NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

TOWNSHIP OF NIPIGON, ONTARIO

APM-REP-06144-0069

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PHASE 1 - GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

PROCESSING AND INTERPRETATION OF GEOPHYSICAL DATA

Township of Nipigon, Ontario

Prepared for

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EXECUTIVE SUMMARY

In May 2013, the Township of Nipigon, Ontario (Nipigon) 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 Nipigon area 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, 2014). The objective of the geoscientific desktop preliminary assessment was to determine whether the Township of Nipigon, and their periphery, referred to as the "Nipigon area", 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 Nipigon area (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 Nipigon area. 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 Nipigon area.

The geophysical data covering the Nipigon area 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 Nipigon area. One magnetic/radiometric survey obtained from the Ontario Geological Survey (OGS) and one OGS magnetic/electromagnetic survey provided higher resolution coverage over approximately 40% of the Nipigon area. The magnetic/radiometric survey and an associated higher resolution OGS ground gravity survey greatly improved the data quality over the western part of the Nipigon area.

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 in good agreement where high resolution data are available in the western part of the Nipigon area, but less so to the east. The Nipigon diabase sills are evident from the magnetic data, obscuring some of the responses from the host lithologies. Nevertheless, the magnetic data are useful in locating contacts between granitic, metasedimentary and intrusive rocks, as well as identifying inhomogeneities. The gravity and radiometric data further characterize these rocks, and indicate a greater degree of complexity than evident from the published geological mapping.

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1 INTRODUCTION

In May 2013, the Township of Nipigon, Ontario 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 Nipigon area 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, 2014).

This report presents the findings of a geophysical data interpretation assessment completed by Paterson, Grant & Watson Limited (PGW) as part of the geoscientific desktop preliminary assessment of the Nipigon area (Golder, 2014). The objective of the geoscientific desktop preliminary assessment was to determine whether the Nipigon area contains general areas that have the potential to meet NWMO's geoscientific site evaluation factors. The assessment focused on the Township of Nipigon, Ontario and their periphery, referred to as the "Nipigon area".

1.1 Objective of the Assessment

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 Nipigon area, 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 Nipigon area.

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 distributions of rock units may change at depth. Drill holes, wells and other underground information may be available in some areas at individual points to supplement geological data acquired on surface. However, where these individual data points are limited (or non-existent), such as for the Nipigon area, 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, such as in the Nipigon area. 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 Township of Nipigon and Surrounding Area

The Nipigon area incorporates the Township of Nipigon and surrounding areas (as shown on Figure 1). It is approximately 59.9 km by 22.7 km in size, encompassing an area of about 1,359 km^2 (Figure 1). The approximate western, northern, eastern and southern limits of the Nipigon area are (UTM Zone 16, NAD83): 379208, 5447276, 439088, and 5424551 m. The Township of Nipigon is located on the west shore of the Nipigon River, between Helen Lake and Nipigon Bay.

1.3 Qualifications of the Geophysical Interpretation Team

The team responsible for the geophysical review, processing and interpretation investigation component of the Phase 1 geoscientific desktop preliminary assessment of potential suitability for the Nipigon area 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., P.Geo. – 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 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 of Geomatics and Cartography for Watts, Griffis and McOuat Limited (geological consultants) since 2006 and has been with the company since 2001. His work there has included a nationwide GIS of geology, ores and industrial minerals for Egypt, a GIS compilation of geological maps for a large part of Saudi Arabia and a Radarsat and DEM study for gold exploration in Sumatra. He has also worked part-time for PGW for the last 12 years, and most recently prepared a nationwide GIS for the geophysical interpretation of Nigeria. In 2011, he incorporated World GeoMaps Inc. for consulting in geomatics, cartography and GIS.

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 SUMMARY OF PHYSICAL GEOGRAPHY AND GEOLOGY

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

2.1 Physical Geography

A detailed discussion of the physical geography of the Nipigon area is provided in a separate terrain analysis report (JDMA, 2014a) and the following is a summary of that information. The Nipigon area 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.

The landscape within the Nipigon area ranges in elevation from about 183 m on the surface of Lake Superior to a maximum of 583 m on the highest point of the Kama Hills. Topographic highs generally correspond to bedrock while topographic lows are generally areas of thicker overburden. Two major topographic lows are present within the Nipigon area. The first is located in the western part of the area and is associated with the Black Sturgeon River and Shillabeer Creek. The second, and much larger topographic low, is centrally located in the Nipigon area and is represented by a broad area of low elevation located between the Nipigon and Jackfish rivers. Between the Black Sturgeon and Nipigon rivers, there is an area of relatively high ground. The zone of highest elevation in the Nipigon area is located east of the Jackfish River and is associated with the Kama Hills and other areas to the north and east.

Approximately half of the Nipigon area was mapped as bedrock terrain during the NOEGTS program (OGS, 2005), with the largest contiguous zone of bedrock terrain located in the eastern half of the area, generally east of the Jackfish River (Figure 3). Areas mapped as bedrock terrain are generally expected to contain a thin mantle of drift, which is less than one metre thick in most places (Gartner et al., 1981) and is generally composed of bouldery sand-rich till (Mollard and Mollard, 1981a, b). The actual amount of bedrock exposure is generally less than 5% in most areas (JDMA, 2014a).

The Nipigon area is characterized by a general paucity of large ($\geq$ 10 km^2) lakes. Lake Superior and Helen Lake are the two waterbodies that cover the largest parts of the Nipigon area (31.6 km^2 and 16.0 km^2, respectively). Aside from these two waterbodies, the rest of the lakes and rivers in the Nipigon area are less than 5 km^2 in size and over 90% are less than 1 km^2 in extent. Waterbodies cover 6.7% (91.4 km^2) of the Nipigon area. The general paucity of large lakes in the Nipigon area and the fact that the largest lakes are generally widely spaced apart from one another results in a condition where lakes generally do not pose a significant obstruction to the identification of major lineaments. One of the largest lakes in the area may outline a major lineament. That is, the north south trending aspect of the linear topographic low filled by Polly Lake, Helen Lake and the Nipigon River south of Helen Lake perhaps could outline the general trend of a significant bedrock structure.

2.2 Bedrock Geology

The Nipigon area 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 surrounded by younger Proterozoic rocks.

The Nipigon area is underlain by rocks of the Archean-aged Superior Province which are, in turn, locally overlain by younger strata of the 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 through to Minnesota and the northeastern part of South Dakota. The Superior Province is divided into subprovinces, medium- to large-scale regions that are characterized by similar rock-types, structural style, age, metamorphic grade and mineralization. The Nipigon area is within the Quetico Subprovince of the Superior Province. The Southern Province, which borders the Superior Province to the south from the Sudbury area through to Thunder Bay, comprises younger volcanic and sedimentary rocks of Proterozoic age, deposited over the Archean basement.

The geology of the Nipigon area consists of Mesoproterozoic sedimentary and intrusive rocks, and unconsolidated Quaternary deposits overlying the ca. 2.7 billion year old bedrock of the Canadian Shield. Proterozoic strata are widespread throughout the Nipigon area, but since they invariably overlie rocks of the Quetico Subprovince, the entire Nipigon area may be considered structurally part of the Superior Province. Figure 2 shows the bedrock geology and mapped geological faults and dykes of the Nipigon area and surroundings, with topography added as "shaded relief" over top of the bedrock geology. The Quetico Subprovince is approximately 1,200 km long and bounded on the north by the Wabigoon Subprovince and on the south by the Wawa Subprovince. Subprovince boundaries are steeply dipping and take the form of thrust and/or transcurrent fault contacts (Percival and Williams, 1989); although in many areas the exact point of contact between the subprovinces is not precisely defined. The Quetico Subprovince consists primarily of Archean clastic metasedimentary rocks deposited between ca. 2.698 and 2.688 billion years ago (Percival and Sullivan, 1988). These rocks underwent regional melting and recrystallization (migmatization), and were intruded by 2.70 to 2.65 billion year old granitic rocks (Williams, 1991).

In the southern and western portions of the Nipigon region, the Proterozoic sedimentary rocks of the Sibley and Animikie groups unconformably overlie the Archean metasedimentary rocks of the Quetico Subprovince. The metasedimentary rocks of the Quetico Subprovince and the sedimentary rocks of the Sibley Group in the Nipigon area were intruded by Nipigon diabase sills and dykes related to the failed intracontinental rifting event that occurred approximately 1.115 billion years ago, and by localized ultramafic intrusions, such as the Hele intrusion (Hart, 2005), that occurred approximately 1.115 to 1.105 billion years ago (Heaman and Easton, 2006). Tholeiitic flood basalts of the Osler Group were deposited slightly later than the Nipigon sills (Sutcliffe, 1991) and underlie most of the St. Ignace Island chain to the south and east of the Nipigon area.

The Nipigon area is located on the boundary between the metasedimentary rocks of the Quetico Subprovince of the Superior Province and the sedimentary rocks of the Sibley Group of the Southern Province of the Canadian Shield. Archean metasedimentary rocks and migmatites of the Quetico Subprovince form the bedrock at surface over the majority of the Nipigon area. These metasedimentary rocks extend beyond the Nipigon area to the north and over an extensive area east of the Black Sturgeon fault zone. To the south and to the west of the Black Sturgeon fault zone, the metasedimentary rocks of the Quetico Subprovince are unconformably overlain by the largely unmetamorphosed, undeformed sedimentary rocks of the Sibley Group. The latter are found to the south of the Township of Nipigon, and northeast along the Lake Superior shoreline.

A number of small granitic intrusive bodies occur in the west of the Nipigon area, east of the Black Sturgeon fault zone (OGS, 2011). These are elongate or lensoid bodies or massive granodiorite to granite. Some of these intrusions are small in width (up to about 1 km wide) and are sub-parallel to the strike of the metasedimentary rocks of the Quetico Subprovince. Other granitic bodies include two irregular intrusions east of the Black Sturgeon River in the area south of Mound Lake, approximately 10 km northwest of the Township of Nipigon. The more southerly of these is an approximately 20 km^2 body of biotite-bearing massive granodiorite to granite bordered on the north by a slightly larger 38 km^2 muscovite-bearing granite intrusion. Both of these granitic bodies are accompanied by distinct magnetic and radiometric geophysical signatures. A separate muscovite granite body outcrops on either side of Helen Lake at Duncan Bay approximately 5 km north of the Township of Nipigon. This unit is approximately 10 km long and 2 km wide, concordant to the gneissic fabric, and lacks a distinct geophysical signature.

In a number of places in the Nipigon area there are localized outcrops of mafic intrusions, diabase sills and dykes, including the Nipigon sill complex, which intrude both Archean metasedimentary rocks and the Mesoproterozoic sedimentary rocks of the Sibley Group. Nipigon sills occur at surface along the southern and western margins of the Nipigon area. Immediately west of the Black Sturgeon fault zone, approximately 1 km southwest of the Township of Nipigon, is the ultramafic Hele intrusion.

The magnetic responses of the metasedimentary rocks and migmatites of the Quetico Subprovince and the sedimentary rocks of the Sibley Group are generally subdued. By contrast, intrusive bodies such as the Archean granites of the Quetico Subprovince and the Hele intrusion show distinct positive magnetic responses. The positive magnetic response over the Hele intrusion shows criss-crossing linear aeromagnetic minima striking approximately 25^o and 100^o, coincident with prominent topographic lineaments. These linear features have been interpreted to be faults (Coates, 1972; Hart, 2005) as have a number of similar lineaments elsewhere in the Nipigon area. The Nipigon sills have a distinctly low magnetic response in comparison to their surrounding host rocks as a result of their magnetization from the time of emplacement.

The main rock types of the Nipigon area are further described in the following subsections.

2.2.1 Archean Metasedimentary Rocks

Archean metasedimentary rocks of the Quetico Subprovince (Figure 2) underlie the Nipigon area and constitute the uppermost bedrock unit north of the Township of Nipigon and east of the Black Sturgeon River. Metasedimentary rocks of the Quetico Subprovince also extend beneath the sedimentary rocks of the Sibley Group south of the Township of Nipigon and in the area west of the Black Sturgeon River. Depositional age of the original sediments of the Quetico Subprovince are dated at ca. 2.698 to 2.690 billion years (Percival et al., 2006). Although the thickness of the migmatitic metasedimentary rocks in the Nipigon area is not reported in the literature, a regional thickness of up to 18 km has been interpreted from geophysical studies (White et al., 2003; Percival et al., 2006). A number of lineaments have been mapped as faults in the metasedimentary rocks to the east of the Black Sturgeon fault zone (Hart, 2005). Most of these lineaments follow a north or northwest trend and are spaced about 1.5 to 3 km apart.

Hart (2005) describes the metasedimentary rocks as feldspathic and lithic metawackes, and metasiltstone arranged in beds 3 to 30 cm thick with occasional bands of disseminated andalusite and with a schistosity generally oriented east-northeasterly and subparallel to the original bedding. Dip of the foliation/schistosity is variable but generally steep (Hart, 2005).

Rocks of the Quetico Subprovince consist of biotite and/or andalusite schists that are gradually replaced towards the south by amphibolites (Hart, 2005). The schist is composed of fine-grained biotite, plagioclase and quartz, and may be intruded along the schistosity by metre-scale leucocratic dykes of Archean granite (described below). The amphibolite is composed of fine- to medium-grained hornblende, plagioclase and quartz, and shows weakly to moderately well-developed foliation (Hart, 2005).

In the Nipigon area, amphibolite is most often found mixed with leucocratic felsic rocks in the form of irregular interbanded to chaotic mixtures of the two rock types, which Hart (2005) recognized as migmatite. Hart (2005) suggested that migmatites in the Nipigon area could have resulted from the intrusion of felsic granitic intrusive rocks. The complex special arrangement of lithologies displayed in the Nipigon area closely resembles that of an injection complex (Sawyer, 1983), where magma is emplaced in metasedimentary rocks through a myriad of small dykes and veins (Sawyer, 1983; Leitch and Weinberg, 2002). Morfin et al. (2013) report that the migmatites of the Opinaca Subprovince in Quebec display evidence of the repeated injection of magma. Given that the types of rock, rock composition, and age of deposition of rocks of the Opinaca Subprovince are similar to those of the Quetico Subprovince (Morfin et al., 2013), the migmatites of the Quetico Subprovince observed in the Nipigon area could also correspond to an injection complex.

2.2.2 Archean Granites

The metasedimentary migmatites of the Quetico Subprovince in the Nipigon area have been intruded by several irregular shaped granitic bodies, mapped by Hart (2005) as metamorphosed biotite granite within the Township of Nipigon and in the area to the northwest of the Township bordering the Black Sturgeon River canyon. Biotite granite intrusions in the Nipigon area consist of light pinkish grey to light pink granite with less than 10% biotite. These rocks are massive and medium to coarse-grained, with rare, very coarse-grained to pegmatitic sections. Often these granitic intrusions contain xenoliths of the surrounding amphibolites, which are a few metres in diameter. These granitic bodies are in some places cut by pegmatitic dykes.

Muscovite-bearing granitic intrusions are also mapped within the north-central part of the Nipigon area in the form of an approximately 10 km long and 2 km wide body some 5 km north of the Township of Nipigon, and an unnamed, approximately 38 km^2, sub-circular body located south of Mound Lake near the northwest corner of the Nipigon area. The muscovite granite is described as light grey, pinkish grey, to white, massive, and medium to very coarse grained with occasional pegmatitic sections. Xenoliths of metasedimentary and gneissic rocks are present throughout the intrusion, and pegmatitic muscovite granite dykes intrude the granite body and the surrounding gneisses.

Hart (2005) considered the lack of well-developed gneissic textures along with the presence of biotite schist and amphibolite xenoliths in both suites of granitic rocks to be indicative of an intrusive origin, also opening the possibility that both suites may be genetically linked.

2.2.3 Sedimentary Rocks of the Sibley Group

The Sibley Group is a largely unmetamorphosed, relatively flat-lying sedimentary rock sequence that nonconformably overlies the Archean rocks of the Quetico Subprovince. Rocks of the Sibley Group outcrop along the western margin of the Nipigon area to the west of the Black Sturgeon fault zone, along the southern part of the area along the Lake Superior shoreline, and northward in the area east of the Nipigon River.

The rocks of the Sibley Group in the Nipigon area range from approximately 1.5 to 1.3 billion years in age and have been divided into five formations (Hart, 2005; Rogala et al., 2005), three of which are known to be present in the Nipigon area. According to Rogala et al. (2005), the lowermost unit, the Pass Lake Formation, consists of conglomerates overlain by sandstones; the middle unit, the Rossport Formation, consists of dolomite-siltstone layers on the bottom, stromatolites in the middle and mudstone on the top; and the uppermost unit, the Kama Hill Formation, is composed of shales and siltstones. Younger members of the Sibley Group, the Outan Island and Nipigon Bay formations, have not been mapped within the Township of Nipigon and lands to the north but these units are known to be present beneath portions of Nipigon Bay (Rogala et al., 2005).

The sedimentary rocks of the Sibley Group in the Nipigon area are estimated to be up to approximately 200 m thick, based on geological mapping by Hart (2005), sparse diamond drill hole information and airborne geophysical data.

2.2.4 The Hele Intrusion

The Hele intrusion covers a total area of approximately 40 km^2 and is located to the west of the Black Sturgeon fault zone in the southwest corner of the Nipigon area. The Hele intrusion is underlain by sedimentary rocks of the Sibley Group and has a reported maximum thickness of approximately 130 m (Hart, 2005), based on diamond drill hole information and modelling of available airborne magnetic data.

The Hele intrusion was emplaced about 1.106 billion years ago (Heaman and Easton, 2006), and is composed of altered peridotite interlayered with olivine gabbro and feldspathic peridotite. The peridotite is a highly weathered and serpentinized rock containing numerous, subparallel serpentine and chlorite-rich fractures (Hart, 2005). A few major lineaments, mapped by Hart (2005) as faults, cut across the Hele intrusion in north and east-southeast orientations, the latter with spacings of 1 to 2.5 km.

