NUCLEAR WASTE MANAGEMENT ORGANIZATION

SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Phase 1 Geoscientific Desktop Preliminary Assessment of Potential Suitability for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel

TOWNSHIP OF NIPIGON, ONTARIO

APM-REP-06144-0067

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PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT OF POTENTIAL SUITABILITY FOR SITING A DEEP GEOLOGICAL REPOSITORY FOR CANADA'S USED NUCLEAR FUEL

Township of Nipigon, Ontario

REPORT

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Executive Summary

In May 2013, the Township of Nipigon, Ontario, expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process, 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 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 preliminary assessment report (NWMO, 2014).

This report presents the results of a geoscientific desktop preliminary assessment to determine whether the Nipigon area contains general areas that have the potential to meet NWMO's geoscientific site evaluation factors. The assessment builds on the work previously conducted for the Initial Screening and focuses on the Township of Nipigon and its periphery, which are referred to as the "Nipigon area".

The geoscientific preliminary assessment was conducted using available geoscientific information and key geoscientific characteristics that can be realistically assessed at this early stage of the site evaluation process. These include: geology; structural geology; interpreted lineaments; distribution and thickness of overburden deposits; surface conditions; and the potential for economically exploitable natural resources. The geoscientific desktop preliminary assessment included the following review and interpretation activities:

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology and overburden deposits;
- Interpretation of available geophysical surveys (magnetic, gravity, radiometric, electromagnetic);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess factors such as overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification and evaluation of general potentially suitable areas based on key geoscientific characteristics and the systematic application of NWMO's geoscientific site evaluation factors.

The geoscientific desktop preliminary assessment showed that the Nipigon area contains at least two general areas that may warrant further consideration. One of these two areas is underlain by metasedimentary rocks of the Quetico Subprovince within the eastern portion of the Nipigon area. A second small area includes a granitic pluton and the metasedimentary rocks adjacent to it located in the Mound Lake area.

The two identified general siting areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. The areas appear to have sufficient depth and sufficient lateral extent to host a deep geological repository, low potential for natural resources, good bedrock exposure, limited surface constraints (topography and water bodies) and are generally accessible. However, there are several significant uncertainties that, when combined, reduce the likelihood of the two identified areas to satisfy NWMO's geoscientific site evaluation factors. These include:

- The potential for lithological heterogeneity within both the metasedimentary rocks and the granitic pluton in the Nipigon area. The area identified near Mound Lake covers two different rock types (metasedimentary rocks and granitic). The contact between these two rock types would need to be evaluated. In addition, the lithological heterogeneity associated with the metasedimentary rocks in the area would need to be assessed. In general, lithological heterogeneity makes site characterization more difficult and can lead to spatially variable geomechanical, thermal and hydrogeological properties.
- The existence and extent of Nipigon diabase sills in the Nipigon area. Because of their horizontal nature, the presence of sills at depth cannot be ruled out, even in areas where they do not have a surface outcrop. The intrusion of these sills in the geological past may have caused damage to the pre-existing rock. The presence of sills at depth, and associated rock damage, has the potential to create pathways for groundwater movement, which could affect the containment and isolation characteristics of the rock.
- The presence of mafic dykes and the potential presence of smaller dykes not identifiable on available mapping and geophysical data. The intrusion of dykes may have caused damage to the host rock that would need to be assessed. In addition, the thermal and hydraulic conductivity of the dykes (and sills) would need to be investigated.
- The proximity of these two areas to major fault zones and mapped faults such as the Black Sturgeon River fault zone and Jackpine River fault. These fault zones are broad and it is uncertain to what extent the two areas are structurally impacted (degree of fracturing) as a result of their proximity to these major features.

Detailed investigations would be required to resolve these inherent uncertainties and assess with a sufficient level of confidence whether the Nipigon area contains areas that can satisfy the geoscientific site evaluation factors.

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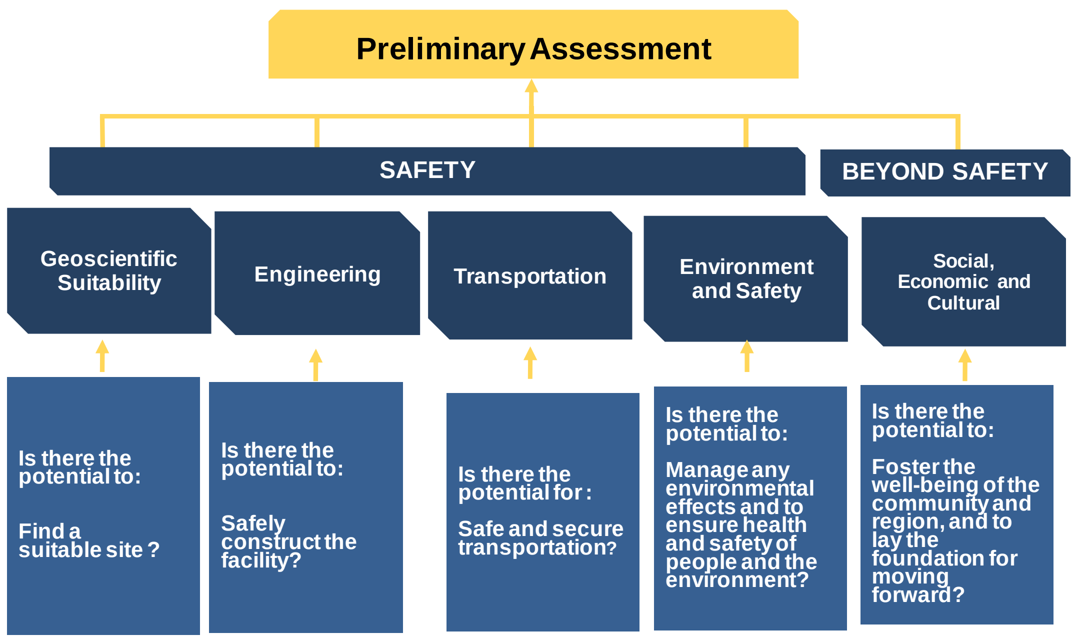
1.0 INTRODUCTION

1.1 Background

In May 2013, the Township of Nipigon expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess their potential suitability 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 (Golder, 2012a).

The overall preliminary assessment is a multidisciplinary study integrating both technical and community well-being assessments as illustrated in the diagram below. The five components of the preliminary assessment address geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. A brief description of the project, the assessment approach, and the findings of the preliminary assessment are documented in an integrated preliminary assessment report (NWMO, 2014).



The objective of the geoscientific preliminary assessment is to assess whether the Nipigon area contains general areas that have the potential to satisfy NWMO's site evaluation factors. The preliminary assessment is conducted in two phases:

- ***Phase 1 - Desktop Study.*** For all communities electing to be the focus of a preliminary assessment. This phase involves desktop studies using available geoscientific information and a set of key geoscientific characteristics and factors that can be realistically assessed at the desktop phase of the preliminary assessment.

- ***Phase 2 - Preliminary Field Investigations.*** For a subset of communities selected by the NWMO, to further assess potential suitability. This phase involves preliminary field investigations that includes high resolution geophysical surveys, geological mapping and the drilling of deep boreholes.

The subset of communities considered in Phase 2 of the preliminary assessment will be selected based on the findings of the overall geoscientific desktop preliminary assessment considering both technical and community well-being factors presented in the above diagram.

1.2 Geoscientific Desktop Preliminary Assessment Approach

The objective of Phase 1 of the preliminary geoscientific assessment was to assess whether the Nipigon area contains general areas that have the potential to satisfy the geoscientific evaluation factors outlined in the NWMO site selection process (NWMO, 2010).

The geoscientific desktop preliminary assessment built on the work previously conducted for the Initial Screening (Golder, 2012a) and focused on the Township of Nipigon and its periphery, referred to as the “Nipigon area” in this report (Figure 1.1). The boundaries of the Nipigon area have been defined to encompass the main geological features within the Township of Nipigon and its surroundings. The Phase 1 of the geoscientific desktop preliminary assessment included the following review and interpretation activities:

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology and overburden deposits;
- Interpretation of available geophysical surveys (magnetic, electromagnetic, gravity, radiometric);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess factors such as overburden type and distribution, bedrock exposure, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification and evaluation of general potentially suitable areas based on key geoscientific characteristics and the systematic application of NWMO’s geoscientific site evaluation factors.

The details of these various studies are documented in three supporting documents: terrain analysis (JDMA, 2014a), geophysical interpretation (PGW, 2014), and lineament interpretation (JDMA, 2014b). Key findings from these studies are summarized in this report.

1.3 Geoscientific Site Evaluation Factors

As discussed in the NWMO site selection process, the suitability of potential sites will be evaluated in a staged manner through a series of progressively more detailed scientific and technical assessments using a number of geoscientific site evaluation factors, organized under five safety functions that a site would need to ultimately satisfy in order to be considered suitable (NWMO, 2010):

- ***Safe containment and isolation of used nuclear fuel*** Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances caused by human activities and natural events?

- ***Long-term resilience to future geological processes and climate change:*** Is the rock formation at the siting area geologically stable and likely to remain stable over the very long term in a manner that will ensure the repository will not be substantially affected by geological and climate change process such as earthquakes and glacial cycles?
- ***Safe construction, operation and closure of the repository:*** Are conditions at the site suitable for the safe construction, operation and closure of the repository?
- ***Isolation of used fuel from future human activities:*** Is human intrusion at the site unlikely, for instance, through future exploration or mining?
- ***Amenable to site characterization and data interpretation activities:*** Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

The list of site evaluation factors under each safety function is provided in Appendix A.

The assessment was conducted in two steps. The first step assessed the potential to find general potentially suitable areas within the Nipigon area using key geoscientific characteristics that can realistically be assessed at this stage of the selection process based on available information (Section 7.2). The second step assessed whether identified potentially suitable areas have the potential to ultimately meet all of the safety functions outlined above (Section 7.3).

1.4 Available Geoscientific Information

Geoscientific information for the Nipigon area was obtained from many data sources including maps, reports, databases and technical papers. In summary, the review of existing information identified that there was sufficient geoscientific information available to conduct the Phase 1 preliminary geoscientific investigation studies and to identify general potentially suitable areas in the Nipigon area. Key geoscientific information sources are summarized in this section, with a complete listing provided in Appendix B.

1.4.1 Digital Elevation Model, Satellite Imagery, and Airborne Geophysics

Canadian Digital Elevation Data (CDED) was obtained for the Nipigon area at 1:50,000 scale (GeoBase, 2013a). The digital elevation model (DEM) used for this assessment was constructed by Natural Resources Canada (NRCan) using data assembled through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (MNR) (Table 1.1; Geobase, 2013a). The source data were 1:20,000 scale topographic map data generated through the Ontario Base Mapping (OBM) program. Satellite Pour l'Observation de la Terre (SPOT) multispectral orthoimagery at a resolution of 20 m and panchromatic imagery at 10 m resolution were used to identify features such as areas of exposed bedrock (Table 1.1; GeoBase, 2013b). In addition, Landsat 7 and 5 orthoimagery were obtained at 30 and 28.5 m resolutions, respectively, thermal infrared imagery at 60 and 120 m resolutions, respectively and panchromatic imagery at 15 m for Landsat 7 only (Table 1.1; GeoBase, 2013b). SPOT 4 and 5 images covering the Nipigon area were obtained from August 2008 and July 2005, respectively. Landsat 7 and 5 images were obtained from July 2001 and May 1988, respectively (Table 1.1; Geobase 2013c). Details on processing and analysis of satellite imagery are provided in JDMA (2014a).

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.

Low-resolution geophysical data, particularly the magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC, 2013), cover the entire Nipigon area. 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 provided higher resolution coverage over approximately 40% of the Nipigon area (Figure 1.2).

Gravity data from the Geological Survey of Canada (GSC, 2013) and the Ontario Geological Survey (OGS, 2004b) provides complete coverage of 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 low resolution radiometric data provide complete coverage of the Nipigon area (GSC, 2013). 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.

Various geophysical data processing techniques were applied to enhance components of the data most applicable to the current assessment. The resolution of the available geophysical data was assessed to determine which datasets were most suitable for use in this assessment (PGW, 2014). Where datasets overlapped (Figure 1.2), the highest quality coverage was used. The integrity of the higher quality data was maintained throughout. Table 1.1 provides a summary of DEM, satellite and geophysical source data information for the Nipigon area.

Table 1.1: Summary of Digital Elevation Model, Satellite Imagery and Geophysical Source Data Information for the Nipigon Area

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	20 m	Entire Nipigon area	1978 - 1995	Hillshaded and slope rasters used for mapping
Satellite Imagery	Spot 4 and 5; Orthoimage, multispectral / panchromatic	Geobase	10 m (panchromatic) 20 m (multispectral)	Entire Nipigon area	2008 and 2005, respectively	
	Landsat 7 and 5 multispectral / panchromatic / thermal	Geobase	15 m (panchromatic) 30 and 28.5 m (multispectral) 60 and 120 m (thermal)	Entire Nipigon area	2001 and 1988, respectively	Landsat 7 ETM, Landsat 5 TM
Geophysics	Ontario #8 Fixed wing magnetic	GSC, 2013	Line Spacing: 805 m Sensor Height: 305 m	Entire Nipigon area	1962	Low resolution coverage over 55% of

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
Geophysics			Line Direction: 0°			area
	GDS1047 Lake Nipigon Embayment Fixed wing magnetic, radiometric	OGS, 2004a	Line Spacing:150 m Sensor Height: 100 m Line Direction: 10°	West 40%	2003	High resolution coverage including radiometric survey
	GDS1226 Nipigon Bay Fixed wing magnetic, TDEM	OGS, 2003	Line Spacing: 350 m Sensor Height: 39 m (mag) 50-52m (TDEM) Line Direction: 143°	Southeast (small area)	1994	Medium resolution coverage, Geotem (dB/dt , X-component)
	Georgia Lake Fixed wing radiometric, magnetic, VLF	GSC, 2013	Line Spacing: 1,000 m Sensor Height: 120 m Line Direction: 0°	East 30%	1989	Medium resolution radiometric survey with VLF
	Thunder Bay Detail Fixed wing radiometric, magnetic	GSC, 2013	Line Spacing: 1,000 m Sensor Height: 130 m Line Direction: 0°	West 20%	1979	Medium resolution radiometric survey
	Thunder Bay Reconnaissance Fixed wing radiometric, magnetic	GSC, 2013	Line Spacing: 5,000 m Sensor Height: 144 m Line Direction: 4°	Central 50%	1979	Low resolution radiometric survey
	GDS1052 Lake Nipigon Embayment Ground gravity measurements	OGS, 2004b	Stn. Spacing: 250 m-12 km	West half	2003-2004	High resolution gravity survey
	GSC Gravity Coverage Ground gravity measurements	GSC, 2013	Stn. Spacing: 5-25 km	Entire Nipigon area	1952-1965	Relatively sparse GSC coverage

1.4.2 Geology

Geological mapping in the Nipigon area began in 1869 when Bell (1870) mapped the shores of Lake Nipigon. Subsequent geological mapping of the Nipigon area included that of McInnes in 1896 and Parks in 1901 (Coates, 1972). Coleman (1909) mapped lands to the south of the lake along the Nipigon and Black Sturgeon rivers while Tanton (1931) was the first to complete detailed mapping of the Sibley Group. Coates (1972) mapped the Black Sturgeon River area in greater detail while Giguere (1975) mapped the geology of the St.

Ignace Island archipelago to the south of the Nipigon area. Studies of the Proterozoic rocks of the Nipigon area were made by Sutcliffe (1986; 1991). More recently, the Ontario Geological Survey (OGS) completed the Lake Nipigon Region Geoscience Initiative, which included geological mapping projects, airborne geophysical surveys, ground gravity surveys, and geochemical and geochronological studies. Key studies under the initiative included: Hart and MacDonald (2003), Hart and Magyarosi (2004), Hart and Préfontaine (2004), and Hart (2005). Detailed studies of the Sibley Group are given by Cheadle (1986) and Rogala et al. (2005; 2007).

Geochronology for the Nipigon area is summarized by Heaman (1997), Heaman and Easton (2006) and Heaman et al. (2007). Geological syntheses and interpretations are given by Pye (1965; 1968), Carter et al. (1973), Johns et al. (2003), and the Ontario Geological Survey's Province-wide seamless geological map coverage (OGS, 2011a). Surficial geology mapping includes a regional reconnaissance study of surficial geology by Zoltai (1965a,b) and more detailed mapping of lands in the vicinity of Thunder Bay to the west of the Nipigon area by Burwasser (1977). In 1979 and 1980, the surficial geology of the Nipigon area was mapped as part of the Northern Ontario Engineering Geology Terrain Study - NOEGTS (Mollard, 1979a,b; Gartner, 1980a,b).

National seismicity data sources were reviewed to provide an indication of seismicity in the Nipigon area (Hajnal et al., 1983; Hayek et al., 2009 and 2011; and NRCan, 2013).

In addition to the above publications, Golder made extensive use of Ontario Ministry of Northern Development and Mines (MNDM) Assessment Files (AFRI) and industry publications.

1.4.3 Hydrogeology and Hydrogeochemistry

Hydrogeologic information for the Nipigon area was obtained from the Ontario Ministry of the Environment (MOE) Water Well Information system (WWIS) database as well as geological (OGS), topographical (MNR) and hydrological maps (MNR, NRCan) of the Nipigon area. These data sources contain hydrogeological information on the overburden and shallow bedrock aquifers for portions of the Nipigon area where development has taken place.

No information is available on deep groundwater flow systems or deep hydrogeochemistry for the Nipigon area, so inferences have been made based on studies at similar sites in the Canadian Shield. Specific reports/studies include: Frape et al. (1984); Gascoyne et al. (1987); Farvolden et al. (1988); Gascoyne (1994; 2000; and 2004); Everitt et al. (1996); Singer and Cheng (2002) and Rivard et al. (2009).

1.4.4 Natural Resources – Economic Geology

Information regarding the mineral resource potential for the Nipigon area has been obtained from a variety of sources including geological mapping and reports, general syntheses of mineralization in the Canadian Shield Region, and economic geology studies and reports, as well as MNDM Mineral Deposit Inventories (MDI), Assessment Files (AFRI) and publications by industry (in particular NI 43-101 reports).

1.4.5 Geomechanical Properties

Little information is available regarding the rock geomechanical properties for the metasedimentary rocks of the Quetico Subprovince in the Nipigon area. As such, inferences have been made from geomechanical information derived from sites with similar types of rock elsewhere in the Canadian Shield. Much of this information is a result of the work done by Atomic Energy of Canada Limited (AECL) in the 1980s and 1990s as part of the Canadian Nuclear Fuel Waste Management Program.

Information on the geomechanical properties of granitic rocks with conditions ranging from intact rock to highly fractured fault zones is available from AECL's Underground Research Laboratory (URL) near Pinawa, Manitoba, and the Atikokan and Chalk River research areas in Ontario (Annor et al., 1979; Stone, 1984; Brown et al., 1989 and 1995; Brown and Rey, 1989; and Stone et al., 1989).

2.0 PHYSICAL GEOGRAPHY

2.1 Location

The Township of Nipigon is approximately 115 km^2 in size and is located on the western shore of Lake Superior's Nipigon Bay, approximately 120 km northeast of Thunder Bay. The settlement area of Nipigon is located along the west shore of the Nipigon River immediately south of Highway 17. The Lake Helen Reserve of the Red Rock Indian Band (also known as Opwaaganisining or the Lake Helen First Nation) is located approximately 2 km east of the community of Nipigon. The Township of Red Rock is located just south of Nipigon, approximately 20 km by road. The Township of Nipigon and its periphery, referred to in this report as the "Nipigon area", is shown on Figure 1.1. Satellite imagery for the area (SPOT panchromatic, taken in 2006 and 2007) is presented on Figure 2.1.

2.2 Topography and Landforms

A detailed terrain analysis was completed as part of the preliminary assessment of potential suitability for the Nipigon area (JDMA, 2014a). This section presents a summary of this analysis.

The Nipigon area lies within the Port Arthur hills physiographic region of the Canadian Shield (Bostock, 1970), which consists of ridges and cuestas produced by the underlying sequence of Proterozoic diabase sills and sedimentary rocks, with the flat-lying diabase sills on the hilltops responsible for shielding the underlying weaker rocks from erosion. As is common throughout the Shield, the rocks in this region are frequently crosscut by fractures and faults (Thurston, 1991).

The topography of the Nipigon area is presented on Figure 2.2. The Lake Superior shoreline, with a chart datum of 183.2 masl, forms the lowest elevation in the area. The zone of highest elevation in the Nipigon area is located east of the Jackfish River and is associated with the Kama Hills where ground surface elevations reach as high as 583 masl. 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.

A series of plateaux or mesas occur within the Nipigon area. These are formed by differential weathering between the relatively erodible rocks of the Sibley Group and the more resistant Nipigon diabase sills. Some of the more impressive hills are named, such as Eagle, Mosseau, Doghead, and Fire Hill mountains. Hills in this area extend as much as 150 to 300 m above the nearby terrain (JDMA, 2014a).

Approximately half of the Nipigon area was mapped as bedrock terrain during the NOEGTS program, with the largest contiguous zone of bedrock terrain located in the eastern half of the area, generally east of the Jackfish River (Figure 2.3). 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). Many of the areas mapped as bedrock terrain coincide with hills, particularly the ones displaying steep slopes around their margins, represent mesas, such as Eagle Mountain and the Kama Hills, which are capped by diabase sills. Others represent hills formed in granitic or metasedimentary rocks. These hills are interpreted to be bedrock-controlled, as no surficial deposits in the Nipigon area, such as eskers or end moraines, are known to have an equivalent surface relief (JDMA, 2014a).

Thicker overburden deposits occur between the areas of bedrock terrain. These include morainal, glaciolacustrine, and organic terrains as shown on Figure 2.3. Fine-grained glaciolacustrine deposits are mapped in low-lying parts of the Nipigon area, including north and south of Cedar Mountain, north of Polly Lake and within the Black Sturgeon and Nipigon valleys. These deposits generally occur as rhythmically bedded or massive silts and clays, and form some of the most extensive overburden deposits mapped in the area.

Areas where the till is generally thick enough to mask any topographic irregularities associated with the bedrock topography are mapped as ground moraine (Mollard and Mollard, 1981b). The Nipigon moraine is the only major end moraine mapped in the Nipigon area, situated in the northwest corner of the area (Figure 2.3). Within the Nipigon area, the Nipigon moraine trends west-northwest and extends through the Black Sturgeon River valley where a channel cut through the moraine contains the Black Sturgeon River. Four different landform types deposited by glacial meltwater are mapped in the Nipigon area: esker, kame, and outwash plain (or valley train). Materials forming these landforms generally consist of gravel, sand and silt.

Eskers are characterized by long, narrow sand and gravel ridges, which can include braided, branching, beaded and kettled segments (Mollard and Mollard, 1981b). One trends north-northeast extending along the west margin of Jessie Lake. The other is located southwest of the Black Sturgeon River near the southern boundary of the Nipigon area. Both features display very little surface relief or definition in general, although the feature on the west bank of Jessie Lake is the better defined feature of the two.

A large area extending north-northwest from the settlement of Nipigon has been mapped as a glaciofluvial kame deposit (Figure 2.3). The kame deposit in the Nipigon area displays no obvious large hills of sand and gravel, like those described in the literature. Best described as a kame terrace, this feature displays an undulating upper surface with a much steeper lower margin. Lofquist Lake and another small lake 2 km to the north have no mapped stream outlets and could represent kettle lakes.

Since the disappearance of the ice sheets and glacial lakes, modern streams have developed alluvial flood plains and organic deposits have accumulated in wet depressions. The largest organic deposits are located adjacent to the north shore of Lake Superior, extending northwest from Fire Hill Bay and Kama Bay.

2.3 Watersheds and Surface Water Features

Surface water flow within the Nipigon area is directed toward Lake Superior, with drainage primarily via the Black Sturgeon, Nipigon, Jackfish and Jackpine rivers and their tributaries. The main drainage features of the Nipigon area are within the Black Sturgeon, Nipigon and Jackpine tertiary watersheds are shown on Figure 2.4.

The Nipigon River extends for a length of about 50 km from Lake Nipigon to Nipigon Bay on Lake Superior. It is the largest tributary to Lake Superior, with a mean annual flow of 365 m^3/s (OPG, 2005). The total drainage area of the Nipigon watershed is 25,230 km^2. The total area drained through the watershed increases by an additional 13,578 km^2 once the drainage area of the Ogoki Diversion (north of Lake Nipigon) is considered (OPG, 2005). The largest tributaries to the Nipigon River in this area are Frazer, Booth, Cash and Stillwater creeks.

The Black Sturgeon River is the seventh largest tributary to Lake Superior, with a mean annual flow of 19 m^3/s (Swainson, 2001). The total drainage area of the Black Sturgeon watershed is 5,507 km^2. The river is approximately 100 km long, extending from Black Sturgeon Lake south to Black Bay, on Lake Superior. The portion of the river extending through the Nipigon area is about 28 km long, dropping 21 m from the north to the south boundaries of the area. Throughout this reach, the river meanders across the wide floor of a drift-filled valley, which is the surface expression of the Black Sturgeon fault zone (Coates, 1972). The river is protected within the Black Sturgeon River Provincial Park over much of its length. Within the Nipigon area, Shillabeer Creek and Larson Creek are the main tributaries. Others include Scooper Creek, Mound Creek, and Moseau Creek.

Multiple rivers and creeks drain the Jackpine watershed, including the Cypress, Dead, Gravel, Jackfish and Jackpine rivers and Ozone Creek. The latter three are the streams dominantly responsible for draining the portion of the watershed within the Nipigon area. The Jackpine watershed has a drainage area of 2,260 km^2, and it includes St. Ignace Island, which is south of the Nipigon area. The Jackpine River extends along a north-northeast-trending trench formed on the Jackpine River fault. The portion of the river within the Nipigon area is about 27.5 km long, with a vertical drop of 208 m across this reach. As a result, its gradient across the Nipigon area is much steeper than that of the Nipigon and Black Sturgeon rivers. The trench it follows is typically 80 to 100 m deep and 400 to 500 m wide in some of the most linear and symmetrical sections.

Waterbodies cover 6.7% (91.4 km^2) of the Nipigon area though few exceed 10 km^2 in area. Lake Superior and Helen Lake are the two waterbodies that cover the largest parts of the Nipigon area (31.6 and 16.0 km^2, respectively). Aside from these two lakes, the rest of the lakes and rivers in the area are less than 5 km^2 in size and over 90% are less than 1 km^2 in extent (JDMA, 2014a). Table 2.1 summarizes surface area information for the larger lakes in the Nipigon area.

Table 2.1: Dimensional Characteristics of Selected Lakes in the Nipigon Area

Name	Type	Area (km^2)	Perimeter (km)
Mound Lake	Lake	1.0	5.9
Eskwanonwatin Lake	Lake	1.3	6.1
Ruby Lake	Lake	1.4	7.3
Nipigon River[1]	River	1.5	28.6
Blair Lake	Lake	1.6	18.3
Black Sturgeon River[2]	River	1.6	83.7
Fog Lake	Lake	1.7	12.0
Jessie Lake	Lake	1.7	24.7
Polly Lake	Lake	2.4	7.4
Purdom Lake	Lake	2.5	25.8
Nipigon River[3]	River	4.2	21.2
Helen Lake	Lake	16.0	33.7
Lake Superior[4]	Lake	31.6	39.6

Metrics obtained from LIO OHN Waterbody file (LIO, 2013)
Metrics refer to portion of waterbody within the Nipigon area
[1]Nipigon River between Jessie Lake and Helen Lake
[2]Black Sturgeon River downstream of Eskwanonwatin Lake
[3]Nipigon River downstream of Helen Lake
[4]Portion within the Nipigon area

Information on the depth of lakes in the Nipigon area is limited. Although the MNR completed depth surveys of various lakes in northern Ontario in the 1970s, Eskwanonwatin Lake, located in the northwest corner of the Nipigon area, is the only lake in the area for which such data is available. The survey indicates a maximum depth of 9.1 m, but this depth was partly a function of the timber crib dam (Dolan's Dam) at the outlet of the lake. The Nipigon River between the Alexander Generating Station and Helen Lake is at most 15 m deep (OPG, 2005). Depth data for the Nipigon River south of Helen Lake and for Lake Superior were obtained from a nautical chart (Canadian Hydrographic Service, 2002). The portion of Lake Superior within the Nipigon area reaches its greatest depth of 19.5 m south of Kama Bay. However, the greatest depth of any waterbody known in the area occurs along the Nipigon River near the southern boundary of the Nipigon area, where a sounding of 17 fathoms (about 31 m) is reported on the nautical chart.

2.4 Land Use and Protected Areas

2.4.1 Land Use

Land ownership for the Nipigon area is presented in Figure 2.5. Forestry is a major industry in the Nipigon area, with forested areas supporting commercial timber harvesting, although recent commodity pricing has had a negative impact on this industry. The northern and eastern parts of the Nipigon area are located within the Lake Nipigon Forest (FMU 815). A southern strip of the Nipigon area, including the Township of Nipigon, is located within the Lakehead Forest (FMU 796). The northwest corner of the Nipigon area is located within the Black Spruce Forest (FMU 035).

There are currently no active mines in the Nipigon area, but this region of Ontario has a long history of mineral exploration, which continues today. There is no record of past metallic mineral production in the Nipigon area. Known non-metallic mineral resources within the Nipigon area include sand, gravel and stone. As shown on Figure 2.3, there are a number of small-scale sand and gravel pits in the area, primarily located in glaciofluvial and coarse-grained glacial lacustrine deposits. Quarrying for stone has also been carried out in the Nipigon area. Natural resource potential is further discussed in Section 5.

Water from the Nipigon River has been used to produce electricity since 1924 (OPG, 2005). There are two hydroelectric generating stations (Cameron Falls and Alexander stations) located within the Nipigon area. These are owned and operated by Ontario Power Generation (OPG).

Other land uses include hunting and trapping.

2.4.2 Parks and Reserves

There are two provincial parks, four conservation reserves and two forest reserves in the Nipigon area. Figure 2.5 shows the location of these eight protected areas. The Black Sturgeon River Provincial Park, partially located within the Nipigon area, covers 237 km^2 and is located along the Black Sturgeon River to the west of the Township of Nipigon. It is classed as a waterway park, which is used for angling, hunting and canoeing (MNR, 2013). The Ruby Lake Provincial Park is located along the north shore of Nipigon Bay and covers an area of 27 km^2; it is classed as a natural environment park and contains extensive hiking trails, wetlands and extensive cliff environments with ravines (MNR, 2013).

Conservation and forest reserves are lands set aside by the government (municipal, provincial or federal) to protect ecosystems that are representative of a natural region, protect significant elements of natural and cultural heritage, and maintain biodiversity. The four conservation reserves in the Nipigon area are the Nipigon River Conservation Reserve, the Kama Cliffs Conservation Reserve, the Seahorse Lake Conservation Reserve and the proposed Lake Superior Archipelago Conservation Reserve (MNR, 2013). The Nipigon River Conservation Reserve is located in the north-central part of the Nipigon area, along the Nipigon River, covering an area of about 27 km^2; it is an important recreational waterway and is also developed for hydroelectric generation. The

Kama Cliffs Conservation Reserve is located 18 km east of the Town of Nipigon along the north shore of Lake Superior. It covers an area of 37 km^2 and its most prominent feature is the vertical bedrock exposure with heights exceeding 200 m. There is also a small Forest Reserve located within this Conservation Reserve. The Seahorse Lake Conservation Reserve is located 30 km northeast of the Town of Nipigon in an isolated area accessible only by aircraft. It covers an area of 6.6 km^2 and contains lakes designated for lake trout (S*alvelinus namaycush*) management (MNR, 2013). One of the islands of the proposed Lake Superior Archipelago Conservation Reserve is also located in the Nipigon area. The second Forest Reserve in the Nipigon area is located within the Ruby Lake Provincial Park.

2.4.3 Heritage Sites

The cultural heritage screening examined known archaeological and historic sites in the Nipigon area, using the Ontario Archaeological Sites Database, the Ontario Heritage Trust Database, the Parks Canada Database, and the National Historic sites Database. There are seven known archaeological sites in the Nipigon area (von Bitter, 2013). There is one provincially designated historic site (OHT, 2013) and a series of federally identified trading posts within the Nipigon area (Voorhis, 1930; MTCS, 2013; Parks Canada, 2013).

