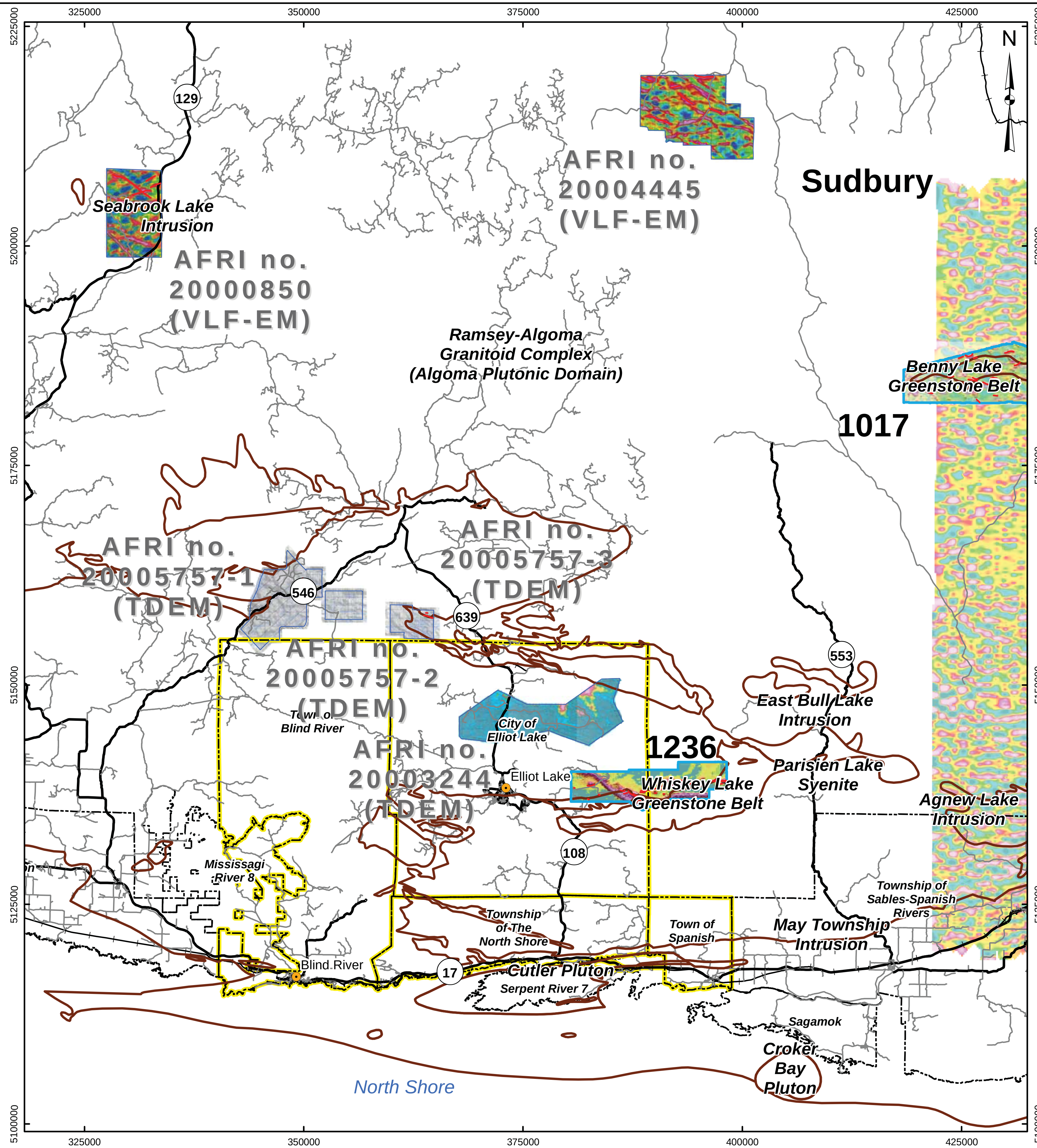


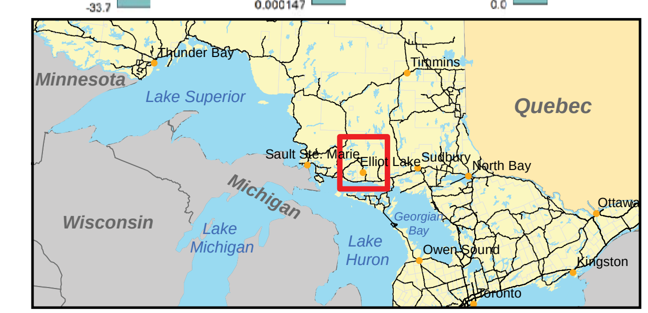
LEGEND

- Community
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Main Road
- Local Road
- Railway
- Major Geological Contact
- High Resolution Geophysical Survey Outlines
- Industry Geophysical Survey Outlines
- EM Conductors

Sudbury - VLF Total Field (%)

1017 - Conductivity (S/m)

1236 - Decay Constant (us)



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REFERENCE

Base Data - MNR LIO, obtained 2009
Geophysics - Ontario Geological Survey - Geophysical Surveys: GDS1017, GDS1236, Assessment File (AFRI) Database
Geological Survey of Canada - VLF-EM Survey - Sudbury
Geology - MRD126-Bedrock Geology of Ontario, 2011
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

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SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
EM conductors over apparent conductivity (GDS1017), decay constant (GDS1236),VLF and assessment file electromagnetic images