2.2.5 Nipigon Diabase Sill Complex

Nipigon diabase sills are relatively thin, generally flat-lying mafic rocks that intrude and sometimes overlie the other rock types in the Nipigon area. Within the Nipigon area, several

small diabase sills occur at surface along a diagonal trend from the northwest corner of the area to the southeast. The outcrops of diabase are typically less than 1 km^2 in size and about 100 m thick (Hart, 2005). Nipigon diabase sills often intrude the older rocks in the area at depth and occur as extensive, relatively flat and thin (less than 50 m thick) intrusive layers (Hart, 2005). Larger Nipigon sill occurrences are mapped north of the Nipigon area.

The sills have been subdivided into several suites including the Logan sills located south of Thunder Bay, Nipigon sills centred on Lake Nipigon, and McIntyre, Inspiration, Jackfish-like and Shillabeer sills. Because the validity of the subdivisions and their nomenclature remains unresolved (Hart, 2005), we have used the term Nipigon sills to encompass all mafic sills in the Nipigon area.

There are no obvious textural or mineralogical differences between the sills; the diabase is commonly medium brown to brownish grey, massive, medium to coarse-grained feldspar and pyroxene with trace olivine and magnetite (Hart and Magyarosi, 2004). Their emplacement is interpreted by Coates (1972), Sutcliffe (1991) and others to be related to the Midcontinent Rift event. The intrusion age of these sill bodies has been constrained to have occurred in the period ca. 1.115 to 1.105 billion years (Heaman et al., 2007).

2.2.6 Mafic Dykes

Widely spaced, northwest to northeast-trending diabase dykes intrude the Archean rocks of the Quetico Subprovince in the east part of the Nipigon area (Figure 2). Four such dykes, ranging from 7 to 25 km in length are mapped in the Nipigon area based on the OGS seamless geological coverage of Ontario (OGS, 2011). They are described as 1.180 to 1.130 billion years in age and are not associated with a named dyke swarm. While not recognized within the Nipigon area, northwest trending dykes of the Matachewan dyke swarm (2.475 to 2.45 billion years old) are mapped about 13 km to the northeast of the Nipigon area.

2.2.7 Faults

There are a number of regional faults within and bordering the Nipigon area. These include the known shear zones and mapped faults that relate to lineaments within the Nipigon area including the northwest trending Black Sturgeon fault zone and the northeast trending Jackpine River fault. The northeast trending Gravel River fault is located just outside the southeast corner of the Nipigon area and is further described in Golder (2014).

The Black Sturgeon fault zone (Figure 2) is at least 65 km long and is composed of a series of northwest-trending faults that are coincident with the Black Sturgeon River. The fault zone forms the northeastern border of a graben structure (Hart, 2005). Rock units to the southwest of the fault zone are downthrown by several hundred metres compared to rocks to the northeast, resulting in the widespread preservation of sedimentary rocks of the Sibley Group to the west of the fault contrasting with the Archean gneissic rocks that dominate to the east (Hart, 2005). Similar vertical offsets of between 200 and 300 m are also reported for north-trending faults in the South Armstrong–Gull Bay area on the west shore of Lake Nipigon approximately 50 km north of the Nipigon area (MacDonald, 2004). Within the west-southwest part of the Nipigon

area, the Black Sturgeon fault zone is marked by a steep canyon, approximately 1 km wide and 200 m deep, through which the Black Sturgeon River flows. The dip and the width of the fault zone are unknown.
The 45 km long northeast-trending Jackpine River fault (Figure 2) is located in the eastern part of the Nipigon area. This fault follows the Jackpine River from Kama Bay and extends beyond the Nipigon area to the northeast to its termination near the northern boundary of the Quetico Subprovince. The fault follows a strongly linear topographic feature that crosscuts the younger Proterozoic cover rocks near its southern extension into Nipigon Bay. The fault (and/or its associated splays) has been the subject of sporadic exploration effort targeting gold mineralization. Trenching in the area south of Shark Lake (MDI 42E04SW00005) revealed anastomosing quartz veining and flooding forming a band up to 3 m wide.

Other mapped faults include an unnamed 12 km long fault located to the east of Mound Lake and an approximately 27 km long fault that follows the course of the Nipigon River from Cameron Falls along the north border of the Nipigon area to north of Pine Portage. Although not mapped in MRD126 or shown on Figure 2, Coates (1968, 1972) shows a fault running along Frazer Creek from just south of Cameron Falls on the Nipigon River to Elizabeth Lake approximately 12 km to the northwest.

2.2.8 Metamorphism

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in a few publications since the 1970s, including Fraser and Heywood (1978), Kraus and Menard (1997), Menard and Gordon (1997), Berman et al. (2000), Easton (2000a,b) and Berman et al. (2005). The thermochronologic record for major parts of the Canadian Shield is provided 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 (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). The distribution of contrasting grades of metamorphism is a consequence of relative uplift, block rotation and

erosion from Neoarchean orogenesis and subsequent local Paleo- and Mesoproterozoic orogenic events and broader epeirogeny during the Neoproterozoic and Phanerozoic.

All rocks in the Quetico Subprovince, except for some of the late-stage granitic intrusions and diabase sills and dykes, were subjected to a complex regional metamorphic history. In the northern Quetico Subprovince, southwest of the Nipigon area in the Atikokan area, M_1 metamorphism is estimated to have occurred between 2.698 and 2.688 billion years ago (Davis et al., 1990). A similar chronology has been proposed in the southern part of the Quetico Subprovince where M_1 is interpreted to have occurred synchronously with D_1 at 2.698 to 2.689 billion years ago (Valli et al., 2004). During D_1, sedimentary rocks of the Quetico Subprovince were structurally stacked and buried up to 20 km deep, reaching upper amphibolite regional metamorphic facies under moderate pressure - moderate temperature conditions in the Jean Lake area (north-northeast of the Nipigon area) (Valli et al., 2004). In the Quetico Subprovince metamorphic grade generally increases progressively southward from greenschist to upper amphibolite facies (Hart, 2005).

Valli et al. (2004) described a second metamorphic event (M_{2-3}) during D_2-D_3, between 2.689 and 2.671 billion years ago, and retrograde, low-pressure, medium-temperature metamorphism associated with D_4 at ca. 2.671 to 2.667 billion years ago. It is possible that this latter event occurred in the Nipigon area, although there is no clear evidence to support it. Rocks of the Sibley Group underwent minor contact metamorphism along the margins of the ultramafic intrusions, such as the Hele intrusion and along the margins of the Nipigon sills. Hornfels textures and skarns usually extend up to 10 m into the sedimentary rocks (Hart, 2005).

2.3 Geological and Structural History

The geological and structural history of the Nipigon area spans nearly 3 billion years, and consists of Archean rocks of the Quetico Subprovince of the Superior Province unconformably overlain by Proterozoic sedimentary rocks of the Southern Province, both of which are intruded by Proterozoic ultramafic intrusions and diabase sills. The geological and structural history of the Nipigon area is discussed below and summarized in Table 1. The discussion integrates the results from studies undertaken mainly within and proximal to the Nipigon area, augmented by studies elsewhere in the Superior Province.

The oldest rocks in the Nipigon area are gneissic metasedimentary rocks of the Quetico Subprovince. Their precursor sediments are dominantly thick sequences of wackes deposited as turbidites in a laterally extensive marine basin beginning approximately 2.698 billion years ago (Davis et al., 1990). Sedimentation was rapid, in the neighborhood of 10 million years (Davis et al., 1990; Valli et al., 2004), with a likely volcanic sediment source from the northern Wabigoon Subprovince for the northern part of the Quetico belt, whereas the southern part of the belt was likely fed from sources of the Wawa Subprovince to the south of the belt (Sawyer and Robin, 1986; Williams, 1991; Zaleski et al., 1999; Fralick et al., 2006). The depositional setting has been the subject of considerable debate, but an accretionary prism is considered most likely (Percival, 1989; Williams, 1991; Valli et al., 2004; Fralick et al., 2006). Deposition of sediments is believed to have been diachronous throughout the Quetico Subprovince, occurring in the

northern part prior to initiation in the south (e.g., Percival, 1989; Davis et al., 1990; Zaleski et al., 1999; Valli et al., 2004; Fralick et al., 2006).

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). The rift setting ultimately evolved into a passive margin setting, allowing development of intracratonic basins in many areas across the Lake Superior region, including deposition of the Huronian Supergroup between ca. 2.497 and 2.10 billion years ago (Corfu and Andrews, 1986; Rainbird et al., 2006) along the north shore of Lake Huron. While it is likely that Huronian strata once covered a much larger area than their present distribution, there is no evidence that this sedimentation took place within the Nipigon area. Though not observed in the Nipigon area, mafic dykes of the ca. 2.475 to 2.45 billion year old Matachewan swarm extend to within roughly 13 km of the northeast corner of the Nipigon area. In addition, Ernst et al. (2006) used paleomagnetic data to attribute some of the mapped mafic dykes in the Nipigon area to the regionally pervasive ca. 2.121 to 2.101 billion year old Marathon swarm.

There was a tectonic and depositional hiatus of approximately 300 million years after deposition of the Huronian Supergroup, which suggests that the southern margin of the Superior craton was maintained as an elevated passive margin during an extended period of ocean opening and closing until the initiation of the ca. 1.89 to 1.84 billion year Penokean Orogeny (Sims et al., 1989; Schulz and Cannon, 2007).

As a consequence of the Penokean Orogeny, sedimentary rocks of the Animikie Group were deposited nonconformably on the Archean basement in a foreland basin over much of the western portion of the Lake Superior area, ca. 1.875 billion years ago (Fralick et al., 2006). Rocks of the Animikie Group are not known to occur within the Nipigon area, but their presence in the Sibley Peninsula to the southwest of the Nipigon area and along the Lake Superior coast to the southeast suggests that rocks of the Animikie Group likely covered much of the Nipigon area during the Paleoproterozoic Era. The Animikie Group includes the Gunflint Formation and the overlying Rove Formation. Only the Rove Formation has been mapped in the immediate vicinity of the Nipigon area, although the Gunflint Formation is extensively preserved further west toward Thunder Bay. The Rove Formation consists of shale grading upwards to shale interbedded with arkosic wacke. The Rove Formation is approximately 600 m thick in the vicinity of Squaw Bay on the Sibley Peninsula (Geul, 1973). Impact of the Penokean Orogeny and a younger ca. 1.75 billion year Yavapai Orogeny (Piercey, 2006) is known in the Lake Superior area; nevertheless, the possible effects of any of these orogenies are not clear in the Nipigon area.

Following the deposition of the Animikie Group, erosional conditions returned and prevailed within the Nipigon area (Cheadle, 1986) reshaping the Archean paleosurface at the time of deposition of the Sibley Group. Deposition of the sedimentary rocks of the Sibley Group began sometime later than ca. 1.657 billion years ago and continued until approximately 1.3 billion years ago (Hart, 2005). Heaman and Easton (2006) give a maximum age of 1.5 billion years for sedimentation in the Sibley Group. The Sibley Group is a generally unmetamorphosed, relatively

flat-lying sedimentary rock sequence that occurs over much of the southern and western margin of the Nipigon area and extends beyond the area to the north, south and west (Figure 2). The Sibley Group unconformably overlies the Rove Formation of the Animikie Group and, more commonly in the Nipigon area, the Archean rocks of the Quetico Subprovince. The preservation of the sedimentary rocks of the Sibley Group to the north of Lake Nipigon suggests an original distribution over a much wider area than at present.

Tectonic activity took place during deposition of the Sibley Group, controlling its deposition with the development of a north-south-oriented half-graben and increasing the basin subsidence (Rogala et al., 2007). The syn-depositional tectonic activity has been ascribed to a sixth deformation period, D_6.

Table 1 Summary of the geological and structural history of the Nipigon Area

Time period (Ga)	Geological event
2.698 to 2.689	Sedimentation within the Quetico Subprovince; initial metamorphic event (M_1). Ca. 2.695 Ga D_1 deformation.
2.689 to 2.671	Main period of deformation (D_{2-3}) and metamorphism (M_{2-3}) of the metasedimentary rocks of the Quetico Subprovince. Characterized by collision between the Quetico accretionary prism and the Wawa-Abitibi terrane.
2.671 to 2.667	D_4 deformation and M_4 greenschist retrograde metamorphism.
<2.667 – 1.7	Supercontinent fragmentation and rifting in Lake Superior area produced voluminous magmatism and development of intracratonic basins. Emplacement of the ca. 2.475 to 2.45 Ga Matachewan dyke swarm. Emplacement of the ca. 2.121 to 2.101 Ga Marathon dyke swarm. Deformation associated with the ca. 1.9 to 1.7 Ga Penokean Orogeny in Lake Superior area; including deposition of the ca. 1.89 Ga Animikie Group. [D_5]
1.5 to 1.339	Deposition of the Sibley Group. [D_6]
1.150 to 1.1	Onset of rifting associated with Midcontinent Rift in the Lake Superior area. [D_7] Emplacement of the ca. 1.119 – 1.106 Ga Hele intrusion. Emplacement of the ca. 1.115 – 1.108 Ga Nipigon diabase sills. Deposition of volcanic rocks of the 1.106 Ga Osler Group.
< ca. 1.1 to present	Gradual erosion of bedrock alternating with deposition and subsequent erosion of strata during marine transgressions in the Paleozoic and Mesozoic, multiple generations of glacial erosion. [D_7]

Around ca. 1.15 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. This major rifting event was associated with the deposition of large volumes of volcanic rocks (e.g., the Osler Group at ca. 1.108 billion years) and voluminous emplacement of

mafic intrusions, including the areally extensive ca. 1.115 to 1.105 Ga Nipigon sill complex (Heaman and Easton, 2006 and Heaman et al., 2007), and the smaller ca. 1.119 to 1.106 billion year old Hele intrusion (Hart, 2005; Heaman and Easton, 2006) located along the west side of the Black Sturgeon River (Figure 2). Nipigon diabase sills are relatively thin, generally flat-lying mafic rocks that intrude and sometimes overlie the other rock types in the Nipigon area, and extend far to the north, beyond the north shore of Lake Nipigon. Uplift and erosion of bedrock occurred over a protracted period following the rifting event.

During the Paleozoic Era, commencing in the late Cambrian Period to early Ordovician Period, some of the Nipigon area might have been submerged beneath shallow seas and overlain by flat lying carbonate and shale formations; however, no Paleozoic cover has been recognized in the Nipigon area, either due to depositional hiatus or to its removal by subsequent uplift and erosion. The preservation of Jurassic and Cretaceous-age sedimentary rocks in the James Bay lowlands of Ontario suggests that marine transgression might also have affected the Nipigon area during the Mesozoic, but as with Paleozoic strata any trace of such sediments would have been subsequently removed through erosion. Weathering and erosion of the re-exposed Precambrian surface continued throughout the Cenozoic.

The structural history in the Nipigon area is complex and poorly understood, owing to the absence of reliable geochronological data for many of the rocks within the area, and multiple lengthy periods of erosion. Recent geological investigations within the Nipigon area and its vicinity conclude that the region has undergone complicated polyphase deformation beginning at the time of sedimentation in the Quetico Subprovince (Valli et al., 2004; Zaleski et al., 1999).

The geological and structural history summarized below integrates the interpretations from throughout and proximal to the regional area. It is understood that there are potential problems in applying a regional deformation numbering (D_x) system into a local geological history. This summary provides an initial preliminary interpretation for the Nipigon area, which would need to be reviewed through detailed site-specific field studies.

The earliest recognized deformation event (D_1), occurred around 2.695 billion years ago, and was synchronous with on-going sedimentation in the Quetico Subprovince (Valli et al., 2004). D_1 involved folding and thrust imbrication and was accompanied by an upper amphibolite grade metamorphic overprint that occurred in response to the northward subduction of the Wawa Subprovince (Wawa-Abitibi terrane) beneath the Wabigoon Subprovince (Corfu and Stott, 1998; Valli et al., 2004). Subsequent deformation and peak metamorphism (D_2-D_3) occurred approximately 2.689 to 2.671 billion years ago, in a transpressive to compressive system (Sawyer, 1983; Williams et al., 1991), which Valli et al. (2004) divided into two deformation periods extending between 2.689 and 2.684 billion years (D_2) and 2.684 and 2.671 billion years (D_3), respectively. D_2-D_3 developed schistose to gneissic textures in the metasedimentary rocks at, in general, upper amphibolite grade metamorphic conditions, which were sufficient for the metasedimentary rocks to undergo in-situ partial melting in addition to attendant granitic intrusions (Williams, 1991; Hart, 2005). D_2-D_3 is attributed to the final collision – or docking – of the Wawa Subprovince (Wawa-Abitibi Terrane) against the Wabigoon Subprovince (Corfu and Stott, 1998). A subsequent deformation period, D_4, is constrained to have occurred between ca. 2.671 and 2.667 billion years. D_4 involved uplift and exhumation of the metasedimentary

rocks of the Quetico Subprovince accompanied by a greenschist facies retrograde metamorphic overprint (Valli et al., 2004).

In addition to these published Archean deformation events, three additional structural events in the Nipigon area have been tentatively defined. D_5 represents a protracted interval of faulting/fracturing events that post-dated Archean deformation but pre-dated the onset of deposition of the sedimentary rocks of the Sibley Group ca. 1.657 billion years ago (Hart, 2005). Though several major dyke swarms were emplaced across the Superior Province during this time interval, the Paleoproterozoic Animikie Group sedimentary sequence is the only clear indicator of activity in the region around the Nipigon area. D_6 includes the faulting/fracturing events that coincided with, and post-dated, deposition of the Mesoproterozoic Sibley Group. Subsequently, rift and post-rift structures associated with development and re-activation of a failed arm of the Midcontinent Rift are included herein as a poorly-constrained D_7 event. The D_7 structures are interpreted to have controlled emplacement of the Nipigon sills, and likely included the re-activation of most pre-existing structures in the Nipigon area. Post-rift deformation, though possibly important in terms of potential continued re-activation of pre-existing structures, cannot at this stage be confidently distinguished from the rift-related structures.