Of the seven archaeological sites, two contain no information about the nature of the site recorded (time period or cultural affiliations are not provided), three are identified as pre-contact (prior to European arrival) Aboriginal sites and the remaining two are historic Euro-Canadian sites. Of the three pre-contact Aboriginal, two sites have been identified as pre-contact Aboriginal findspots. The other site is a pictograph. The historic Euro-Canadian sites include a Hudson’s Bay Company post and the remains of a railway lodge.

A search for Provincial Historic Sites through the Ontario Heritage Trust resulted in one location where a plaque has been placed to commemorate a historic event of provincial significance within the Nipigon area. This plaque is located at the Nipigon River lookout along Highway 11/17, commemorating the Jesuit Mission to the Nipissings in 1667 (OHT, 2013). A search for National Historic Sites in the Nipigon area determined that there are a series of French trading posts from the mid to late 17th century along the Nipigon River (Voorhis, 1930; MTCS, 2013; Parks Canada, 2013). They were designated in 1944 but there are no plaques commemorating these posts, and there is no current mapping showing the location of these posts. Archaeological potential is established by determining the likelihood that archaeological resources may be present on a subject property. In archaeological potential modeling, a distance to water criterion of 300 m is generally employed for water sources, including lakeshores, rivers and large creeks (Government of Ontario, 2011). The potential for archaeological and historical sites along the Nipigon River and its associated tributaries as well as Nipigon Bay and Helen Lake is considered to be high as these water sources were used as part of a major transportation route for both Aboriginal and Euro-Canadian people. The presence of locally protected areas and heritage sites would need to be further confirmed in discussion with the community and First Nation and Métis communities in the vicinity during subsequent evaluation stages, if the community is selected by the NWMO, and remains interested in continuing in the site selection process..

3.0 GEOLOGY

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

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 (Figure 3.1). 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 (Figure 3.1). The Nipigon area is within the Quetico Subprovince of the Superior Province. The Southern Province borders the Superior Province to the south from the Sudbury area through to Thunder Bay, and comprises younger volcanic and sedimentary rocks of Proterozoic age, mostly 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 rocks 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 3.2 shows the regional 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 2.698 to 2.65 billion year old granitic rocks (Williams, 1991).

In the southern and western portions of the Nipigon region (Figure 3.2), 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 (ca. 1.106 Ga) than the Nipigon sills (Sutcliffe, 1991) and underlie most of the St. Ignace Island chain to the south and east of the Nipigon area.

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 north-trending Black

Sturgeon fault zone, the northeast-trending Jackpine River fault, and the Gravel River fault located at the southeast corner of the Nipigon area (Figure 3.2).

3.1.2 Geological 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 3.1. 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 the gneissic metasedimentary rocks of the Quetico Subprovince. Their precursor rocks 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).

The earliest recognized deformation event (D_1), which occurred around 2.695 billion years ago, was synchronous with ongoing sedimentation (Valli et al., 2004). D_1 involved folding and thrust imbrication that buried the sedimentary prism to approximately 20 km depth and was accompanied by an upper amphibolite grade metamorphic overprint (Valli et al., 2004). D_1 may have been related to the northward subduction of the Wawa Subprovince (Wawa-Abitibi terrane) beneath the Wabigoon Subprovince, which at that time formed the southern border of the Superior craton (Stott et al. 2010).

Similarly to deposition of sediments in the Quetico Subprovince, deformation and metamorphism throughout the subprovince is thought to have been diachronous (e.g., Percival, 1989; Davis et al., 1990; Zaleski et al., 1999; Valli et al., 2004). In the Nipigon area, subsequent deformation and peak metamorphism (D_2-D_3) occurred approximately 2.689 to 2.671 billion years ago (Valli et al., 2004) 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 (D_2), and 2.684 and 2.671 (D_3) billion years ago, respectively. D_2-D_3 developed schistose to gneissic textures in the metasedimentary rocks at, in general, upper amphibolite grade metamorphic conditions (Hart, 2005). The metasedimentary rocks were also subjected to variable migmatization and intrusion of granitoids either as injection complexes or batholiths and plutons. 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 ago. 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).

An extended period of time postdating the D_4 event and extending until approximately 1.7 billion years ago is a poorly constrained interval of the geological history of the Nipigon area. Though several major tectonic events occurred across the Superior Province during this time, and likely also impacted the Nipigon region, little documented evidence has been found in the geologic record. Together, they are defined as a poorly constrained D_5 deformation event in the Nipigon Area. The following describes the events that occurred during the D_5 interval, as understood from other areas of the Superior Province.

At the beginning of the Proterozoic Eon, approximately 2.5 billion years ago, an Archean supercontinent (Williams et al., 1991) began fragmentation into several continental masses, including the Superior craton, caused by a widespread and voluminous magmatic event that took place in the Lake Superior region (Heaman, 1997). 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) gave a maximum age of 1.5 billion years for sedimentation in the Sibley Group. The Sibley Group is an unmetamorphosed, relatively flat-lying sedimentary rock sequence that occurs over much of the southern and western margins of the Nipigon area and extends beyond the area to the north, south and west (Figure 3.3). 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.

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; 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 3.3). Nipigon diabase sills are relatively thin generally flat-lying mafic rocks that intrude and overlie other rock types in the Nipigon area, and extend far to the north, beyond the eponymous lake. Uplift and erosion of bedrock occurred over a protracted period following the rifting event. Syn- to post-rift structures are ascribed to a D_7 deformation event in the Nipigon area.

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 sedimentary rocks in the James Bay lowlands of Ontario suggests that marine transgression might also have affected the Nipigon area during the Mesozoic Era, 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 Era.

Table 3.1: Summary of the Geological and Structural History of the Nipigon Area

Approximate Time Period (billion years ago)	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]

Approximate Time Period (billion years ago)	Geological Event
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 Eras, multiple generations of glacial erosion. [D_7]

The Nipigon area was glaciated during the Pliocene-Pleistocene ice ages when a series of continental ice sheets moved southward across the area (Barnett et al., 1991). The advance of the ice sheets and the subsequent outwash of meltwaters during glacial retreat scoured the bedrock surface, removing residual soil and weathered rock, and exposed fresh polished bedrock surfaces. Glacial erosion may have enhanced the numerous linear geological features that characterize the Nipigon area where deeper residual soils and weathered rock occurs in association with faults, dykes and contacts between geological units of contrasting hardness (e.g., greenstone/granite contacts). Glacial erosional features can also be linked to established drainage patterns and lakes.

3.1.3 Structural History

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 (Zaleski et al., 1999; Valli et al., 2004).

The geological and structural history summarized below integrates interpretations from throughout, and proximal to, the regional area shown on Figure 3.2. 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 extending to present. 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. In addition, it is possible that at least some of the D_5 to D_7 faulting was controlled by the re-activation of pre-existing structures in the older bedrock including effects resulting from anisotropy in the pre-existing fabric/structure.

3.1.4 Mapped Regional Structures

Mapped regional structures in the Nipigon area include several major fault zones as well as a series of dykes and sills that may reflect regional tectonic events. These structures are shown on Figure 3.2 (regional geology) and where present, on Figure 3.3 (local geology).

The most significant structural feature in the Nipigon area is the Gravel River fault located just beyond the southeast corner of the Nipigon area (Figure 3.2). This is a major >400 km long shear zone having a sinistral sense of displacement (Williams, 1991). It strikes from the shore of Nipigon Bay in Lake Superior where it crosscuts rocks of the Sibley Group and follows a northeasterly trend until it disappears beneath Phanerozoic rocks of the James Bay Lowland. To the southwest, the geophysical signature of the fault is marked by a positive aeromagnetic anomaly beneath Lake Superior. Its ultimate southwestern extent is unknown although its strike is aligned with a prominent lineament separating the St. Ignace Islands from Nipigon and Black Bay. The fault offsets the Quetico-Wabigoon boundary by at least 70 km, and greenstone belts of the Wabigoon Subprovince by up to 40 km (Williams, 1991).

The Black Sturgeon fault zone (Figures 3.2 and 3.3) is at least 65 km long and is composed of a series of northwest-trending faults that are coincident with the trace of 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 zone 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 3.2 and 3.3) 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.

Other mapped faults include an unnamed 12 km long fault located to the east of Mound Lake (Figure 3.2 and 3.3) 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 (Figure 3.2). Although not mapped in MRD126 or shown on Figure 3.3, 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.

In addition to mapped faults, several unnamed and widely spaced, north- to northwest-trending diabase dykes intrude the Archean rocks of the Quetico Subprovince in the east part of the Nipigon area. Four such dykes, ranging from 7 to 25 km in length, are mapped in the OGS seamless geological coverage of Ontario (OGS, 2011a). Mafic dykes have also been recognized immediately to the west of the Nipigon area (Hart and Magyarosi, 2004; Hart, 2005).

3.1.5 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).

3.1.6 Erosion

During the Archean and early Proterozoic Eons, the terrain in the Nipigon area was progressively levelled through erosion prior to the onset of Animikie Group sedimentation. The area was again eroded following deposition of the Animikie Group and the current Precambrian bedrock topography in the Nipigon area likely compares closely to that upon which the Sibley Group strata were deposited. In the intervening 1.3 billion years, the Nipigon area seems to have undergone repeated episodes of uplift and erosion, followed by crustal depression. The absence of significant metamorphism in sedimentary rocks of the Sibley Group constrains the maximum depth of burial of these strata. Limited burial depth suggests that erosion and deposition remained in near balance over the Neoproterozoic and Phanerozoic Eons. The most recent period of depression of the crustal sequence beneath the Nipigon area was associated with isostatic adjustments due to loading by the continental ice sheet of the last glaciation which depressed the land surface approximately 200 to 300 m below its current level (Lewis et al., 2005).

There is no site-specific information on erosion rates for the Nipigon area; however, the striking landscape of flat-topped plateaux and steep-sided valleys allows some speculation as to Quaternary erosion rates. The deeply incised Pijitawabik canyon immediately north of the Nipigon area, and the mesa-like uplands along the southern part of the Nipigon area combine local relief of up to 250 m with morphology suggesting shaping by glacial action and meltwaters over repeated glacial cycles. This implies that up to 250 m of erosion may be attributable to Quaternary glaciations within the erosion-susceptible sedimentary rocks of the Sibley Group and their overlying Nipigon sills. This is equivalent to an erosion rate of about 15 m per 100,000 years, although it is likely that this erosion rate was accelerated by the presence of pre-glacial river valleys that were enlarged laterally in a manner analogous to the Wisconsinan and Holocene retreats of the Niagara gorge.

Much lower erosion rates would have been experienced in the resistant Archean basement, similar to those reported for the broader Canadian Shield in studies by McMurry et al. (2003) and Hallet (2011). The average Quaternary erosion rate from wind and water on the Canadian Shield is estimated to be about 2 m per 100,000 years (Merrett and Gillespie, 1983) with higher erosion rates associated with periods of glaciation.

The depth of glacial erosion depends on regionally specific factors, such as the ice geometry and topography, and local geological conditions, such as overburden thickness, rock type and pre-existing weathering. Flint (1947) made one of the first efforts to map and determine the volume of all the terrestrial glacial sediment in North America, and concluded that all of the Plio-Pleistocene advances of the Laurentide ice-sheet had resulted in erosion of about 10 m of the Canadian Shield. White (1972) pointed out that this ignored the much larger quantity of sediment deposited in the oceans, and revised the estimate upward by about an order of magnitude. Subsequently, Laine (1980; 1982) used North Atlantic deposits and Bell and Laine (1985) used all the marine sediment repositories of the Laurentide ice-sheet (excluding the Cordilleran Ice Sheet) to arrive at an average erosion estimate of 120 m over 3 million years. Bell and Laine (1985) considered this to be a minimum value, although they made no allowance for non-glacial erosion or the role of rock weathering on erosion rates during the initial glacial advances in the late Pliocene Epoch. Hay et al. (1989) contended that in the Gulf of Mexico the depth of sediment of Laurentide provenance was greatly overestimated by Bell and Laine (1985), and thereby reduced Bell and Laine's (1985) estimate of regional erosion to 80 m over the same time period.

3.2 Local Bedrock and Quaternary Geology

3.2.1 Bedrock Geology

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. The bedrock geology of the Nipigon area is shown on Figure 3.3 and conceptual geological cross sections for the western portion of the Nipigon area are presented on Figure 3.4 based on recent work by Hart (2005). 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, 2011a). These are elongate or lensoid bodies of 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 and overlie 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.

A detailed interpretation of available geophysical data is provided in PGW (2014). The geophysical data over the Nipigon area exhibits variability in its responses associated with the distribution of metasedimentary and granitic rocks of the Quetico Subprovince. Variation in the geophysical responses are most evident in the magnetic data, which tend to be locally influenced by the occurence 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. The reduced to pole magnetic data and its first vertical derivative for the Nipigon area are shown on Figures 3.5 and 3.6, respectively, and include high-resolution data recently acquired to support the mapping work by Hart (2005), covering the western half of the Nipigon area. The remaining magnetic data shown on the figures were acquired at significantly lower resolution.

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

3.2.1.1 Metasedimentary Rocks of the Quetico Subprovince

Archean metasedimentary rocks of the Quetico Subprovince (Figure 3.3) 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) while Percival (1989) gives a minimum thickness of 7.5 km. 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) described 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 usually subparallel to the original bedding (Hart and Magyarosi, 2004). 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 veinlets (Sawyer, 1983; Leitch and Weinberg, 2002). Morfin et al. (2013) report that the migmatites of the Opinaca Subprovince in Québec 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.

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 (PGW, 2014). Within the areas with higher resolution data inhomogeneities that show a pronounced east-west trending fabric that parallel the Quetico Subprovince boundary are also observed, 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.

3.2.1.2 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 Mound Lake area in the northwest 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 suite of granitic rocks to be indicative of an intrusive origin, also opening the possibility that both suites may be genetically linked.

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 (PGW, 2014). PGW (2014) noted that the geophysical interpretation of the Mound Lake granite pluton is complicated by the presence of Nipigon diabase intrusions along its margins, which affects the magnetic and radiometric responses. The geophysical response supports the presence of the mapped intrusion. The two other instances of muscovite-bearing granitic rocks are located further east within a broad, regional magnetic low (PGW, 2014).

3.2.1.3 Sedimentary Rocks of the Sibley Group

The Sibley Group is an 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).

As noted on the conceptual geological cross sections developed by Hart (2005) and shown on Figure 3.4, the sedimentary rocks of the Sibley Group are estimated to be up to approximately 200 m thick where they occur in the Nipigon area. These conceptual cross sections were developed using geological mapping by Hart (2005), sparse diamond drillhole information and airborne geophysical data.

PGW (2014) noted that the Sibley Group generally has a low magnetic susceptibility and does not display a magnetic response. West of the Black Sturgeon fault zone, the thickness of Sibley Group rocks present there results in a slight dampening of the magnetic response from the underlying Archean rocks. These formations are relatively dense and likely contribute to the positive gravity responses near the western boundary of the Nipigon area, together with the Nipigon diabase sills (PGW, 2014). The radiometric responses over the Sibley Group delineate four distinct units, that correlate with topography, suggesting that different formations of the Sibley Group may be exposed at the different elevations (PGW, 2014).

3.2.1.4 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 drillhole 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.

PGW (2014) noted that the Hele intrusion has a distinct magnetic response with sharp contacts, and low radioelement concentrations that is consistent with contact metamorphism apparent in the surrounding formations of the Sibley Group.

3.2.1.5 Nipigon Diabase Sill Complex

Nipigon diabase sills are relatively thin generally flat-lying mafic rocks that intrude and overlie 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 Nipigon 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 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 ca. 1.115 to 1.105 billion years (Heaman et al., 2007).

The presence and extent of sills beneath overburden and within deeper horizons of the metasedimentary rocks of the Quetico Subprovince is largely unknown within the Nipigon area, although, stacked sills in strata of the Sibley Group have been identified in the Eagle Mountain area to the immediate west of the Nipigon area (Hart, 2005). In the western part of the Nipigon area where high resolution geophysical data is available, PGW (2014) has intepRereted probable locations of sills in the shallow subsurface (Figure 15, PGW (2014)) based on their magnetic response. The sills significantly influence the magnetic response due to their proximity to ground surface, magnetic susceptibility, strong magnetic remanence (variable in direction but usually antiparallel to the present geomagnetic field) and geometry. In the area of higher resolution magnetic data, the interpreted sill locations appear as uniform and continuous anomalies, where the anomaly edges tend to be consistent with the the locations of sills mapped by Hart (2005). In addition, the magnetic data provided evidence to map the location of the sills where they extend into the subsurface. Geophysical data resolution over the eastern part of the Nipigon area is insufficient to make a similar interpretation.

3.2.1.6 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 3.3). 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, 2011a). 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.

PGW (2014) interpreted 19 dykes in the Nipigon area based on the geophysical data, and noted that two dykes interpreted along the western margin of the Nipigon area have strong negative magnetic responses, suggesting that they possess antiparallel magnetic remanence and therefore may be related to the Nipigon diabase sill intrusions.

3.2.2 Quaternary Geology

Continental ice sheets have advanced and retreated across northern parts of North America numerous times during the last 2.4 million years (Shackleton et al., 1990; Peltier, 2002) – a period of time known as the Quaternary Period. All unconsolidated deposits in the Nipigon area are attributed to the Wisconsinan stage. The Wisconsinan glaciation began approximately 115,000 years ago and peaked about 21,000 years before present, during the late Wisconsinan glaciation, at which time the glacial ice front extended south of Ontario into Ohio and Indiana (Barnett, 1992). After the ice sheet had reached its maximum extent at about 20,000 years ago, it began retreating northward, interrupted occasionally by readvances. Data on ice flow directions from the literature (Zoltai, 1965a) reveal that glacial ice flowed in a generally westerly to southwesterly direction across the Nipigon area from the Hudson Bay basin.

The northward retreat of the ice sheet in the Nipigon area started approximately 10,500 years ago when the area temporarily became partially ice-free (Dyke et al., 2003). 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, which was formed along the west and south side of Lake Nipigon (Zoltai, 1965b). The orientation of the Nipigon moraine indicates that the most recent glacial advance was in a south-southwesterly direction from a glacial centre further to the north-northeast.

Extensive ice-marginal deltas along the Nipigon moraine, observed a short distance northwest of the Nipigon area, indicate that a high-level proglacial lake fronted the glacier during moraine formation (Barnett, 2004), most likely glacial Lake Minong, which occupied the Lake Superior basin. As the ice sheet began its recession northward from the Nipigon moraine, glacial Lake Minong expanded into low-lying, newly deglaciated areas. About 9,500 years ago, glacial Lake Minong had reached its maximum extent, coalescing with the ancestral Lake Nipigon (glacial Lake Kelvin) (Barnett, 1992; Slatterly et al., 2007). Further to the north, drainage was blocked by the residual ice mass remaining over the Hudson Bay basin. This created the glacial Lake Agassiz, which covered a maximum area of approximately 1 million km^2 (Bajc et al., 2000) including the majority of lands to the north of the present Lake Nipigon.

Beginning about 9,500 years ago, Lake Agassiz began draining through the Lake Nipigon basin into Lake Superior (Clayton, 1983). At least six outlets from Lake Agassiz via Lake Nipigon to Lake Superior are thought to have been present during deglaciation of the area (Teller and Thorleifson, 1983; Lemoine and Teller, 1995) though it is unlikely that these were active simultaneously. The most prominent of these outlets is the Pijitawabik canyon located north of the Nipigon area. This deeply (>150 m) incised steep-walled valley cuts through Nipigon sills for a distance of about 20 km. The canyon follows a southeasterly trend to a point about 14 km north of the Nipigon area, where it then turns sharply to the southwest at a nearly right-angled bend. The outlet leaves the canyon immediately north of the Nipigon area and in the last 7 km before Helen Lake its path follows relatively low-relief Archean basement. Other outlets of Lake Agassiz include the Black Sturgeon River canyon, the Shillabeer and Cash channels of the Wolf Lake drainage system immediately southwest of the Nipigon area, and the Nipigon River. Drainage of Lake Agassiz through the Lake Nipigon basin into the Lake Superior basin halted at about 9,000 years ago, as indicated by the cessation of glacial clay sedimentation at multiple locations on the floor of Lake Superior (Breckenridge et al., 2004; Hyodo and Longstaffe, 2011).

From about 10,000 to 5,000 years ago, water levels in the Lake Superior basin dropped from about 300 m elevation through several Minong and post-Minong stages to a low level of about 140 m, at the start of the Houghton phase (Farrand and Drexler, 1985). As lake levels dropped, erosion of surficial deposits by river and lake currents resulted in the redistribution of sediment onto adjacent low-lying areas. In some areas within the confines of glacial Lake Minong, erosion around the receding lakeshore was effective at removing overburden deposits from the bedrock surface, producing areas of bare rock (Zoltai, 1965a).

A kame terrace on the west margin of the Nipigon valley, west of Helen Lake, would have 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 2.3). 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, 1981b) 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.

As the ice sheet retreated northward, newly deglaciated areas to the south began to rise isostatically, recovering from the weight of the ice sheet. This uplift caused water levels in the Great Lakes to rise (Barnett, 1992). By about 5,000 years ago, differential isostatic uplift in the north and south parts of the Great Lakes basins resulted in high water levels in lakes Superior, Huron and Michigan and Georgian Bay, referred to as the Nipissing Great Lakes (Barnett, 1992). East of Thunder Bay, these high water levels produced strong shoreline features about 30 m above the present shoreline of Lake Superior (Farrand and Drexler, 1985).

Since the disappearance of the ice sheets and glacial lakes, modern streams have developed alluvial flood plains and organic deposits have accumulated in wet depressions. The largest organic deposits are located adjacent to the north shore of Lake Superior, extending northwest from Fire Hill Bay and Kama Bay.

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 (2014a). Diamond drill hole records and water well records in the area show overburden thickness to be up to about 100 m. The reported overburden thicknesses from the diamond drill holes and water wells are from localized pockets of overburden that may not be evident at the 1:100,000 scale mapping shown on Figure 2.3.

3.2.3 Lineament Investigation

A detailed lineament investigation was completed for the Nipigon area (JDMA, 2014b) using publicly available remote sensing datasets, including airborne geophysical (aeromagnetic) data, digital elevation model data (CDED), and satellite imagery data (SPOT), digital elevation model data (CDED) and geophysical (magnetic) survey data. Lineaments are linear features that can be observed on remote sensing and geophysical data, which may represent geological structures (e.g., fractures). However, at this stage of the assessment, it is uncertain if interpreted lineaments are a reflection of real geological structures, and whether such structures, if present, extend to depth. The assessment of these uncertainties would require detailed geological mapping and borehole drilling.

The lineament investigation identified interpreted brittle structures, dykes and ductile lineaments in the Nipigon area, and evaluated their relative timing relationships within the context of the local and regional geological setting. A detailed analysis of interpreted lineaments is provided by JDMA (2014b) and key aspects of the lineament investigation are summarized in this section.

At this desktop stage of lineament investigation, the remotely sensed character of interpreted features allows only for their preliminary categorization, based on expert judgement, into three general lineament classes, including ductile, brittle and dyke lineaments. Each of these three lineament categories is described in more detail below in the context of its usage in this preliminary assessment.

- **Ductile lineaments**: Features which were interpreted as being associated with the internal fabric of the rock units (including sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation) were classified as ductile lineaments. This category also includes recognizable penetrative shear zone fabric.

- **Brittle lineaments**: Features interpreted as fractures (joints or joint sets, faults or fault zones, and veins or vein sets), including those that offset the continuity of the ductile fabric described above, were classified as brittle lineaments. This category also includes brittle-ductile shear zones, and brittle partings interpreted to represent discontinuous re-activation parallel to the ductile fabric. At the desktop stage of the investigation, this category also includes features of unknown affinity. This category does not include interpreted dykes, which are classified separately.

- **Dyke lineaments**: For this preliminary desktop interpretation, dyke lineaments were interpreted on the basis of their distinct character, e.g., scale and composition of fracture in-fill, orientation, geophysical signature and topographic expression. Dyke interpretation is largely made using the aeromagnetic data set, and is often combined with pre-existing knowledge of the bedrock geology of the Nipigon area.

The desktop interpretation of remotely-sensed datasets necessarily includes a component of uncertainty as a result of data quality, scale of the Nipigon area, expert judgement, and to a certain extent, the quality of the pre-existing knowledge of the bedrock geology of the Nipigon area. Therefore, the ductile, brittle or dyke categorization of each identified feature, as described herein, is preliminary.

For each dataset, brittle lineaments and dykes were interpreted by two independent experts using a number of attributes, including Certainty and Reproducibility (JDMA, 2014b). The certainty attribute describes the clarity of the lineament within each dataset based on the expert judgement and experience of the interpreter (i.e., with what certainty a feature is interpreted as a lineament). Reproducibility was assessed in two stages (RA_1 and RA_2). Reproducibility assessment RA_1 reflects the coincidence between lineaments interpreted by the two experts. Reproducibility assessment RA_2 reflects the coincidence of interpreted lineaments between the various different datasets used.

A total of 659 lineaments were identified by the two interpreters from the CDED digital elevation data. These lineaments range in length from 376 m to 73.7 km, with a geometric mean length of 2.1 km and a median length of 1.9 km. When plotted on a rose diagram weighted by length, CDED orientations (Figure 3.8) show a dominant trend to the north-northwest (about 340°) with secondary trends to the north (about 005°) and north-northeast (about 025°) and less prominent but consistent trends to the west-northwest (about 295°) and east-northeast (about 060°). A total of 497 of the CDED lineaments (75%) were assigned a certainty value of 3. Certainty values of 2 and 1 were assigned to 135 (21%) and 27 (4%) of the CDED lineaments, respectively. The RA_1 reproducibility assessment shows coincidence between the two pickers for 310 of the CDED lineaments (47%, RA_1 = 2) and a lack of coincidence for 349 of the CDED lineaments (53%, RA_1 = 1).

The SPOT lineament dataset compiled from the merger of lineaments identified by the two interpreters yielded a total of 1,374 lineaments (Figure 3.8). The length of the SPOT lineaments ranges from 163 m to 163.1 km, with both a geometric mean length and a median length of 1.2 km. When the azimuths of the lineaments are plotted on a rose diagram weighted by length (Figure 3.8), several distinct trends appear. The strongest trend appears to the east-northeast (060º). Other main tends include to the northwest (330º), north (two trends at 355º and 005º), and north-northeast (025º). Less prominent, but consistent trends appear to the east-southeast (about 295°) and west-southwest (about 080°). Seventy eight percent (78%) of the SPOT lineaments, a total of 1,068, were assigned a certainty value of 3. Certainty values of 2 and 1 were assigned to 285 (21%) and 21 (1%) of the SPOT lineaments, respectively. The reproducibility assessment shows coincidence for 454 (33%) of the SPOT lineaments (RA_1 = 2), and a lack of coincidence for 920 (67%) of the SPOT lineaments (RA_1 = 1).

Orientation data for the SPOT lineaments appear to be more uniformly distributed than those for the CDED lineaments, with only broadly comparable dominant orientations of west-northwest and east-northeast. Both the surficial datasets show a northerly trend. The more uniform distribution of the SPOT lineament orientations reflects, in part, the higher resolution of this dataset which allowed for the identification of numerous short subtle lineaments that were not discernible in the coarser CDED.

The airborne geophysical data interpretation was able to distinguish between features that could be interpreted as brittle or dyke (Figure 3.9), or ductile (Figure 3.10) lineaments. In this report, the ductile lineaments are shown to provide context to the understanding of the tectonic history of the Nipigon area, but were not included in the statistical analysis undertaken with the lineament dataset. Therefore the following discussion relates only to those lineaments interpreted as brittle or dyke lineaments.

A total of 269 lineaments comprise the dataset of merged lineaments identified by the two interpreters from the geophysical data (Figure 3.9). Of these geophysical lineaments, 250 are interpreted as brittle lineaments, while 19 are interpreted as dykes (Figure 3.9). Among the geophysical lineaments interpreted as brittle, most were unclassified with respect to relative displacement, but both dextral (3) and sinistral (5) movements were identified. The lengths of the brittle lineaments ranged from 358 m to 47.6 km, with a geometric mean length of 3.0 km and a median length of 2.2 km. Orientations of the brittle lineaments, weighted by length and plotted on a rose diagram (Figure 3.9 inset), exhibit several strong trends, particularly to the east-northeast (065º) and north-south, east-west, and northwest (330º).

Geophysical lineaments interpreted as dykes (19) ranged in length from 570 m to 10.1 km, with a geometric mean length of 3.5 km and a median length of 3.2 km. Orientations of the dyke lineaments include notable trends to the north (010º) north-northeast (025º), east-northeast (065º) and northwest (330º).

Certainty values of 3, 2, and 1 were assigned to 201 (80%), 31 (12%), and 18 (8%) geophysical lineaments, respectively. The reproducibility assessment (RA_1) identified coincidence for 13 faults (5%) (RA_1 = 2) and a lack of coincidence for 237 of the interpreted faults (92%) (RA_1 = 1). The reproducibility assessment identified coincidence for 5 of the interpreted dykes (26%) (RA_1 = 2) and a lack of coincidence for 14 of the interpreted dykes (74%) (RA_1 = 1). The low RA_1 for interpreted faults in the geophysical dataset reflects a number of factors including the reassessment of the Black Sturgeon fault zone as a broad corridor rather than a single fault set, and the variable quality of the aeromagnetic data which is characterized by contrasting resolutions and numerous contacts between magnetically distinct lithologies.

Aeromagnetic features interpreted as ductile lineaments have been mapped separately and are shown on Figure 3.10. Such features are useful in identifying the degree of deformation within the rocks of the Nipigon area, most notably the Archean metasedimentary rocks, granites and granodiroites, and the younger Mesoproterozoic rocks of the Sibley Group. It should be noted that the density of these features is strongly influenced by the resolution of the geophysical coverage.

The geophysical lineament dataset has advantages over surficial lineament data in that it is minimally affected by overburden cover, which may partially or completely mask surficial lineaments. Importantly, aeromagnetic data allows interpretation of lineaments from the surface to potentially great depths.

Figure 3.11 shows the distribution of merged surficial and geophysical lineaments interpreted for the Nipigon area, classified by length. The merged lineament dataset yielded a total of 1,711 lineaments, ranging from 163 m to 167.2 km in length, with a mean length of 1.4 km. Azimuths of the merged lineaments exhibit numerous trends that cluster to the north-northwest, north, and northeast. The north-northwest cluster features a dominant trend at about 340º. Lineaments oriented northward follow two main trends at about 355º and 005º. The strongest trend in the data is toward the east-northeast at 060º.

Lineament orientation trends for the individual geological units in the Nipigon area (i.e., Nipigon sills, sedimentary rocks of the Sibley Group and metasedimentary rocks of the Quetico Subprovince) are presented on Figure 3.12 and further discussed in the geologic unit-specific sub sections below.

JDMA (2014b) noted the following trends in the final merged lineament dataset:

- Longer lineaments generally have higher certainty and reproducibility.
- There is a greater coincidence between surficial lineaments (32% of the total merged lineaments are interpreted from both CDED and SPOT) than between geophysical lineaments and surficial lineaments (18% of the total merged lineaments are observed in geophysical data and at least one of the surficial datasets), presumably since surficial lineaments interpreted from CDED and SPOT are expressions of the same bedrock feature.
- The lower coincidence between surficial and geophysical lineaments is presumably due to a variety of factors. For example, the structures identified in the aeromagnetic data may not have a surface expression; surficial features may not extend to great depth; structural features may not possess a magnetic susceptibility contrast with the host rock; surface expressions of lineaments may be masked by the presence of infilling or overburden; and the geometry of the feature (e.g., dipping versus vertical). These factors are further constrained by the resolution of the differing datasets. At 805 m flight line spacing, small features or features in the aeromagnetic dataset available for the easternmost two-thirds of the Nipigon area may not be recognizable.