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.3
DESIGN	PRM	13 Mar 2013	**FIGURE 18**	
GIS	WP	18 Apr 2013		
CHECK	SWR	20 June 2014		
REVIEW	GWS	20 June 2014		

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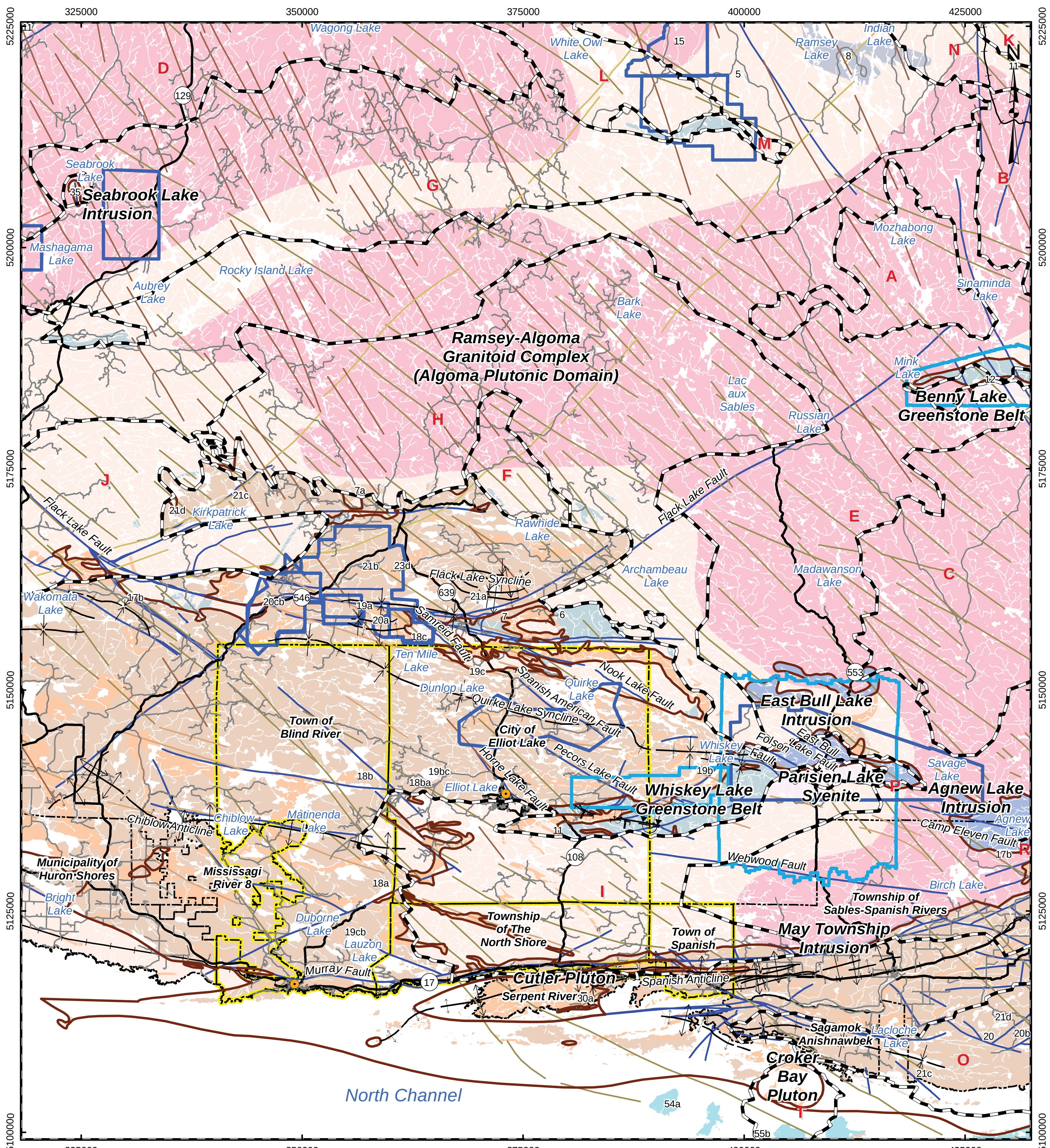

LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse
- High Resolution Geophysical Survey Outlines
- Industry Geophysical Survey Outlines
- Geophysical Unit
- Major Fold (syncline)
- Major Fold (anticline)
- Synform with inclined axial plane
- Mapped Fault

Mapped Dyke

- Biscotasing Mafic Dyke
- Matachewan Mafic Dyke
- North Channel Mafic Dyke
- Sudbury Mafic Dyke
- Unsubdivided Mafic Dyke
- Major Geological Contact

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011, Johns, G.W., et al. 2003.
Precambrian geology compilation map—Sault Ste. Marie–Blind River sheet; OGS, Map 2670.
Produced by Golder Associates Ltd under licence from
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT
GEOPHYSICAL STUDY, COMMUNITIES OF ELLIOT LAKE,
BLIND RIVER, THE NORTH SHORE AND SPANISH, ONTARIO

TITLE
Geophysical interpretation for the communities of Elliot Lake, Blind River, The North Shore and Spanish and surrounding area

Golder Associates
Mississauga, Ontario

PROJECT No. 12-1152-0245			SCALE AS SHOWN	REV. 1.3
DESIGN	PRM	13 Mar. 2013	**FIGURE 19**	
GIS	PM/JB	19 Jun. 2014		
CHECK	SWR	25 Jun. 2014		
REVIEW	GWS	25 Jun. 2014		

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