2.4 Quaternary Geology

Information on Quaternary geology in the Nipigon area is described in detail in the terrain report (JDMA, 2014) and is summarized here. The Quaternary deposits in the Nipigon area (Figure 3) accumulated during and after the last glacial maximum, known as the Late Wisconsinan glaciation. The Mackenzie and Dog Lake moraines, located to the southwest of the Nipigon area, are thought to have been formed during the Marquette advance about 10,000 years ago (Burwasser, 1977). Ice front fluctuations led to the subsequent deposition of the Eagle-Finlayson, Hartman and Lac Seul moraines, successively from south to north in the area to the west of Nipigon. Within the Nipigon area the most prominent moraine is the Nipigon moraine that was formed along the west and south side of Lake Nipigon (Zoltai, 1965b) and extends into the northwest and south central portion of the Nipigon area including the settlement area of Nipigon.

A kame terrace on the west margin of the Nipigon valley, west of Helen Lake was formed against the ice margin when the ice sheet partly occupied the valley (Mollard and Mollard, 1981a, b). Outwash sediments consisting of sand and gravel, interpreted to have been deposited in flooded lowlands and valley bottoms in front of the ice sheet (Mollard and Mollard, 1981a, b), are mapped south of Fog Lake and along parts of the Black Sturgeon and Jackpine rivers (Figure 3). Rhythmically bedded silts and clays deposited in glacial Lake Minong are mapped in low-lying parts of the Nipigon area. The thickness of these lake sediments is about 3 m on average and up to a possible maximum of 10 m (Zoltai, 1965a). Glaciolacustrine deltas expected to range in texture from sandy gravel and coarse sand to fine sand and silty sand (Mollard and Mollard, 1981a, b) are mapped locally within the Nipigon area, such as near the mouths of the Nipigon and Jackpine rivers. Raised beach deposits composed of sand, silt, clay and gravel are mapped along the margins of rock ridges and mesas fronting onto Lake Superior.

Information on the thickness of Quaternary deposits in the Nipigon area was largely derived from a small number of water well records for rural residential properties predominantly along

the highways, and from diamond drill holes. A more detailed accounting of recorded depths to bedrock in the Nipigon area is provided by JDMA (2014). Diamond drill hole records and water well records in the area show overburden thickness to be up to about 100 m.

2.5 Land Use

Land use within the Nipigon area includes mostly forestry and linear infrastructure corridors like roads, railways, pipelines and electrical transmission lines. Several active gravel pits are present. These features do not negatively impact the interpretation of bedrock lineaments. There are currently no active mines in the Nipigon area. The Nipigon area is also popular for recreation.

3 GEOPHYSICAL DATA SOURCES AND QUALITY

For the Nipigon area, 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 Nipigon area 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 Nipigon area 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 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 Nipigon area show variability in dataset resolution. Low-resolution geophysical data, particularly the magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC), cover the entire Nipigon area. One magnetic/radiometric survey obtained from the Ontario Geological Survey (OGS) and one OGS magnetic/electromagnetic survey provided higher resolution coverage over approximately 40% of the Nipigon area (Figure 4). The magnetic/radiometric survey (OGS, 2004a) and an associated higher resolution OGS ground gravity survey (OGS, 2004b), both acquired for the Lake Nipigon Regional Geoscience Initiative, greatly improved the data quality over the western part of the Nipigon area. The geophysical data sets are summarized in Table 2 and the characteristics of each of the data sources are discussed in detail below.

3.1.1 Magnetic Data

Magnetic data over the Nipigon area were collected by various surveys using different survey parameters outlined in Table 2. 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 Nipigon area. Surveys were flown over a period of 42 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 the GSC provide complete coverage of the entire Nipigon area (GSC, 2013). Magnetic data from these surveys forms part of the GSC Regional Magnetic Compilation data. The Ontario #8 survey was flown at a terrain clearance of 305 m and flight line spacing of 805 m, providing it with a relatively low spatial resolution. The Georgia Lake survey was flown at a terrain clearance of 120 m and flight line spacing of 1,000 m. Although data from this survey was acquired digitally, the Ontario #8 survey tends to provide slightly better spatial resolution. Additional high-resolution surveys from the OGS (Lake Nipigon Embayment Survey (OGS, 2004a) and Nipigon Bay Survey (OGS, 2003)) were flown at a lower terrain clearance (100 and 39 m respectively) compared to the GSC surveys, and with tighter flight line spacing (150 m and 350 m). These surveys focused primarily on areas of exploration interest. The high resolution coverage amounts to approximately 40 percent of the Nipigon area.

Assessment files archived at the OGS were reviewed for the Nipigon area. Nine were identified that could potentially provide improved high resolution coverage in addition to the surveys available from GSC and OGS. However, all were located on the margins of the Nipigon area and none provided data of interest, either due to the high OGS data quality in the western part of the area or the lack of legible maps in the assessment file.

3.1.2 Gravity Data

Gravity data provides complete coverage of the Nipigon area (GSC, 2013), consisting of an irregular distribution of 602 station measurements within the Nipigon area. In the western part of the Nipigon area the gravity stations are roughly every 250 m along a network of roads, and where there are no roads, are spaced upwards of 12 km (OGS, 2004b). In the eastern part of the Nipigon area the gravity stations have a spacing of roughly 5 km to 15 km (GSC, 2013). The gravity data acquired from the OGS (OGS, 2004b) have previously incorporated all of the GSC measurements, with the exception of four additional gravity measurements. All of the gravity measurements have been incorporated into this assessment.

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 eastern part of the Nipigon area 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 Nipigon area (GSC, 2013). 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 144 m above the surface over the central part of the Nipigon area. Along the eastern boundary, the resolution improves where the line spacing is 1,000 m at a terrain clearance of 119 m (Table 2). In the western 40% of the area, higher resolution coverage at 150 m line spacing and 100 m terrain clearance (OGS, 2004a) improves the resolution significantly.

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).

3.1.4 Electromagnetic Data

One electromagnetic survey (OGS, 2003) and one VLF-EM survey (GSC, 2013) provide coverage in the east part of the Nipigon area. The time-domain electromagnetic (TDEM) survey was carried out for industry and later acquired by the OGS and incorporated into the Nipigon Bay survey (GDS1226; OGS, 2003) (Figure 4). 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 Nipigon survey was a Geotem system to measure the on-time (1 channel) and off-time (12 channels) X component dB/dt response. The transmitter was mounted on a fixed wing aircraft and the receiver was mounted on a bird 50-52 m beneath the aircraft at an altitude of 70 m above terrain (Beattie, pers. comm., 2014). The survey was flown at 350 m flight line spacing providing moderate spatial resolution.

As indicated in Table 2, the Georgia Lake survey also incorporated VLF data. This survey recorded the VLF total field and quadrature channels for an unknown transmitter, although the orientation of the responses suggests it was the Cutler, Maine transmitter. The survey was flown on lines oriented north-south spaced 1,000 m apart at a nominal terrain clearance of 120 m.

Table 2. Summary of the characteristics for the geophysical data sources in the Township of Nipigon and Surrounding Area

Product	Source	Type	Line Spacing/ Sensor Height	Line Direction	Coverage	Date	Additional Comments
Ontario #8	GSC, 2013	Fixed wing magnetic	805 m/305 m	0°	Entire Nipigon area	1962	Low resolution coverage over 55% of area.
GDS1047 Lake Nipigon Embayment	OGS, 2004a	Fixed wing magnetic, radiometric	150 m/100 m	10°	West 40%	2003	High resolution coverage including radiometric survey.
GDS1226 Nipigon Bay	OGS, 2003	Fixed wing magnetic, TDEM	350 m/ 75 m (mag) 54 m (TDEM)	143°	Southeast (small area)	1994	Medium resolution coverage, Geotem (dB/dt, X-component).
Georgia Lake	GSC, 2013	Fixed wing radiometric, magnetic, VLF	1,000 m/120 m	0°	East 30%	1989	Medium resolution magnetic, radiometric and VLF-EM survey.
Thunder Bay Detail	GSC, 2013	Fixed wing radiometric, magnetic	1,000 m/130 m	0°	West 20%	1979	Medium resolution radiometric survey.
Thunder Bay Reconnaissance	GSC, 2013	Fixed wing radiometric, magnetic	5,000 m/144 m	4°	Central 50%	1979	Low resolution radiometric survey.
GDS1052 Lake Nipigon Embayment	OGS, 2004b	Ground gravity measurements	250 m-12 km		West half	2003-2004	High resolution gravity survey.
GSC Gravity Coverage	GSC, 2013	Ground gravity measurements	5-25 km		Entire Nipigon area	1952-1965	Relatively sparse GSC coverage.

GSC – Geological Survey of Canada
OGS – Ontario Geological Survey

3.2 Data Limitations

There is a fairly stark contrast between the high resolution of the magnetic survey that covers the western 40% of the Nipigon area and the older regional low resolution coverage elsewhere. Nevertheless, the magnetic data reflect quite coherent responses that elucidate the mapped geology, particularly in areas of limited bedrock exposure. The smaller intrusions, few dykes, sills 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 Nipigon area 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 usability of each data set also depends on its quality, especially resolution. There are no geophysical rock property data available for the Nipigon area. However, MacDonald (2004) tabulates several hundred measurements of magnetic susceptibility and density taken from samples of the Nipigon diabase sills and Sibley Group sedimentary formations north of the area. The implications of these measurements applied to the magnetic and gravity interpretations are discussed in Sections 5.2.1 and 5.2.2 respectively.

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 Nipigon area where projected to the UTM16N/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 but microlevelling was not required. The resultant grids were regridded to a common grid cell size of 30 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 this grid was 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 Nipigon area, the residual magnetic intensity grid was reduced to the pole using a magnetic inclination of 77.7° N and magnetic declination of 0.6° W (Figure 5).

The RTP filter, computed from 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(θ) = 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 6). This is particularly useful for locating contacts (e.g. from changes in the anomaly texture) and mapping structure (Telford et al., 1990). It is expressed as:

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

where Z is vertical distance upwards.

To reduce noise that resulted from aliasing during the minimum curvature gridding process, an 8th-order 200 m low pass Butterworth filter was also applied.

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

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

where Z is 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 8th-order 200 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 8). This is particularly useful for mapping texture, structure, and edge contacts of weakly magnetic sources. It is expressed as:

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

where *X* and *Y* are the horizontal offsets in the east and north directions. The first vertical derivative is computed in the Fourier domain whereas the horizontal derivatives in X and Y are computed in the space domain. To reduce noise that resulted from aliasing during the minimum curvature gridding process, an 8th-order 200 m low-pass Butterworth filter was also applied.

Analytic Signal Amplitude

The amplitude of the analytic signal (AS) (Figure 9) 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):

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

where T is the magnitude of the magnetic field.

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.

Depth to Magnetic Sources Using Source Parameter Imaging (SPI™)

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 (Lake Nipigon Embayment and Nipigon Bay), 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 Nipigon area, taking into account that the elevation of the magnetic sensor (Figure 10). 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 30 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 requires a minimum valid line length to be specified.

The smallest filter wavelength used in this analysis for the Nipigon area was four cells (equivalent to 120 m), over three scales. The filter sizes were therefore 120 m, 240 m and 480 m. All orientations were considered in the search for symmetry. A threshold value of 0.1 was applied, and a minimum line length of 3 cells (90 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):

$$TDX = \tan^{-1}\left\{\frac{\sqrt{\left([\frac{dRTP}{dX}]^2+[\frac{dRTP}{dY}]^2\right)}}{\frac{dRTP}{dZ}}\right\} \qquad \text{(eq. 4.6)}$$

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 gravity data and their station locations (602 gravity measurements) were downloaded for the Nipigon area from the GSC gravity compilation (GSC, 2013) and the OGS Lake Nipigon Embayment survey (OGS, 2004b). Due to the presence of the higher resolution coverage in the western part of the Nipigon area, new gravity grids were prepared at a 200 m grid cell size:

- Bouguer gravity field (Figure 11);
- First vertical derivative of the Bouguer gravity field (Figure 12);
- Total horizontal gradient of the Bouguer gravity field; and
- Isostatic residual gravity field.

All grids were reprojected to a UTM16N/NAD83 coordinate system. The first vertical derivative was computed using the same methodology applied to the pole reduced magnetic field, as described in Section 4.1. 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 Nipigon area, 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 Nipigon area 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.

4.3 Radiometric

The following seven radiometric grids (radioelement concentrations and ratios) were downloaded for the Nipigon area 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 high resolution survey in the western part of the Nipigon area (OGS, 2004a) was not incorporated in the GSC grids. Thus, the radiometric grids were prepared at 30 m cell size by merging the higher resolution data in the west with the regridded version of the lower resolution data to the east.

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 UTM16N/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 13 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

The OGS has not flown any electromagnetic surveys in the Nipigon area. It did acquire a fixed wing Geotem (TDEM) survey from industry and reprocessed the data (OGS, 2003).

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. This older generation TDEM system measured the X-component of dB/dt, which best couples with subvertical conductors.

All OGS 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 methodology for analysis of the TDEM data herein consisted mainly of plotting the EM anomalies over the gridded images provided by OGS and, if present, joining bedrock anomalies into quasi-linear conductors, where the character of the EM response remained consistent along strike.

The VLF-EM data were gridded and compared to topography. Conductors that did not show strong topographic correlations are more likely to reflect bedrock sources (e.g. fractures) and were interpreted (Figure 14).

For the electromagnetic surveys in the Nipigon area, the following data products were available:

- Nipigon Bay (GDS1226) – Decay constant grid (X-component) at 70 m cell size and EM anomaly database (OGS, 2003).
- Georgia Lake – Channels of VLF-EM total field and quadrature, which were gridded with the minimum curvature algorithm at 200 m cell size (GSC, 2013).

5 GEOPHYSICAL INTERPRETATION

5.1 Methodology

The coincidence of geophysical units with mapped lithology and structural features were identified and interpreted for the Nipigon area using all available geophysical data sets. The Lake Nipigon Region Geoscience Initiative provided high-resolution magnetic and radiometric coverage (OGS, 2004a) and relatively dense ground gravity coverage (OGS, 2004b) over the western 40% of the Nipigon area. These surveys contrast greatly with the standard regional geophysical data (GSC, 2013) over most of the remainder of the area. 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 Nipigon area (JDMA, 2014b). The first and second vertical derivatives were used to trace quasilinear magnetic anomaly peaks to infer the presence of ductile features. These ductile features are interpreted to be associated with the internal fabric of the rock units and may include in places sedimentary layering, tectonic foliation or gneissosity, and magnetic foliation (shown on Figure 7).

Enhanced grids of the magnetic field data were used to assist in the interpretation:

- Pole-reduced magnetic field – magnetic units (Figure 5);
- Pole-reduced first and second vertical derivatives – boundaries, texture, foliation (Figures 6 and 7);
- Analytic signal – anomaly character, texture, boundaries (Figure 8); and
- Tilt angle – subtle magnetic responses (Figure 9).

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 (Figure 11 and 12). Similar comments apply to the radiometric data (Figure 13), except where the high resolution data and images were available. The electromagnetic data (Figure 14) were not used for interpreting lithologies as the magnetic data proved greatly superior from a mapping perspective in the Nipigon area. 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). Results of the coincidence between the geophysical interpretation and the bedrock geologic map are presented in Figures 15 and 16. Figure 15 presents the interpreted near surface extent of the Nipigon diabase sills, whereas Figure 16 presents an interpretation of the remainder of the bedrock geology (Geologic Units A to O, as interpreted from geophysics). 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, 2011) (Figure 2)
- OGS Map P.3562 Precambrian Geology – Southern Black Sturgeon River - Seagull Lake - Disraeli Lake Area (Hart, 2005)
- OGS Map P.3562 Precambrian Geology – Southern Black Sturgeon River - Seagull Lake Area, Geological Cross-sections (Hart, 2005).

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

5.2 Results

The following section presents a regional-scale description and interpretation of each geophysical data set in the Nipigon area, followed by detailed interpretations of geophysical responses within the metasedimentary rocks and the granitic rocks of the Quetico Subprovince in the Nipigon area. Using the published 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 Nipigon area. Outlines of geophysical units are presented in Figure 15 (interpreted sills) and 16 (other interpreted geologic units). In many cases, the interpreted geophysical units generally match those of the published bedrock geology (OGS, 2011).

5.2.1 Magnetic

The magnetic data over the Nipigon area exhibits variability in its magnetic responses associated with the metasedimentary and granitic rocks of the Quetico Subprovince. These responses are locally influenced by the responses of the younger Nipigon diabase sills. These diabase sills are more readily distinguishable in the western 40% of the area where the high-resolution magnetic data is available. However, some continuity of the regional magnetic trends to the east is also evident. The western limits of certain interpreted magnetic units (units J, K, L and M) are located near the boundary between the high-resolution magnetic and radiometric survey flown over the

western part of the Nipigon area and the low-resolution surveys to the east. Their continuity across the survey boundary is difficult to determine due to the marked contrast in data resolution.

Within the higher resolution data, subtle east-west trending fabric is observed where the metasedimentary rocks have been mapped. Along the southern part of the Nipigon area this fabric is characterized by a high magnitude east-west trending response, which is assumed to extend under the sedimentary rocks of the Sibley Group and continue further east into the lower resolution magnetic data. This magnetic response tends to be the most dominant regional scale feature in the Nipigon area, and predominantly corresponds to areas that have been mapped as metasedimentary units. This feature is disrupted by the Hele intrusion and in places is transected by regional faults, such as the Black Sturgeon fault zone.

For the most part, the granitic rocks do not show distinct magnetic responses relative to the surrounding metasedimentary units, and tend to predominantly correspond to areas of relatively subdued magnetic responses. However, in few cases where the granitic rocks have been mapped, there tends to be some correlation between the east-striking massive granite to granodiorite in and west of the Township of Nipigon, and unique east-trending linear magnetic high responses that are outlined as unit I (Figure 16). The geophysical character of unit I (see Figures 5 and 6) generally shows a mixture of high and low magnitude responses, which in some cases is traced for a significant distance to the east into lower resolution magnetic data coverage. Despite this area being mapped as a predominantly metasedimentary unit, the magnetic response of unit I may suggest an intermixing of massive granodiorite to granite with the metasedimentary rocks in this area, perhaps at depth. In addition, the presence of the east-trending character observed in the magnetic data may also reflect a strong east-trending fabric preserved in the bedrock. This fabric may indicate a possible change in the metamorphic grade where the magnetic magnitude tends to increase towards the southern boundary of the Nipigon area.