In order to gain insight into the influence of lineament length on lineament density, Figures 3.13 to 3.16 illustrate how lineament density varies across the Nipigon area when lineaments are progressively “filtered” by length (i.e., plots showing all lineaments and only lineaments longer than 1 km, >5 km and >10 km, respectively). The density plots with lineament lengths filtered are presented to allow one to more clearly see the longer lineaments. The figures show that filtering out the shorter lineaments significantly increases the spacing between lineaments, including within those areas mapped as bedrock terrain with good exposure and areas with high resolution aeromagnetic surveys. For example, Figures 3.16 shows that there are areas of metasedimentary rocks, the Mound Lake granite pluton and other granitic intrusive rocks in the Nipigon area that contain relatively few lineaments that are longer than 10 km, leaving large volumes of rock between interpreted long lineaments. Also, filtering out the shorter lineaments appears to reduce the effects of both overburden cover (in the case of surficial lineaments) and low resolution aeromagnetic surveys on lineament density. For example, the Mound Lake granite pluton with well-exposed bedrock and high resolution aeromagnetic surveys exhibits moderate to high lineament density when all lineaments are shown, but the lineament density is greatly reduced and becomes more comparable to other areas when the shorter lineaments are filtered out.

Figure 3.17 shows the combined datasets (i.e., mapped regional faults, brittle lineaments, dykes and ductile lineaments), which helps provide a structural understanding of the Nipigon area. The mapped regional faults within the Nipigon area include the Black Sturgeon fault zone, which has coincident geophysical and surficial lineaments, and the Jackpine River fault, which has a good surficial lineament coincident but a poor geophysical lineament coincidence. The correlation between the lineament orientations and these major mapped structures is much stronger for the Black Sturgeon fault zone than for the Jackpine River fault. The regional mapped faults ultimately reflect regional stress conditions, noting that it is probable that the major mapped faults have undergone multiple episodes of brittle reactivation caused by the same stress conditions that gave rise to some of the identified brittle lineaments.

The following subsections describe the characteristics of the interpreted lineaments for each of the main geological units in the area, as well as the relative age of the lineaments identified in the Nipigon area.

3.2.3.1 Archean Metasedimentary Rocks and Granitic Intrusions

Archean gneissic metasedimentary rocks and granitic intrusions cover 807 km^2 of the Nipigon area, east of the Black Sturgeon fault zone, and are cross-cut by a total of 1,298 lineaments. These geological units exhibit relatively rugged topography with the most extensive bedrock exposure in the Nipigon area, allowing for confident identification of lineaments. Because surficial cover is limited in extent and thickness, there is a high density of interpreted surficial lineaments. Throughout the gneissic metasedimentary rocks, the lineaments exhibit a distinct east-west trend that represents the gneissic foliation. There are also strong trends to the north, northwest, and northeast.

Lineament orientations were compared for two domains defined by the boundary between high- and low-resolution aeromagnetic datasets (Figure 1.2). Lineaments that cross this boundary were counted twice (once for each side). The western domain, over which there is high-resolution aeromagnetic data, covers an area of about 275 km^2 and contains 459 lineaments ranging from 308 m to 73.7 km in length. Orientation data for these lineaments (JDMA, 2014b) show prominent trends to the north-northwest, north, and east-northeast. The larger eastern domain, covering 532 km^2, contains 858 lineaments ranging in length from 170 m to 167.2 km. While the orientation trends noted from the western domain appear in the eastern domain, there are several notable differences; specifically, a dominant trend to the east-northeast (060º) influenced by the exceedingly long lineament representing the Gravel River fault, a trend to the north-northeast (025º) and to the west-northwest (300º).

3.2.3.2 Sedimentary Rocks of the Sibley Group

The Nipigon area features extensive sedimentary rocks of the Sibley Group that cover an area of 235 km^2 from which a total of 278 lineaments were mapped. Sedimentary rocks of the Sibley Group appear mostly to the west of the Black Sturgeon fault zone and in a smaller area east of Helen Lake. Lineaments interpreted from the Sibley Group exhibit orientations to the northwest and northeast and appear to extend across the unit boundaries. Lineament densities are much lower in the Sibley Group than in the Archean metasedimentary rocks.

3.2.3.3 Nipigon Sills

Nipigon sills, often expressed as topographic highs, such as the Kama hills, cover approximately 166 km^2 of the Nipigon area. Lineaments mapped from the sills (414 in total) appear as distinct traces that extend into adjacent rock units and are often relatively long and unbroken.

3.2.4 Relative Age Relationships of Lineaments

The main period of metamorphism in the metasedimentary rocks of the Quetico Subprovince resulted in folding, and the development of gneissic fabrics that effectively destroyed any pre-existing lineaments. Therefore, it is probable that all brittle fractures visible as surface lineaments within the Nipigon area post-date M_2 at approximately 2.684 to 2.671 billion years in age. Other stratigraphic age constraints are offered by the sedimentary rocks of the Sibley Group at ca. 1.670 to 1.339 billion years old and the younger Nipigon sills at ca. 1.113 to 1.110 billion years old. Up to four deformation events have been recognized within the Quetico Subprovince (Sawyer, 1983; Williams, 1987 and 1991; Zaleski et al., 1999) but all of these date to the Archean Eon with the youngest D_4 represented by small-scale shear zones that cut the earlier formed planar and folded fabrics (Sawyer, 1983). Valli et al. (2004) gave an age of 2.671 to 2.667 billion years for D_4.

In addition to these published Archean deformation events, three additional, hypothetical, structural events are identified for the Nipigon area. D_5 represents faulting/fracturing events that post-date Archean deformation but predate the deposition of the sedimentary rocks of the Sibley Group, ca. 1.657 to 1.450 billion years ago (Hart, 2005). D_6 includes faulting/fracturing events that crosscut the Sibley Group but do not crosscut the younger ca. 1.113 to 1.111 billion year old Nipigon sills (Heaman et al., 2007). Finally, D_7 includes events that postdate the emplacement of the Nipigon sills and their near-contemporaneous mafic intrusions such as the Hele intrusion.

Examination of mapped surface lineaments reveals that the greatest proportion crosscut the Nipigon sills and hence post-date 1.113 to 1.111 billion years. Few obvious truncations are visible and these are mostly ambiguous. Therefore, all mapped surface lineaments must be assigned to the D_5 to D_7 interval, with the understanding that they may also represent the reactivation of pre-existing (pre-D_5) structures in the underlying and older bedrock units.

With respect to the three main named faults on the Nipigon area, the Black Sturgeon fault zone clearly cuts and displaces sedimentary rocks of the Sibley Group and must therefore have been active post ca. 1.5 billion years (D_6 or younger). It also contains mineralized quartz veins indicating that it existed at sufficient depth for hydrothermal fluids to circulate. The Gravel River fault offsets metasedimentary rocks of the Quetico by up to 50 km and so must post-date M_2. The Jackpine River fault and Gravel River fault appear to truncate rocks of the Sibley Group, but in this case the relationship is ambiguous owing to the degree of lateral removal of these strata, possibly resulting from the action of glacial melt waters in the Quaternary Period. A possible southern extension of the Gravel River fault cuts Osler Group volcanics in the St. Ignace archipelago, suggesting that movement along this fault post-dates ca. 1.0 billion years ago and may be assigned to D_7.

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

The Nipigon area lies within the Canadian Shield, where large parts have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). Hayek et al. (2009) indicated that this area of the Canadian Shield has experienced a number of low magnitude, shallow seismic events. Figure 3.18 presents the location of earthquakes with a magnitude 3 or greater that are known to have occurred in Canada from 1627 until 2012 (NRCan, 2013). Figure 3.19 shows the locations and magnitudes of seismic events recorded in the National Earthquake Database (NEDB) for the period between 1985 and 2013 in the Nipigon area (NRCan, 2013). In the last 25 years there has been only a single recorded seismic event within the Nipigon area and eight events within 75 km. Note that these events occurred along the Lake Superior shoreline and that none of these seismic events measured greater than a magnitude of 3.

In summary, available literature and recorded seismic events indicate that the Nipigon area is located within a region of low seismicity: the tectonically stable central Superior Province of the Canadian Shield.

3.3.2 Neotectonic Activity

Neotectonics refers to deformations, stresses and displacements in the earth's crust of recent age or which are still occurring. These processes are related to tectonic forces acting in the North American plate as well as those associated with the numerous glacial cycles that have affected the northern portion of the plate during the last million years, including all of the Canadian Shield (Shackleton et al., 1990; Peltier, 2002).

The movement and interaction of tectonic plates creates horizontal stresses that result in the compression of crustal rocks. The mean of the current major horizontal principal stress orientation in central North America, based on the World Stress Map (Zoback, 1992) is northeast (63° ± 28°). This orientation coincides roughly with both the absolute and relative plate motions of North America (Zoback, 1992; Baird and McKinnon, 2007), and is controlled by the present tectonic configuration of the North Atlantic spreading ridge (Sbar and Sykes, 1973), which has likely persisted since the most recent Paleocene-Eocene plate reorganization (Rona and Richardson, 1978; Gordon and Jurdy, 1986).

The geology of the Nipigon area is typical of many areas of the Canadian Shield, which has been subjected to numerous glacial cycles during the last million years (Shackleton et al., 1990; Peltier, 2002), resulting in post-glacial isostatic rebound in the northern portion of the North America Plate. During the maximum extent of the Wisconsinan glaciation, approximately 21,000 years ago (Barnett, 1992), the earth's crust was depressed by more than 340 m in the Minnesota/North Dakota area (Brevic and Reid, 1999), due to the weight of glacial ice. The amount of crustal depression in the Nipigon area would be of a somewhat greater magnitude due to its closer proximity to the main center of glaciation located over Hudson's Bay.

Post-glacial isostatic rebound began with the waning of the continental ice sheets and is still occurring across most of Ontario. Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella et al., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1-2 mm/yr) south of the Great Lakes. The ''hinge line'' separating uplift from subsidence is consistent with data from water level gauges along the Great Lakes, showing uplift along the northern shores and subsidence along the southern ones (Mainville and Craymer, 2005). Current rates of isostatic uplift in the Nipigon area are not precisely known, although Lee and Southam (1994) estimated that the land is rising at a rate of 2.9 mm/yr at Michipicoten, Ontario, some 260 km to the southeast.

As a result of the glacial unloading, horizontal stresses are amplified locally in shallow bedrock in many areas of Ontario. Natural stress release features include elongated compressional ridges or pop-ups such as those described in horizontally layered rocks of southern Ontario by White et al. (1973), McFall (1993), and Karrow and White (2002).

No neotectonic structural features are described in the readily available literature for the Nipigon area. It is therefore useful to review the findings of previous field studies involving fracture characterization and evolution as it may pertain to glacial unloading. McMurry et al. (2003) summarized several studies conducted in a number of plutons in the Canadian Shield and in the crystalline basement rocks in northwestern Ontario. These various studies found that fractures below a depth of several hundred metres in the plutonic rock are often ancient features. Early-formed fractures have tended to act as stress domain boundaries. Subsequent stresses, such as those caused by plate movement or by continental glaciation, generally have been relieved by reactivation along the existing zones of weakness rather than by the formation of large new fracture zones.

Under the appropriate conditions, glaciolacustrine deposits may preserve neotectonic features indicative of paleo-seismic activity (JDMA, 2014a). Existence of such features can be used to extend the seismic record for a region well into the past. As shown on Figure 2.3, glaciolacustrine terrain in the Nipigon area is generally located within an arcuate zone extending from the southwest part of the area in McMaster Township to the north central part of the Nipigon area. Some road and water access is available across this region, which may allow for the future investigation of the presence of neotectonic features if the Nipigon area is selected for more detailed studies.

4.0 HYDROGEOLOGY

4.1 Groundwater Use

Information concerning groundwater in the Nipigon area was obtained from the Ontario Ministry of the Environment (MOE) Water Well Information System (WWIS) (MOE, 2013). The Township of Nipigon obtains its municipal water supply from the Nipigon River on Lake Superior; however, a large number of wells exist in the Nipigon area serving individual private residences. Most of these are located along the Trans-Canada Highway and obtain water from the overburden or the shallow bedrock. Figure 4.1 shows the location of water wells in the Nipigon area. The MOE water well database contains a total of 143 water well records for the Nipigon area for which useful information is available (wells with no recorded depth are excluded). A summary of these wells is provided in the table below.

Table 4.1: Water Well Record Summary for the Nipigon Area

Water Well Type	Number of Wells	Total Well Depth (m)	Median Well Depth (m)	Static Water Level (m below surface)	Tested Well Yield (L/min)	Depth to Top of Bedrock (m)
Overburden	57	3 to 99	36.6	0 to 43.8	9 to 450	NR
Bedrock	86	15 to 140.5	45.7	0 to 32.0	4.5 to 675	0 to 82

NR – not reached

4.2 Overburden Aquifers

There are 57 water well records in the Nipigon area that can be confidently assigned to the overburden aquifer, which is generally found in the sand and gravel deposits above bedrock and at the base of the glaciolacustrine deposits that form the most widespread surficial soil materials. The overburden wells are generally 3 to 50 m deep, but depths of up to 99 m have been recorded. Well yields are variable with recorded values ranging from 9 L/min to 450 L/min. These values reflect the purpose of the wells (i.e., the majority being private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from the aquifer. Tested yields reflect the short term hydraulic performance of the wells and may not be sustainable over long periods.

The most significant shallow aquifers in the Nipigon area are associated with thick outwash, kame, end moraine and delta deposits flanking the west side of Helen Lake. Potentially suitable groundwater aquifers may also exist beneath fine-textured glaciolacustrine deposits in the central portion of the Nipigon area but any interpretation of aquifer potential is constrained by the absence of water wells in this area.

4.3 Bedrock Aquifers

No information was found on deep bedrock groundwater conditions in the Nipigon area at a typical repository depth of approximately 500 m. In the Nipigon area, there are 86 well records that can be confidently assigned to the shallow bedrock aquifer. These wells range from 15 to 104.5 m in depth, with most wells between 30 to 60 m deep. Measured pumping rates in these wells are variable and range from 4.5 L/min to 675 L/min with yields typically between 10 to 30 L/min. These values reflect the purpose of the wells (i.e., private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from the aquifers. Long-term groundwater yield in fractured bedrock will depend on the number and size of fractures, their connectivity, transmissivity, storage and on the recharge properties of the fracture network in the wider aquifer.

The MOE water well database shows no potable water supply wells which exploit aquifers at typical repository depths in the Nipigon area or anywhere else in northwestern Ontario.

4.4 Regional Groundwater Flow

In many shallow groundwater flow systems the water table is generally a subdued replica of the topography. The variation of the water table elevation across an area reflects the changes in hydraulic head and therefore the driving force within the flow system. However, the pattern of groundwater flow will also be influenced by horizontal and vertical variations in the hydraulic properties of the medium, for example associated with interbedding of sand and clay layers in overburden sediments and the presence of fracture networks in bedrock. As a general concept, shallow groundwater flow in Canadian Shield terrain will tend to be directed from areas of higher hydraulic head, such as highlands, towards areas of lower hydraulic head such as adjacent or nearby valleys and depressions. The extent of these localized flow systems are defined by local, topography-controlled, drainage divides across which flow will not readily occur. However, the geometry of shallow flow systems can be more complex in the presence of permeable fracture zones and more complex topography.

With the general concept in mind and with reference to the drainage features in the Nipigon area shown on Figure 2.4, it is inferred that regional shallow groundwater flow in the Black Sturgeon, Nipigon, and Jackpine watersheds will be generally to the southeast, south, and southwest, respectively, toward Lake Superior. Within each of the above tertiary-scale watersheds, local topography and terrain conditions will influence the distribution and nature of smaller-scale, localized, groundwater flow systems that may be delineated by the watersheds shown on Figure 2.4. Recharge patterns will be a function of local conditions with the highest rates generally occurring in elevated areas underlain by permeable sand or gravel deposits or by fractured bedrock in areas where it is exposed or covered by thin overburden. Lowland areas, especially muskeg, store substantial amounts of water and may act simultaneously as discharge and recharge areas according to seasonal variations.

No information was found in the available literature regarding groundwater recharge rates and temporal patterns in the Nipigon area. However, it is expected to be typical for the shield region with elevated recharge in spring and fall, reduced recharge in late summer, and essentially no recharge during frozen winter conditions. Rivard et al. (2009) analyzed trends in groundwater levels and surface water baseflow over the past 50 years throughout Canada. This analysis found no significant temporal trend with respect to long-term changes in surface water drainage and a stable to slight downward trend with respect to regional groundwater levels in northwestern Ontario.

Deeper into the bedrock, fracture frequency in a mass of rock will tend to decline, and eventually, the movement of ions will be diffusion-dominated. However, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion-controlled conditions.

There is little known about the hydrogeologic properties of the deep bedrock in the Nipigon area, as no deep boreholes have been advanced for this purpose. Experience from other areas in the Canadian Shield has shown that active groundwater flow in bedrock is generally confined to shallow fractured localized systems, and is dependent on the secondary permeability associated with the fracture networks (Singer and Cheng, 2002). For example, in Manitoba's Lac du Bonnet batholith, groundwater movement is largely controlled by a sub-horizontal fractured zone down to about 200 m depth (Everitt et al., 1996). The low topographic relief of the Canadian Shield tends to result in low hydraulic gradients for groundwater movement in the shallow active region (McMurry et al., 2003). In deeper regions, rock mass hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater flow systems (Stevenson et al., 1996; McMurry et al., 2003). Rock mass hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell and Atikokan research areas range from approximately 10^{-10} to 10^{-15} m/s (Ophori and Chan 1996; Stevenson et al. 1996). Data reported by Raven et al. (1985) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400 to 500 m.

As the fracture frequency in a rock mass tends to decline with depth, eventually the movement of ions becomes diffusion-dominated. However, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion-controlled conditions. The orientation of these fracture networks relative to the in-situ stress field may influence their hydraulic properties. For example, in the fractured crystalline rock at SKB's Forsmark site, Follin and Stigsson (2014) documented that the transmissivities of large-scale, fracture zones generally decreased with depth by four orders of magnitude from ground surface to nearly 800 m, but specifically-orientated fracture zone groupings tended to have different ranges of transmissivities. The sub-vertical fracture zones orientated at high angles (near perpendicular) to the northwest-southeast, maximum horizontal compressive stress direction tended to have a greater frequency of low transmissivities compared to sub-vertical fracture zones oriented at low angles to the maximum horizontal stress direction. Notably, the sub-horizontal fracture zones had even higher transmissivities regardless of depth, presumably because of the lower normal effective stresses acting across these zones as a result from their preferential orientation to the minimum vertical stress. Horizontal stress measurements from various locations in the Canadian Shield (Kaiser and Maloney, 2005; Maloney et al., 2006) indicate that the axis of maximum horizontal stress is oriented approximately east-west in the Nipigon area. This is generally consistent with the World Stress Map; however, anomalous stress orientations are known to exist throughout the Canadian Shield (Brown et al., 1995; Kaiser and Maloney, 2005; Maloney et al., 2006).

There is no site-specific information on the hydraulic characteristics of the dykes interpreted for the Nipigon area. Information from other geological settings shows that dykes may act as either pathways or barriers for groundwater flow in a host rock. Their hydraulic characteristics depend on a wide range of factors that include their frequency and location within the host rock, their orientation with respect to the direction of groundwater flow, their mineralogical composition, degree of alteration and their potential association with brittle deformation structures (e.g., Ryan et al., 2007; SKB, 2010; Gupta et al., 2012; Holland, 2012).

4.5 Hydrogeochemistry

No information on groundwater hydrogeochemistry was found for the Nipigon area. Existing literature, however, has shown that groundwater within the Canadian Shield can be subdivided into two main hydrogeochemical regimes: a shallow, generally fresh water flow system, and a deep, typically saline water flow system (Singer and Cheng, 2002).

Gascoyne et al. (1987) investigated the saline brines found within several Precambrian plutons and identified a chemical transition at around 300 m depth marked by a uniform, rapid rise in total dissolved solids (TDS) and chloride. This was attributed to advective mixing above 300 m, with a shift to diffusion-controlled flow below that depth. It was noted that major fracture zones within the bedrock can, where present, extend the influence of advective processes to greater depths and hence lower the transition to the more saline conditions characteristic of deeper, diffusion-controlled conditions.

In the deeper regions, where groundwater transport in unfractured or sparsely fractured rock tends to be very slow, long residence times on the order of a million years or more have been reported (Gascoyne, 2000; 2004). Groundwater research carried out in AECL's Whiteshell Underground Rock Laboratory (URL) in Manitoba found that crystalline rocks from depths of 300 to 1,000 m have TDS values ranging from 3 to 90 g/L (Gascoyne et al. 1987; Gascoyne, 1994; 2000; 2004). However, TDS exceeding 250 g/L have been reported in some regions of the Canadian Shield at depths below 500 m (Frape et al., 1984). Site-specific conditions will influence the depth of transition from advective to diffusion-dominated flow, which may occur at a depth other than the typical 300 m reported by Gascoyne et al. (1987).

5.0 NATURAL RESOURCES — ECONOMIC GEOLOGY

Information regarding the mineral resource potential for the Nipigon area has been obtained from a variety of sources including general syntheses of mineralization in the Canadian Shield Region (e.g., Fyon et al., 1992; Vaillancourt et al., 2003), studies within the Nipigon area (Coates, 1968; 1972; Franklin et al., 1980; Cheadle, 1986; Hart and MacDonald, 2003; Hart and Préfontaine, 2004; Hart and Magyarosi, 2004; MacDonald, 2004; Hart, 2005; and Rogala et al., 2005; 2007), economic geology studies and reports (e.g., Robertson and Gould, 1983; Scott, 1987; Smyk and Franklin, 2007; and Breaks et al., 2008), as well as MNDM Mineral Deposit Inventories (MDI), Assessment Files (AFRI) and publications by industry (in particular NI 43-101 reports).

There are currently no active mines in the Nipigon area, but the region has a history of mineral exploration, which continues today. Figure 5.1 shows the current areas of exploration in the Nipigon area based on active mining claims and known mineral occurrences identified in the Mineral Deposit Inventory (OGS, 2011b).

5.1 Metallic Mineral Resources

There is no record of metallic mineral production in the past in the Nipigon area (OGS, 2011b). A few mineral occurrences have been identified within the area, but their economic potential has not been proven. As shown on Figure 5.1 there are a number of active exploration claims in the Nipigon area, with the greatest concentration in the vicinity of the Hele intrusion. Metallic mineral deposit types in the Nipigon area include: platinum group metals, cobalt-copper-nickel, silver-lead-zinc, uranium and rare metals. All of these occurrences are considered to be of sub-economic potential.

Platinum Group Elements (PGE)

The Hele intrusion in the southwest corner of the Township of Nipigon is mineralogically similar to the Seagull intrusion (about 40 km northwest of the Township of Nipigon), which contains sub-economic platinum group element (PGE) mineralization (Hart and Magyarosi, 2004). The potential feeder zones to the Hele intrusion have been suggested to have potential for PGE and nickel-copper mineralization (Hart, 2005; Smyk and Franklin, 2007). Anomalous concentrations of PGE have been identified in the Foxden Occurrence (described under 'Nickel and Copper' below). HTX Minerals Corp. is currently exploring the Hele intrusion for PGE-Ni-Cu (Transition Minerals Inc., 2013).

Nickel and Copper

The Foxden Cu-Ni Occurrence is located west of the Hele intrusion, approximately 10 km west of the Township of Nipigon (Figure 5.1). The occurrence is contained within an extension of the Hele intrusion and is hosted in medium-grained pyroxenite in contact with dolostone of the Rossport Formation. A grab sample collected by OGS staff yielded 412 ppm Cu, 1,011 ppm Ni, 36 ppb Pt, and 27 ppb Pd (Schnieders et al., 2002).

The Hughes Point Copper Occurrence is located south of Nipigon Township outside the Nipigon area on the west side of Hughes Point. Calcareous sedimentary rocks of the Sibley Group host a number of narrow, Cu-mineralized calcite veinlets near the upper contact with a flat-lying diabase sill.

Silver, Lead, and Zinc

The Nipigon Silver Occurrence is located along the west side of Nipigon River approximately 3.5 km south of Highway 17 and consists of sub-economic traces of argentiferous galena and sphalerite. Sub-economic silver, lead and zinc mineralization is also reported at the Gordon and Ozone siding occurrences to the east of Nipigon River and north of the Trans-Canada Highway near the eastern limit of the Nipigon area.

Uranium

Narrow but high grade veins of pitchblende occur in the Eagle Mountain area and east of Black Sturgeon Lake (approximately 50 km northwest of Nipigon). Grades of up to 12% U have been reported (Scott, 1987) in the Black Sturgeon Lake area, although this occurrence was in a relatively small zone and the zone is not considered to have economic potential. Rocks of the Quetico Subprovince are anomalously high in uranium, and the uranium has been remobilized into faults and geochemical traps and veins associated with the unconformity between the Archean metasedimentary rocks of the Quetico Subprovince and the younger Sibley Group.

Uranium-bearing pegmatite dykes are associated with felsic plutonic rocks in the Quetico Subprovince. Several occurrences have been documented by Scott (1987), including the Lake Helen occurrence on the western shore of Helen Lake. Trenching and sampling of this occurrence in 1967 by Aggressive Mining Limited yielded values up to 0.135% U_3O_8. The Hele Uranium Occurrence is located along the east side of the Black Sturgeon River, approximately 4 km west of the Township of Nipigon. It consists of a number of granitic dykes in granite gneisses. The main dyke strikes east-west and dips 40 degrees north. A grab sample assayed 0.096% U_3O_8 (Robertson and Gould, 1983). Hart (2005) reported that a number of properties in the Nipigon area were explored for uranium between 1977 and 1980 including the Eagle Mountain, and Fog Lake deposits along the west side of the Black Sturgeon fault zone, approximately 10 km to the northwest of the Township of Nipigon. No economic uranium mineralization was reported from this work.

Rare Metals and Rare Earths

Rare metals include Li, Rb, Cs, Be, Nb, Ta and Ga and the lanthanide elements (rare earth elements or REE) which are often associated with minerals such as spodumene, lepidolite, beryl and columbite-tantalite in highly fractionated phases of the peraluminous granite suite. Rare element-bearing pegmatites are known within the Nipigon area and surrounding lands. Smyk and Franklin (2007) described four types of rare element pegmatite in the area: albite-spodumene, complex type, petalite, and albite type. The most significant economically are the pegmatites of the Georgia Lake field northeast of the Nipigon area where Li, Ta, and Be-bearing pegmatite bodies are associated with peraluminous leucogranites. At least 38 occurrences are known, 10 of which are spodumene-bearing pegmatites having a combined tonnage of more than 10 million tonnes at an average grade of 1.14% Li (Smyk and Franklin, 2007). Breaks et al. (2008) have also reported REE to exist in S-type peraluminous granites and pegmatites that occur in the Helen Lake area, with total REE contents of up to 459 ppm in the granitic rocks and 288 ppm in the pegmatitic rocks.

5.2 Non-Metallic Mineral Resources

Known non-metallic mineral resources within the Nipigon area include building stone, sand and gravel, peat, amethyst and barite.

Stone, Sand and Gravel

Small sand and gravel pits are also present within the Nipigon area, although there is no available inventory of sites. Sand and gravel deposits have been locally exploited for construction of forest access roads in the Melgund Lake area and similar potential exists elsewhere along the Hartman, Lac Seul and Eagle-Finlayson moraines as well as coarser deposits such as those of the former glacial Lake Agassiz (Figure 2.4).

Quarrying for stone and/or manufactured aggregate has been carried out at a number of locations in the Nipigon area, including the Nipigon River Marble Quarry, located in the southeast part of Nipigon Township along the Nipigon River, and the Ruby Lake Marble Quarry, located approximately 5 km east of Ruby Lake.

Peat

A number of peat deposits are identified within the wetlands of Black Bay Peninsula south of the Township of Nipigon, however, no commercial peat extraction is known to have occurred in the area.

Diamonds

No diamond-bearing kimberlites or lamproites have been identified in the Nipigon area, although the potential for the Canadian Shield to host economic diamond deposits has been demonstrated by a number of mines in the Northwest Territories, Nunavut, and Ontario.

Industrial Minerals

A barite deposit is recorded along the west shore of Kama Bay to the east of the Nipigon area, while the Stenlund Amethyst Occurrence (which also contains minor barite) is located approximately 5 km east of the Highway 11 turnoff at Nipigon.

5.3 Petroleum Resources

The Township of Nipigon is located in a largely crystalline geological setting with relatively thin Mesoproterozoic sedimentary rocks and mafic sills overlying the gneissic metasedimentary rocks of the Archean Quetico Subprovince. There are no known hydrocarbon exploration activities in the Nipigon area and the potential for petroleum resources is considered to be negligible.

6.0 GEOMECHANICAL AND THERMAL PROPERTIES

Geomechanical information including intact rock properties, rock mass properties and *in situ* stress are needed to design stable underground openings, predict the subsequent behaviour of the rock mass around these openings and predict the response of the groundwater flow system. As such, geomechanical information associated with a potential host rock can be used when addressing several geoscientific, safety-related factors defined in the site selection process document (NWMO, 2010). There is no readily available geomechanical information on the potentially suitable bedrock units in the Nipigon area. However, there is geomechanical information from bedrock units elsewhere in the Canadian Shield with rock types similar to those of interest in the Nipigon area (granitic intrusive bodies and gneissic metasedimentary rocks) as summarized in Table 6.1. These sites are the Lac du Bonnet granite at AECL's Underground Research Laboratory (URL) in Pinawa, Manitoba, the Eye-Dashwa granite near Atikokan, Ontario, and the gneissic metasedimentary rocks of Chalk River, Ontario. The majority of the geomechanical characterization work for the URL was conducted on these rocks as part of AECL's Nuclear Fuel Waste Management Program in the 1990s.

6.1 Intact Rock Properties

Intact rock properties tabulated in Table 6.1 are based on laboratory testing of rock core specimens from boreholes. The table also includes rock properties such as density, porosity, uniaxial compressive strength and tensile strength for use in engineering design and structural analyses. These parameters feed into the rock mass classification schemes. In the absence of site-specific information on the intrusions and gneissic metasedimentary rocks of the Nipigon area, at this early stage of the site assessment process, it is useful to look at the geomechanical properties of other intact crystalline rocks such as the Lac du Bonnet batholith, Eye-Dashwa pluton, Chalk River gneissic metasedimentary rocks and similar rock types elsewhere. The rock property values presented in Table 6.1 are consistent with the values selected for numerical modelling studies conducted to evaluate the performance of hypothetical repository designs in a similar crystalline rock environment (SNC-Lavalin, 2011; Golder, 2012b).

Table 6.1: Summary of Intact Rock Properties for Selected Canadian Shield Rocks

Property	Lac du Bonnet Granite	Eye-Dashwa Granite	Chalk River Gneiss
Uniaxial Compressive Strength (MPa)	185 ± 24[a]	212 ± 26[a]	216 ±33[b] 121 ±44[e] 189 ±51[f]
Split Tension Strength (Brazilian) (MPa)	4 to 9[b]	NA	7 to 14[e,f]
Porosity (%)	0.35[a]	0.33[a]	0.1 to 3 0.5 average[d]
P-wave velocity (km/s)	3.220 - 4.885[c]	NA	3.8 to 6[e,f]
S-wave velocity (km/s)	2.160 – 3.030[c]	NA	2.1 to 3.5[e,f]
Density (Mg/m^3)	2.65[a]	2.65[a]	2.6 to 3[e,f]
Young's Modulus (GPa)	66.8[a]	73.9[a]	76[b]
Poisson's Ratio	0.27[a]	0.26[a]	0.26[b]
Thermal Conductivity (W/(m°K))	3.4[a]	3.3[a]	NA

Property	Lac du Bonnet Granite	Eye-Dashwa Granite	Chalk River Gneiss
Coef. Thermal Expansion ($x10^{-6}/°C$)	6.6[a]	15[a]	NA

NA = Not Available

[a]Stone et al., 1989
[b]Annor et al., 1979
[c]Eberhardt et al., 1999
[d]Thomas & Hayles, 1988
[e]Gorski et al., 2009
[f]Gorski and Conlon, 2010

6.2 Rock Mass Properties

Fracture spacing, orientation and condition (width or aperture, mineral fill, evidence of relative displacement, etc.) of the fractures tend to influence the overall mechanical response of the rock mass. The only readily available information on rock mass properties for the Nipigon area is a brief description of joint orientation and spacing contained in some assessment files.

In general, there will be a downward decreasing fracture density from highly fractured rocks in shallow horizons (ca. < 300 m below ground surface) to sparsely fractured intact rock at greater depths as recorded at other shield sites (e.g., Everitt, 2002). Fractures observed on surface bedrock exposures may occur as well-defined sets of geological discontinuities, or as randomly oriented and variably-dipping features. Based on observations from other shield sites (e.g., Everitt, 2002) and stress measurement data (e.g., Maloney et al., 2006), it could be inferred that a shallowly-dipping to sub-horizontal fracture set may exist as a result of either strain released during the rebound from the last glacial cycle or the presence of pre-existing fabric anisotropy (e.g., bedding, tectonic foliation) in the rock structure.