The muscovite-bearing granitic intrusion referred to by Golder (2014) as the Mound Lake granite pluton, located in the northwest part of the Nipigon area, tends to be surrounded by a Nipigon diabase sill, which is mapped along most of its margin (Figure 2). Based on the outline of the granitic unit shown on the bedrock geology map (Figure 2), it tends to show a weak to moderate magnitude response in the pole reduced magnetic data (Figure 5) and slightly increased variability in subtle responses shown in the vertical derivative images (Figure 6 and 7). This feature has been outlined as Unit O, shown in Figure 16. The vertical derivative images tend to show the granitic unit has higher variability around the margins of the mapped intrusion, which decreases towards the center. Although the magnetic data tend to coincide well with the majority of the mapped granitic intrusion, there appears to be some discrepancy along the eastern margin with the mapped metasedimentary unit. Regardless of the difference along this contact, the general outline of the granitic intrusion and the adjacent metasedimentary unit forms an oval shaped feature that is preserved as a topographic high (for topography see JDMA, 2014a; Figure 4). Based on the bedrock geology map, the perimeter of this feature is predominantly mapped as exposed Nipigon diabase sill. This surrounding sill is clearly reflected in the magnetic data as a strong negative response. Hart (2005; cross-section D-F provided in Main Report Figure 3.4, Golder (2014) interpreted this sill unit to transect the upper horizons of the muscovite-bearing granitic intrusion, with its edges exposed along areas of high topographic relief and the remainder forming a slightly concave shape to a depth of approximately 50 m in the center of the

intrusion. The more extensive negative magnetic response towards the southeast part of unit O suggests that the sill is closer to surface and/or thicker in that area (Figure 15).

At a number of locations through the Nipigon area, there is a strong coincidence between the small segments of Nipigon sills that have been mapped (Figure 15) and clear magnetic responses. These magnetic responses are generally characterized by a stronger negative response along the inside of the sill contact based on the bedrock geology maps, and a positive response along its outer margin (Figures 5 to 7). The magnetic responses along the sill edges may also be complicated by their geometry where the effects of dip, thickness and magnetic remanence are combined. These effects are reduced in the analytic signal response (Figure 8), which transformed the pole reduced magnetic field response to a positive peak over the sill edge and ultimately proved to be useful for mapping the sill edges. In general, the locations of mapped Nipigon sills tend to be exposed in fairly small segments, corresponding to areas of topographic relief (for topographic relief see JDMA, 2014a; Figure 4). Based on the magnetic data, these exposed sills have been traced beyond the mapped extent, presumably cutting within the adjacent mapped bedrock units (Figure 15). In some cases, these sills show evidence of possible overlap between them (e.g. in the northwest corner of the Township of Nipigon and extending several kilometers to the north), possibly at different depths.

In general it is inferred that the sills possess some degree of magnetic remanence, resulting in a localized negative magnetic anomaly. Middleton et al. (2004) describe a complex thermal history during emplacement and cooling of the sills. The result is that the sills generally possess magnetic remanence that is much stronger than the induced field and antiparallel to the current geomagnetic field. However, the strength and direction of the remanence does vary, sometimes within the same sill, including a component oriented parallel to the induced field. The effect of these sill responses is to generally reduce and interfere with the responses of the underlying bedrock, which appear to be little affected by magnetic remanence. Hart (2005) describes the difficulty modelling the magnetic responses of the sills due to the strength and variability of the remanence.

MacDonald (2004) took magnetic susceptibility measurements from 469 samples of Nipigon diabase sills located west of Lake Nipigon (north of the Nipigon area). The values ranged from 5 x 10^{-3} SI to 140 x 10^{-3} SI, with a mean of 24.6 x 10^{-3} SI. These data as well as density measurements were used to undertake 3D inversions of the magnetic and gravity data (Reed and Rainsford, 2006). Two magnetic models (lnm110 and lnm112) and two gravity models (lng4 and lng112) overlap the Nipigon area. One of the magnetic models (lnm110) focused on a sill intruding Sibley Group sedimentary sediments along the northwest boundary of the Nipigon area. The inversion located a northwest-striking cylindrical buried magnetic source which the authors suggested may reflect a sill at depth. Although, the variability in magnetic remanence of the sills makes modelling them a difficult task without comprehensive sampling of the source bodies (Middleton et al., 2004).

The delineation of the sills east of the high-resolution data coverage tends to be much more ambiguous, provided the limitation of the data resolution. Although sills are shown on the bedrock geology map (Figure 2), the lower resolution magnetic data does not show a strong correlation with the location of mapped sills, other than partial coincidence with the somewhat

more intense magnetic lows. As a result, the interpretation of the sills (Figure 15) is limited to the western part of the Nipigon area where high-resolution magnetic data are available for interpretation. In general, magnetic responses in the area of low resolution coverage may simply reflect inhomogeneities within the metasedimentary rocks of the Quetico Subprovince.

The mapped extent of the Hele intrusion shows a distinct positive magnetic response in the pole reduced magnetic field data (Figure 5), with a mottled texture shown in the vertical derivative images (Figures 6 and 7). The outline of unit C coincides very well with the mapped outline of the Hele Intrusion, which has been mapped as peridotite and gabbro by Hart (2005). This coincidence between the contacts is well shown in all of the enhanced magnetic figures, in particular the first vertical derivative (Figure 6) and analytic signal (Figure 9). The magnetic low along its margins is indicative of its limited depth extent, which was confirmed by magnetic modelling (Hart, 2005), gravity modelling (lng112; Reed and Rainsford, 2006) and 130 m thickness from drilling (Hart, 2005). Although the emplacement of the Hele intrusion is contemporaneous with the Nipigon diabase sills, the intrusion does not exhibit the antiparallel magnetic remanence associated with most of the sills in the Nipigon area (Middleton et al., 2004).

Units D and E reflect magnetic responses from within the Black Sturgeon fault zone. These responses form a corridor of 1.0 to 2.5 km width along the north-northwest oriented fault. Unit D has a relatively low and subdued magnetic response whereas unit E has a fairly strong positive response. To some extent, this may reflect influence from topography where the broad river valley truncates the underlying bedrock units. It also reflects the vertical displacement of the fault itself, estimated to be downthrown by several hundred metres on the southwest side (Hart, 2005). Locally, there may also be minor contributions from alluvial sediments within the Black Sturgeon fault zone; however this is assumed to be limited.

The Sibley Group sedimentary formations do not appear to have a distinct magnetic response, and the magnetic anomalies where the formations are mapped are interpreted to reflect the underlying bedrock of the Quetico Subprovince, as well as the Nipigon diabase sills where they occur. This is in agreement with MacDonald (2004), where 7 of 9 Sibley Group samples taken west of Lake Nipigon (north of the Nipigon area) had magnetic susceptibilities of less than 5 x 10^{-3} SI. The other two samples did have significantly higher magnetic susceptibilities.

Relatively few dyke responses are present in the Nipigon area. To the east, two dykes show relatively distinct magnetic responses, one striking north-northeast and the second striking north-northwest, both extending northwards well beyond the Nipigon area. A few shorter dyke segments with a northerly strike and weak magnetic response are also interpreted. More of these may be present but the low resolution of the data in this area prevents their interpretation with any certainty. Most of the interpreted dykes in the eastern part of the Nipigon area are either coincident or on strike with mapped dykes.

Two dykes interpreted along the western margin of the Nipigon area strike northeasterly and have strong negative magnetic responses, suggesting they may possess magnetic remanence and may be related to the Nipigon diabase sill intrusions. A third dyke strikes northwest with a strong

magnetic response, cutting a massive granite to granodiorite intrusion and continuing west of the Black Sturgeon fault zone beneath the Sibley Group sedimentary formations.

5.2.2 Gravity

The Bouguer gravity data and gravity station locations across the Nipigon area are presented in Figure 11, and its first vertical derivative in Figure 12. Care must be exercised when interpreting these images, since some of the more significant anomalies are extrapolated between measurements, as indicated by the station locations on Figures 11 and 12. The gravity field generally grades from low in the east and southeast to high in the west and northwest. The area to the west can be subdivided further between zones of high and moderate response, aided by the higher resolution coverage in this area.

MacDonald (2004) took density measurements from samples located west of Lake Nipigon (north of the Nipigon area). The Nipigon diabase sills (213 samples) produced a mean density value of 2.98 g/cm^3 and the Sibley Group sedimentary formations (4 samples) produced a mean density value of 2.84 g/cm^3. The latter is a relatively high value for sedimentary formations but caution is required due to the low number of samples. However, if this value is representative, significant variations in thickness and depth of both the Nipigon diabase sills and the Sibley Group sedimentary formations would result in variations in the gravity response, especially relative to the less dense granitic rocks that may underlie them.

The broader positive gravity anomalies north of the Township of Nipigon correlate fairly well with the interpreted extent of the larger Nipigon diabase sills, noted above for their relatively high density. Other high responses to the north, east and west do not show the same correlation, although the moderate to high gravity responses tend to occur in areas where the sills are mapped and/or interpreted (Figure 15).

The larger granitic intrusions in the northwest part of the area correlate with gravity lows, which is to be expected, as the density of granitic rocks is typically on the order of 2.60 g/cm^3 (Telford et al., 1990). These anomalies are only defined by stations along the margins of the mapped intrusions, with gaps of 3.5 km or more across the centre of the intrusions, making any discussion of the geometry uncertain (e.g. thickness). The gravity high in the northwest corner forms part of a regional gravity anomaly that increases in size and amplitude along strike to the southwest, where it is associated with mafic volcanic and sedimentary rocks that are denser than the metasedimentary rocks (Reed and Rainsford, 2006).

Although only defined by two gravity measurements within the Nipigon area and a seven more to the south of the Nipigon area, the Hele intrusion shows a weak, but discrete higher gravity response. This response may reflect either a higher bulk rock density of the intrusion or limited depth extent. The gravity response associated with this intrusion is more prominent in the first vertical derivative of the Bouguer gravity (Figure 12).

5.2.3 Radiometric

The radiometric data across the Nipigon area is presented in Figure 13. These data display broad trends in radioelement distributions at a regional scale. Where the higher resolution coverage is available over the western 40% of the Nipigon area they were useful for interpretation of exposed geological units and boundaries. Although bedrock exposure is extensive in the Nipigon area, 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 eastern part of the area, where the lower resolution coverage occurs, there are three main types of radiometric response (in addition to the lack of response over lakes). The Quetico Subprovince metasedimentary rocks to the northeast are relatively high in all three radioelements, whereas the responses are more subdued further west. The latter is also a reflection of Sibley group sedimentary formations where present. The Nipigon diabase sills to the south are somewhat lower in three radioelements.

Within the high resolution coverage east of the Black Sturgeon fault zone, the granitic rocks are generally high in all three radioelements. This response provides a nice contrast to the Nipigon diabase sills that are generally low in all three radioelements, which is useful to compare and contrast with the geological mapping and the magnetic responses, since the radiometric responses reflect surface exposure. The hilltops composed of diabase sill units are reflected by a more distinct contrast with the surrounding rocks. A broad area of lower response through the center of this area correlates fairly well with a generally unmapped sill interpreted from the magnetic data (Figure 15), and indicates that the sill is exposed or eroded into the overburden. The Quetico Subprovince metasedimentary rocks show variability in responses from moderate to low, with the latter possibly influenced by the diabase sills. There is a general north-northwest grain to the radiometric responses which matches fabric of the terrain (hills, ridges and valleys). However, towards the south some responses strike to the east correlating with the metasedimentary rocks and their magnetic foliation.

Within the high resolution coverage west of the Black Sturgeon fault zone, there is more localized variability in the radiometric responses. The Hele intrusion is relatively low in all three radioelements, with an elevated response in all three radioelements around its margin, most pronounced for potassium. The elevated responses are located in the Sibley Group sedimentary formations, perhaps reflecting a halo of contact metamorphism that may have formed when they were intruded by the Hele intrusion. The Nipigon diabase sills are generally low in all three radioelements, having similar character to the sills east of the fault. The Sibley Group sedimentary formations can be separated into at least three distinct units, with two showing moderate responses characterized by different levels of potassium and uranium, and the third showing lower responses, possibly influenced by the diabase sills. These responses may reflect surface exposures of different formations within the Sibley Group.

For the GSC radiometric compilation within the Nipigon area, the radioelement responses are summarized in Table 3.

Table 3. Radioelement response statistics

Radioelement	Minimum*	Maximum	Mean
Potassium (%)	-0.13	4.02	0.98
Equivalent uranium (ppm)	-0.85	11.45	1.12
Equivalent thorium (ppm)	-0.92	14.01	3.33
Natural air absorbed dose rate (nGy/h)	-3.45	104.31	27.43

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

These levels are typical of metasedimentary and granitic rocks (IAEA, 2003), reduced somewhat by the presence of the Nipigon diabase sills.

The low uranium levels 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 highest uranium response in the area is located 5.8 km west-northwest of the northwest corner of Nipigon Township.

5.2.4 Electromagnetic

The two electromagnetic surveys are located in the eastern part of the Nipigon area (Figure 14). The electromagnetic survey responses 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 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).

Most of the coverage is provided by a GSC VLF-EM survey. Several smaller linear conductors (i.e. a kilometre or more in length) striking east to east-southeast are evident in the Quetico Subprovince metasedimentary rocks. The strike of these conductive features is more likely to be recorded in the VLF-EM data due to their orientation relative to the VLF transmitter and the north-south flightline direction. A significant number of these conductors tend to be coincident with the trend of small rivers and streams, as well as elongated water bodies in the area. Any VLF-EM conductors with a more northerly strike, if present, would not likely be apparent in this data set. The background VLF-EM response tends to be distinctly stronger over the exposed Nipigon diabase sills.

The decay constant (X-component) grid from the Nipigon Bay (GDS1226, OGS, 2003) survey showed no significant electromagnetic responses in the Nipigon area. Overall, the EM coverage over the geological formations of interest in the Nipigon area is rather limited and has not proven to be particularly useful as a geological mapping tool.

5.3 Geophysical Interpretation of the Quetico Subprovince Rocks

The following section provides more detailed geophysical interpretations of the Quetico Subprovince rocks in the Nipigon area. The interpretations include a description of the geophysical characteristics of the metasedimentary rocks, the Mound Lake granite pluton and other muscovite-bearing granitic rocks, and the granodiorite to granite units, 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 16,

noting that the interpretations are preliminary and based partially on low resolution geophysical data and require future geologic validation.

5.3.1 Metasedimentary Rocks

The magnetic responses associated with the mapped distribution of metasedimentary rocks of the Quetico Subprovince tend to be dominated by a weak magnetic background, although locally they are interpreted to exhibit some inhomogeneities compared to the simple distribution shown in the bedrock geology map (Figure 2). The weaker magnetic responses tend to be distributed over a significant portion of the mapped metasedimentary units, and in particular correspond to the interpretation of Units A, F, H and L that have been traced within the Nipigon area. These larger scale weak responses tend to be typical of the metasedimentary units observed elsewhere in the Quetico subprovince, perhaps reflecting a lower amount of magnetic minerals within these bedrock units (PGW, 2013).

In the higher resolution magnetic data several inhomogeneities are observed that show a pronounced east-west trending fabric through the areas mapped as metasedimentary rocks. In particular, Unit I has been identified with an east-west trend through the higher resolution data (Figure 16). Although less discrete, this east-west trending fabric can be traced into the lower resolution magnetic data on the eastern half of the Nipigon area, where it is characterized as broader east-west trending magnetic responses (Figure 16). Units G, I and K show a more subdued positive magnetic response, whereas units B, J, M and N show a pronounced and quasi-linear positive magnetic response. The easterly trending fabric presumably reflects internal rock foliations or gneissosity preserved within the metasedimentary units, which tends to parallel the orientation of the Quetico Subprovince boundary. Similar correlations have been made elsewhere in the Quetico Subprovince where the high intensity responses tend to reflect the occurrence of amphibolite grade metamorphism within the metasedimentary rocks (Hart, 2005). Despite the presence of the Nipigon diabase sills, the magnetic responses of the metasedimentary rocks tend to remain well distinguished by their easterly fabric. The influence of the diabase sills tends to only be emphasized along the sill margins.

Where there are Nipigon diabase sills present, especially within the high-resolution coverage to the west, the magnetic responses of the sill margins show a predominantly northern orientation. In contrast, the metasedimentary rocks are distinguished by their easterly orientation of penetrative ductile fabric. East of the Black Sturgeon fault zone, the magnetic foliation is similarly reflected in the radiometric responses and associated topography. West of the fault, the magnetic responses of the metasedimentary units do not correlate with the radiometric responses, which tends to more predominantly reflect the overlying Sibley sedimentary formations exposed at the surface.

The lower resolution radiometric data over the metasedimentary units in the eastern most portion of the Nipigon area display very regional anomalies that are elevated in all radioelements. This distribution of radioelements is depicted in Figure 13 as showing a predominantly white colour. Through the central portion of the Nipigon area, the resolution of the radiometric data is too low to provide any valuable interpretation. In the western portion of the Nipigon area, in the higher resolution coverage, the metasedimentary rocks tend to be elevated in all three radioelements.

Heterogeneity of the responses in Figure 13 tends to reflect lower radioelement concentrations where overburden units are present at both lower and higher elevations. Areas that appear to be completely depleted in all radioelements (black) coincide with areas covered by larger water bodies (Figure 3).

5.3.2 Muscovite-bearing Granitic Rock

There are several instances of muscovite-bearing granitic rock mapped in the Nipigon area. Unit L delineates a broad, smooth, regional magnetic low that incorporates two of the east-trending granites in the north-central part of the area. Largely due to the limitation of the lower resolution magnetic data, these granitic rock intrusions do not tend to coincide with any magnetic responses. This lack of magnetic response is similarly reflected where the granitic rock is partially covered by higher resolution magnetic data. Additionally, the lack of gravity coverage in the area prevents these granitic units from showing a discrete gravity response.

Another instance is the Mound Lake granite pluton in the northwest part of the Nipigon area, situated just east of the Black Sturgeon Fault zone. This granitic unit has a distinct magnetic signature (unit O), attributed to Nipigon diabase sill exposure along a significant portion of its perimeter. This exposed sill is clearly reflected in the magnetic data as a strong negative response. Hart (2005) interpreted this sill unit to cut through the entire muscovite-bearing granitic intrusion, with its edges exposed along areas of high topographic relief. Although the outline of unit O (Figure 16) tends to coincide well with the majority of the mapped granitic intrusion, there appears to be some discrepancy along the eastern margin with the mapped metasedimentary units. Regardless of the difference along this contact, the general outline of the granitic intrusion and the adjacent metasedimentary unit forms an oval shaped feature that is preserved as a topographic high (for topography see JDMA, 2014a; Figure 4).

The radiometric data over the granitic unit shows a high concentration of all radioelements, which broadly coincides with the mapped bedrock geology. Similar to the magnetic data, it is difficult to define the contact along the eastern margin of the granite, adjacent to the mapped metasedimentary units; although, the mapped metasedimentary unit tend to be slightly elevated in uranium concentrations.

The gravity data in the Mound Lake granite pluton area show a low to the west, suggesting a thickening of the granite, although the gravity stations that define this response are all located on the margins of the intrusion. A gravity high to the east is consistent with the mapped metasedimentary rocks.

5.3.3 Massive Granodiorite to Granite

For the most part, the massive granodiorite to granite units do not show distinct magnetic responses relative to the surrounding metasedimentary units, and tend to predominantly correspond to areas of relatively subdued magnetic responses. Locally, a few unique east-trending magnetic responses that are outlined as unit I tend to be broadly related to the location of the mapped massive granodiorite to granite units (Figure 16). These geophysical responses generally show a mixture of east-west trending, high to low magnitude responses that can be

traced for a significant distance to the east into lower resolution magnetic data coverage (Unit I; Figure 16). Despite these areas being mapped as predominantly metasedimentary rock, the resulting interpretation suggests that much of the east-west trending fabric may in fact reflect the intermixing of massive granodiorite to granite units with the metasedimentary rocks. In locations where the small massive granodiorite to granites have been mapped along the southern part of the Nipigon area, the gravity data tends to show a broad low magnitude response oriented in an east-west direction similar to the magnetic fabric identified in Unit I. The larger massive granodiorite to granite unit in the north tends to correlate well with a gravity low, although the gravity stations are primarily located on its margins.

The radioelement levels of the larger massive granodiorite to granite intrusion are relatively high and very similar to those of the nearby muscovite-bearing granite intrusion (unit O) to the north. However, both the magnetic and radiometric responses indicate that these are two separate intrusions of different composition, as the geological mapping confirms. The radioelement responses over the southern granitic bands tend to be obscured by being mixed with those of the diabase sills and overburden sediments.

6 SUMMARY OF RESULTS

The purpose of this assessment was to identify and obtain the available geophysical data for the Township of Nipigon, 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 Nipigon area.

The geophysical data covering the Nipigon area 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 Nipigon area. One magnetic/radiometric survey obtained from the Ontario Geological Survey (OGS) and one OGS magnetic/electromagnetic survey provided higher resolution coverage over approximately 40% of the Nipigon area (Figure 4). The magnetic/radiometric survey and an associated higher resolution OGS ground gravity survey, both acquired for the Lake Nipigon Regional Geoscience Initiative, greatly improved the data quality over the western part of the Nipigon 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. The analytic signal amplitude provided a critical contribution for mapping the complex responses of the Nipigon diabase sills. At a regional scale, the coincidence between the geophysical interpretations and the published geological maps is in good agreement.

The Nipigon area hosts older metasedimentary and granitic rocks, intruded by the Nipigon diabase sills and the related Hele intrusion, and overlain to a significant extent by Sibley Group

formations and Quaternary sediments. This results in a complicated mixture of magnetic, radiometric and gravity anomalies that are due to material at surface and buried rocks. East of the Black Sturgeon fault zone, the metasedimentary and granitic rocks show an east to east-northeast orientation. This orientation continues west of the fault along the southern margin of the area, but for the most part the orientation of the rocks west of the fault follow the north-northwest trend of the fault itself.

The metasedimentary rocks of the Quetico Subprovince tend to be dominated by a weak magnetic background, although locally they exhibit some inhomogeneities relative to the geological mapping. There are larger scale zones of weak magnetic response that are typical of the metasedimentary units observed elsewhere within the Quetico Subprovince, and may reflect a lower proportion of magnetic minerals. Within the areas with higher resolution data are also observed inhomogeneities that show a pronounced east-west trending fabric that parallel the Quetico Subprovince boundary, some of which are traceable to the east into the area of low resolution data. These areas show either a subdued positive magnetic response, or else a more pronounced quasi-linear positive magnetic response, with the higher response thought to reflect the occurrence of amphibolite grade metamorphism (Hart, 2005). There is some correlation between the magnetic heterogeneity of the metasedimentary rocks and the radiometric and gravity responses, but interference from the Nipigon diabase sills and glacial sediments, and the low data resolution to the east, reduces the effectiveness of those data types to characterize these rocks.

The Black Sturgeon fault zone appears in the magnetic data as a 1 to 2.5 km wide corridor with a north-northwest south-southeast trend of magnetic highs (east) and lows (west) along the western margin of the metasedimentary and granitic rocks and extending west into the Sibley Group formations (and underlying lithologies). These magnetic responses result from a combination of geomorphology, where the broad river valley associated with the fault truncates the geology, including the remanently magnetic Nipigon diabase sills, and the several hundred metre vertical displacement of the fault (downthrown rocks to the southwest).

The Mound Lake granite pluton in the northwest part of the Nipigon area has a distinct magnetic low signature that is complicated by a Nipigon diabase sill outcropping along it margins and inferred to likely intrude it, which affects the magnetic and radiometric responses. The general outline of the granitic intrusion and the adjacent metasedimentary unit to the east forms an oval shaped feature that is preserved as a topographic high. The radiometric data over this area shows a high concentration of all radioelements. The two other instances of muscovite-bearing granitic rocks are located further east within a broad, regional magnetic low.

The granite to granodiorite intrusion east of the Black Sturgeon fault zone is distinguished by a smooth magnetic response (cut by a northwest-striking dyke), a distinct gravity low and relatively high radioelement concentrations. It may extend eastwards below the metasedimentary rocks. The bands of granite to granodiorite further south are characterized mainly by magnetic banding in contrast to the smoother response of the adjacent metasedimentary rocks.

The Nipigon diabase sills significantly influence the magnetic response due to their proximity to ground surface, magnetic susceptibility, strong magnetic remanence and geometry. Sills spread

across a wide area result in magnetic lows, with internal variations due to changes in thickness, surface geometry and/or susceptibility. At a few locations in the high resolution coverage to the west, overlapping sills are evident indicating sills at different depths. In the low resolution coverage to the east, it is difficult to determine which magnetic lows are due to sills and which reflect heterogeneities within the metasedimentary rocks. The sill edges typically produce a magnetic low inside the contact and magnetic high outside the contact, which is typical of a reversely magnetized magnetic horizon of limited thickness. The analytic signal (Figure 9) is useful to locate the contacts or edges as it is the least influenced by geometry and magnetic remanence. The sills have a relatively high density and low radioelement concentrations, thus contributing to the gravity and radiometric responses as well.

The Hele ultramafic intrusion in the southwest corner of the Nipigon area is contemporaneous with the Nipigon diabase sills. It has a distinct magnetic response typical of gabbro-peridotite and low radioelement concentrations with contact metamorphism apparent in the surrounding Sibley sedimentary formations. Despite its limited thickness of 130 m, it also produces a weak gravity low.

The Sibley Group formations generally have a low magnetic susceptibility. In the Nipigon area, they do not display a magnetic response. West of the Black Sturgeon fault zone, where the vertical offset has resulted in the preservation of a few hundred metres of these formations, the result is a slight dampening of the magnetic response from the older underlying rocks. These formations are denser than most sedimentary rocks and likely contribute to the positive gravity responses near the western boundary of the Nipigon area, together with the Nipigon diabase sills. The radiometric responses over the Sibley Group delineate four distinct units, with radioelement concentrations that vary from high to low and relative differences as well (e.g. thorium enrichment). These units correlate well with topography, suggesting that different formations are exposed at different elevations. Nipigon diabase sills and glacial sediments within the areas of Sibley Group also have distinct radiometric signatures.

Respectfully Submitted,

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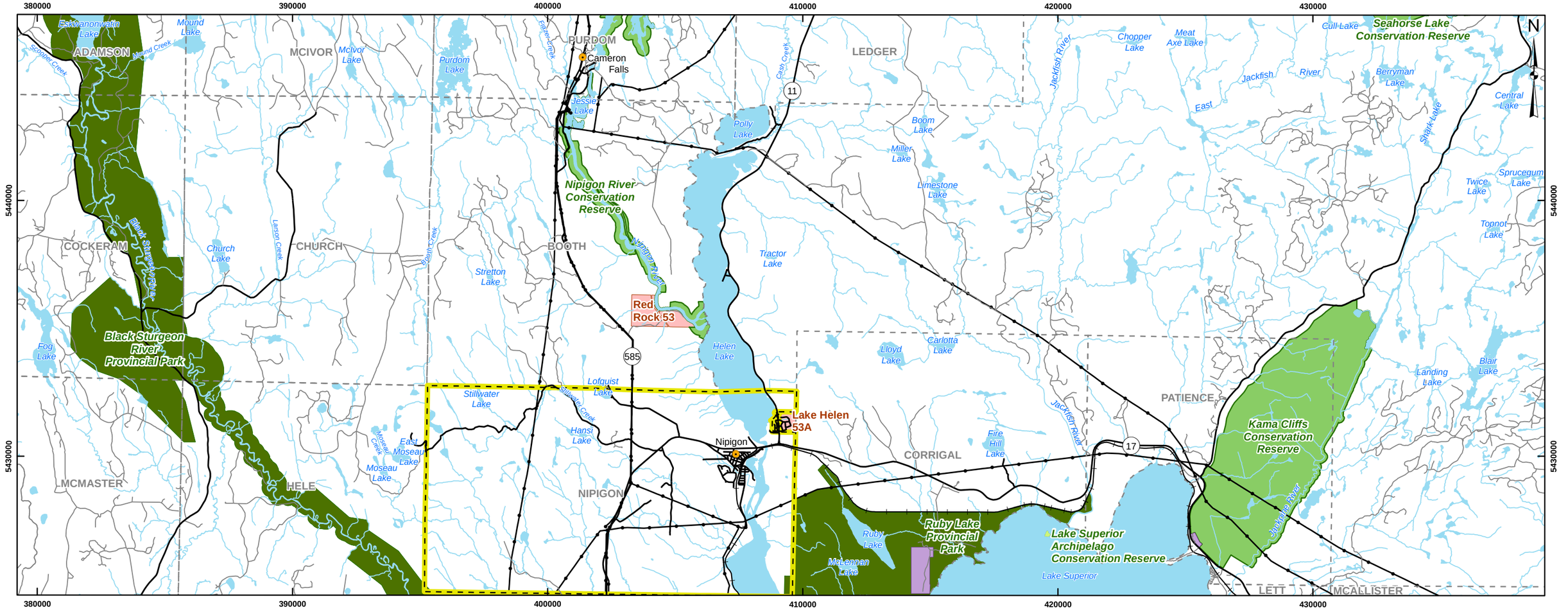
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LEGEND

- Municipal Boundary (Township of Nipigon)
- Geographic Township
- Community
- Main Road
- Local Road
- Railway
- Transmission Line
- Watercourse
- Waterbody
- First Nation - Indian Reserve
- Forest Reserve
- Recommended Conservation Reserve
- Conservation Reserve
- Provincial Park

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Golder Associates

2.5 1.25 0 2.5 5 7.5
SCALE 1:150,000 KILOMETRES



PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

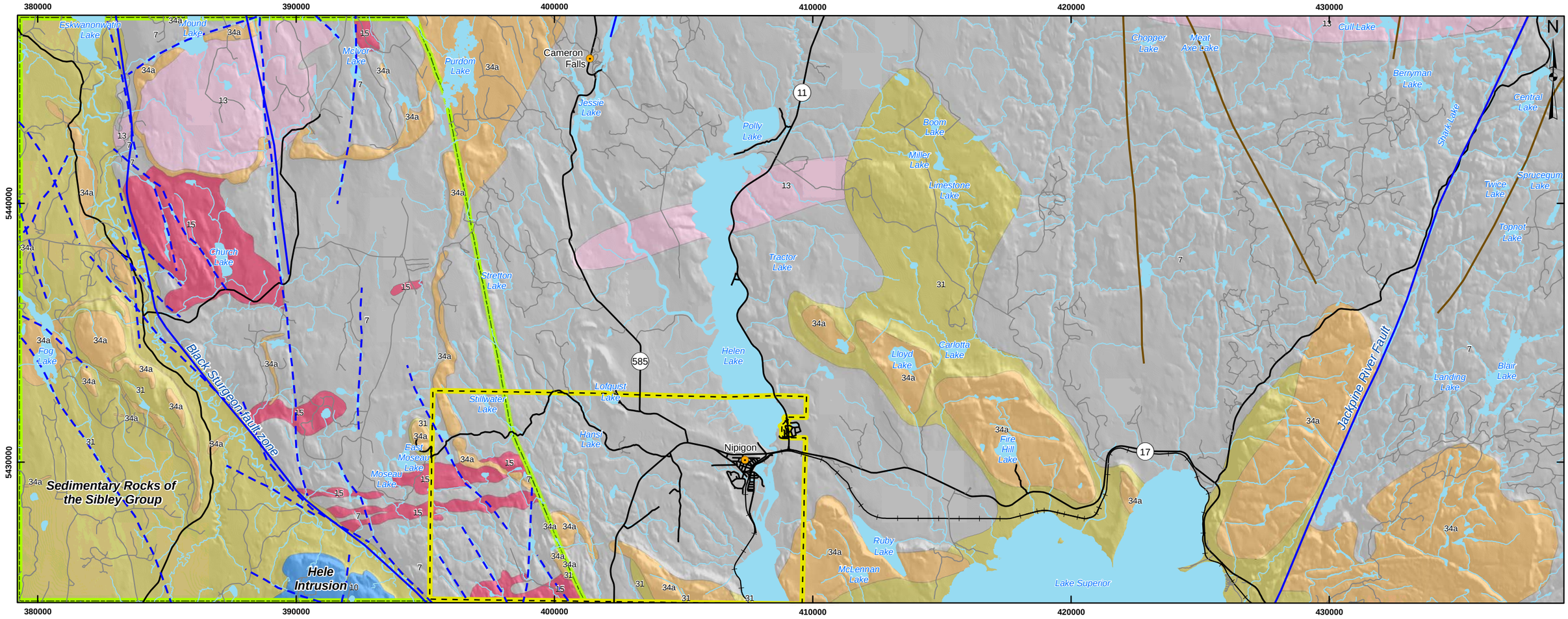
TITLE
Township of Nipigon and surrounding area

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.1
DESIGN	PRM	19 Aug. 2013		
GIS	PM/JB	18 Feb. 2014		
CHECK	CWM	18 Feb. 2014		
REVIEW	GWS	18 Feb. 2014		

FIGURE 1

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LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Lineament / Fault (Hart, 2005)
- Mapped Dyke
- Revised mapping (Hart, 2005)

Bedrock Geology

- 34 Mafic and related intrusive rocks (Keweenawan age)
- 34a Logan and Nipigon sills (1109 Ma): diabase sills
- 31 Sibley Gp.
- 15 Massive granodiorite to granite
- 15a Potassium feldspar megacrystic units
- 13 Muscovite-bearing granitic rock
- 10 Mafic and ultramafic rocks
- 7 Metasedimentary rocks

REFERENCE

Base Data: MNR LIO, obtained 2009-2013
Hillshade: GeoBase CDED 1:50,000
Geology: Modified 1:250 000 Scale MRD126 - Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Golder Associates

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SCALE 1:150,000 KILOMETRES



PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

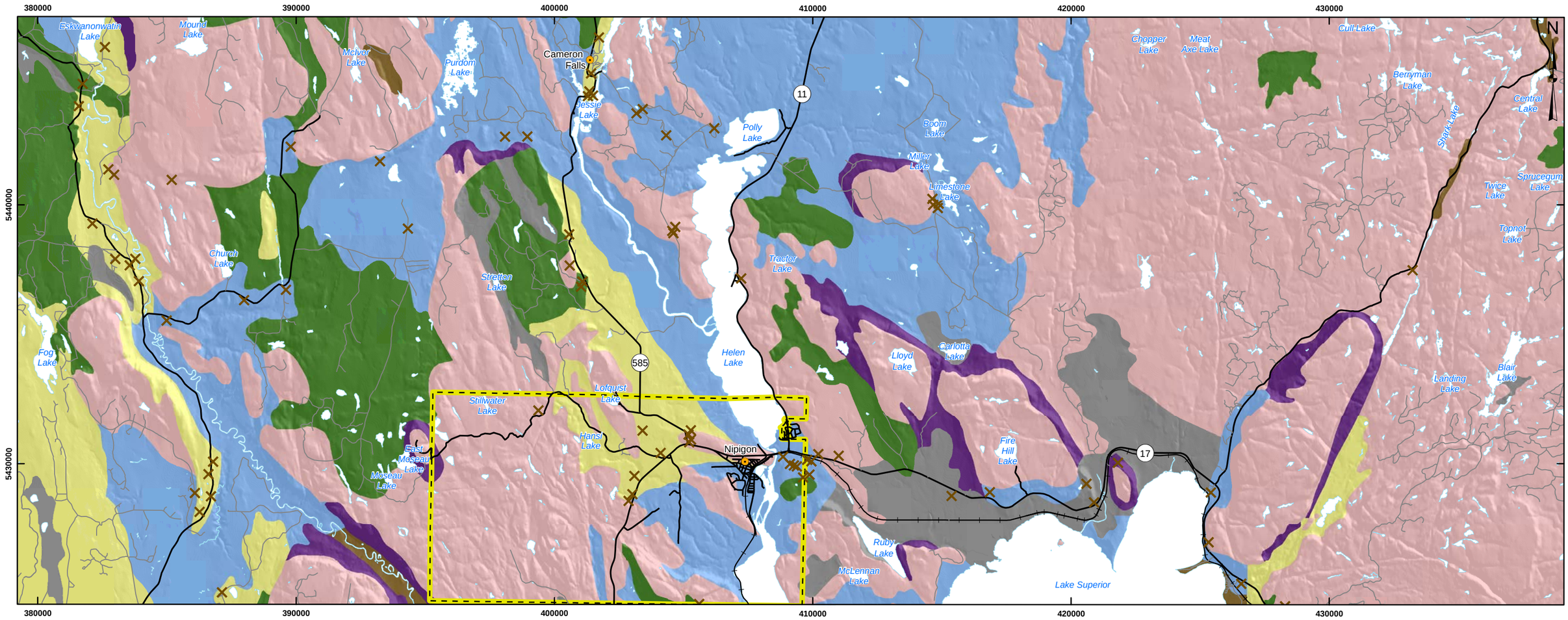
TITLE
Bedrock geology of the Nipigon area