6.3 *In Situ* Stresses

Knowledge of the *in situ* stresses at a site is required to model the stress concentrations around underground excavation designs. These stress concentrations are ultimately compared to the strength of a rock mass to determine if conditions are stable or if the excavation design needs to be modified. This is particularly important in a repository design scenario, where minimization of excavation-induced rock damage is required.

Horizontal stress conditions are more difficult to estimate. Over-coring or hydraulic fracturing methods can be used to determine the stresses on a plane at depth and resolve the horizontal *in situ* stress conditions (or resolve inclined principal stresses). A large set of such horizontal stress measurements is available from various locations in the Canadian Shield (Kaiser and Maloney, 2005; Maloney et al., 2006). These data are presented on Figure 6.1. Herget and Arjang (1990), Arjang (1991) and Arjang and Herget (1997) indicate pre-mining, major horizontal compressional stress directions of about northeast-southwest, based on stress testing and analyses completed at depths of 1,000 mbgs at the David Bell Mine located near Marathon, Ontario (Kaiser and Maloney, 2005). The reported maximum principal stress data available from two sets of tests were 34.7 and 44.6 MPa oriented north-south, with the minimum principal stress being subvertical. *In situ* stress conditions are also given for the palladium-platinum mine at Lac Des Illes some 70 km to the west of the Nipigon area. At this location, the maximum principal horizontal stress direction is reported to be east-west (Tetra Tech, 2013) although no test data was included.

The observation that the stress state is neither constant nor linear (Maloney et al., 2006) suggests that variability should be expected in the Canadian Shield. Based on the available stress measurement data, Maloney et al. (2006) developed a conceptual model that describes the variable stress state in the upper 1,500 m of the Canadian Shield. The conceptual model identifies a shallow stress released zone from surface to a depth of 250 m, a transition zone from 250 to 600 m and an undisturbed stress zone below 600 m. The undisturbed stress zone can be expected to be representative of far-field boundary stress conditions, whereas stresses within the shallow zone tend to be lower as they have been disturbed through exhumation and influenced by local structural weaknesses such as faults (Maloney et al., 2006). Typical repository depths of approximately 500 m fall within the transition zone, where the maximum principal stress may range from approximately 20 to 50 MPa.

The data presented by Maloney et al. (2006) indicate an average northeast-southwest orientation for the maximum horizontal stress, which is consistent with the World Stress Map, although north-south stress orientations appear to be common in northwest Ontario including a 90° change in azimuth of the maximum compressive stress axis which was identified in the near surface of the Whiteshell area of Manitoba (Brown et al., 1995). A roughly north-south orientation of maximum horizontal compressive stress was also found for the Sioux Falls Quartzite in South Dakota (Haimson, 1990).

Local stress relief features such as faults and shear zones can be expected to locally affect the stress regime. For example, thrust faults at AECL's URL were shown to be boundaries between significant changes in the magnitude and orientation of the principal stresses. Above a major thrust fault, located at depth of 270 m (referred to as Fracture Zone 2, or FZ2 at the site), the magnitude was close to the average value for the Canadian Shield and the orientation of the maximum horizontal stress was consistent with the average predicted by the World Stress Map (i.e., southwest) (Heidbach et al., 2009). Below the same thrust fault, the stress magnitudes are much higher than the average data for the Canadian Shield, and the maximum principal stress rotates approximately 90° to a southeast orientation (Martino et al., 1997). The principal maximum horizontal stress magnitude below the Fracture Zone 2 thrust fault remains relatively constant around 55 to 60 MPa, which is more typical of the values found at greater depths. The southeast orientation of the maximum principal horizontal stress is consistent with the data presented by Herget (1980) for the area which indicates maximum compression clustered in the southwest and southeast for the Canadian Shield.

In addition to loading history and geologic structure, *in situ* stress conditions are further influenced by rock mass complexity (i.e., jointing, heterogeneities and mineral fabric). As such, local stresses may not resemble the average stress state for a region (Maloney et al., 2006). The conceptual model presented by Maloney et al. (2006) is considered appropriate for sub-regional scale modelling activities. Due to wide scatter in the data (Figure 6.1), site-specific measurements would be needed for more detailed design activities.

6.4 Thermal Conductivity

Thermal conductivity values for potential host rocks provide information on how effectively the rock will transfer heat from the repository and dissipate it into the surrounding rock. The thermal conductivity of a rock is in part dependent on its mineral composition, with rocks composed of higher quartz content generally having higher thermal conductivities. The thermal conductivity of quartz (7.7 W/(m˚K)) is greater than that of other common rock-forming minerals such as feldspars (1.5 to 2.5 W/(m˚K)) or mafic minerals (2.5 to 5 W/(m˚K)) (Clauser and Huenges, 1995).

There are no site-specific thermal conductivity values or detailed quantitative mineral compositions for the metasedimentary rocks of the Quetico Subprovince or the biotite-muscovite granite suite in the Nipigon area. The quartz mineral content of the granitic rocks that are of interest as a potential repository host are likely to range from approximately 20% to 60% by volume (Streckeisen, 1976). The range of measured thermal conductivity values for plutonic rock types found in the literature are presented in Table 6.2.

Table 6.2: Thermal Conductivity Values for Granite, Granodiorite and Tonalite

Rock type	Average thermal conductivity (W/(m˚K))	Minimum thermal conductivity (W/(m˚K))	Maximum thermal conductivity (W/(m˚K))
Granite[a,b,c,d,e,f,g]	3.15	2.60	3.63
Granodiorite[a,f,g]	2.69	2.44	2.86
Tonalite[h,i]	3.01	2.95	3.14

a Petrov et al., 2005; b POSIVA, 2011; c Stone et al., 1989; d SKB, 2007; e Liebel et al., 2010; f Fountain et al., 1987; g Fernandez et al., 1986; h de Lima Gomes and Mannathal Hamza, 2005; i POSIVA, 2007a

Although no thermal conductivity values are available for the Nipigon area, some useful comparisons are provided by Stone et al. (1989) in their summary of thermal conductivity values for two late Archean granitic intrusions of the Superior Province of the Canadian Shield, the Lac du Bonnet batholith and the Eye-Dashwa pluton (Table 6.1). Both intrusions were described as having similar mineralogical compositions, with quartz content generally varying between 23 and 27%. The average thermal conductivity for the Eye-Dashwa pluton was 3.3 W/(m˚K) based on 35 samples. The average thermal conductivity for the Lac du Bonnet batholith was 3.4 W/(m˚K) based on 227 samples.

The above literature values for thermal conductivity are considered useful for comparison purposes as part of this preliminary assessment.

7.0 POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE NIPIGON AREA

7.1 Approach

The objective of the Phase 1 geoscientific desktop preliminary assessment was to assess whether the Nipigon area contains general areas that have the potential to satisfy the geoscientific evaluation factors and safety functions defined in the site selection process document (NWMO, 2010). The repository is expected to be constructed at a depth of about 500 mbgs. The surface facilities will require a dedicated surface area of about 600 by 550 m for the main buildings and about 100 by 100 m for the ventilation exhaust shaft (NWMO, 2014). The actual underground footprint at any particular site would depend on a number of factors, including the characteristics of the rock, the final design of the repository and the inventory of used fuel to be managed. For the purpose of this preliminary assessment, it was assumed that the repository would require a footprint in the order of 2 by 3 km.

The geoscientific assessment of potential suitability was carried out in two steps. The first step (Section 7.2) was to identify general potentially suitable areas using the key geoscientific characteristics described below. The second step (Section 7.3) was to verify that identified general areas have the potential to meet all NWMO's geoscientific site evaluation factors (NWMO, 2010). Areas closer to two First Nation reserves were not assessed for their potential, but rather were included to improve the understanding of the geology of the Nipigon area. The potential for finding general potentially suitable areas was assessed using the following key geoscientific characteristics:

- ***Geological Setting:*** Areas of unfavourable geology identified during the Initial Screening (Golder, 2011) were not considered. These include areas underlain by the Mesoproterozoic sedimentary rocks of the Sibley Group and areas covered by surface outcroppings of the Nipigon sills. These groups of rock are too thin within the Nipigon area to host a geological repository and their presence at the ground surface hinders detailed investigation of the underlying rock units. The Archean metasedimentary rocks of the Quetico Subprovince exposed at surface across the northern part of Nipigon area and related granitic plutons in the northwest part of the Nipigon area near Mound Lake were inferred to have sufficient thickness for the purpose of siting a deep geological repository and were investigated further.

- ***Structural Geology:*** Areas within or immediately adjacent to regional faults and fault zones were avoided. The main structural features in the Nipigon area include major fault zones such as the Black Sturgeon fault zone and the Jackpine River fault, as well as the Gravel River fault that borders the southeast corner of the Nipigon area. There are also several mapped but unnamed brittle faults of lesser extent within the Nipigon area.

- ***Lineament Analysis:*** In the search for general potentially suitable areas, there was a preference to select areas that have a relatively low density of lineaments, particularly a low density of longer lineaments, as they are considered more likely to extend to greater depth than shorter lineaments. For the purpose of this assessment, all interpreted lineaments (fractures and dykes) were conservatively considered as conductive (permeable) features. In reality, many of these interpreted features may be sealed due to higher stress levels at depth and the presence of infilling.

- ***Overburden:*** The distribution and thickness of overburden cover was an important site characteristic to consider when assessing amenability of an area to site characterization. For practical reasons, it was considered that areas covered by more than 2 m of overburden deposits would not be amenable to trenching for the purpose of structural mapping. This consideration is consistent with international practices related to site characterization in areas covered by overburden deposits (e.g., in Finland; POSIVA, 2007b). At this stage of the assessment, preference was given to areas with greater mapped bedrock exposures. The extent of bedrock exposure in the Nipigon area is shown on Figure 2.3. Bedrock exposure is greatest in the eastern part of the Nipigon area near the Jackpine River fault and in the west part of the Nipigon area in a belt running from the Mound Lake area in the north to, and including, the Township of Nipigon. Outside of these two larger areas, areas of exposed bedrock are more variable and extensive overburden cover exists within the central portion of the Township of Nipigon. Localized areas of bedrock exposure along the shores of the Nipigon River were considered less favourable given their relatively limited areal extent and the proximity of the Nipigon River and large lakes such as Helen Lake.

- ***Protected Areas:*** All provincial parks and conservation reserves within the Nipigon area were excluded from consideration in the selection of potentially suitable areas. There are two provincial parks, four conservation reserves and two forest reserves in the Nipigon area (Figure 1.1). The largest of these is the Black Sturgeon River Provincial Park, partially located within the Nipigon area, which covers 237 km^2 and is located along the Black Sturgeon River to the west of the Township of Nipigon. The Ruby Lake Provincial Park is also partially within Nipigon area along the north shore of Nipigon Bay. There are a number of conservation and forest reserves also in the Nipigon area, including the Kama Cliffs Conservation Reserve, the Seahorse Lake Conservation Reserve and the proposed Lake Superior

Archipelago Conservation Reserve. Archaeological sites are present along the north shore of Nipigon Bay and along the Nipigon River. Areas closer to two First Nation reserves were also not assessed.

- ***Natural Resources:*** Areas with known potential for exploitable natural resources were not considered. The potential for natural resources in the Nipigon area is shown on Figure 5.1. These include mafic to ultramafic intrusions such as the Hele intrusion in the southwestern western part of the Nipigon area to the west of the Black Sturgeon River. Sporadic exploration continues elsewhere across the Nipigon area, particularly for rare earth elements and rare metals within pegmatites cross cutting metasedimentary and intrusive rocks of the Quetico Subprovince, but the overall potential for economically exploitable mineralization is considered low and no economic mineral deposits are known to exist within the Nipigon area. At this stage of the assessment, areas covered by active mining claims were not systematically excluded if the claims were located in geological environments judged to have low mineral resource potential, particularly where the claims were of short tenure.

- ***Surface Constraints:*** For the identification of potentially suitable areas, the principal factors considered were topography and the size and location of water bodies and wetlands. While there are some areas of significant relief, there are few large lakes within the Nipigon area. The similar nature of conditions resulted in no areas being directly excluded from further consideration by this constraint. The majority of the Nipigon area is accessible from the Trans-Canada Highway (Highway 17) via a network of secondary and logging roads.

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the above geoscientific evaluation factors and constraints revealed that the Nipigon area contains at least two general areas that may warrant further consideration. One general area is located within the Archean metasedimentary rocks of the Quetico Subprovince in the east part of the Nipigon area to the west of the Jackpine River fault zone. A second small area is located within the muscovite granite pluton and surrounding Archean metasedimentary rocks in the northwest part of the Nipigon area in the vicinity of Mound Lake. Figure 7.1 shows features illustrating some of the key characteristics and constraints used to identify general potentially suitable areas including: bedrock geology, protected areas, areas of thick overburden cover, surficial and geophysical lineaments, the existing road network, the potential for natural resources, and mining claims. The legend of this figure includes a 2 by 3 km box to illustrate the approximate surface area of potentially suitable rock that would be needed to host a repository.

The following sections describe how the key geoscientific factors and constraints discussed above were applied to the various geological units within the Nipigon area to assess whether they contain general areas that have the potential to satisfy the NWMO's geoscientific site evaluation factors. The assessment indicated that there are substantial geological uncertainties associated with the two identified general areas that reduce the likelihood of identifying sites that will satisfy NWMO's geoscientific site evaluation factors.

7.2.1 Metasedimentary Rocks of the Quetico Subprovince

As discussed in Section 3.2.1.1, Archean rocks of the Quetico Subprovince consist of ca. 2.698 to 2.690 billion year old gneissic-textured metasedimentary rocks with a probable thickness exceeding 7.5 km. Rocks of the Quetico Subprovince cover the majority of the Nipigon area and also extend beneath the younger sedimentary rocks of the Sibley Group and the Nipigon sills.

The metasedimentary rocks in the east part of the Nipigon area to the west of the Jackpine River fault and to the north of the Kama Cliffs Conservation Reserve have a number of favourable geoscientific characteristics for hosting a repository. These rocks have low potential for natural resources and are mostly free of surface constraints (i.e., topography and large water bodies). Therefore, the main factors used to identify this general potentially suitable area within the metasedimentary rocks of the Quetico Subprovince were bedrock exposure, structural geology, and long lineament density.

In this area, large portions of metasedimentary rocks of the Quetico Subprovince are either exposed or covered by a thin till or glaciolacustrine veneer (generally less than 2 m). The prominent Jackpine River fault borders the east part of the area running in a northeasterly direction along the east side of the Kama Hills and extending beyond the Nipigon area to the northeast. The proximity of a major fault zone to the east side of the area represents a degree of structural uncertainty that would have to be further assessed. Other mapped faults in the area include the Gravel River fault located at the southeast corner of the Nipigon area, and the Black Sturgeon fault zone in the west part of Nipigon area.

The magnetic response over metasedimentary rocks west of the Jackpine River fault is generally quiescent but this may reflect the low resolution of the survey coverage in this area. While the bedrock in the potentially suitable area is mapped entirely as gneissic-textured metasedimentary rock, lithological homogeneity is uncertain at this stage due to the presence of gneissic banding and varying degrees of metamorphism that these rocks experienced in the past. Lithological heterogeneity has the potential to make site characterization more difficult and lead to spatially variable geomechanical, thermal and hydrogeological properties.

The identification of general potentially suitable areas also took into consideration the analysis of interpreted lineaments (Section 3.2.3.1). The density of interpreted surficial lineaments in this area is moderate to high and largely reflects the high percentage of bedrock exposure in the area (Figure 3.13). The frequency of surficial lineaments is suspected to be broadly similar across the Nipigon area if the effects of overburden and vegetative cover were removed. The orientation of surficial lineaments shows prominent trends to the north-northwest, north, and east-northeast. At the desktop stage of the assessment, the nature of bedrock structure associated with surficial lineaments is uncertain, as it is unknown how far such features extend to depth, particularly those associated with the shorter lineaments. The dip of structural lineaments is also uncertain.

Figures 3.9 and 7.1 show the distribution of geophysical lineaments over the metasedimentary rocks of the Quetico Subprovince. Geophysical lineaments tend to be sparsely distribution in the east, and more prominent in the west, where higher resolution geophysical data is available. It is probable that the geophysical lineament density interpreted for areas with high-resolution data is in fact more generally representative of the metasedimentary rocks in the Nipigon area. Nonetheless, the spacing between geophysical lineaments in the area with high-resolution data is generally on the order of 1 to 3 km.

The distribution of lineament density as a function of lineament length over the metasedimentary rocks is shown on Figures 3.13 to 3.16 for all lineaments and lengths greater than 1 km, 5 km and 10 km, respectively. The figures show that in general the density of lineaments progressively decreases throughout the metasedimentary rocks as shorter lineaments are filtered out. The spacing between longer lineaments (i.e., those longer than 10 km) over the metasedimentary rocks is typically on the order of 5 km or more.

There are three mapped dykes identified in the general potentially suitable area. Two of these strike north-northwest and are located in the area west of the Jackpine River fault. The third strikes northeasterly, and is located east of and broadly parallel to the Jackpine River fault. There remain some uncertainties regarding the nature and distribution of the dykes. For example, the potential existence of thin dykes, which are too small to be identified with any confidence from the geophysical data, cannot be ruled out. Another aspect of uncertainty associated with the presence of dykes relates to understanding the extent of damage to the host rock as a result of dyke emplacement. It is well understood, but not easily quantifiable from geophysical data alone, that dyke propagation will induce damage to the host rock within an envelope around the dyke that varies with the size of the intrusion (e.g., Meriaux et al., 1999).

As discussed in Section 3.2.1.6, Nipigon diabase sills occur widely within the Nipigon area along a diagonal trend from the northwest corner of the Township to the southeast. The outcrops of diabase are typically less than 1 km^2 in size and about 100 m thick (Hart, 2005), although their subsurface extent may be greater. In this general potentially suitable area there is no outcrop of diabase sills at surface. The geophysical interpretation by PGW (2014) suggests that the sills are present in the western part of the area of metasedimentary rocks beyond the extent that is shown in the bedrock geology map, but the geophysical data over the eastern part is too low in resolution to interpret whether or not there are also sills present. There is no evidence that sills are present at depth beneath the Nipigon area, however, stacked sills have been identified in outcrop of strata of the Sibley Group in the Eagle Mountain area to the immediate west of the Nipigon area, and a hypothetical buried sill is illustrated on conceptual cross-section D-F on Figure 3.4. A buried sill, approximately 50 m thick, was encountered in diamond drilling at the Seagull Lake intrusion some 20 km west of the Nipigon area, but no buried sills were identified in diamond drill holes in the closer Hele intrusion, nor were buried sills encountered in diamond drilling along the Jackpine River fault in the eastern part of the Nipigon area (Noranda, 1990) or in diamond drilling to the immediate north of the Nipigon area (Fenwick, 2000). Similar to dykes, intrusions of sills can cause damage to the surrounding host rock. The presence of sills at depth, and associated rock damage, has the potential to create pathways for groundwater movement, which could affect the containment and isolation characteristics of the rock. The potential presence and impact of diabase sills at depth would require further assessment.

Active mining claims (as of December, 2013) are present only in the area adjacent to the Jackpine River fault (Figure 5.1 and 7.1). No economic mineralization occurs within the area and the mineral resource potential is considered low. Access is good throughout the area via Highway 17 and a network of secondary and logging roads. There are no significant topographic features that would make site investigation or construction exceptionally difficult. The area is generally well drained with few areas of wetland and these are generally of small areal extent. Terrain mapping (see Figure 2.3) shows that approximately 91% of the area is mapped as bedrock terrain.

In summary, the general area of metasedimentary rocks of the Quetico Subprovince in the east part of the Nipigon area to the west of the Jackpine River fault and to the north of the Kama Cliffs Conservation Reserve (Figure 7.1) appears to be potentially suitable based on its favourable geology and structural setting. However, there are significant uncertainties that reduce the likelihood of the identified potentially suitable area to satisfy NWMO's site evaluation factors. These uncertainties include: the potential presence of dykes and sills not identifiable in areas where there is low resolution geophysical data; the potential for host rock damage due to the intrusion of these features; the potential effect of the Jackpine River fault; and lithological homogeneity of the metasedimentary rocks in the area.

7.2.2 Mound Lake Pluton and Surrounding Metasedimentary Rocks

An approximately 38 km^2, elliptical pluton of muscovite granite is located south of Mound Lake near the northwest corner of the Nipigon area (Figure 7.1). No information as to the age or thickness of the pluton was found in the available literature, but the presence of xenoliths of metasedimentary gneissic rocks throughout the intrusion (Hart, 2005) indicates that it intruded into the metasedimentary rocks of the Quetico Subprovince and hence must post-date their deposition, deformation and metamorphism. The granite is described as medium- to very coarse-grained with occasional pegmatitic sections (see Section 3.2.1.2). The characterization of the granite as coarse-grained (Hart, 2005) suggests slow cooling following emplacement, and its late intrusion relative to the surrounding country rock suggests a less complex structural history than experienced by the enclosing gneissic metasedimentary rocks.

The Mound Lake granite pluton and surrounding metasedimentary rocks of the Quetico Subprovince have a number of favourable geoscientific characteristics for hosting a repository including sufficient size and probable sufficient vertical extent. The granite pluton is surrounded by metasedimentary rocks of the Quetico Subprovince along all margins except the south where it is bordered by an approximately 10 km^2 body of massive granite to granodiorite. This bordering granitic body is proximal to the Black Sturgeon River Provincial park and on its own may be considered too small to potentially host a deep geological repository. Approximately 84% of the Mound Lake pluton and adjacent metasedimentary and granitic rocks are mapped as bedrock terrain (Figure 2.3). The mineral potential in the area is low, and there is no history of mineral exploration. The prominent Black Sturgeon fault zone runs in a northwest-southeast direction to the immediate west of the pluton. This fault is approximately 65 km long and coincident with the Black Sturgeon River over much of its extent. The fault zone forms the northeastern border of a graben structure with rocks to the west of the fault downdropped by several hundred metres compared to rocks to the east (Hart, 2005). A second smaller unnamed fault is mapped running north-south though the eastern boundary of the pluton. While sufficient area to host a deep geological repository is present on either side of this unnamed fault, the presence of a major fault zone to the west, and lithological heterogeneity to the east of the unnamed fault represents substantial structural and geological uncertainty. Other mapped faults in the Nipigon area are located at a substantial distance (i.e. >30 km) and do not have potential to directly affect rocks in the Mound Lake area.

The Mound Lake granite and surrounding metasedimentary rocks are within an area of high-resolution geophysical coverage (Section 1.4.1). The outline of the pluton has a distinct magnetic signature, partly because it is surrounded to the north, west, and south by the outcropping of a Nipigon diabase sill that is clearly discernible in the aeromagnetic data (Figures 3.5 and 3.6). Although the outline the pluton tends to coincide well with the majority of the mapped granitic intrusion, there appears to be some discrepancy along the pluton's eastern contact with the mapped metasedimentary units (PGW, 2014). The gravity data over the pluton (Figure 3.7) shows a low response in the area mapped as granite, which increases in magnitude into the mapped metasedimentary unit to the east.

The distribution of lineament density as a function of lineament length over the metasedimentary rocks is shown on Figures 3.13 to 3.16 for all lineaments and lengths greater than 1 km, 5 km, and 10 km, respectively. The figures show that in general the density of lineaments progressively decreases within the granite pluton and the metasedimentary rocks as shorter lineaments are filtered out. The spacing between longer lineaments (i.e., those longer than 10 km) over the metasedimentary rocks is typically on the order of 5 km or more.

No mafic dykes are mapped in the Mound Lake area and the detailed mapping and high-resolution geophysical coverage suggests a low likelihood that there are unmapped dykes in the area. Outcrops of Nipigon diabase are mapped along portions of the contact between the Mound Lake granite intrusion and the surrounding rock, suggesting that a diabase sill might cross-cut the pluton at shallow depth (see Section D-F on Figure 3.4). Geomechanically the sills have potential to induce damage to the host rock within an envelope around their contact. Their horizontal planar morphology limits the depth of any associated structural effects, but may affect the amenability of the area to detailed investigation by masking underlying rocks.

The Mound Lake granite and surrounding metasedimentary rocks are located outside of protected areas but the Black Sturgeon River Provincial Park abuts its western border. Lands within the pluton are Crown lands, free of mining claims. No economic mineralization occurs within the area and the mineral potential is considered low. Access is good throughout the area via secondary roads from Highway 17. There are no significant topographic features in the area that would make site investigation or construction notably difficult. The area is generally well drained with only small, discontinuous areas of wetland, and no lakes present of any significant size. The area is a local topographic high with low to moderate relief. Terrain mapping (see Figure 2.3) shows that approximately 84% of the area is mapped as bedrock terrain.

In summary, the Mound Lake granite and metasedimentary rocks of the Quetico Subprovince to the immediate east were identified as a general potentially suitable area. However, substantial geologic uncertainties remain. These include the potential influence that the nearby Black Sturgeon fault zone may have had on the structural geology and fracture network of the area; the potential for a Nipigon diabase sill to cross-cut the pluton at shallow depth; and the lithological homogeneity of the area, such as the presence of xenoliths of metasedimentary gneissic rocks within the granitic intrusion.

7.2.3 Other Areas

No other prospective areas were identified within the Nipigon area. Small granitic plutons of uncertain origin are mapped within the metasedimentary rocks of the Quetico Subprovince within the central (Helen Lake area) and western (Stretton Lake area) portion of the Nipigon area, but these appear to have insufficient areal extent to host a repository and they generally occur as “islands” within more extensive areas of unfavourably thick overburden. Potentially suitable areas of metasedimentary rocks to the east of the Jackpine River fault are generally similar to those described in Section 7.2.1, but they were excluded from that general siting area on the basis of a higher density of intermediate length lineaments (Figure 3.15) and the limited amount of available area between the Jackpine River fault and the eastern boundary of the Nipigon area.

Given the above considerations, the potential for identifying additional general potentially suitable siting areas appears to be limited. The two general areas identified are those judged with the best potential to meet the preferred site characteristics outlined in Section 7.1.

7.2.4 Summary of Geoscientific Characteristics of the General Potentially Suitable Areas

Table 7.1 provides a summary of the key geoscientific descriptive characteristics of the two identified general areas in the Nipigon area.

Table 7.1: Summary of Geoscientific Characteristics of the Potentially Suitable Ares in the Metasedimentary Rocks of the Quetico Subprovince and Mound Lake Pluton - Nipigon

Geoscientific Descriptive Characteristic	*Metasedimentary Rocks of the Quetico Subprovince*	*Mound Lake pluton and surrounding metasedimentary rocks of the Quetico Subprovince*
Rock Type	Predominantly gneissic and migmatized metasedimentary rocks	Predominantly muscovite granite emplaced within metasedimentary rocks of the Quetico Subprovince. Flanking diabase sill – likely cross-

Geoscientific Descriptive Characteristic	***Metasedimentary Rocks of the Quetico Subprovince***	***Mound Lake pluton and surrounding metasedimentary rocks of the Quetico Subprovince***
		cutting
Age	ca. 2.698 to 2.690 Ga	ca. 2.698 to 2.690 Ga
Inferred host rock thickness	> 7.5 km	> 7.5 km for the metasedimentary rocks; unknown for the granite plutons but anticipated to exceed 1 km
Extent of rock unit within the Nipigon area	325 km^2	307 km^2
Relative proximity to mapped regional geological features	Jackpine River fault – 10 km Gravel River fault – 20 km Black Sturgeon River fz – 31 km Midcontinent Rift – ca. 40 km	Jackpine River fault – 43 km Gravel River fault – 50 km Black Sturgeon River fz – 7 km Midcontinent Rift – ca. 60 km
Structure: faults, foliation, dykes, joints	Jackpine River fault bounds the east site of the area; Foliation parallel to the gneissic fabric; Moderate apparent surficial lineament density; Low apparent geophysical lineament density; Potential presence of dykes and sills.	Black Sturgeon fault zone bounds the west side of the area; Foliation parallel to the gneissic fabric; Moderate apparent surficial lineament density; Moderate apparent geophysical lineament density; N-S oriented mapped fault bisects area; Potential presence of dykes and sills.
Aeromagnetic characteristics and resolution	Quiescent to moderately noisy, Low resolution	Quiescent to moderately noisy, high resolution
Terrain: topography, vegetation	Low to moderate relief, variable forest cover	Moderate relief, variable forest cover
Access	Good access via secondary roads from Highway 17	Good access via secondary roads from Highway 17
Resource Potential	Low	Low
Bedrock Exposure	Very high approximately 91% bedrock terrain	Very high approximately 84% bedrock terrain
Drainage	Generally good throughout; mostly within the Jackpine River drainage basin	Generally good throughout; mostly within the Black Sturgeon River drainage basin

7.3 Evaluation of the General Potentially Suitable Areas in the Nipigon Area

This section provides a brief description of how the identified potentially suitable areas were evaluated to verify whether they have the potential to satisfy the geoscientific safety functions outlined in NWMO's site selection process (NWMO, 2010). At this early stage of the site evaluation process, where limited geoscientific information is available, the intent is to assess whether there are any obvious conditions within the identified potentially suitable areas that would fail to satisfy the geoscientific safety functions. These include:

- ***Safe containment and isolation of used nuclear fuel:*** Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances caused by human activities and natural events?
- ***Long-term resilience to future geological processes and climate change:*** Are the rock formation at the siting area geologically stable and likely to remain stable over the very long term in a manner that will ensure the repository will not be substantially affected by geological and climate change process such as earthquakes and glacial cycles?
- ***Safe construction, operation and closure of the repository:*** Are conditions at the site suitable for the safe construction, operation and closure of the repository?
- ***Isolation of used fuel from future human activities:*** Is human intrusion at the site unlikely, for instance, through future exploration or mining?
- ***Amenable to site characterization and data interpretation activities:*** Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

The evaluation factors under each safety function are listed in Appendix A. An evaluation of the two identified general potentially suitable areas in the metasedimentary rocks of the Quetico Subprovince and the Mound Lake pluton and surrounding Quetico metasedimentary rocks is provided in the following subsections.

7.3.1 Safe Containment and Isolation of Used Nuclear Fuel

The geological, hydrogeological, chemical and mechanical characteristics of a suitable site should promote long-term isolation of used nuclear fuel from humans, the environment and surface disturbances; promote long-term containment of used nuclear fuel within the repository; and restrict groundwater movement and retard the movement of any released radioactive material.

This requires that:

- The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events;
- The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities;
- The hydrogeological regime within the host rock should exhibit low groundwater velocities;
- The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multiple-barrier system;
- The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement; and

- The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.

The above factors are interrelated as they contribute to more than one safety function. The remainder of this section provides an integrated assessment of the above factors based on information that is available at the desktop stage of the evaluation.

As discussed in Section 3 and summarized in Table 7.1, available geophysical information indicates that the estimated thickness of metasedimentary rocks of the Quetico Subprovince is greater than 7.5 km. While no information regarding the thickness of the Mound Lake pluton was found in the available literature, it is considered likely to exceed 1 km in depth based on comparison with other similar plutons within the Canadian Shield. Based on this, the thicknesses of the rock in the two general areas (Section 7.2) are likely to extend well below typical repository depths (approximately 500 m).

Analysis of existing information and of lineaments interpreted during this preliminary assessment (Section 3.2.3) indicates that the two general areas in the Nipigon area have the potential to contain structurally-bounded rock volumes of sufficient size to host a deep geological repository. The distribution of lineament density as a function of lineament length over the potentially suitable host rock units shows that the variable density and spacing of shorter brittle lineaments is influenced by the amount of exposed bedrock. By classifying the lineaments according to length, this local bias is reduced in both general areas because shorter lineaments are more heavily influenced by local variability in overburden cover. Spacing between longer lineaments (i.e., > 5 and 10 km in length) is generally on the order of 2 to 5 km, suggesting there is potential for there to be sufficient volumes of structurally favourable rock at typical repository depth. The proximity of these two areas to the Black Sturgeon fault zone and Jackpine River fault requires consideration. It is uncertain to what extent the two areas may be structurally affected (fractured) as a result of their proximity to these two features.