Paterson, G & Watson Li
Consulting Ge
www.pgw.on.c

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	PM/JB	3 Jan. 2014		
CHECK	CWM	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 2

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LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Pit (Gravel)

Landform

- Man made
- End moraine
- Ground moraine
- Esker
- Kame
- Outwash plain
- Raised beach
- Glaciolacustrine delta
- Glaciolacustrine plain
- Alluvial
- Talus pile
- Slopewash and debris creep
- Organics
- Bedrock terrain

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Landform - OGS, MND Mines, and Northeast Science and Information Section, MNR 2005. Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Wells - Ministry of the Environment, 2013
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Golder Associates

2.5 1.25 0 2.5 5 7.5
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PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

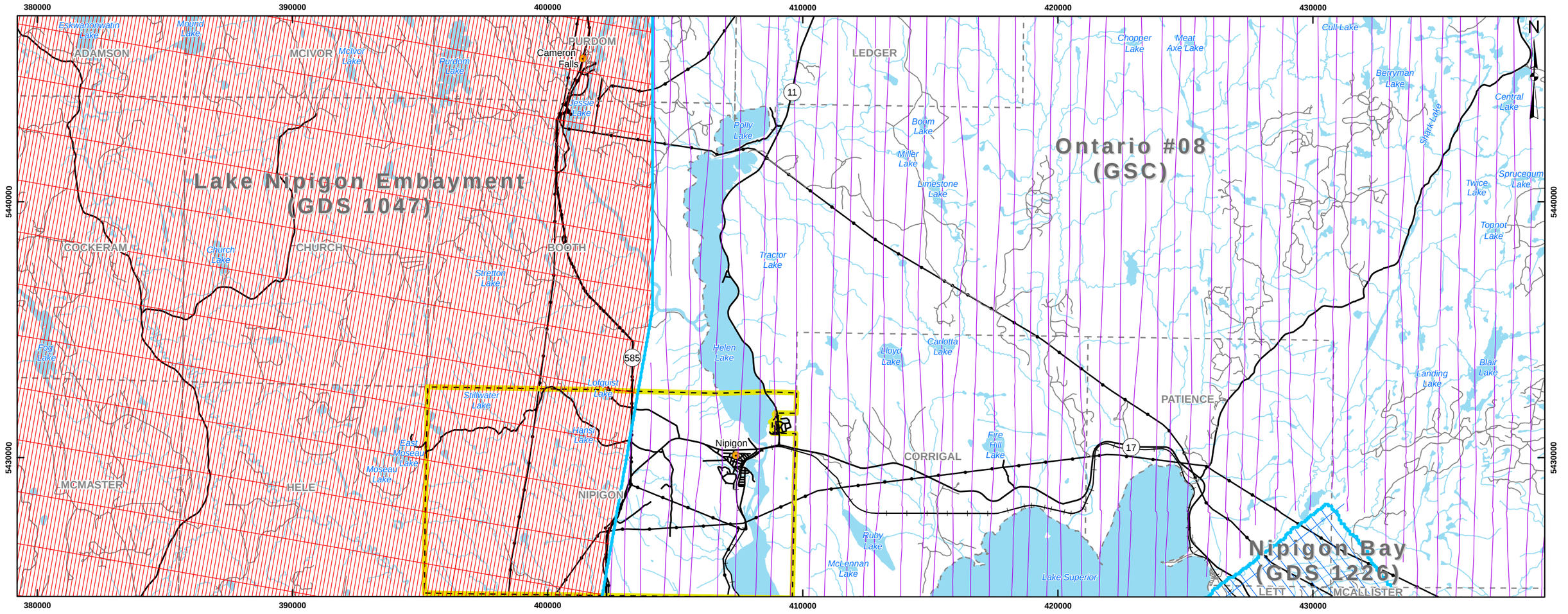
TITLE
Surficial geology of the Nipigon area

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.1
DESIGN	PM	19 Aug. 2013		
GIS	PM/JB	3 Oct. 2013		
CHECK	CWM	27 Feb. 2014		
REVIEW	GWS	27 Feb. 2014		

FIGURE 3

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LEGEND

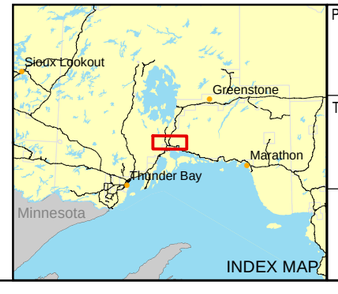
- Municipal Boundary (Township of Nipigon)
- Geographic Township
- Community
- Main Road
- Local Road
- Railway
- Transmission Line
- Watercourse
- Waterbody
- High resolution geophysical survey outlines
- Flightpath GDS1047 Lake Nipigon Embayment
- Flightpath OGS GDS1226 Nipigon Bay
- Flightpath GSC Ontario #08

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys: Ontario #8, Ontario Geological Survey - Geophysical Surveys: GDS1047, GDS1226
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

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2.5 1.25 0 2.5 5 7.5
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PROJECT
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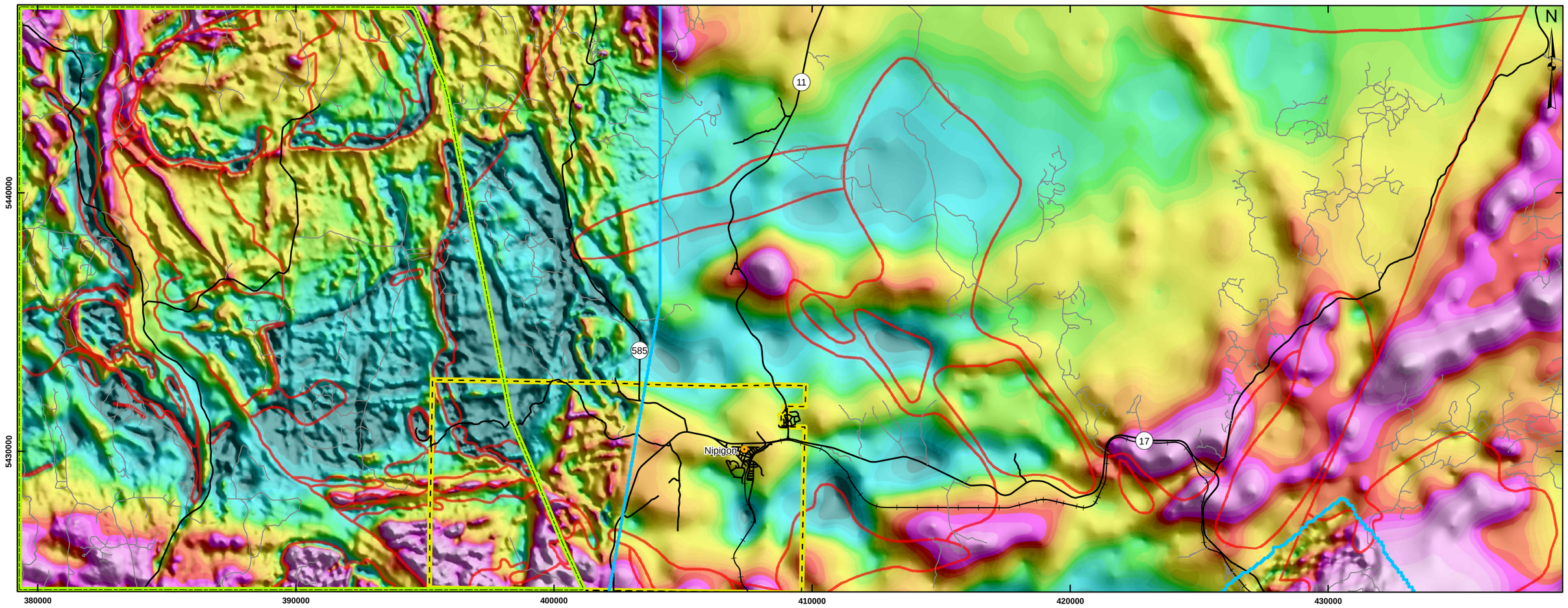
TITLE
Airborne geophysical coverage of the Nipigon area

Paterson, Grant & Watson Limited
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PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.1
DESIGN	PRM	19 Aug. 2013		
GIS	PRM	3 Oct. 2013		
CHECK	CWM	27 Feb. 2014		
REVIEW	GWS	27 Feb. 2014		

FIGURE 4

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Pole-reduced Magnetic Field (nT)

1038
190
110
75
55
35
20
5
0
-10
-20
-30
-40
-45
-55
-60
-65
-70
-75
-85
-90
-95
-100
-110
-120
-130
-140
-155
-175
-569

LEGEND

- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)
- High resolution geophysical survey outlines

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys: Ontario #8, Ontario Geological Survey - Geophysical Surveys: GDS1047, GDS1226
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

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2.5 1.25 0 2.5 5 7.5
SCALE 1:150,000 KILOMETRES



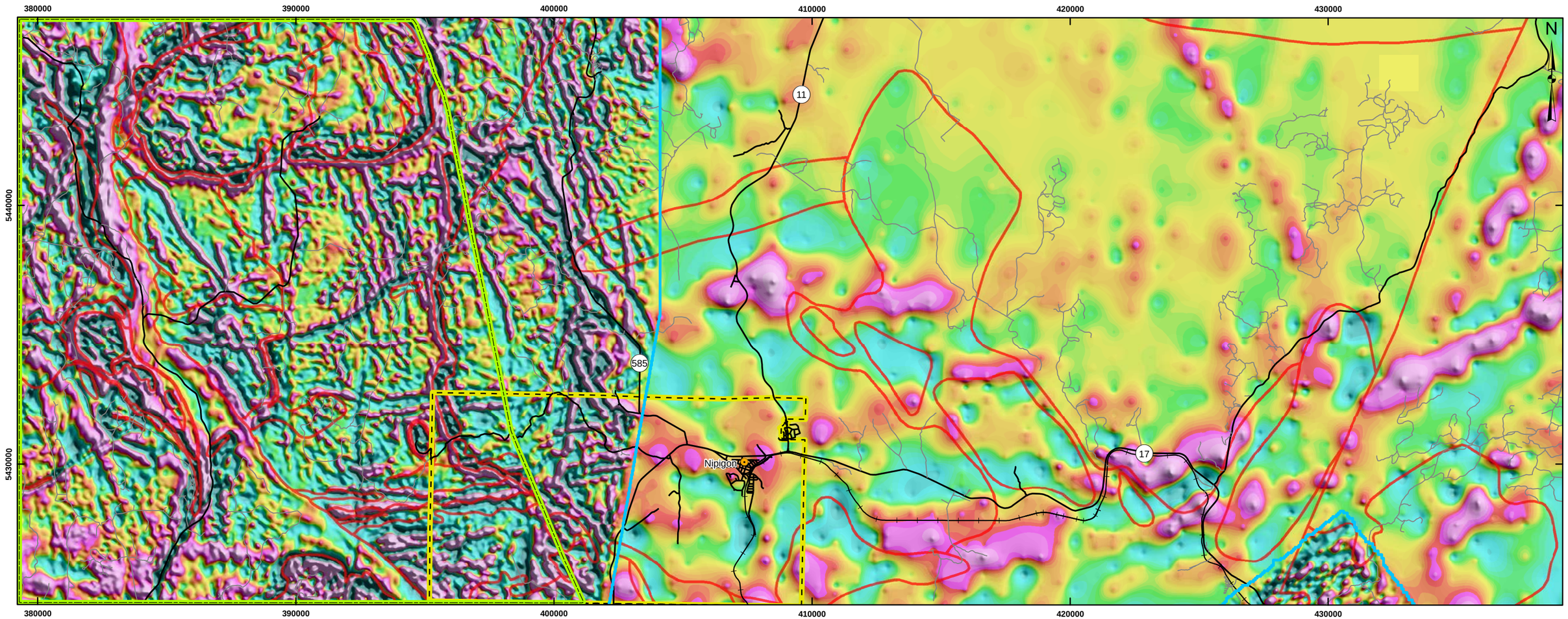
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

TITLE
Residual magnetic field reduced to pole

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	WP	19 Sep. 2013		
CHECK	SWR	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 5



First vertical derivative of the
Pole-reduced Magnetic Field (nT/m)

4.066
0.350
0.214
0.152
0.112
0.084
0.064
0.046
0.034
0.022
0.014
0.004
0.000
-0.006
-0.010
-0.014
-0.018
-0.022
-0.026
-0.032
-0.038
-0.046
-0.056
-0.066
-0.082
-0.102
-0.132
-0.186
-0.322
-7.006

LEGEND

- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)
- High resolution geophysical survey outlines

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys: Ontario #8, Ontario Geological Survey - Geophysical Surveys: GDS1047, GDS1226
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Golder Associates

2.5 1.25 0 2.5 5 7.5
SCALE 1:150,000 KILOMETRES



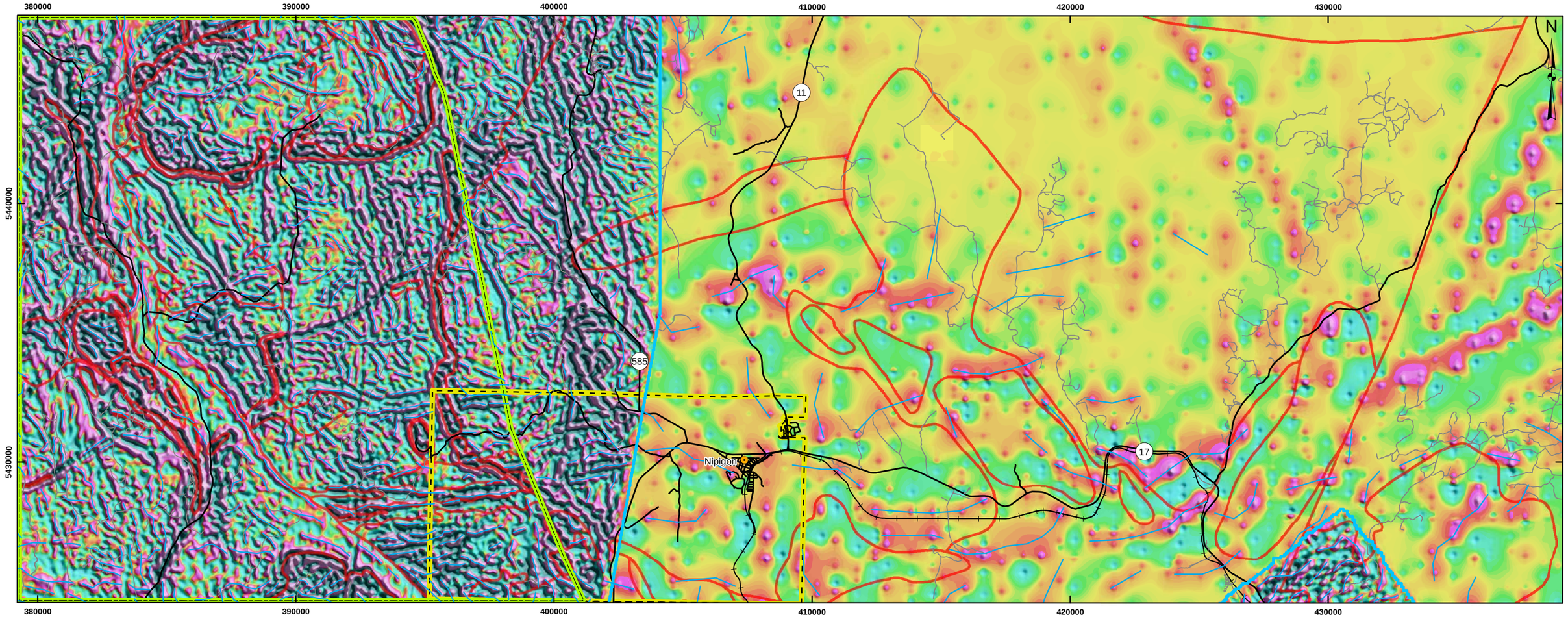
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

TITLE
First vertical derivative of the pole reduced magnetic field

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	WP	19 Sep. 2013		
CHECK	SWR	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 6



Second vertical derivative of the
Pole-reduced Magnetic Field (nT/m2)

4.066
0.350
0.214
0.152
0.112
0.084
0.064
0.048
0.034
0.022
0.014
0.004
0.000
-0.006
-0.010
-0.014
-0.018
-0.022
-0.026
-0.032
-0.038
-0.046
-0.056
-0.066
-0.082
-0.102
-0.132
-0.188
-0.322
-7.006

LEGEND

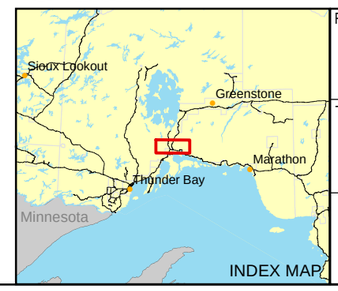
- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)
- High resolution geophysical survey outlines
- Ductile feature