As discussed in Section 4.4, there is limited information on the hydrogeologic properties of the deep bedrock in the Nipigon area. It is therefore not possible at this stage of the evaluation to predict the nature of the groundwater regime at repository depth in the two identified potential siting areas. The potential for groundwater movement at repository depth is, in part, controlled by the fracture frequency, the degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of mineral infilling. Available information for other granitic intrusions (plutons and batholiths) within the Canadian Shield, indicates that active groundwater flow within structurally-bounded blocks tends to be generally limited to shallow fracture systems, typically less than 300 m. In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). However, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion-controlled conditions. Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan range from approximately 10^{-15} to 10^{-10} m/s (Ophori and Chan, 1996; Stevenson et al., 1996). Data reported by Raven et al. (1985) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400-500 m.

Experience from other areas in the Canadian Shield indicates that ancient faults, similar to those in the Nipigon area, have been subjected to extensive periods of rock-water interaction resulting in the long-term deposition of infilling materials that contribute to sealing and a much reduced potential for groundwater flow at depth. Site-specific conditions that can influence the nature of deep groundwater flow systems (such as *in situ* stress orientations or bounding effects created by rock damage associated with sill emplacement). Information on other geoscientific characteristics relevant to the containment and isolation functions of a deep geological repository, such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, and the thermal and geomechanical properties of the rock is limited for the Nipigon area. The review of available information from other locations with similar geological settings did not reveal any obvious conditions that would suggest unfavourable mineralogical or hydrogeochemical characteristics for the gneissic metasedimentary rocks or granitic plutonic rocks characterizing the two general potentially suitable areas identified within the Nipigon area.

Because of their horizontal nature, the existence and extent of Nipigon diabase sills at depth cannot be ruled out, even in areas where they do not have a surface outcrop. The intrusion of these sills in the geological past may have caused damage to the pre-existing rock. The presence of sills at depth, and associated rock damage, has the potential to create pathways for groundwater movement, which could affect the containment and isolation characteristics of the rock. The presence of mafic dykes and the potential presence of smaller dykes not identifiable on available mapping and geophysical data is also a consideration. Similar to the sills, the intrusion of dykes may have caused damage to the host rock that would need to be assessed. In addition, the thermal and hydraulic conductivity of the dykes and sills present in the area, relative to their host rock, requires investigation.

In summary, the review of available information, including completion of a lineament analysis and geophysical interpretation of the area, did not reveal any obvious geological or hydrogeological conditions that would indicate that the two identified general areas would be unable to satisfy the containment and isolation function. However, the extent to which the two areas may be structurally impacted as a result of their proximity to the Black Sturgeon fault zone and Jackpine River fault represents a significant uncertainty. Furthermore, the existence, extent and potential impact of diabase sills and mafic dykes in the Nipigon area would require additional investigation.

7.3.2 Long-term Resilience to Future Geological Process and Climate Change

The containment and isolation functions of the repository should not be unacceptably affected by future geological processes and climate changes, including earthquakes and glacial cycles.

The assessment of the long-term stability of a suitable site would require that:

- Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long term;
- The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository;
- The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository; and

- The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.

A full assessment of the above factors requires detailed site-specific data that would be typically collected and analyzed through detailed field investigations. The assessment would include understanding how the site has responded to past glaciations and geological processes and would entail a wide range of detailed studies involving disciplines such as seismology, hydrogeology, hydrogeochemistry, paleohydrogeology and climate change. At this desktop preliminary assessment stage of the site evaluation process, the long-term stability factor is evaluated by assessing whether there is any evidence that would raise concerns about the long-term stability of the two general potentially suitable areas identified in the Nipigon area. The remainder of this section provides assessment summary of the factors listed above.

The Nipigon area is located within the central Superior Province of the Canadian Shield, where large portions of land have remained tectonically stable for more than a billion years. In the last 25 years there has been only a single recorded seismic event within the Nipigon area (Figure 3.19) and eight events within 75 km. These events occurred along the Lake Superior shoreline and none measured greater than a magnitude of 3.

As discussed in Section 3.2, several prominent fault zones occur within or proximal to the Nipigon area including the Gravel River fault, the Jackpine River fault, and the Black Sturgeon fault zone. There is no available evidence of any recent movement within these fault zones in the Nipigon area, and the majority of the movement along these faults is inferred to have occurred during the Precambrian Era, although more recent reactivation cannot be ruled out at the desktop stage of assessment.

The geology of the Nipigon area is typical of many areas of the Canadian Shield and has been subjected to numerous glacial cycles during the last million years. Glaciation is a significant past perturbation that could occur in the future. However, findings from studies conducted in other areas of the Canadian Shield suggest that deep crystalline rocks, particularly plutonic intrusions, have remained largely unaffected by past perturbations such as glaciation. Findings of a comprehensive paleohydrogeological study of the fractured crystalline rock at the Whiteshell Research Area, located within the Manitoba portion of the Canadian Shield (Gascoyne, 2004), indicated that the evolution of the groundwater flow system was characterized by periods of long-term hydrogeological and hydrogeochemical stability. Furthermore, there is evidence that only the upper approximately 300 m have been affected by glaciations within the last million years. McMurry et al. (2003) summarized several studies conducted in a number of plutons in the Canadian Shield and in the crystalline basement rocks of northwestern Ontario. These various studies found that fractures below a depth of several hundred metres in the plutonic rock were typically ancient features. Subsequent geological processes such as plate movement and continental glaciations have caused reactivation of existing zones of weakness rather than the formation of large new zones of fractures.

The Nipigon area is still experiencing isostatic rebound following the end of the Wisconsinan glaciation (Section 3.3.2). Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the location of thickest ice at the last glacial maximum (Sella et al., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1 to 2 mm/yr) south of the Great Lakes. Lake level records (Mainville and Craymer, 2006) indicate that present day rebound rates in the Nipigon area should be well below 10 mm/yr, likely between 2 and 4 mm/yr. There is no site-specific information on erosion rates for the Nipigon area. However, as discussed in Section 3.1.6, the erosion rates from wind, water and past glaciations on the Canadian Shield are reported to be low.

In summary, available information indicates that the identified general siting areas in the Nipigon area have the potential to meet the long-term stability factor. The review did not identify any obvious geological or hydrogeological conditions that would cause the performance of a repository to be substantially altered by future geological and climate change processes, or prevent the identified areas from remaining stable over the long term.

7.3.3 Safe Construction, Operation and Closure of the Repository

The characteristics of a suitable site should be favourable for the safe construction, operation, closure and long term performance of the repository.

This requires that:

- The available surface area should be sufficient to accommodate surface facilities and associated infrastructure;
- The strength of the host rock and *in situ* stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities; and
- The soil cover depth over the host rock should not adversely impact repository construction activities.

There are few surface constraints that would limit the construction of surface facilities in the two general potentially suitable areas identified in the Nipigon area. These areas are characterized by low to moderate relief and each contains enough surface land outside protected areas and major water bodies to accommodate the required repository surface facilities.

From a constructability perspective, limited site-specific information is available on the local rock strength characteristics and *in situ* stresses for the plutons in the Nipigon area. However, there is abundant information at other locations of the Canadian Shield with similar types of rock that could provide insight into what should be expected for the Nipigon area in general. As discussed in Section 6, available information suggests that granitic crystalline rock units within the Canadian Shield generally possess good geomechanical characteristics that are amenable to the type of excavation activities involved in the development of a deep geological repository for used nuclear fuel (Arjang and Herget, 1997; Everitt, 1999; McMurry et al., 2003; Chandler et al., 2004). The conceptual model developed by Kaiser and Maloney (2005), based on available stress measurement data, describe the variable stress state in the upper 1,500 m of the Canadian Shield. Although this model can be used as an early indicator of average stress changes with depth, significant variations such as the principal horizontal stress rotation and the higher than average stress magnitudes found at typical repository depth (500 m) at AECL's URL (Martino et al., 1997) could occur as a result of local variations in geological structure and rock mass complexity.

The two general siting areas within the Nipigon area have excellent bedrock exposure. Overall, mapped bedrock terrain over the identified area of metasedimentary rocks of the Quetico Subprovince and the Mound Lake pluton and surrounding areas is very high (91% and 84%, respectively).

In summary, the two general potentially suitable areas in the Nipigon area have potential to meet the safe construction, operation, closure, and long term performance factors required of a repository.

7.3.4 Isolation of Used Fuel from Future Human Activities

A suitable site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities.

This requires that:

- The repository should not be located within rock units containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today; and
- The repository should not be located within geological units containing groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.

The mineral potential in the Nipigon area (Section 5) is considered low. No known economic mineralization has been identified to date within the two general siting areas, and few active mining claims exist in their vicinity.

The review of available information did not identify any groundwater resources at repository depth for the Nipigon area. As discussed in Section 4.3, the Ontario Ministry of the Environment's Water Well Record database shows that all water wells known in the Nipigon area obtain water from overburden and bedrock sources at depths of less than 140.5 m. Experience from other areas in the Canadian Shield has shown that active groundwater flow in crystalline rocks is generally confined to shallow fractured localized systems (Gascoyne et al., 1987; Gascoyne, 1994; 2000; and 2004). Water well records indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Nipigon area or anywhere else in northern Ontario. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits potential yield, even if suitable water quality were to be found.

In summary, the potential for groundwater resources and economically exploitable natural resources at repository depth is considered low.

7.3.5 Amenability to Site Characterization and Data Interpretation Activities

In order to support the case for demonstrating long-term safety, the geologic conditions at a potential site must be amenable to site characterization and data interpretation.

Factors affecting the amenability to site characterization include geological heterogeneity, structural and hydrogeological complexity, accessibility, and the presence of lakes or overburden with thickness or composition that could mask important geological or structural features. There is potential for lithological heterogeneity within both the metasedimentary rocks and the granitic pluton in the Nipigon area. The metasedimentary rocks of the Quetico Subprovince are mapped as a thick sequence of highly metamorphosed and migmatized metasedimentary rocks with a pervasive and predictable gneissic fabric. The area identified near Mound Lake covers two different rock types (metasedimentary rocks and granitic). The contact between these two rock types would need to be evaluated. In general, lithological heterogeneity makes site characterization more difficult and can lead to spatially variable geomechanical, thermal and hydrogeological properties.

The orientation of lineament features in three dimensions represents another degree of structural complexity that would require assessment through detailed site investigations. In the western part of the Nipigon area where high resolution geophysics is available, geophysical lineaments exhibit trends to the north and east-northeast. The orientation of surficial lineaments displays similar north and east-northeast trends with an additional prominent trend to the north-northwest. As discussed in Section 7.1, interpreted lineaments represent the observable two-dimensional expression of three-dimensional features. The ability to detect and map such lineaments is influenced by topography, the character of the lineaments (e.g., their width, orientation, age, etc.), overburden cover, and the resolution of the data used for the mapping. Hence, the apparent lineament density may not reflect the true presence or absence of lineaments in areas where geophysical survey coverage is of low resolution or where their surface expression is masked by overburden or heavy vegetation cover.

The identification and mapping of geology and structure is strongly influenced by the extent and thickness of overburden cover and the presence of large lakes. The Nipigon area is characterized by very good bedrock exposure over the identified general siting areas. These areas are dominated by exposed bedrock or a thin (<1 m) till veneer. There is also limited surface water bodies in the two general siting areas. Access is good throughout the areas via secondary roads from Highway 17 which follows the Lake Superior and Nipigon Bay shoreline and passes through the Township of Nipigon.

8.0 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

The objective of the Phase 1 geoscientific preliminary assessment was to assess whether the Nipigon area contains general areas that have the potential to satisfy the geoscientific site evaluation factors outlined in NWMO's site selection process document (NWMO, 2010).

The preliminary geoscientific assessment built on the work previously conducted for the Initial Screening (Golder, 2011) and focused on the Town of Nipigon and its periphery, which are referred to as the "Nipigon area" in this report (Figure 1.1). The assessment was conducted using available geoscientific information and key geoscientific characteristics that can be realistically assessed at this early stage of the site evaluation process. The key evaluation factors used relate to: geology; structural geology and distribution of lineaments; distribution and thickness of overburden deposits; surface conditions; and the potential for economically exploitable natural resources. Where information for the Nipigon area was limited or not available, the assessment drew on information and experience from other areas with similar types of rock on the Canadian Shield. The geoscientific desktop preliminary assessment included the following review and interpretation activities:

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, overburden deposits;
- Interpretation of available geophysical surveys (magnetic, electromagnetic, gravity and radiometric);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on the characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess factors such as overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification of general potentially suitable areas based on key geoscientific characteristics and the systematic application of NWMO's geoscientific site evaluation factors.

The geoscientific desktop preliminary assessment showed that the Nipigon area contains at least two general areas that may warrant further consideration. One of these two areas is underlain by metasedimentary rocks of the Quetico Subprovince within the eastern portion of the Nipigon area. A second small area includes a granitic pluton and the metasedimentary rocks adjacent to it located in the Mound Lake area.

The two identified general siting areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. The areas appear to have sufficient depth and sufficient lateral extent to host a deep geological repository, low potential for natural resources, good bedrock exposure, limited surface constraints (topography and water bodies) and are generally accessible. However, there are several significant uncertainties that, when combined, reduce the likelihood of the two identified areas to satisfy NWMO's geoscientific site evaluation factors. These include:

- The potential for lithological heterogeneity within both the metasedimentary rocks and the granitic plutons in the Nipigon area. The area identified near Mound Lake covers two different rock types (metasedimentary rocks and granitic). The contact between these two rock types would need to be evaluated. In addition, the lithological heterogeneity associated with the metasedimentary rocks in the area would need to be assessed. In general, lithological heterogeneity makes site characterization more difficult and can lead to spatially variable geomechanical, thermal and hydrogeological properties.

- The existence and extent of Nipigon diabase sills in the Nipigon area. Because of their horizontal nature, the presence of sills at depth cannot be ruled out, even in areas where they do not have a surface outcrop. The intrusion of these sills in the geological past may have caused damage to the pre-existing rock. The presence of sills at depth, and associated rock damage, has the potential to create pathways for groundwater movement, which could affect the containment and isolation characteristics of the rock.
- The presence of mafic dykes and the potential presence of smaller dykes not identifiable on available mapping and geophysical data. The intrusion of dykes may have caused damage to the host rock that would need to be assessed. In addition, the thermal and hydraulic conductivity of the dykes (and sills) would need to be investigated.
- The proximity of these two areas to major fault zones and mapped faults such as the Black Sturgeon River fault zone and Jackpine River fault. These fault zones are broad and it is uncertain to what extent the two areas are structurally impacted (degree of fracturing) as a result of their proximity to these major features.

Detailed investigations would be required to resolve these inherent uncertainties and assess with a sufficient level of confidence whether the Nipigon area contains areas that can satisfy the geoscientific site evaluation factors.

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REPORT SIGNATURE PAGE

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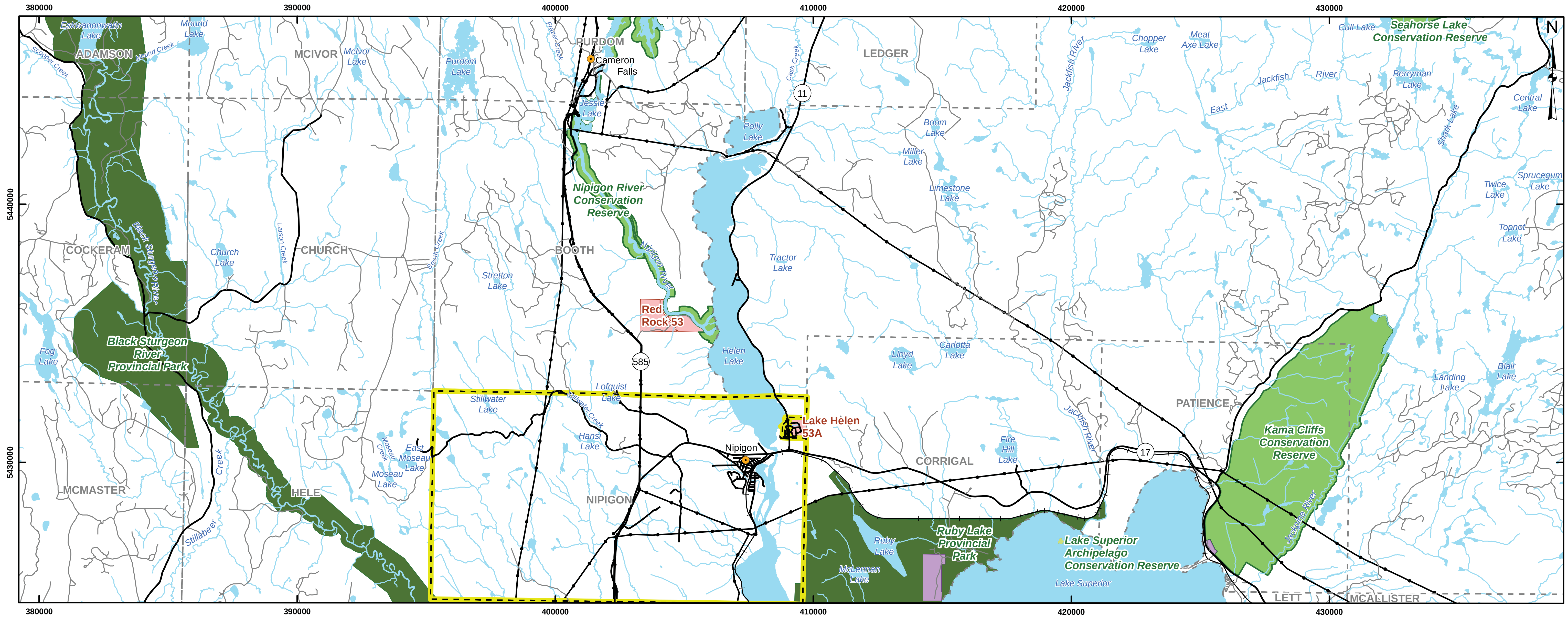
FIGURES



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

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

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

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Township of Nipigon and Surrounding Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013	FIGURE: 1.1	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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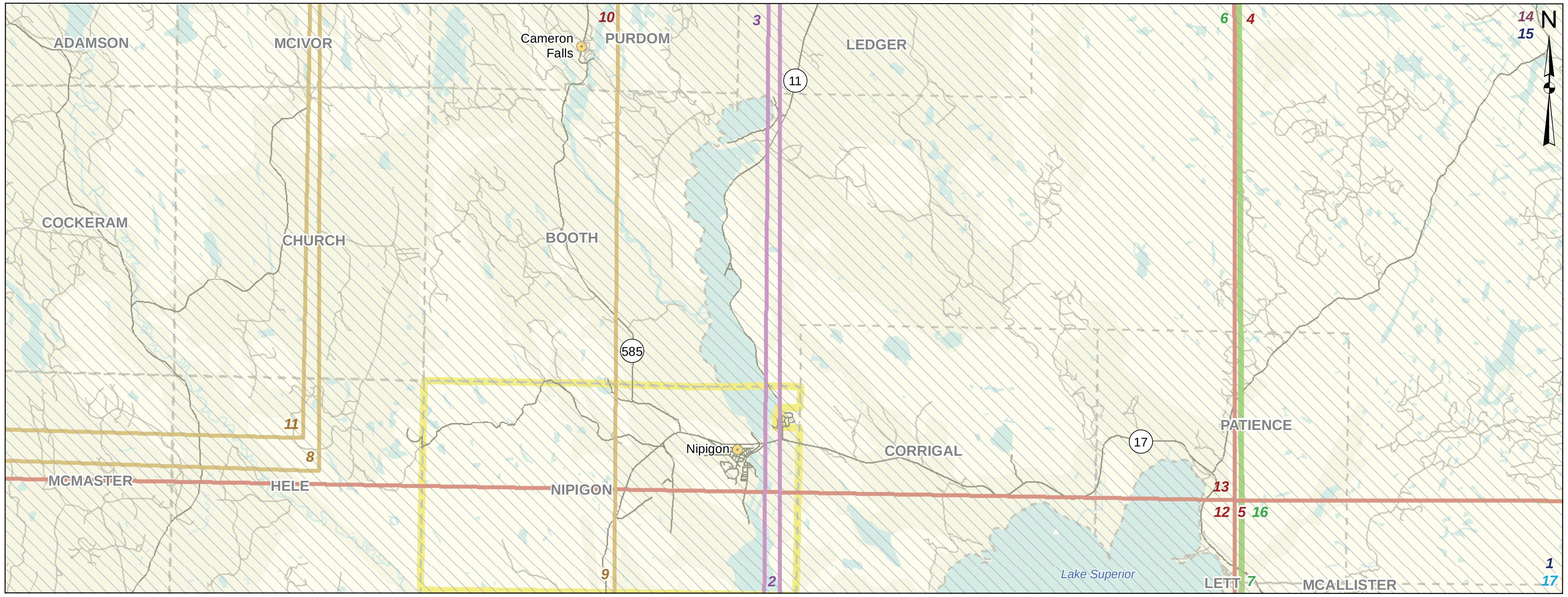
Geology Mapping Coverage



LEGEND

- Community
- Main Road
- Local Road
- Waterbody
- Geographic Township
- Municipal Boundary (Township of Nipigon)
- Overburden Cover

Detailed Geology Extent

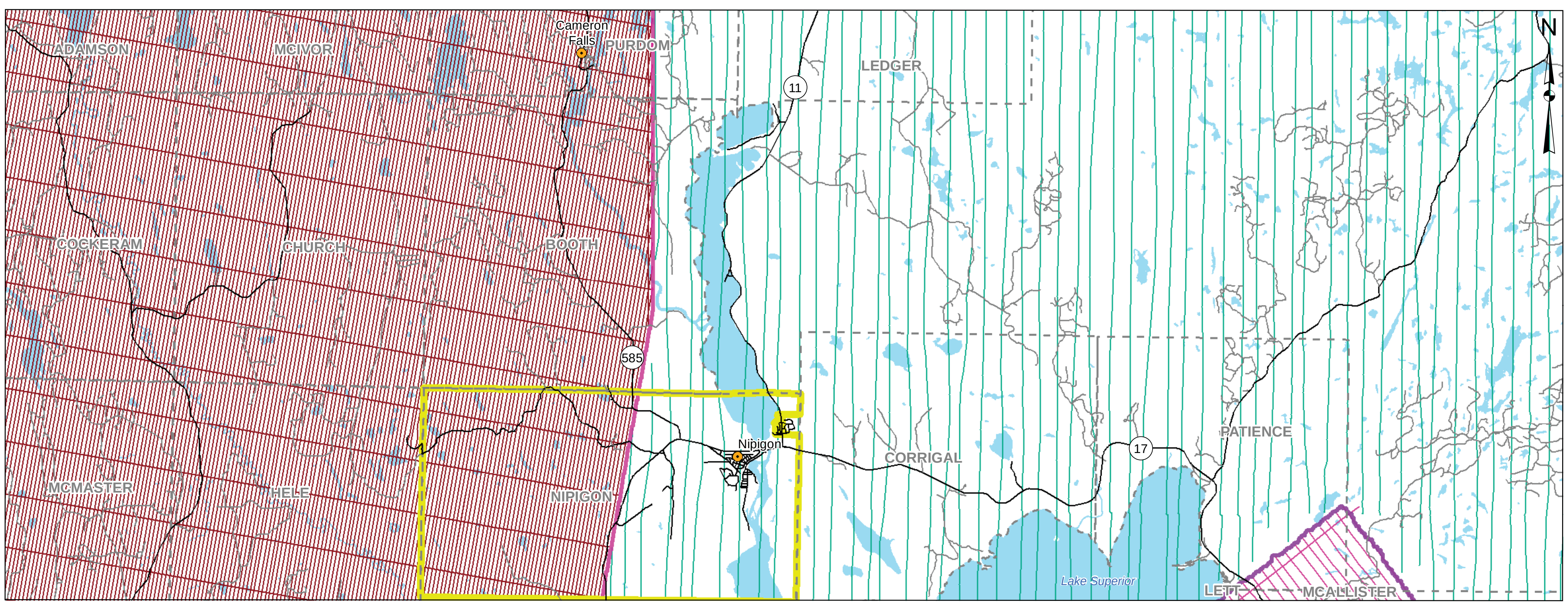
MapScale

- 1 : 50,000
- 1 : 63,360
- 1 : 100,000
- 1 : 126,720
- 1 : 250,000
- 1 : 253,440
- 1 : 506,880

1 - Carter et al. (1973)
2 - Coates (1968)
3 - Coates (1971)
4 - Gartner (1980)
5 - Gartner (1980)
6 - GSC, OGS (1978)
7 - GSC, OGS (1978)
8 - Hart et al. (2004)
9 - Hart et al. (2005)
10 - Hart et al. (2005)
11 - Magyarosi et al. (2004)
12 - Mollard (1979)
13 - Mollard (1979)
14 - Pye (1966)
15 - Pye (1968)
16 - Santaguida (2002)
17 - Zoltai (1965)

Full Geology Coverage
OGS Bedrock Geology of Ontario 2011 (MRD 126)

Geophysics Mapping Coverage



LEGEND

- Community
- Main Road
- Local Road
- Waterbody
- Geographic Township
- Municipal Boundary (Township of Nipigon)

Geophysical Survey Flight Paths

- Flightpath OGS GDS1047
- Flightpath OGS GDS1226
- Flightpath GSC Ontario #8

Geophysical Survey Extent

- Ontario Geological Survey OGS GDS1226
- Ontario Geological Survey OGS GDS1047

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
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Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

4 2 0 4 8 12
SCALE 1:200,000 KILOMETRES

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Geoscience Mapping and Geophysical Coverage of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Oct. 2012	FIGURE: 1.2	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWS	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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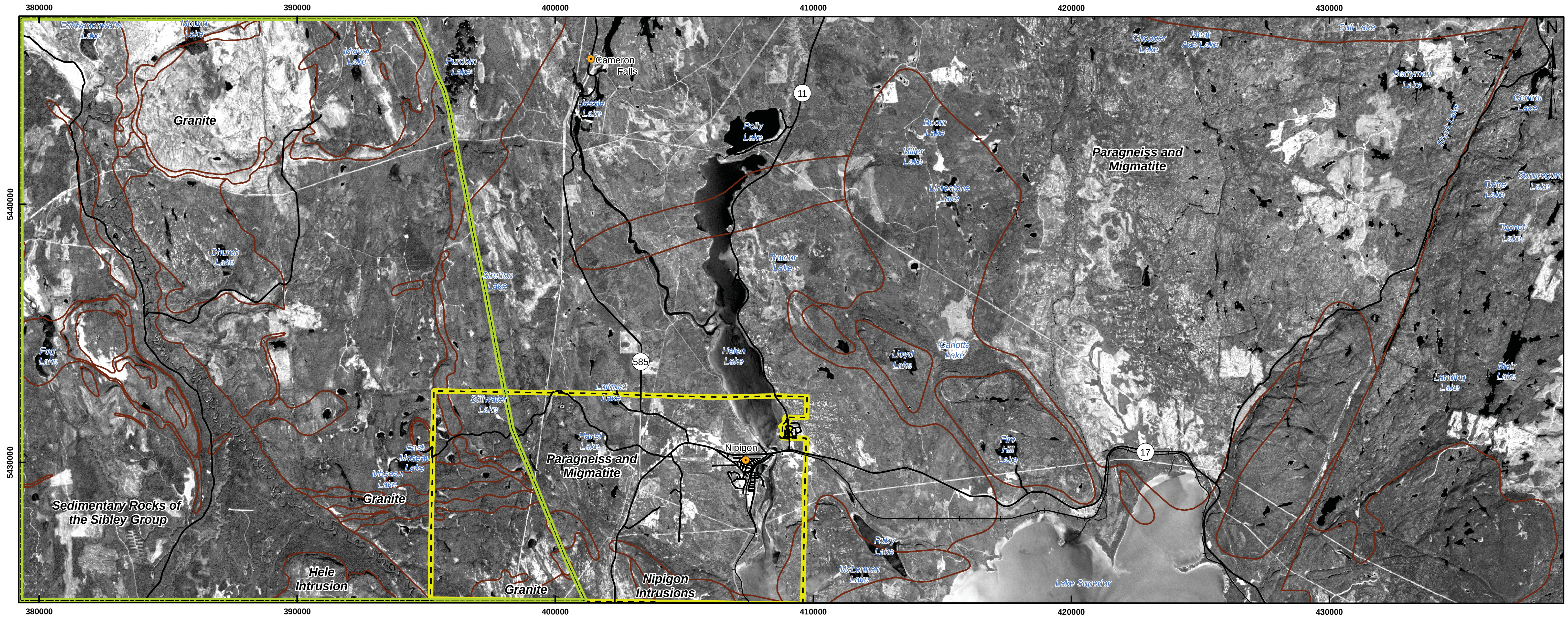

LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Railway
- Revised Mapping (Hart, 2005)
- Geologic Contact

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Imagery - SPOT 5, Obtained from Geobase (2006, 10 m resolution)
Geologic Contact: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

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

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Satellite Imagery of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013	FIGURE: 2.1	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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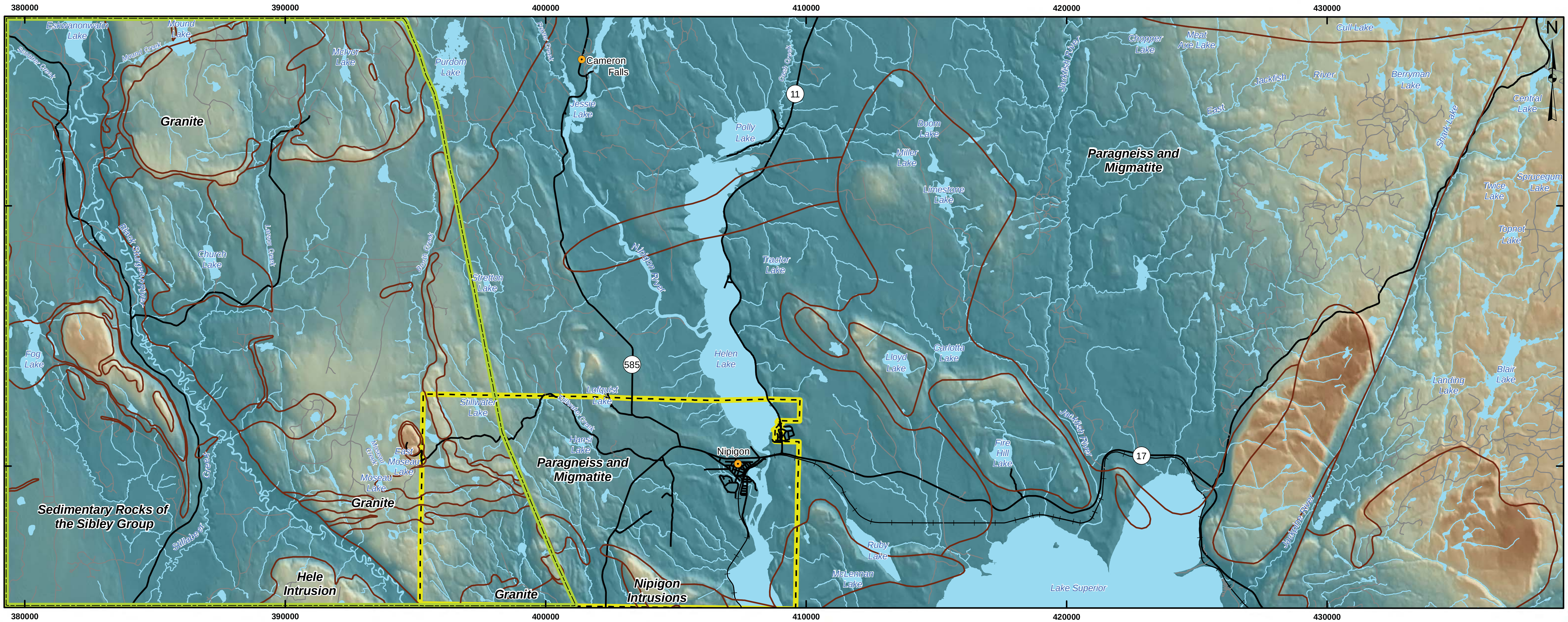


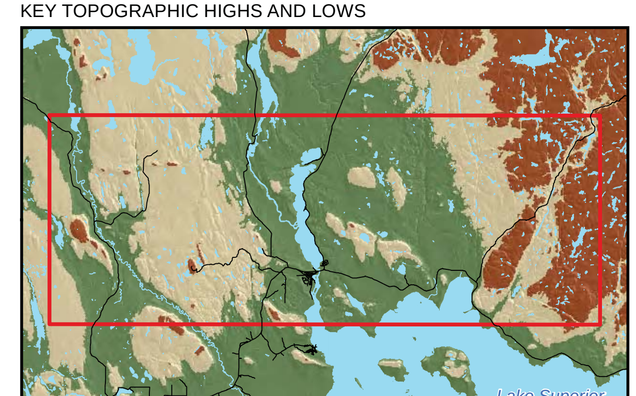
LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Geologic Contact
- Revised Mapping (Hart, 2005)

Elevation (masl)

583
502
421
340
259
178

KEY TOPOGRAPHIC HIGHS AND LOWS



Elevation (m)

178 - 290 | 290.1 - 425 | 425.1 - 583

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Digital Elevation Model - CDED slope raster: Geobase.ca (1:50,000)
Geologic Contact: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

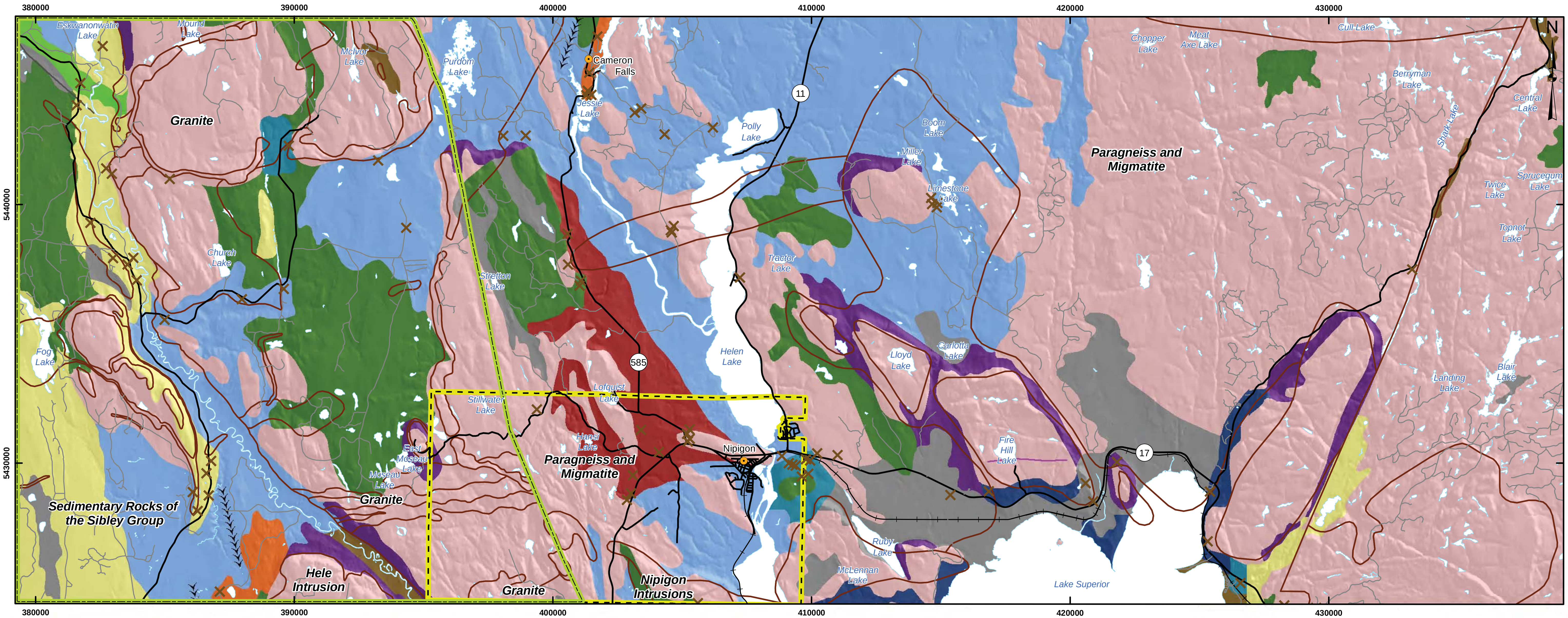
TITLE

Digital Elevation Model (DEM) of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013	FIGURE: 2.2	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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



LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Pit (Gravel)
- Esker or Area of Eskers
- Terrace Escarpment (Abandoned Shore Bluff)
- Trend of End Moraine Crest
- Geologic Contact
- Revised Mapping (Hart, 2005)

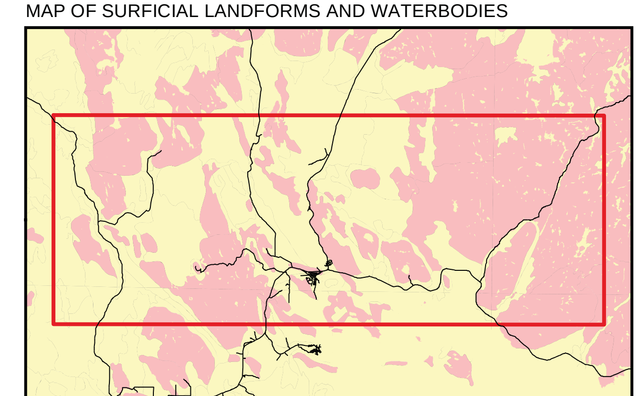
Landform

- Man Made
- Ground Moraine
- End Moraine
- Glaciofluvial Kame
- Glaciofluvial Esker
- Glaciofluvial Outwash
- Glaciolacustrine Delta
- Glaciolacustrine Plain
- Glaciolacustrine Beach
- Colluvium
- Alluvial
- Organics
- Bedrock

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
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geologic Contact: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

MAP OF SURFICIAL LANDFORMS AND WATERBODIES



Surficial/water Bedrock terrain

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

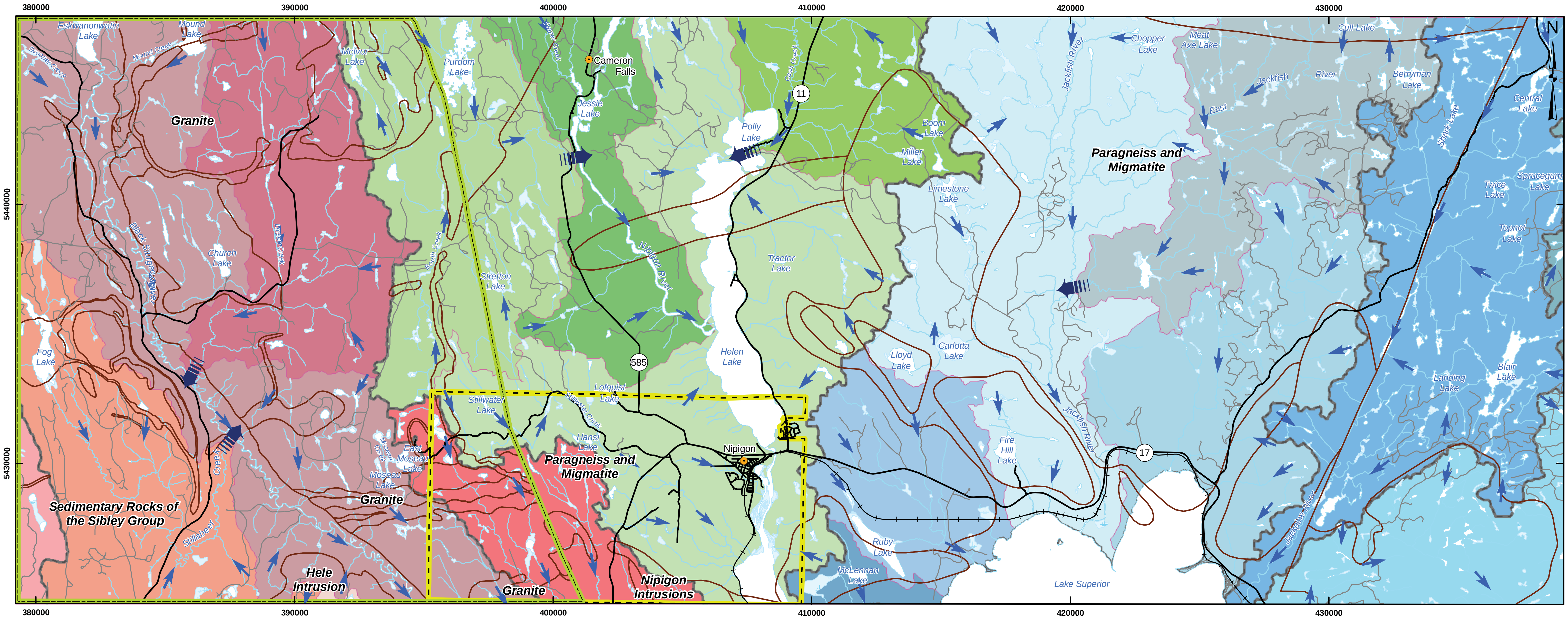
TITLE

Terrain Features of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013		
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

FIGURE: 2.3



LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Surface Water Flow Direction
- Watershed Outflow Point
- Geologic Contact
- Revised Mapping (Hart, 2005)

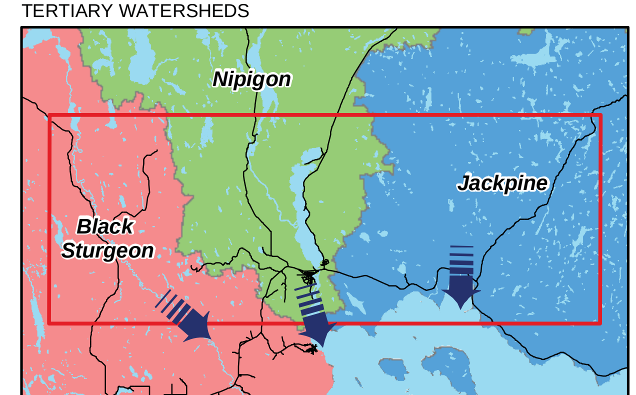
Quaternary Watersheds

- Delineated by JDMA
- Delineated by MNR/JDMA
- Watercourse
- Waterbody
- Wetland

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Drainage Divides - Terrain and remote sensing study, Township of Nipigon (JDMA, 2014)
Geologic Contact: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

TERTIARY WATERSHEDS



Black Sturgeon | Jackpine | Nipigon

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Drainage Features of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013	FIGURE: 2.4	
GIS	PM/JB	29 Jul. 2014		
CHECK	CWM	29 Jul. 2014		
REVIEW	GWS	29 Jul. 2014		

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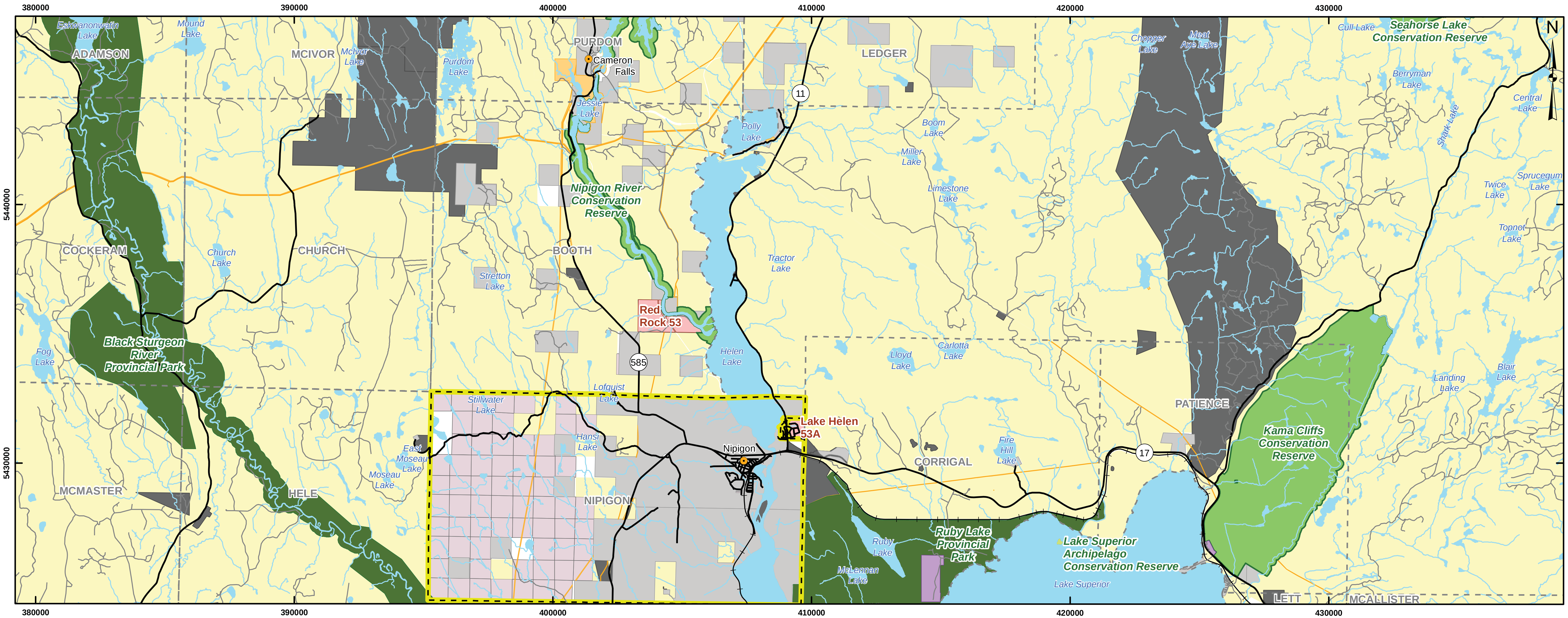

LEGEND

Municipal Boundary (Township of Nipigon)	Forest Reserve	Crown Reserves
Geographic Township	Recommended Conservation Reserve	Private Land
Community	Conservation Reserve	Federal Land - Indian Reserve
Main Road	Provincial Park	
Local Road	Crown Land Acquired	
Railway	Crown Land - Non-Freehold Dispositions Public	
Watercourse	Crown Land - Unpatented Public Land	
Waterbody		

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Crown Reserves - Ministry of Northern Mines and Development (April 4, 2013)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Nipigon Land Ownership

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013		
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

FIGURE: 2.5

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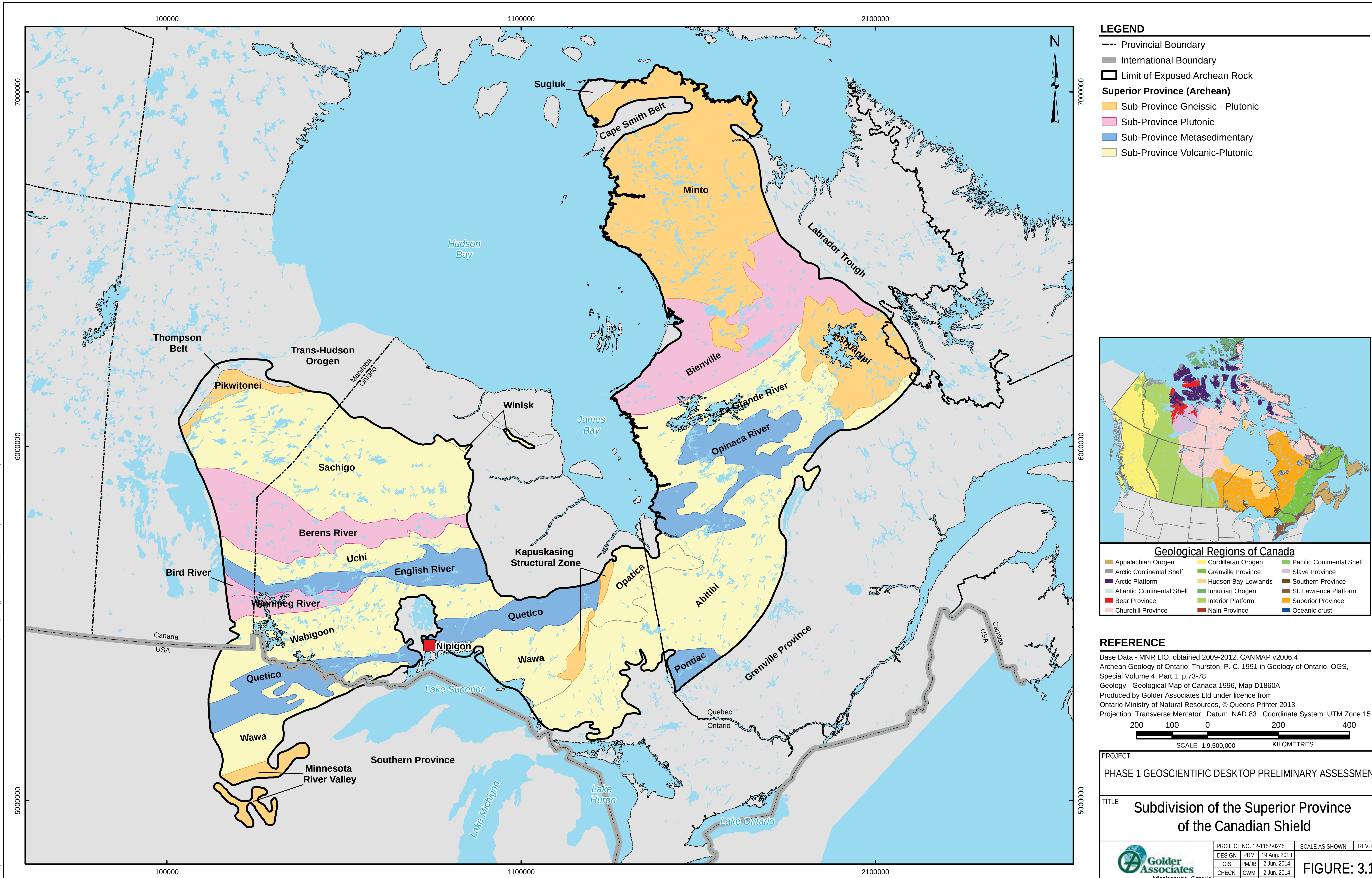
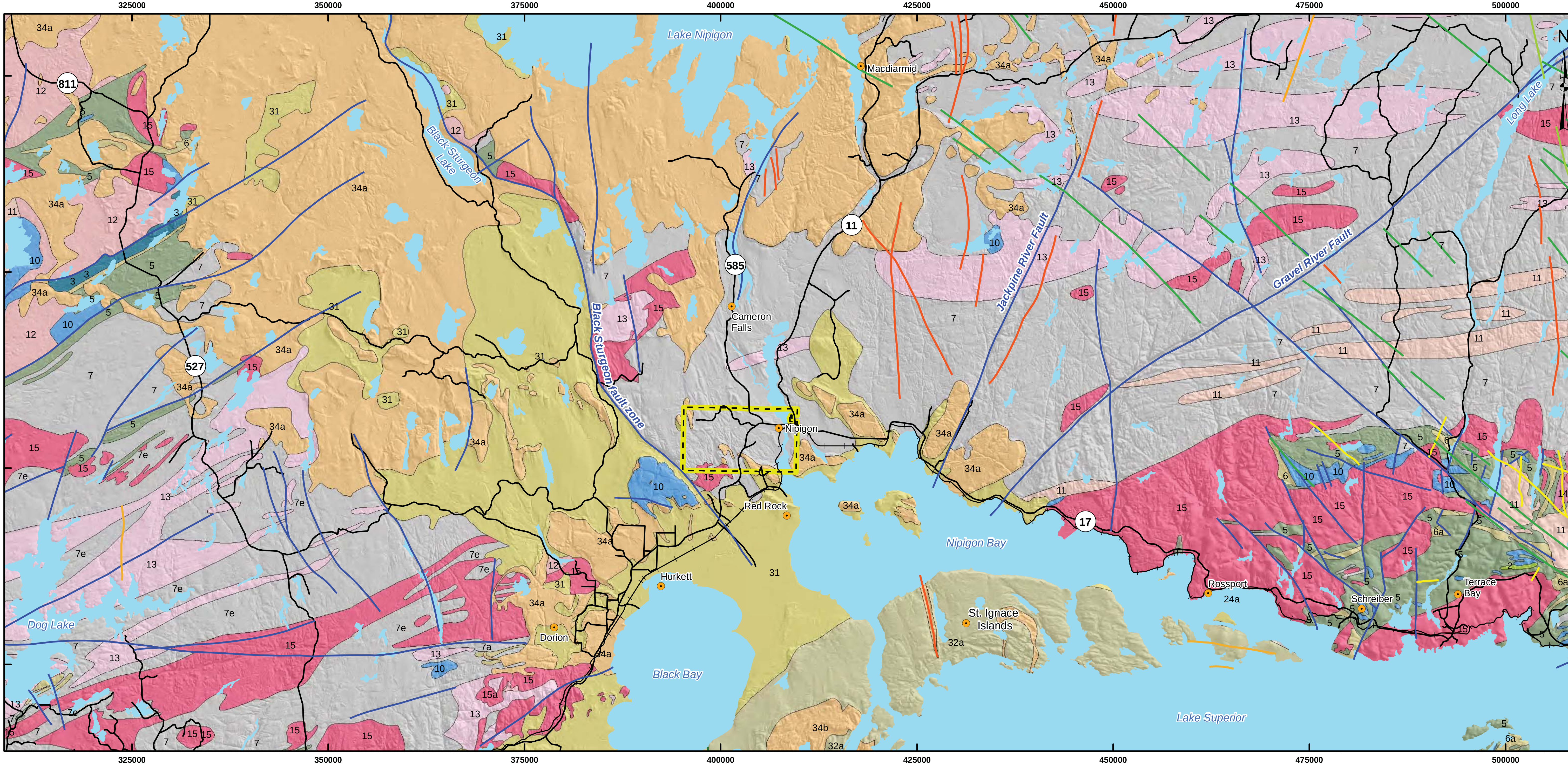


LEGEND
Provincial Boundary
International Boundary
Limit of Exposed Archean Rock
Superior Province (Archean)
Sub-Province Gneissic - Plutonic
Sub-Province Plutonic
Sub-Province Metasedimentary
Sub-Province Volcanic-Plutonic
Geological Regions of Canada
Appalachian Orogen
Arctic Continental Shelf
Arctic Platform
Atlantic Continental Shelf
Bear Province
Churchill Province
Cordilleran Orogen
Grenville Province
Hudson Bay Lowlands
Innuitian Orogen
Interior Platform
Nain Province
Pacific Continental Shelf
Slave Province
Southern Province
St. Lawrence Platform
Superior Province
Oceanic crust
REFERENCE
Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Archean Geology of Ontario: Thurston, P. C. 1991 in Geology of Ontario, OGS, Special Volume 4, Part 1, p.73-78
Geology - Geological Map of Canada 1996, Map D1860A
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15
200 100 0 200 400
SCALE 1:9,500,000
KILOMETRES
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT
TITLE
Subdivision of the Superior Province of the Canadian Shield
PROJECT NO. 12-1152-0245
SCALE AS SHOWN
REV. 0.0
DESIGN PRM 19 Aug. 2013
GIS PM/JB 2 Jun. 2014
CHECK CWM 2 Jun. 2014
REVIEW GWS 2 Jun. 2014
Golder Associates
Mississauga, Ontario
FIGURE: 3.1
N
100000
1100000
2100000
7000000
6000000
5000000
Sugluk
Cape Smith Belt
Minto
Labrador Trough
Hudson Bay
Bienville
Ashuanipi
La Grande River
Opinaca River
James Bay
Thompson Belt
Trans-Hudson Orogen
Manitoba
Ontario
Pikwitonei
Winisk
Sachigo
Berens River
Uchi
English River
Bird River
Winnipeg River
Kapuskasing Structural Zone
Opatica
Abitibi
Quetico
Wabigoon
Nipigon
Wawa
Pontiac
Grenville Province
Lake Superior
Canada
USA
Quebec
Ontario
Minnesota River Valley
Southern Province
Lake Michigan
Lake Huron
Lake Ontario
G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\Nipigon\Draft_Integrated_Report\SubdivisionSuperiorProvinceCanadianShield.mxd



LEGEND

Municipal Boundary (Township of Nipigon)
Community
Main Road
Railway
Waterbody
Mapped Fault

Dyke Swarm

- Felsic to intermediate intrusive rocks
- Logan and Nipigon mafic sills
- Mafic sills and dykes
- Marathon, Kapuskasing or Biscotasing mafic dyke
- Matachewan mafic dyke
- Pickle Crow mafic dyke (Molson swarm) normal
- Unsubdivided mafic dyke (Keweenawan age)

Bedrock Geology

- 34 Mafic and related intrusive rocks (Keweenawan age)
- 34a Logan and Nipigon sills
- 34b Pigeon River and Pukaskwa swarms: diabase dykes
- 32 Osler Gp., Maminse Point Fm., Michipicoten Island Fm.
- 32a Basalt and associated conglomerate and arkose
- 31 Sibley Gp.
- 24 Sedimentary rocks (Animikie Group)
- 24a Rove Formation: argillite, shale, wacke, minor volcanic rocks
- 15 Massive granodiorite to granite
- 15a Potassium feldspar megacrystic units
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 7 Metasedimentary rocks (Paragneisses and Migmatites)
- 6 Felsic to intermediate metavolcanic rocks
- 6a Dacitic and Andesitic flows, tuffs and breccias
- 5 Mafic to intermediate metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks
- 2 Felsic to intermediate metavolcanic rocks

10 5 0 10 20

SCALE 1:500,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geologic Contact: Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Regional Bedrock Geology of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013	FIGURE: 3.2	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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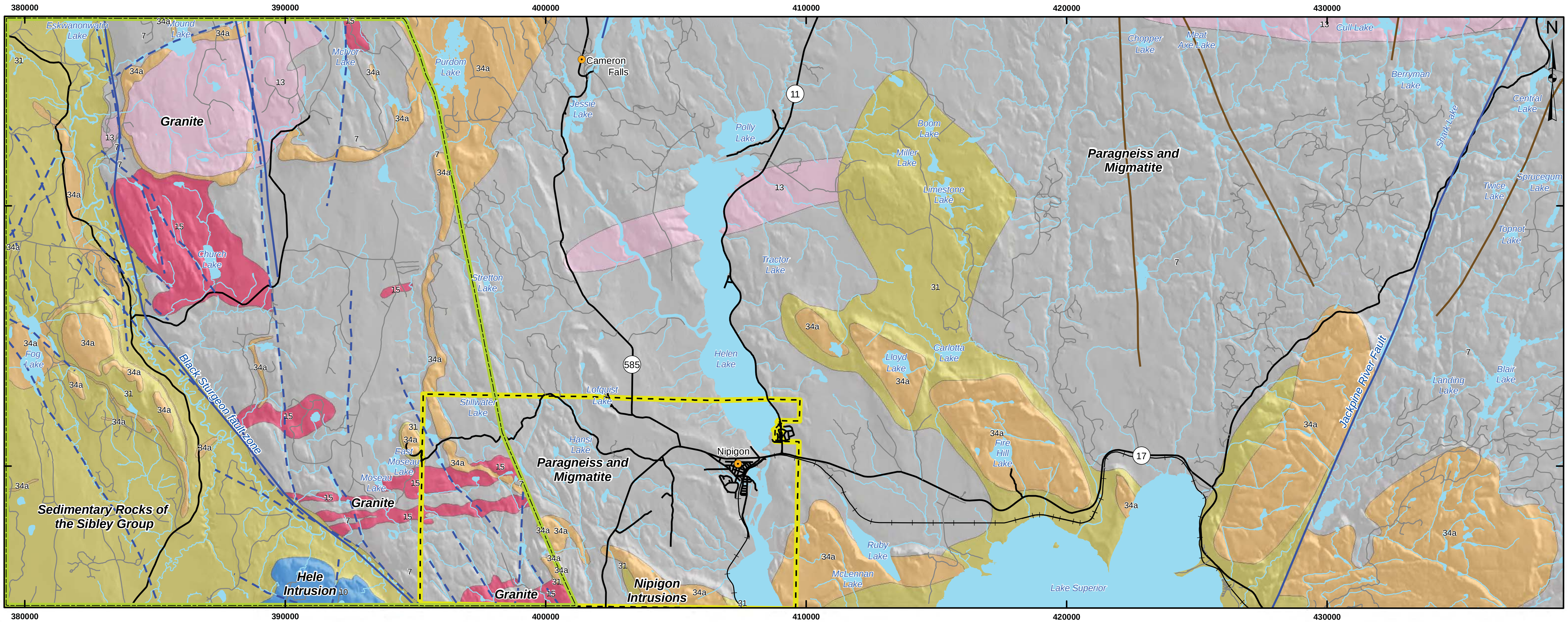

LEGEND

- 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
- 31 Sibley Gp.
- 15 Massive granodiorite to granite
- 13 Muscovite-bearing granitic rock
- 10 Mafic and ultramafic rocks
- 7 Metasedimentary rocks (Paragneisses and Migmatites)

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Local Bedrock Geology of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013		
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

FIGURE: 3.3

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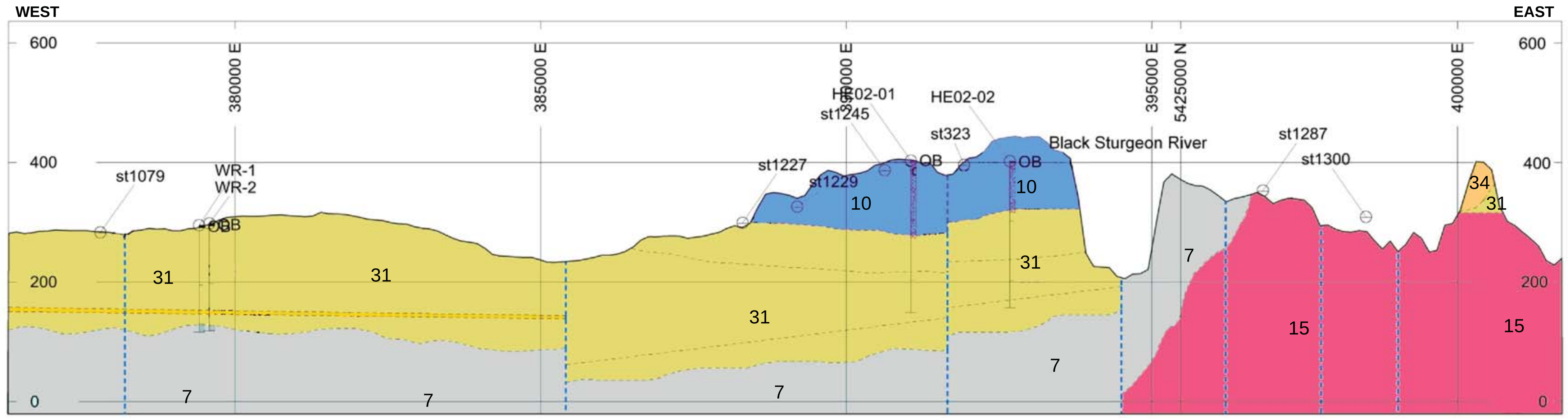
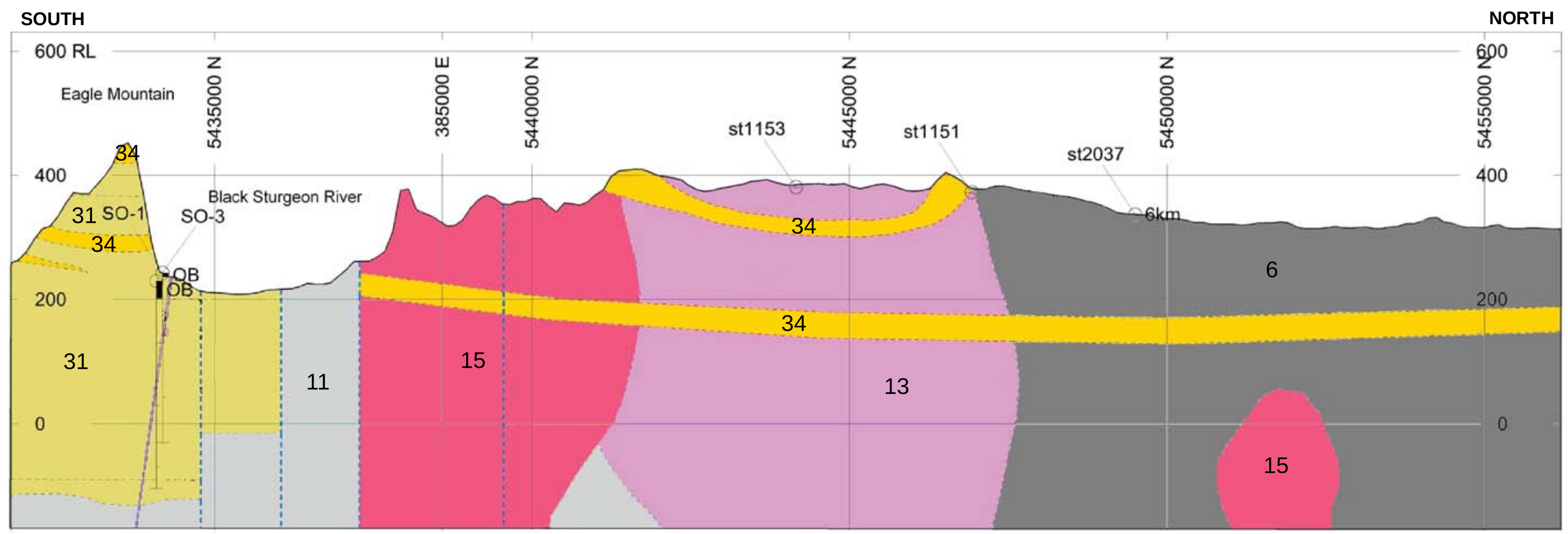
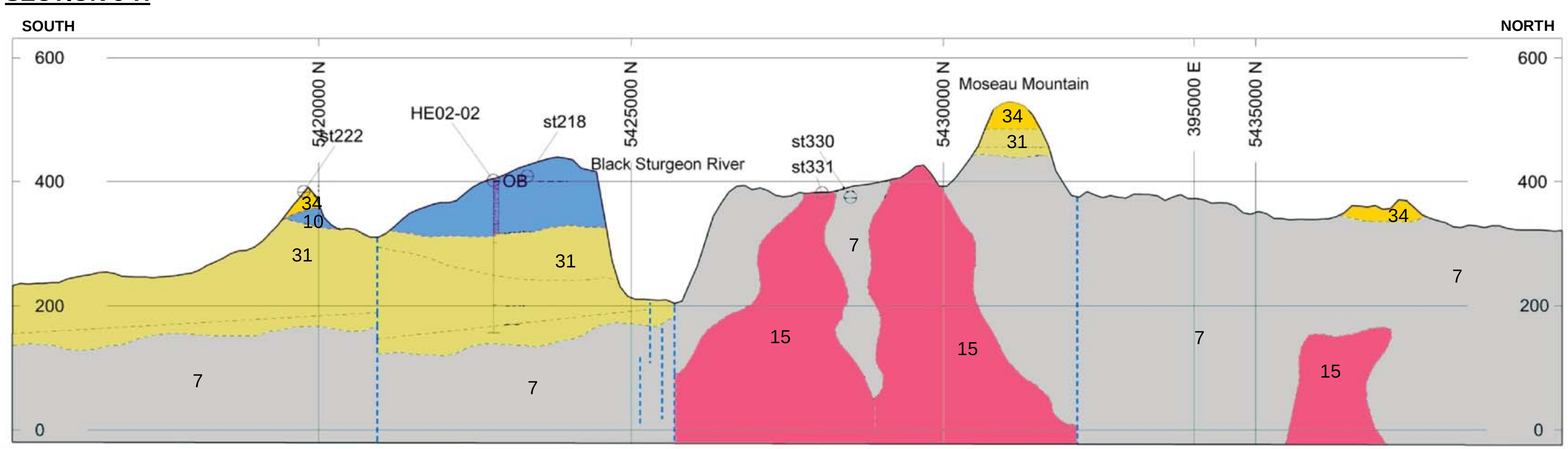
SECTION B-I