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys: Ontario #8, Ontario Geological Survey - Geophysical Surveys: GDS1047, GDS1226
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Golder Associates

2.5 1.25 0 2.5 5 7.5
SCALE 1:150,000 KILOMETRES



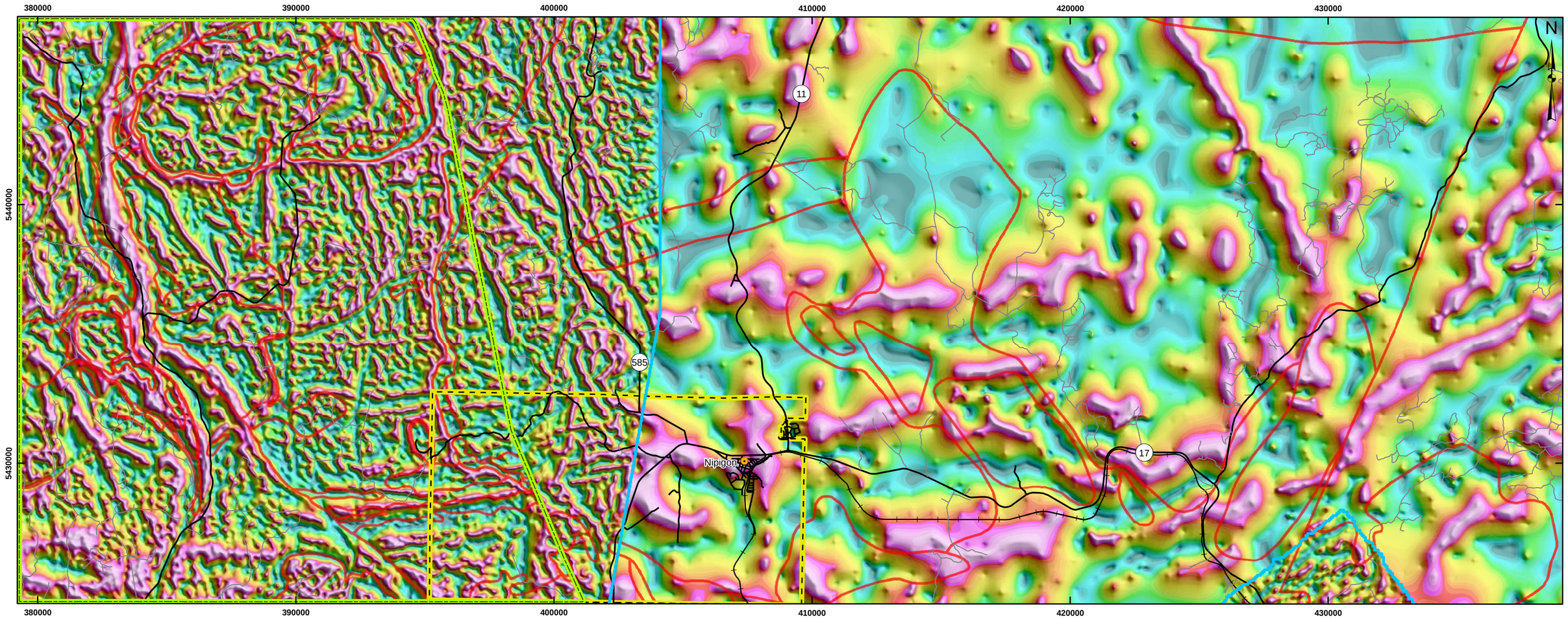
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

TITLE
Second vertical derivative of the pole reduced magnetic field

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PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	WP	19 Sep. 2013		
CHECK	SWR	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 7



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

1.59
1.25
1.10
1.00
0.85
0.75
0.65
0.50
0.40
0.30
0.15
0.05
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.75
-0.85
-0.90
-1.00
-1.05
-1.10
-1.20
-1.25
-1.35
-1.65

LEGEND

- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)
- High resolution geophysical survey outlines

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys: Ontario #8, Ontario Geological Survey - Geophysical Surveys: GDS1047, GDS1226
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Golder Associates

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SCALE 1:150,000 KILOMETRES



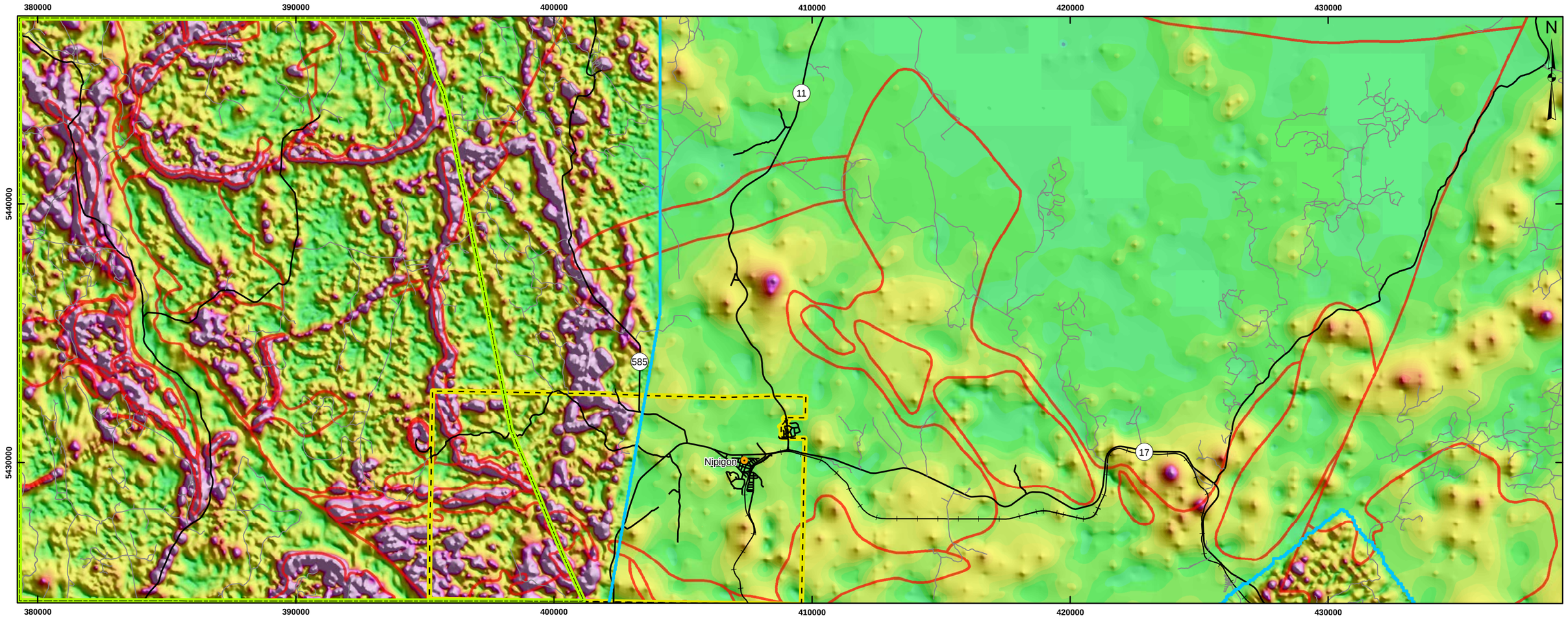
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

TITLE
Tilt angle of the pole reduced magnetic field

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PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	WP	19 Sep. 2013		
CHECK	SWR	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 8



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

7.475
0.594
0.514
0.464
0.422
0.394
0.362
0.336
0.310
0.286
0.264
0.242
0.220
0.200
0.176
0.162
0.140
0.120
0.096
0.076
0.054
0.030
0.004
0.002
0.001

LEGEND

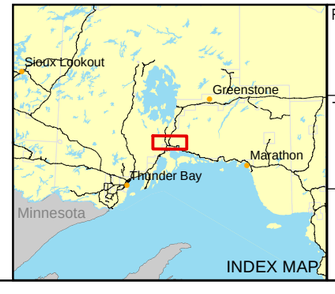
- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)
- High resolution geophysical survey outlines

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys: Ontario #8, Ontario Geological Survey - Geophysical Surveys: GDS1047, GDS1226
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

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SCALE 1:150,000 KILOMETRES



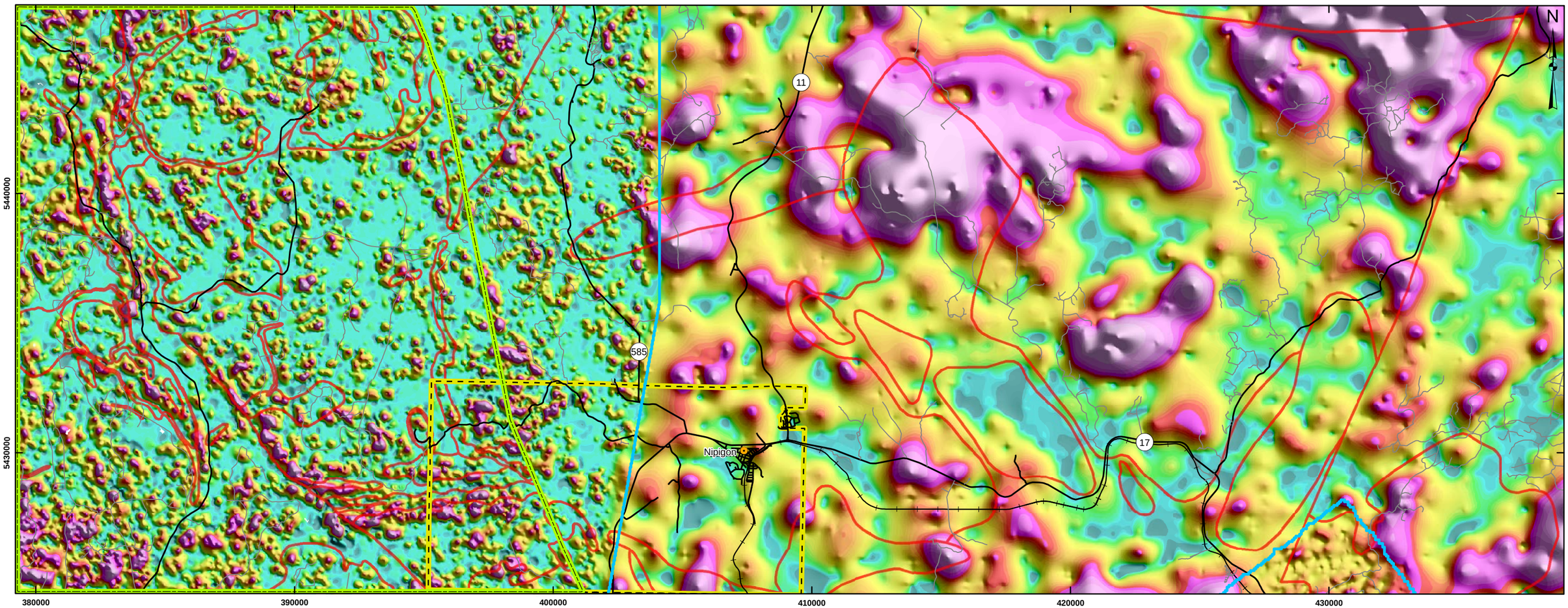
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

TITLE
Analytic signal amplitude of the total magnetic field

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	WP	19 Sep. 2013		
CHECK	SWR	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 9



Depth to Magnetic Sources
(m below surface)

18575
1293
858
646
522
434
369
320
280
245
214
186
165
142
121
102
84
66
53
40
29
19
11
5
3
2
1
-1
-6
-503

LEGEND

- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)
- High resolution geophysical survey outlines

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys: Ontario #8, Ontario Geological Survey - Geophysical Surveys: GDS1047, GDS1226
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

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SCALE 1:150,000 KILOMETRES



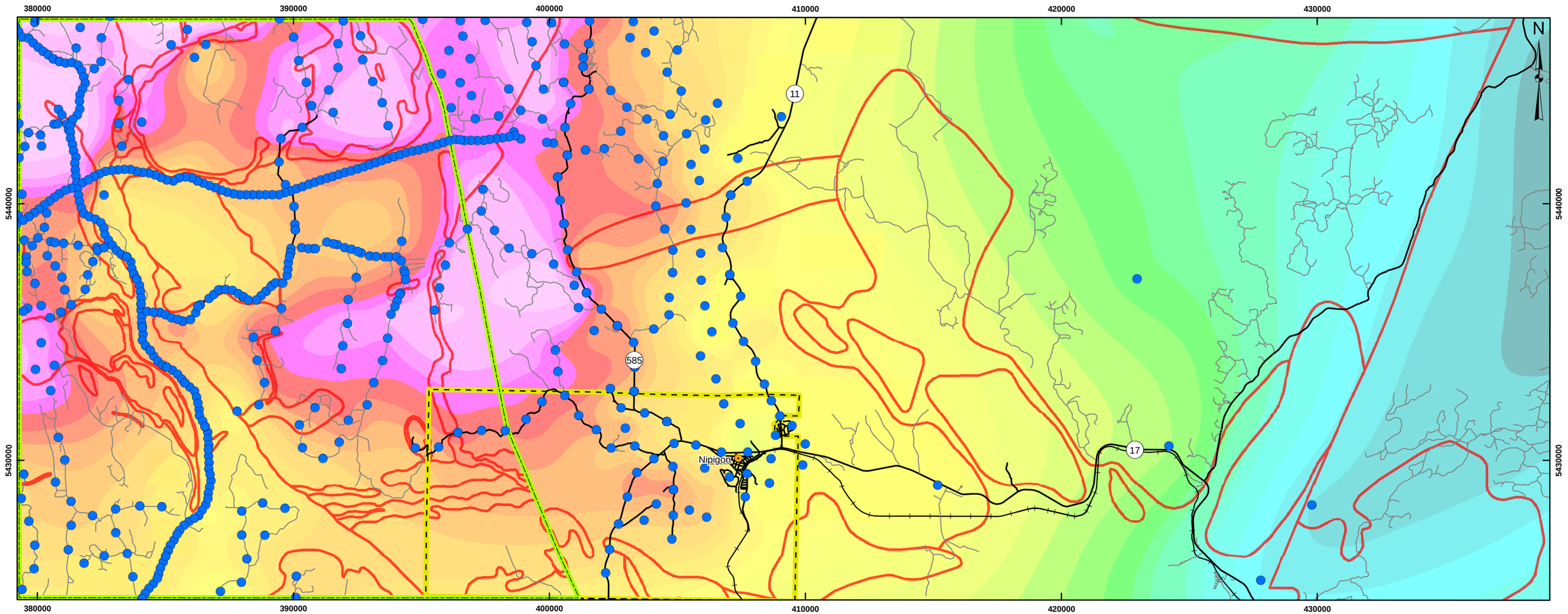
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

TITLE
Depth to magnetic sources from source parameter imaging

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	WP	19 Sep. 2013		
CHECK	SWR	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 10



Bouguer Gravity Field
(mGal)

-50.1
-52.2
-53.4
-54.2
-54.6
-55.0
-55.6
-56.0
-56.4
-56.8
-57.4
-57.8
-58.4
-58.8
-59.2
-59.8
-60.6
-61.6
-62.4
-63.2
-64.0
-64.6
-65.0
-65.8
-66.2
-67.0
-67.6
-68.2
-68.8
-70.4

LEGEND

- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)
- Gravity station locations

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Nationwide Gravity Compilation, Ontario Geological Survey - Geophysical Surveys: GDS1052
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

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SCALE 1:150,000 KILOMETRES



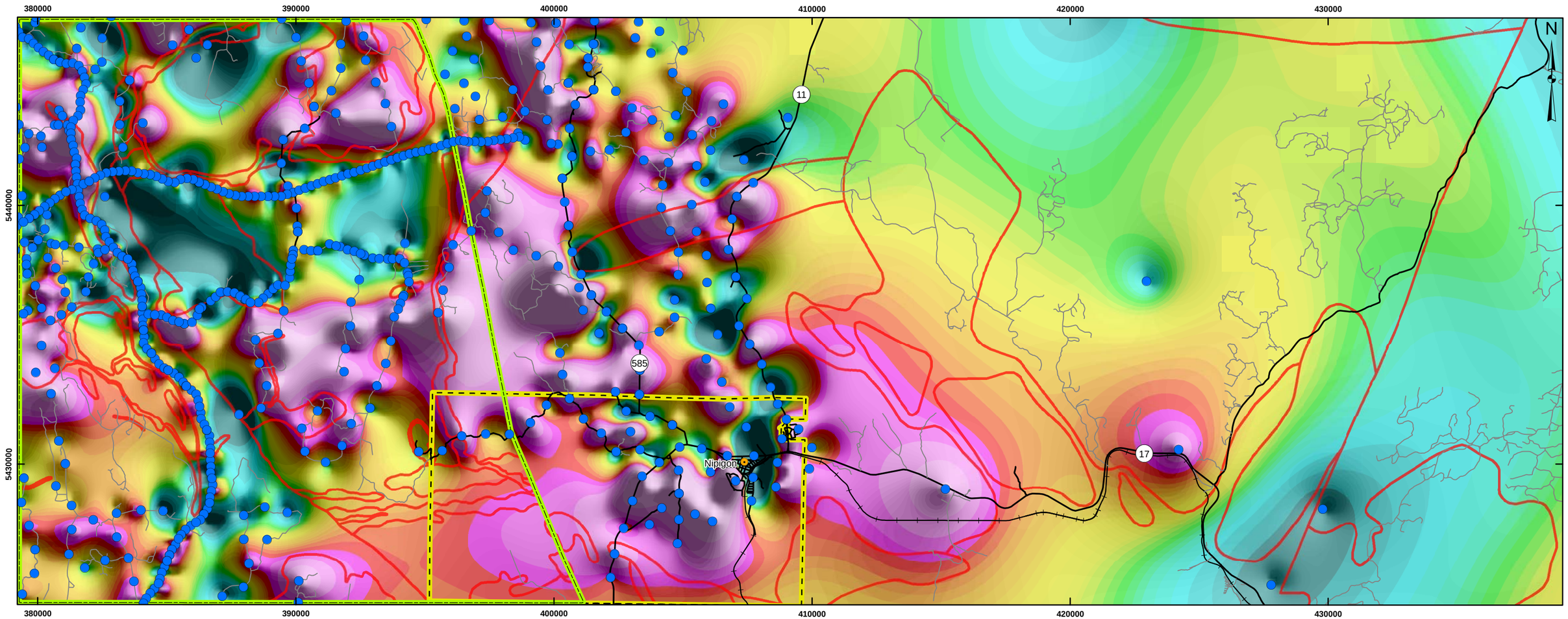
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