SECTION D-F



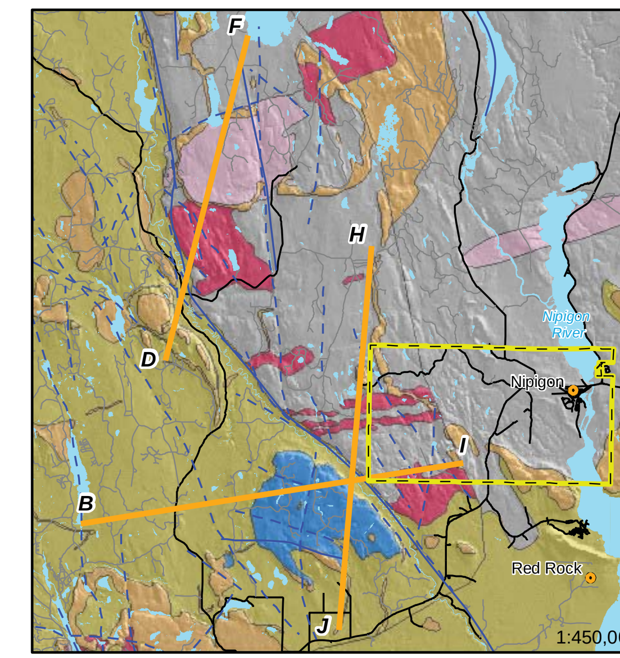
SECTION J-H



LEGEND

- Fault; Unknown Vertical Component (trend only, interpreted)
- 34 - Mafic Intrusive Rocks (Nipigon Sills)
- 31 - Sibley Group Sedimentary Rocks
- 15 - Biotite Granite Suite
- 13 - Muscovite Granite Suite
- 10 - Mafic to Ultramafic Intrusive Rocks
- 7 - Gneissic to Migmatitic Suite
- 6 - Clastic Metasedimentary Rocks

CROSS SECTION KEY MAP



REFERENCE

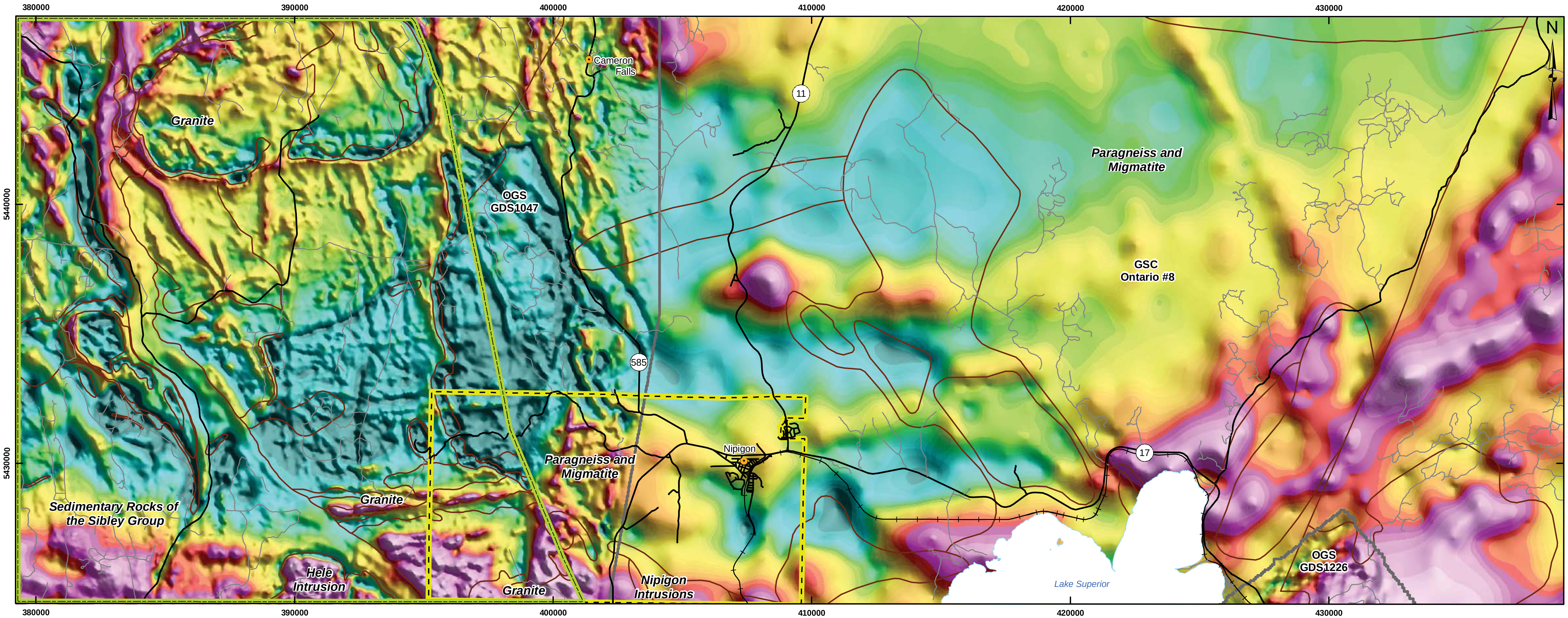
Hart, 2005, Precambrian Geology of the Southern Black Sturgeon River and Seagull Lake Area
Projection: Transverse Mercator Datum: NAD 83
Coordinate System: UTM Zone 16N

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Conceptual Geological Cross Sections Near the Nipigon Area

Golder Associates
Mississauga, Ontario

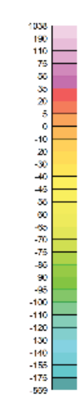
PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PB	22 Nov. 2011	FIGURE: 3.4	
GIS	PM/JB	29 Jul. 2014		
CHECK	CWM	29 Jul. 2014		
REVIEW	GWS	29 Jul. 2014		



LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Revised Mapping (Hart, 2005)
- Geologic Contact
- Higher Resolution Geophysical Surveys

Residual Total Magnetic Field (nT)



2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - GSC Canada - 200m - Magnetic - Residual Total Field, 2008; Canadian Aeromagnetic Data Base,
Airborne Geophysics Section, GSC - Central Canada Division, Geologic Survey of Canada, Earth Sciences Sector, Natural Resources Canada
Geologic Contact - 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

PROJECT

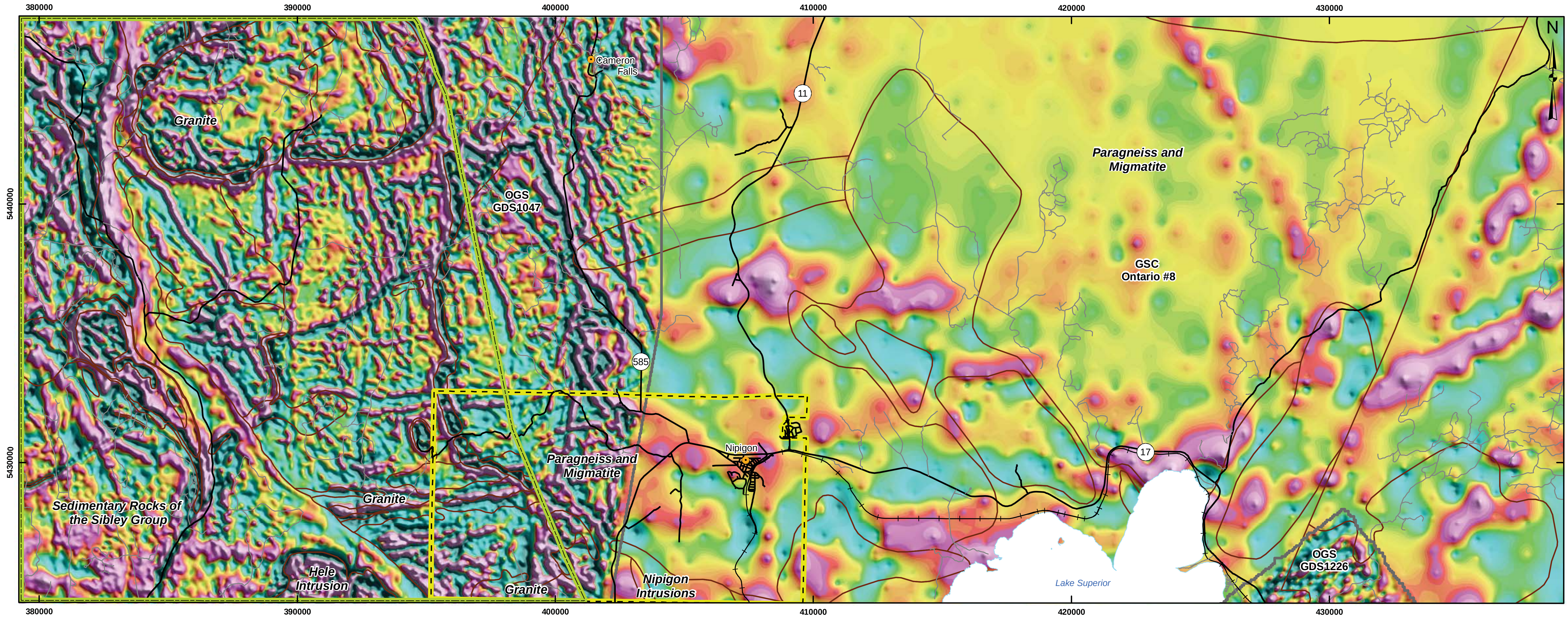
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Total Magnetic Field (Reduced to Pole) of the Nipigon Area

Golder Associates
Mississauga, Ontario

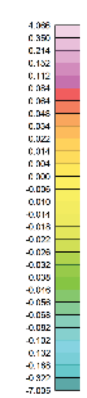
PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013	FIGURE: 3.5	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		



LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Revised Mapping (Hart, 2005)
- Geologic Contact
- Higher Resolution Geophysical Surveys

1st Vertical Derivative of the Residual Magnetic Field (nT/m)



2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - GSC Canada - 200m - Magnetic - Residual Total Field, 2008; Canadian Aeromagnetic Data Base,
Airborne Geophysics Section, GSC - Central Canada Division, Geologic Survey of Canada, Earth Sciences Sector, Natural Resources Canada
Geological Contact - 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

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

First Vertical Derivative (Reduced to Pole) of the Magnetic Field of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013	FIGURE: 3.6	
GIS	PM/JB	30 Jul. 2014		
CHECK	CWM	30 Jul. 2014		
REVIEW	GWS	30 Jul. 2014		

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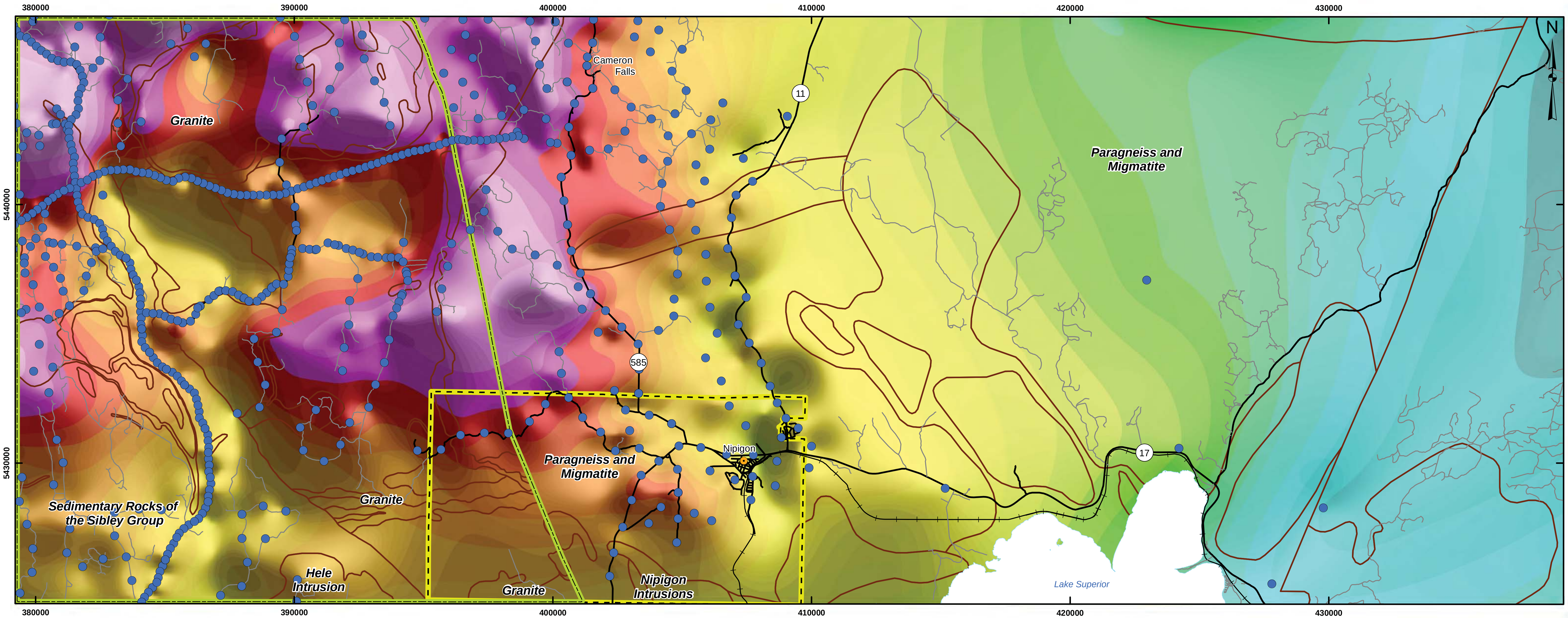

LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Gravity Station
- Revised Mapping (Hart, 2005)
- Geologic Contact

Gravity Anomaly (mGal)

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - GSC Canada - 2km resolution - Gravity Anomalies, 2010; Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada Division, Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada
Geologic Contact - 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

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Bouguer Gravity of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013	FIGURE: 3.7	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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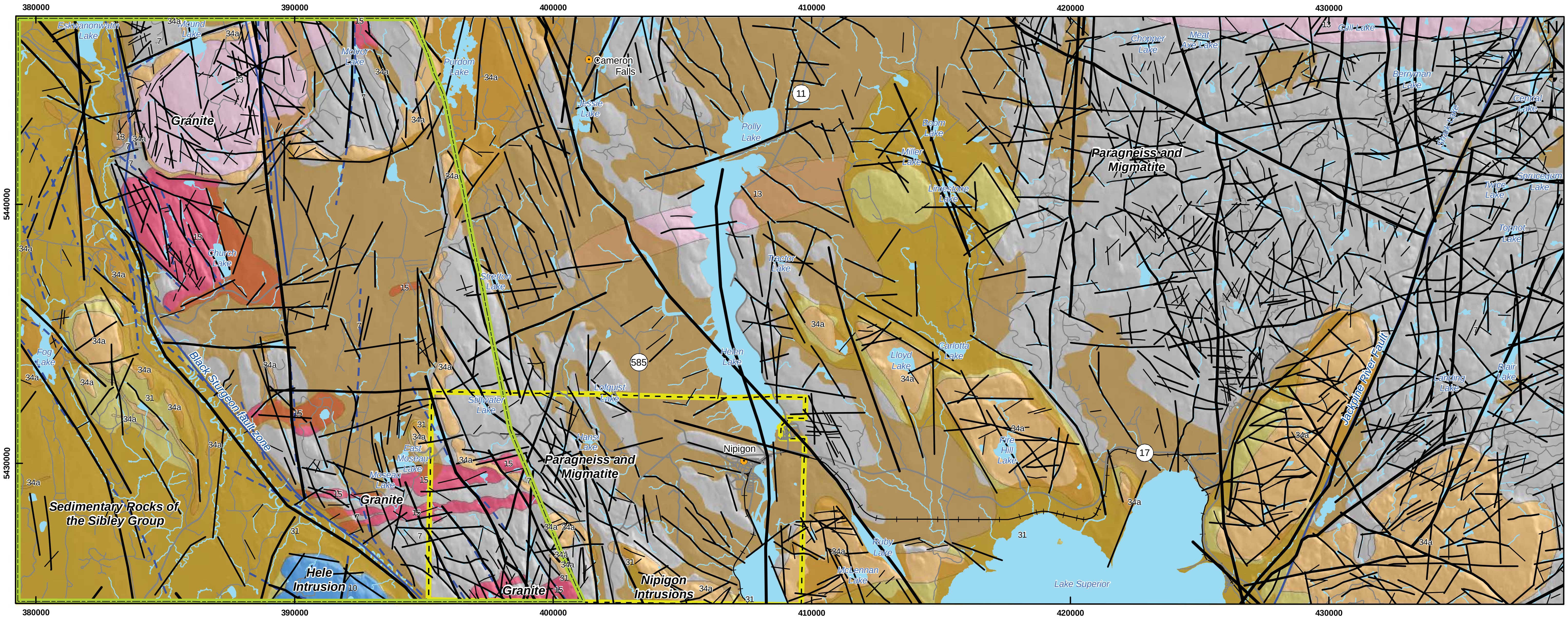
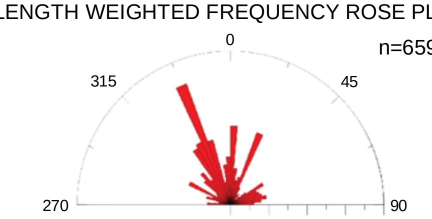
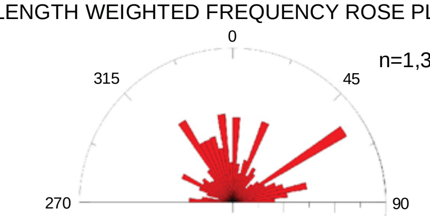


NIPIGON SURFICIAL CDED LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



NIPIGON SURFICIAL SPOT LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

LEGEND

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

Surficial Lineament (SPOT and CDED)

- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km

- Revised Mapping (Hart, 2005)
- Overburden Cover

Bedrock Geology

- 34 Mafic and related intrusive rocks (Keweenawan age)
- 34a Logan and Nipigon sills
- 31 Sibley Gp.
- 15 Massive granodiorite to granite
- 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)
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR 2005. Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Lineaments - Lineament interpretation - Township of Nipigon (JDMA, 2014)
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Surficial Lineaments of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013	FIGURE: 3.8	
GIS	PM/JB	30 Jul. 2014		
CHECK	CWM	30 Jul. 2014		
REVIEW	GWS	30 Jul. 2014		

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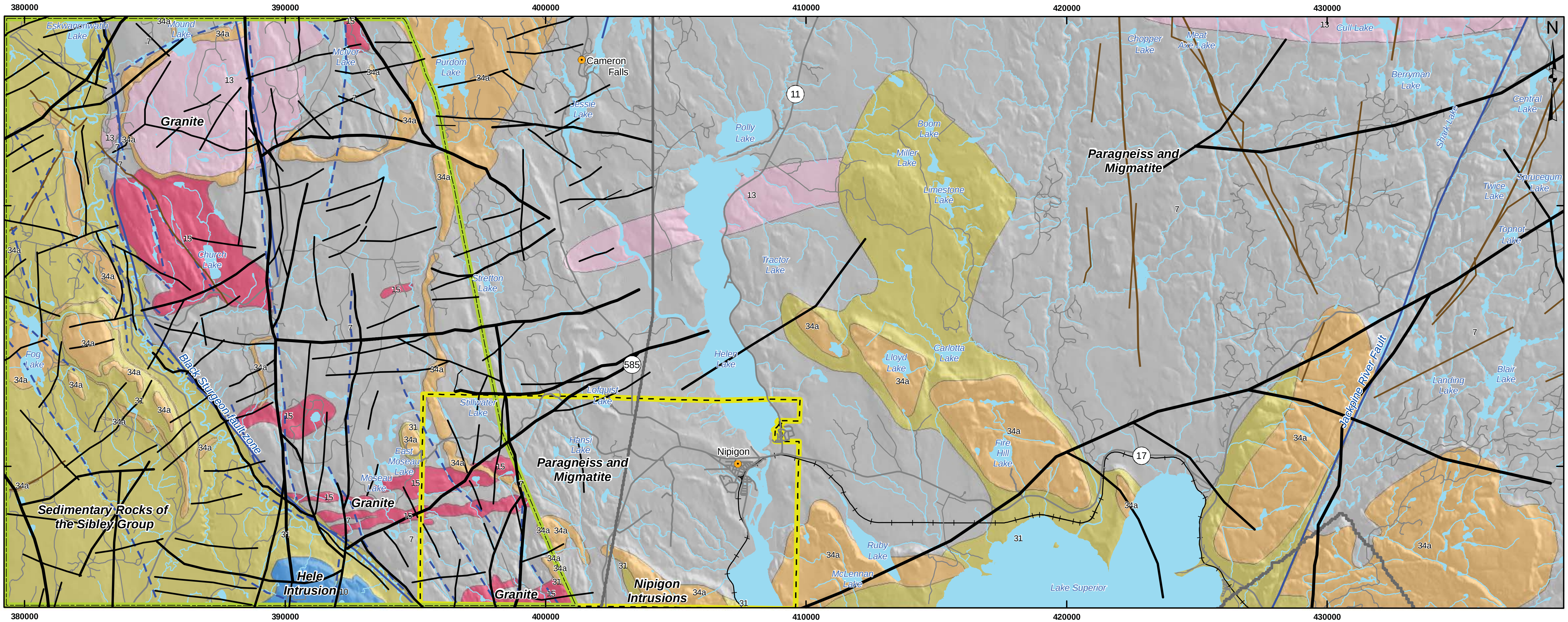

LEGEND

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

Geophysical Lineament (RA-1)

- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km
- Revised Mapping (Hart, 2005)
- Higher Resolution Geophysical Surveys

Bedrock Geology

- 34 Mafic and related intrusive rocks (Keweenawan age)
- 34a Logan and Nipigon sills
- 31 Sibley Gp.
- 15 Massive granodiorite to granite
- 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)
Lineaments - Lineament interpretation - Township of Nipigon (JDMA, 2014)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
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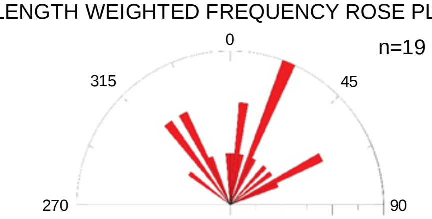
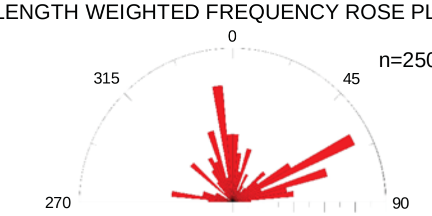
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

NIPIGON GEOPHYSICAL DYKE LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



NIPIGON GEOPHYSICAL FAULT LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



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

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Geophysical RA-1 Lineaments of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013		
GIS	PM/JB	30 Jul. 2014		
CHECK	CWM	30 Jul. 2014		
REVIEW	GWS	30 Jul. 2014		

FIGURE: 3.9

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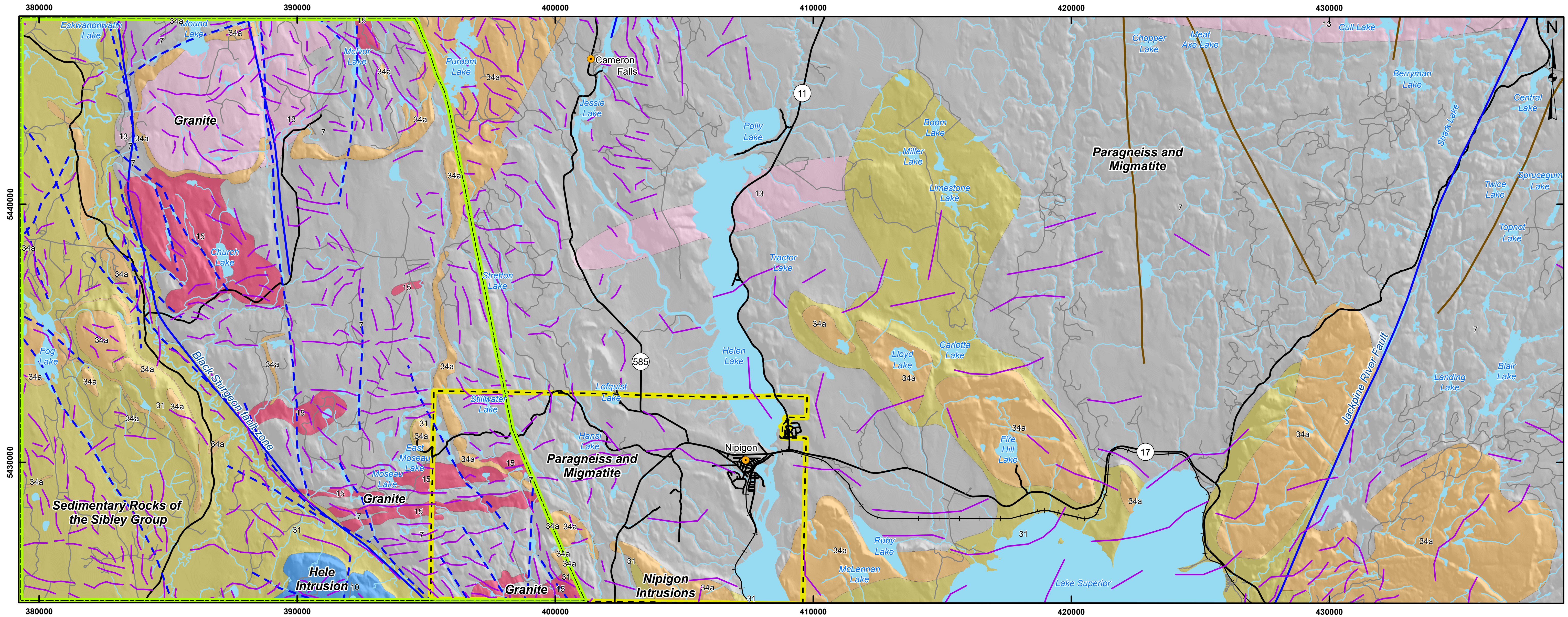

G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\Nipigon\Draft_Integrated_Report\DuctileLineamentsNipigonArea.mxd

LEGEND

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

Bedrock Geology

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

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Ductile Lineaments - Processing & Interpretation of Geophysical Data, Township of Nipigon (PGW, 2014)
Geology - Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

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

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

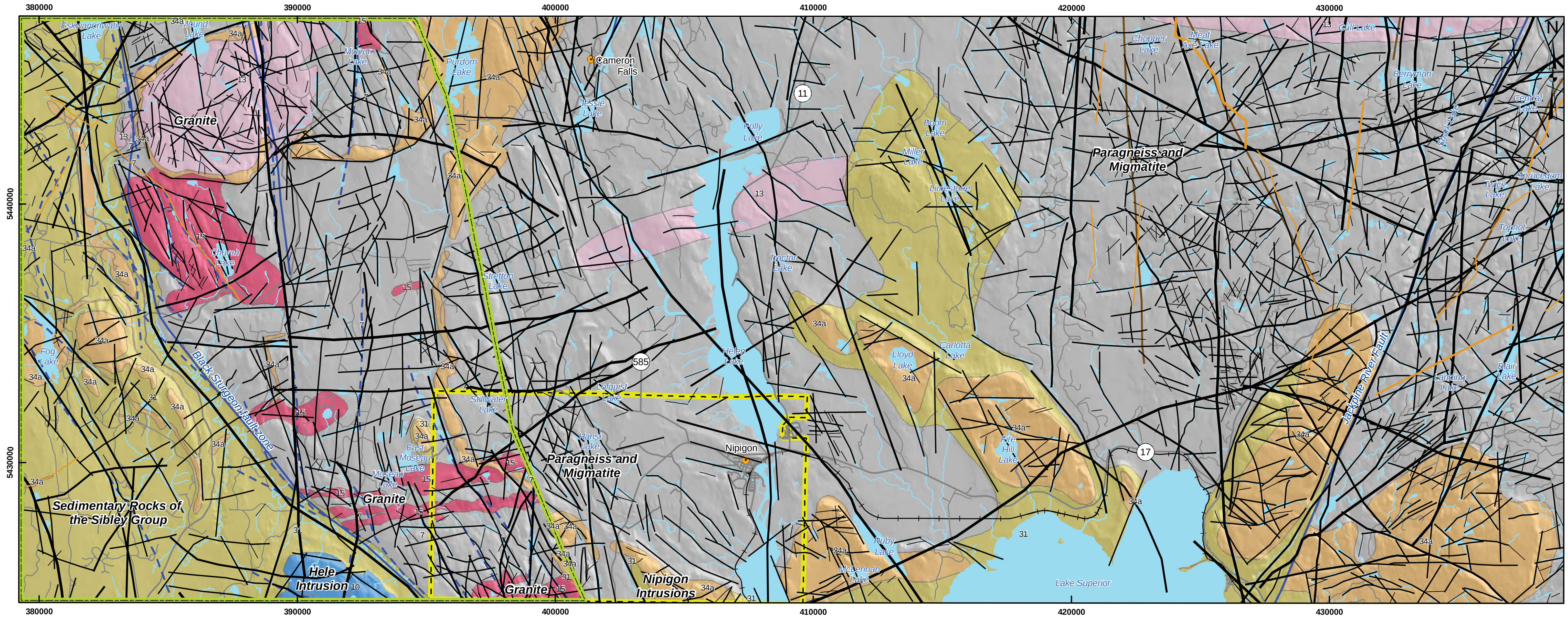
TITLE

Ductile Lineaments of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013		
GIS	PM/JB	17 Nov. 2014		
CHECK	CWM	17 Nov. 2014		
REVIEW	GWS	17 Nov. 2014		