TITLE
Bouguer gravity field

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013	
GIS	WP	19 Sep. 2013	
CHECK	SWR	2 June 2014	
REVIEW	GWS	2 June 2014	

FIGURE 11



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

0.00540
0.00112
0.00080
0.00062
0.00050
0.00042
0.00034
0.00026
0.00020
0.00014
0.00008
0.00002
-0.00002
-0.00006
-0.00012
-0.00016
-0.00022
-0.00024
-0.00028
-0.00032
-0.00036
-0.00040
-0.00044
-0.00048
-0.00054
-0.00062
-0.00070
-0.00082
-0.00100
-0.00922

LEGEND

- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)
- Gravity station locations

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Nationwide Gravity Compilation, Ontario Geological Survey - Geophysical Surveys: GDS1052
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

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SCALE 1:150,000 KILOMETRES



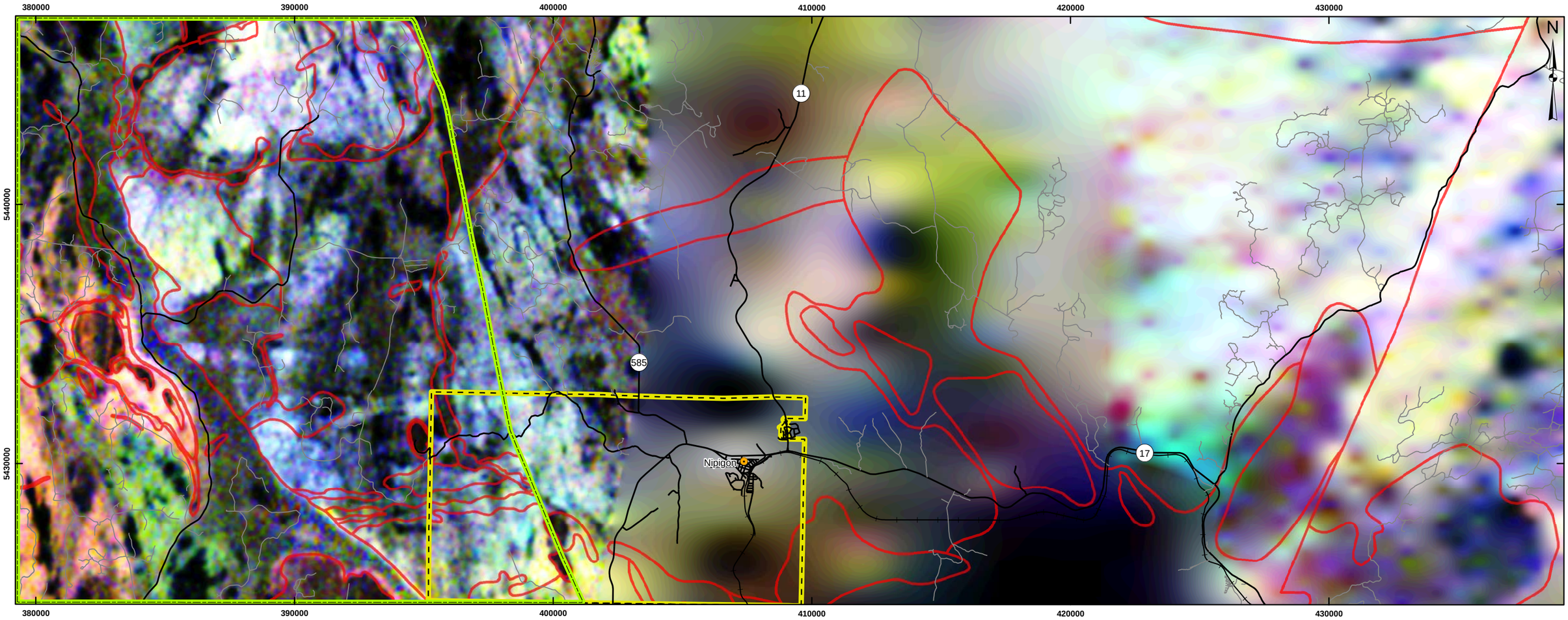
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

TITLE
First vertical derivative of the Bouguer gravity field

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	WP	19 Sep. 2013		
CHECK	SWR	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 12



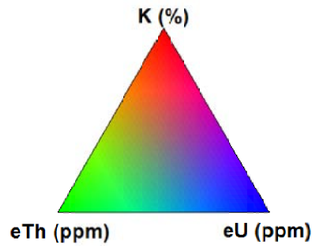
LEGEND

- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Nationwide Radiometric Compilation, Ontario Geological Survey - Geophysical Surveys: GDS1047
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Radiometric Ternary Image
RGB = K-eTh-eU



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2.5 1.25 0 2.5 5 7.5
SCALE 1:150,000 KILOMETRES



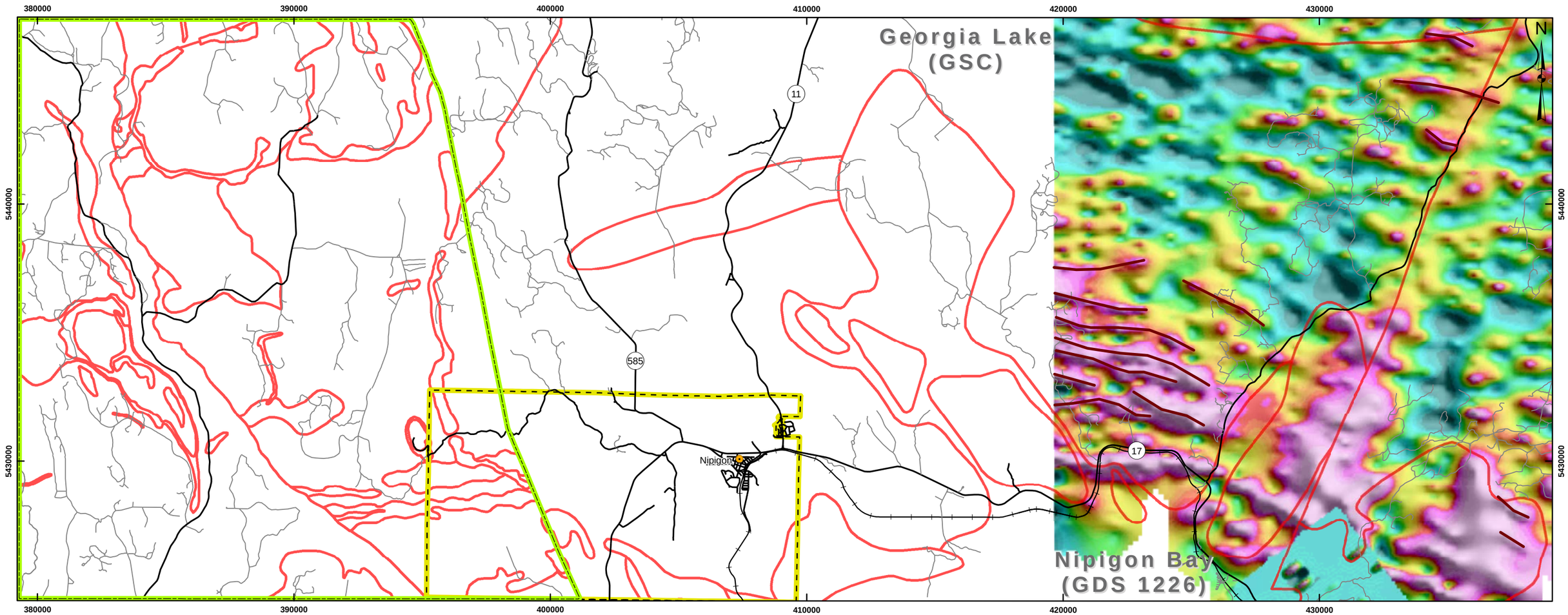
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

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

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

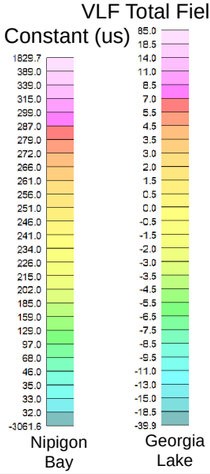
PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	WP	19 Sep. 2013		
CHECK	SWR	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 13



VLF Total Field (mV)

Decay Constant (us)



LEGEND

- Township of Nipigon
- Municipal Boundary, Lower Tier
- Community
- Main Road
- Local Road
- Railway
- Bedrock geology contacts
- Revised mapping (Hart, 2005)
- VLF-EM Conductors

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics: Geological Survey of Canada - VLF-EM Survey: Georgia Lake, Ontario Geological Survey - TDEM Survey: GDS1226
Geology: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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2.5 1.25 0 2.5 5 7.5
SCALE 1:150,000 KILOMETRES



PROJECT

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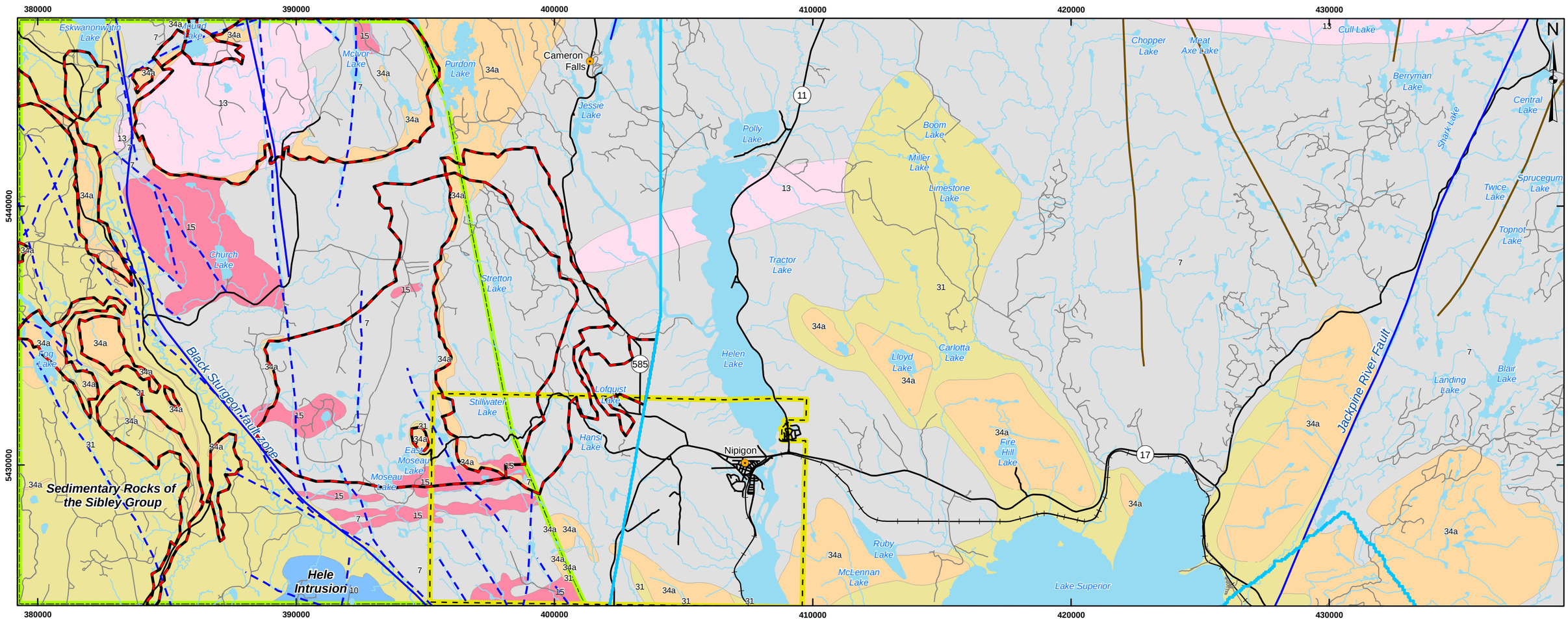
TITLE

VLF-EM conductors over VLF total field and decay constant

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PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.2
DESIGN	PRM	19 Aug. 2013		
GIS	WP	8 Nov. 2013		
CHECK	SWR	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 14



LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Lineament / Fault (Hart, 2005)
- Mapped Dyke
- Revised mapping (Hart, 2005)
- High resolution geophysical survey outlines
- Nipigon diabase sills interpreted from geophysics

Bedrock Geology

- 34 Mafic and related intrusive rocks (Keweenawan age)
- 34a Logan and Nipigon sills (1109 Ma): diabase sills
- 31 Sibley Gp.
- 15 Massive granodiorite to granite
- 15a Potassium feldspar megacrystic units
- 13 Muscovite-bearing granitic rock
- 10 Mafic and ultramafic rocks
- 7 Metasedimentary rocks (Paragneisses and Migmatites)

REFERENCE

Base Data: MNR LIO, obtained 2009-2013
Geology: Modified 1:250 000 Scale MRD126 - Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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SCALE 1:150,000 KILOMETRES



PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

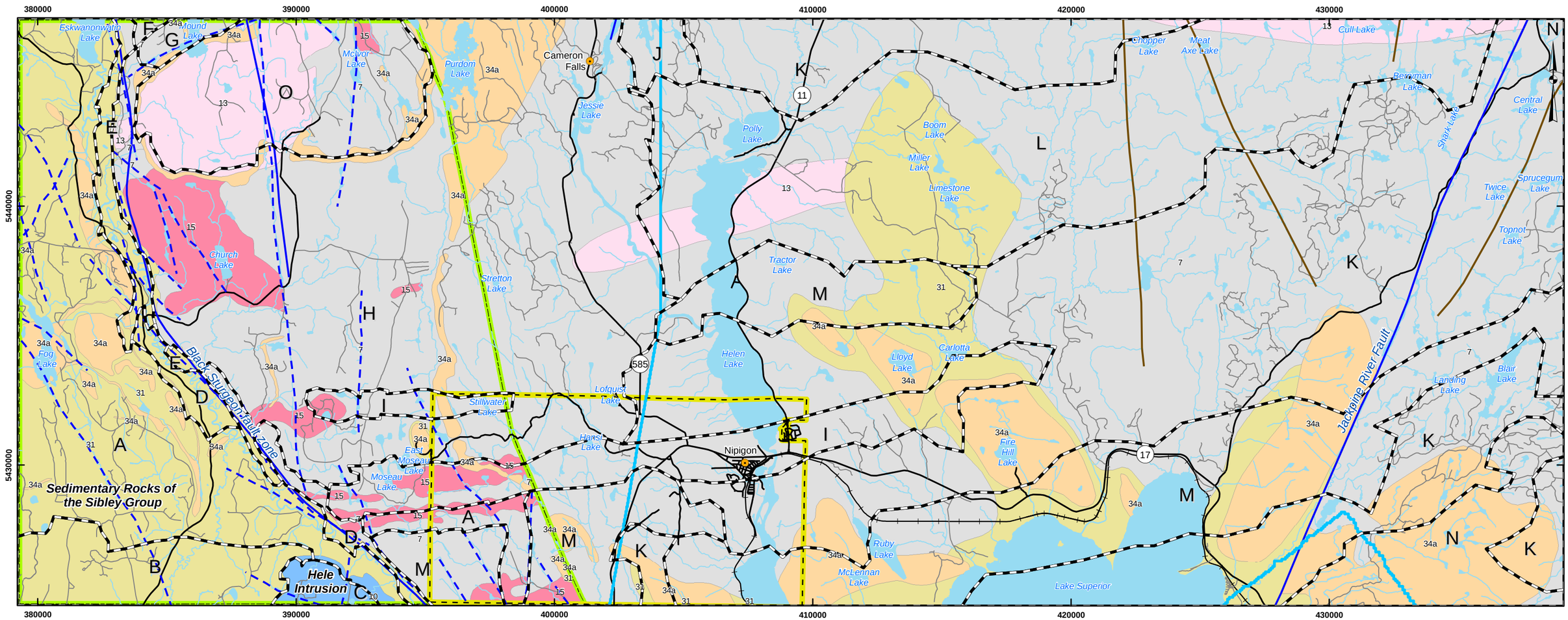
TITLE
Geophysical interpretation showing distribution of Nipigon diabase sills for the Nipigon area

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.3
DESIGN	PRM	19 Aug. 2013		
GIS	PM/SR	1 May 2014		
CHECK	EMM	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 15

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



LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Lineament / Fault (Hart, 2005)
- Mapped Dyke
- Revised mapping (Hart, 2005)
- High resolution geophysical survey outlines
- Geologic units interpreted from geophysics

Bedrock Geology

- 34 Mafic and related intrusive rocks (Keweenawan age)
- 34a Logan and Nipigon sills (1109 Ma): diabase sills
- 31 Sibley Gp.
- 15 Massive granodiorite to granite
- 15a Potassium feldspar megacrystic units
- 13 Muscovite-bearing granitic rock
- 10 Mafic and ultramafic rocks
- 7 Metasedimentary rocks

REFERENCE

Base Data: MNR LIO, obtained 2009-2013
Geology: Modified 1:250 000 Scale MRD126 - Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

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2.5 1.25 0 2.5 5 7.5
SCALE 1:150,000 KILOMETRES



PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, NIPIGON AREA, ONTARIO

TITLE
Geophysical interpretation showing distribution of bedrock units for the Nipigon area

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

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.3
DESIGN	PRM	19 Aug. 2013		
GIS	PM/SR	1 May 2014		
CHECK	EMM	2 June 2014		
REVIEW	GWS	2 June 2014		

FIGURE 16

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