FIGURE: 3.10



LEGEND

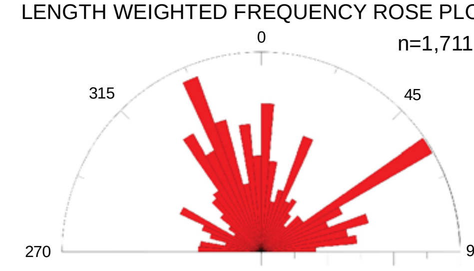
- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Lineament / Fault (Hart, 2005)
- Mapped Dyke

Brittle Lineament
- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km

Interpreted Dyke
- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km
- Revised Mapping (Hart, 2005)

Bedrock Geology
- 34 Mafic and related intrusive rocks (Keweenawan age)
- 34a Logan and Nipigon sills
- 31 Sibley Gp.
- 15 Massive granodiorite to granite
- 13 Muscovite-bearing granitic rock
- 10 Mafic and ultramafic rocks
- 7 Metasedimentary rocks (Paragneisses and Migmatites)

NIPIGON ALL LINEAMENTS (RA2) - LENGTH WEIGHTED FREQUENCY ROSE PLOT



2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Brittle Lineaments - Lineament Interpretation, Township of Nipigon (JDMA, 2014)
Geology - Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

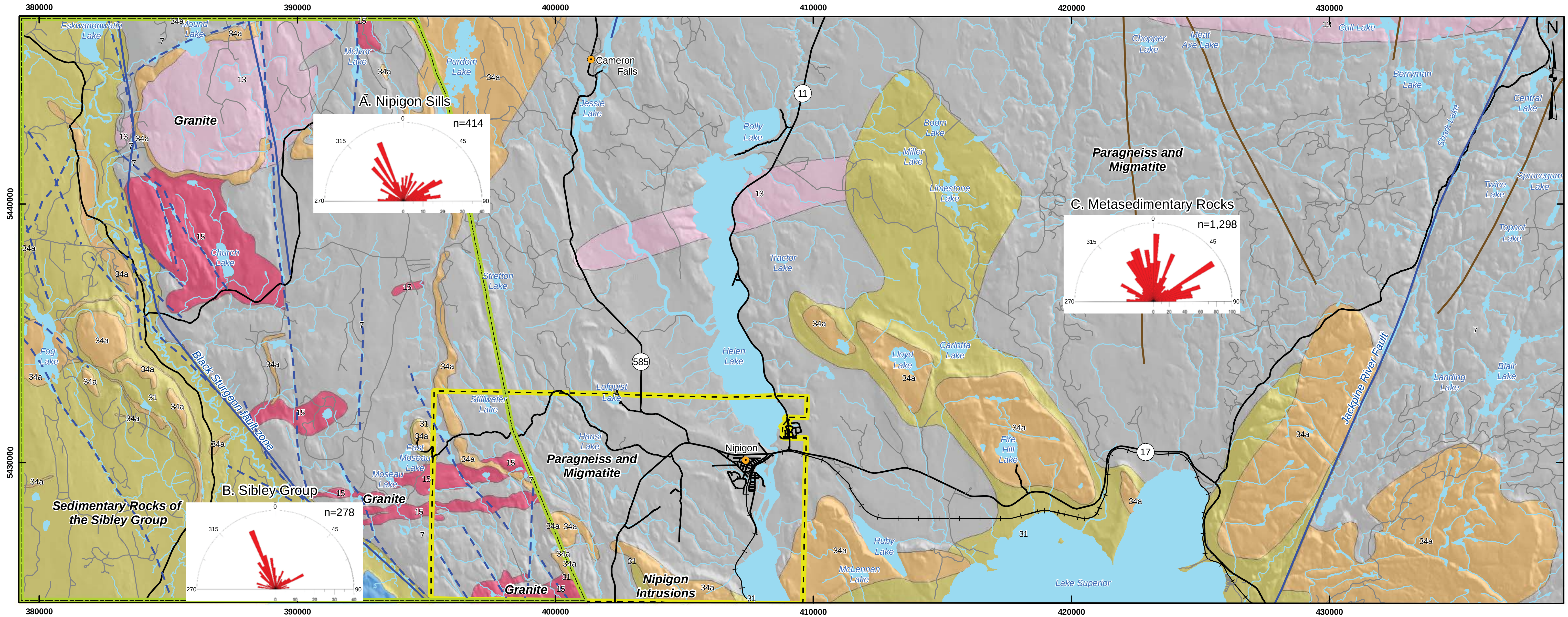
Merged Lineaments of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245		
DESIGN	PM	19 Aug. 2013
GIS	PM/JB	30 Jul. 2014
CHECK	CWM	30 Jul. 2014
REVIEW	GWS	30 Jul. 2014

SCALE AS SHOWN REV. 0.0

FIGURE: 3.11



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
- 31 Sibley Gp.
- 15 Massive granodiorite to granite
- 13 Muscovite-bearing granitic rock
- 10 Mafic and ultramafic rocks
- 7 Metasedimentary rocks (Paragneisses and Migmatites)

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

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)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Rose Diagrams - Lineament interpretation - Township of Nipigon (JDMA, 2014)
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

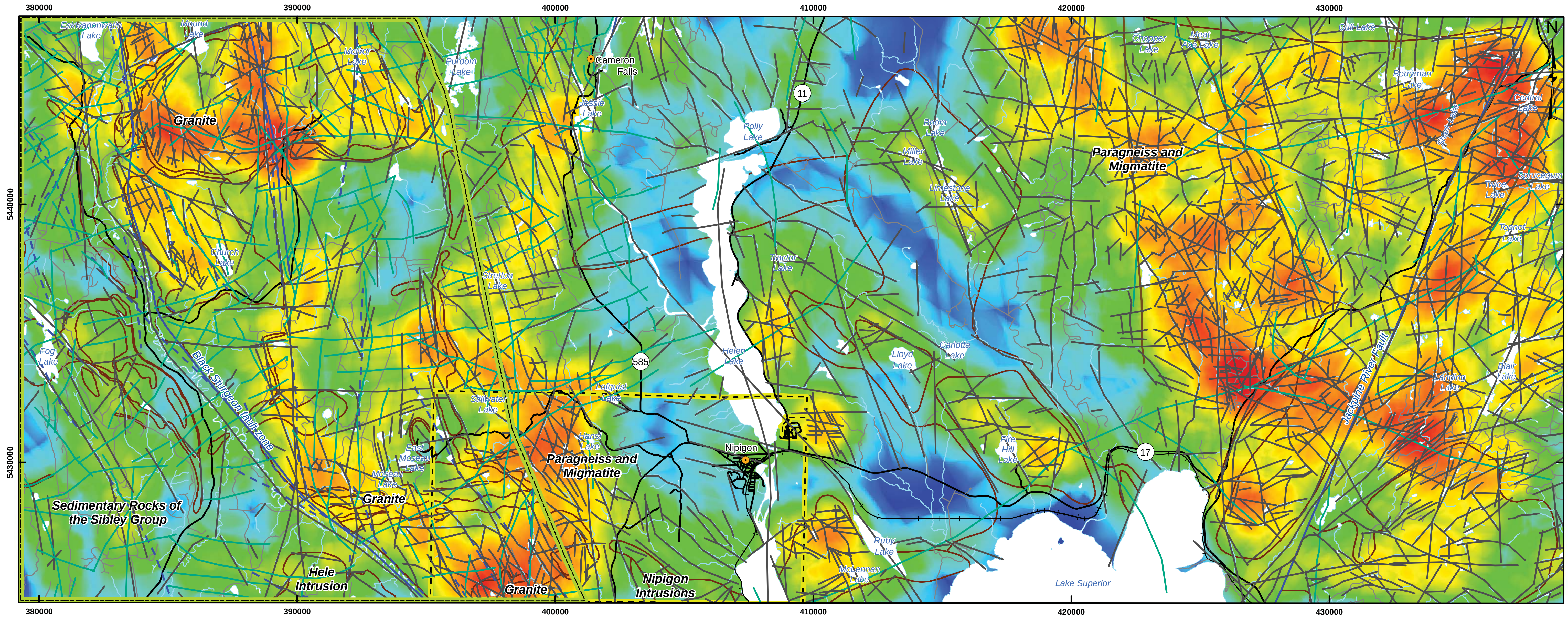
TITLE

Lineament Orientations of Principal Geological Units of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013		
GIS	PM/JB	30 Jul. 2014		
CHECK	CWM	30 Jul. 2014		
REVIEW	GWS	30 Jul. 2014		

FIGURE: 3.12



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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
- Geophysical Lineament
- Surficial Lineament
- Revised Mapping (Hart, 2005)
- Geologic Contact

Lineament Density (km/km²)
High : 6
Low : 0

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

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Lineaments - Lineament Interpretation - Township of Nipigon (JDMA, 2014)
Geologic Contact - Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
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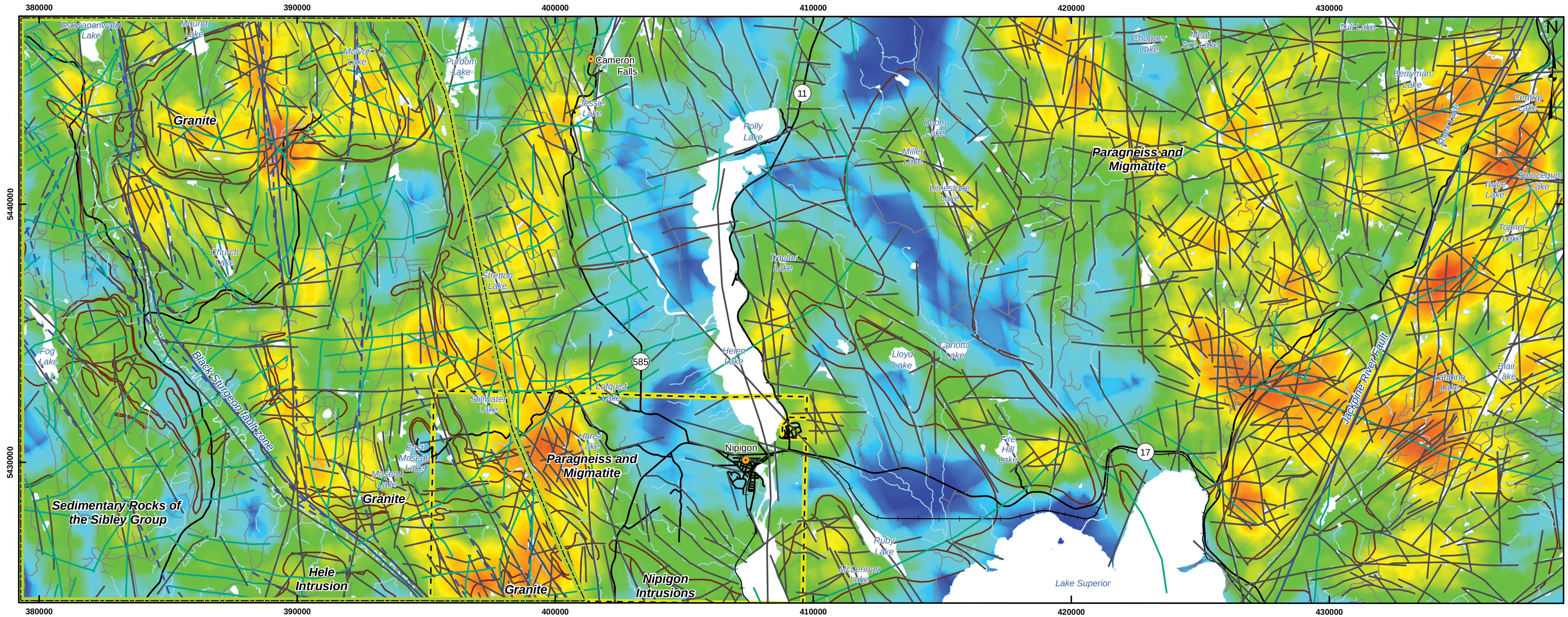
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Brittle Lineament Density Calculated for Lineaments of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013	FIGURE: 3.13	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		



LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Lineament / Fault (Hart, 2005)
- Mapped Dyke
- Geophysical Lineament (> 1km)
- Surficial Lineament (> 1km)
- Revised Mapping (Hart, 2005)
- Geologic Contact

Lineament Density (km/km²)
High : 6
Low : 0

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

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Lineaments - Lineament Interpretation - Township of Nipigon (JDMA, 2014)
Geologic Contact - 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

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Brittle Lineament Density Calculated for Lineaments (>1 km) of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013	FIGURE: 3.14	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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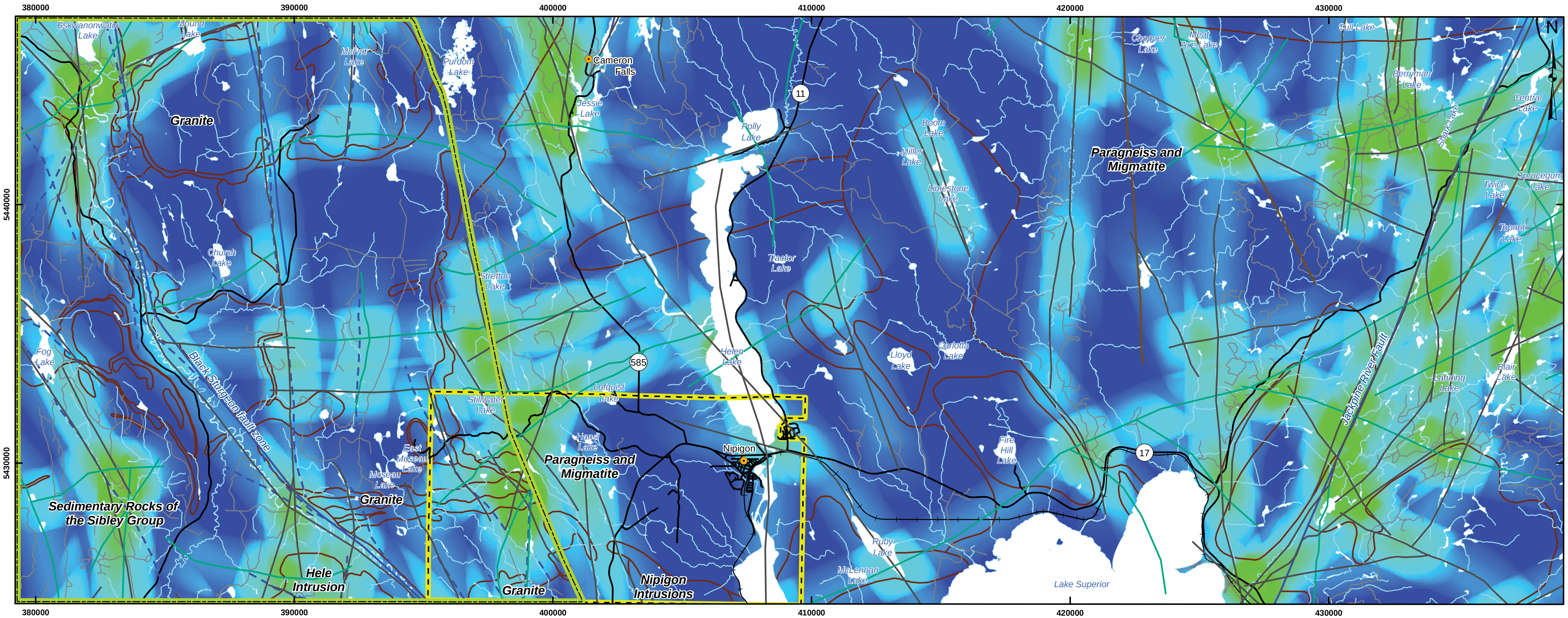

LEGEND

Municipal Boundary (Township of Nipigon)	Mapped Fault	**Lineament Density (km/km²)**
Community	Lineament / Fault (Hart, 2005)	High : 6
Main Road	Mapped Dyke	Low : 0
Local Road	Geophysical Lineament (> 5km)	
Railway	Surficial Lineament (> 5km)	
Watercourse	Revised Mapping (Hart, 2005)	
Waterbody	Geologic Contact	

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Lineaments - Lineament Interpretation - Township of Nipigon (JDMA, 2014)
Geologic Contact - 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

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

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Brittle Lineament Density Calculated for Lineaments (>5 km) of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013	FIGURE: 3.15	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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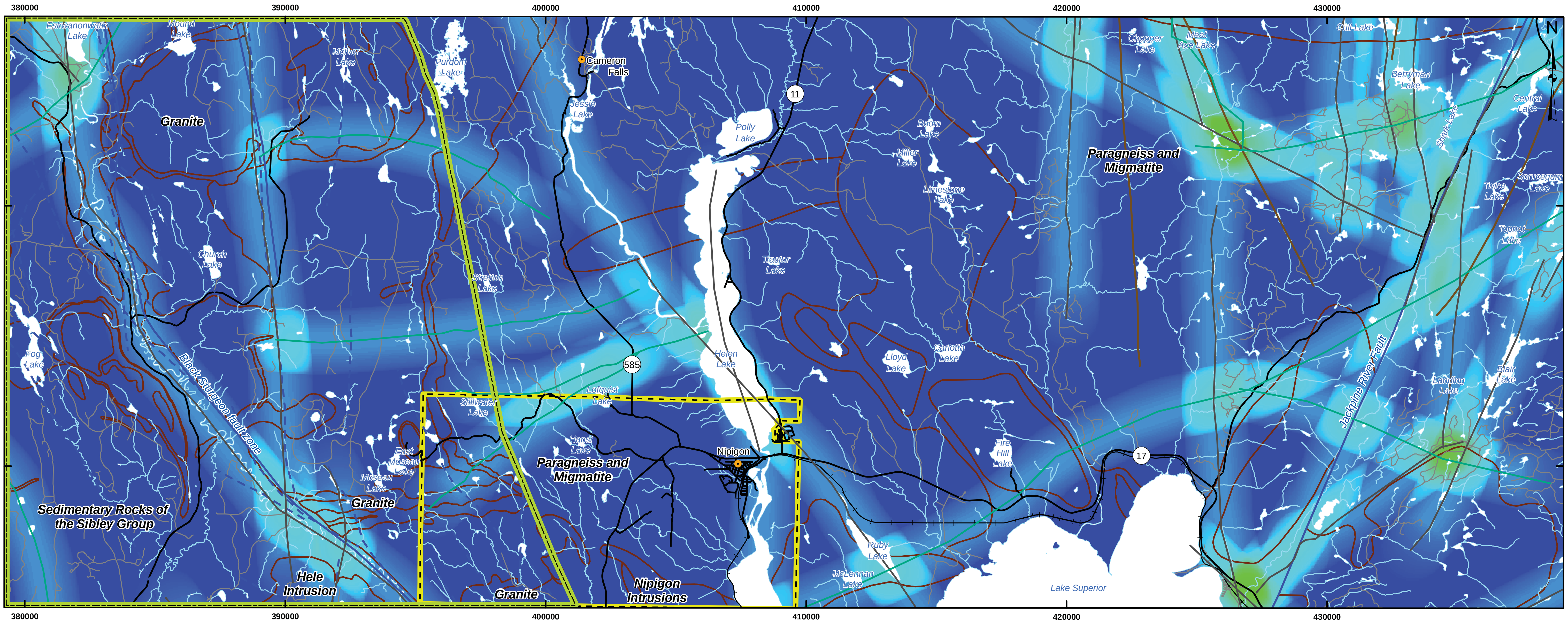

LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Lineament / Fault (Hart, 2005)
- Mapped Dyke
- Geophysical Lineament (> 10km)
- Surficial Lineament (> 10km)
- Revised Mapping (Hart, 2005)
- Geologic Contact

Lineament Density (km/km²)

High : 6

Low : 0

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Lineaments - Lineament Interpretation - Township of Nipigon (JDMA, 2014)
Geologic Contact - 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

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Brittle Lineament Density Calculated for Lineaments (>10 km) of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013	FIGURE: 3.16	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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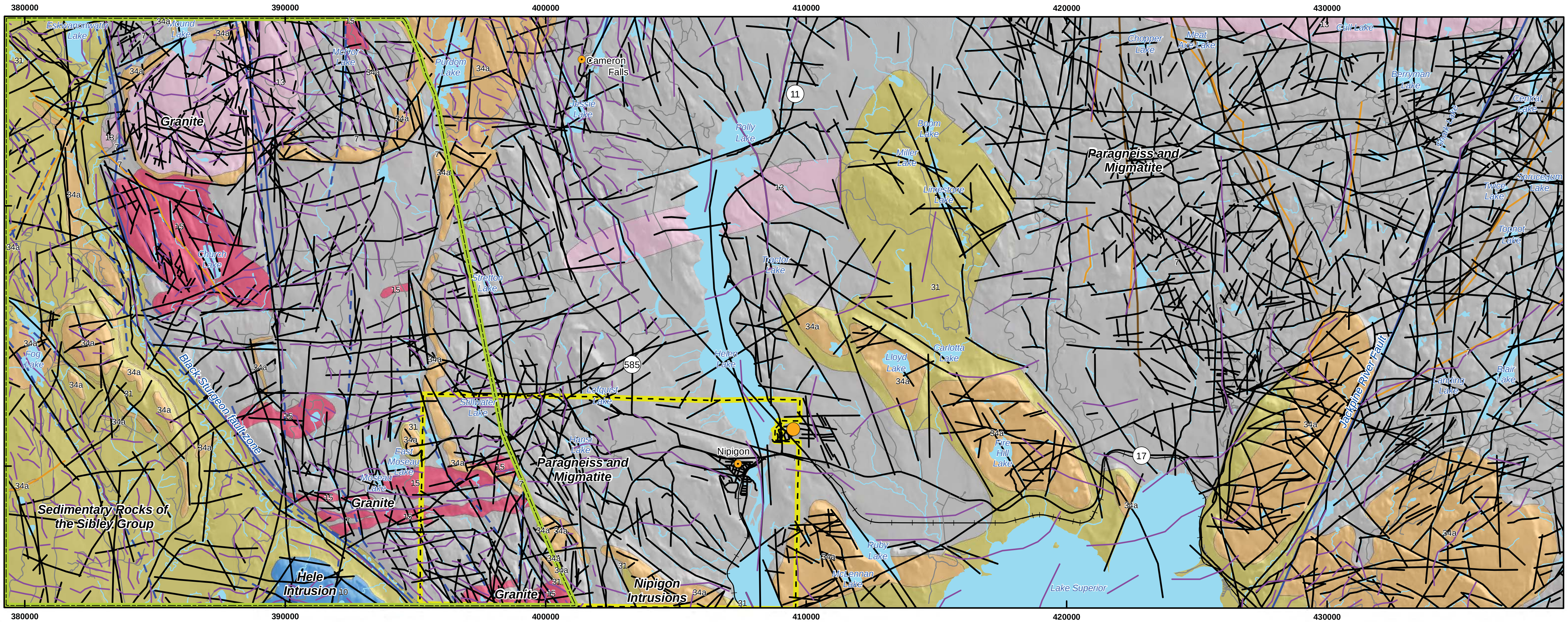

LEGEND

Municipal Boundary (Township of Nipigon)

Community

Main Road

Local Road

Railway

Watercourse

Waterbody

Seismic Events (Magnitude)

< 1.0

1.1 - 2.0

2.1 - 3.0

> 3.0

Mapped Fault

Lineament / Fault (Hart, 2005)

Mapped Dyke

Interpreted Ductile Lineament

Interpreted Brittle Lineament

Interpreted Dyke

Revised Mapping (Hart, 2005)

Bedrock Geology

34 Mafic and related intrusive rocks (Keweenawan age)

34a Logan and Nipigon sills

31 Sibley Gp.

15 Massive granodiorite to granite

13 Muscovite-bearing granitic rock

10 Mafic and ultramafic rocks

7 Metasedimentary rocks (Paragneisses and Migmatites)

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013

Brittle Lineaments - Lineament Interpretation - Township of Nipigon (JDMA, 2014)

Ductile Lineaments - Processing & Interpretation of Geophysical Data, Township of Nipigon (PGW, 2014)

Geology - Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)

Hillshade - CDED slope raster: GeoBase.ca (1:50,000)

Seismic - Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), April 2013

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Combined Structural Features of the Nipigon Area

Golder Associates

Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013		
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

FIGURE: 3.17

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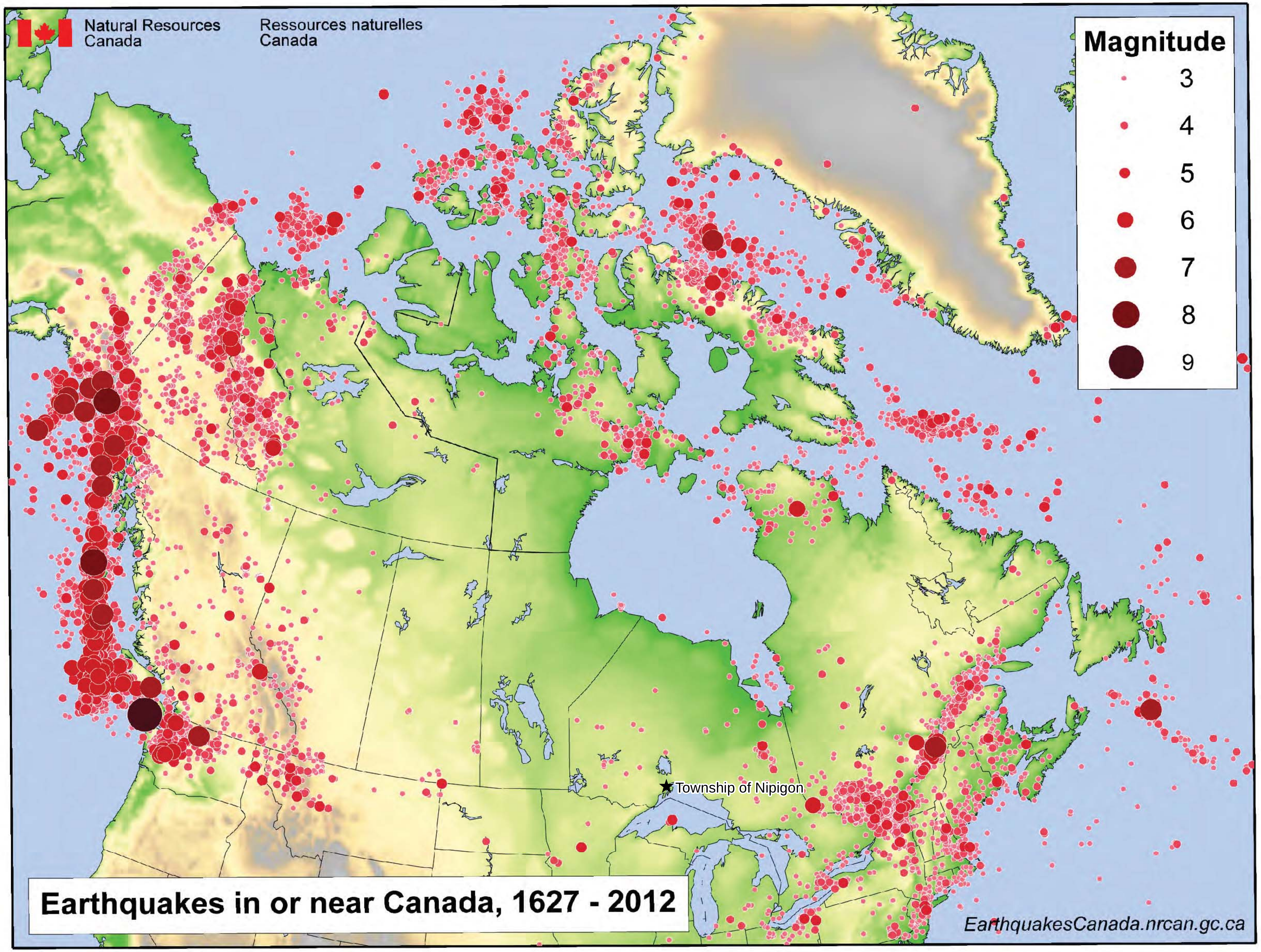

LEGEND

★ Township of Nipigon

REFERENCE

Seismic - Resources Canada (NRC). Earthquakes Canada Website. http://earthquakescanada.nrcan.gc.ca

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Earthquakes Map of Canada 1627-2012

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026		
DESIGN	PRM	4 Oct. 2013
GIS	PM/JB	2 Jun. 2014
CHECK	CWM	2 Jun. 2014
REVIEW	GWS	2 Jun. 2014

REV. 0.0

FIGURE: 3.18

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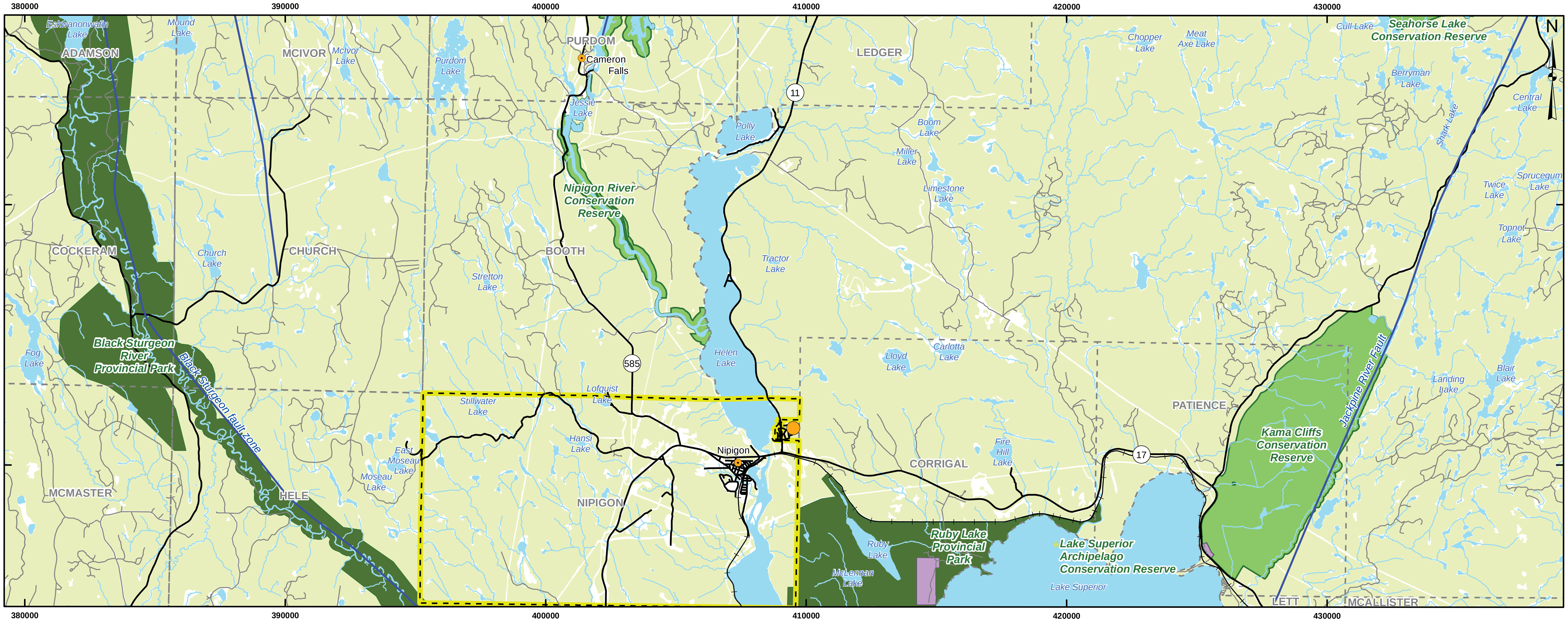

LEGEND

- Municipal Boundary (Township of Nipigon)
- Geographic Township
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Wooded Area
- Forest Reserve
- Recommended Conservation Reserve
- Conservation Reserve
- Provincial Park

Seismic Events (Magnitude)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- > 3.0

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Fault - MRD126-Bedrock Geology of Ontario, 2011
Seismic - Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), April 2013
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

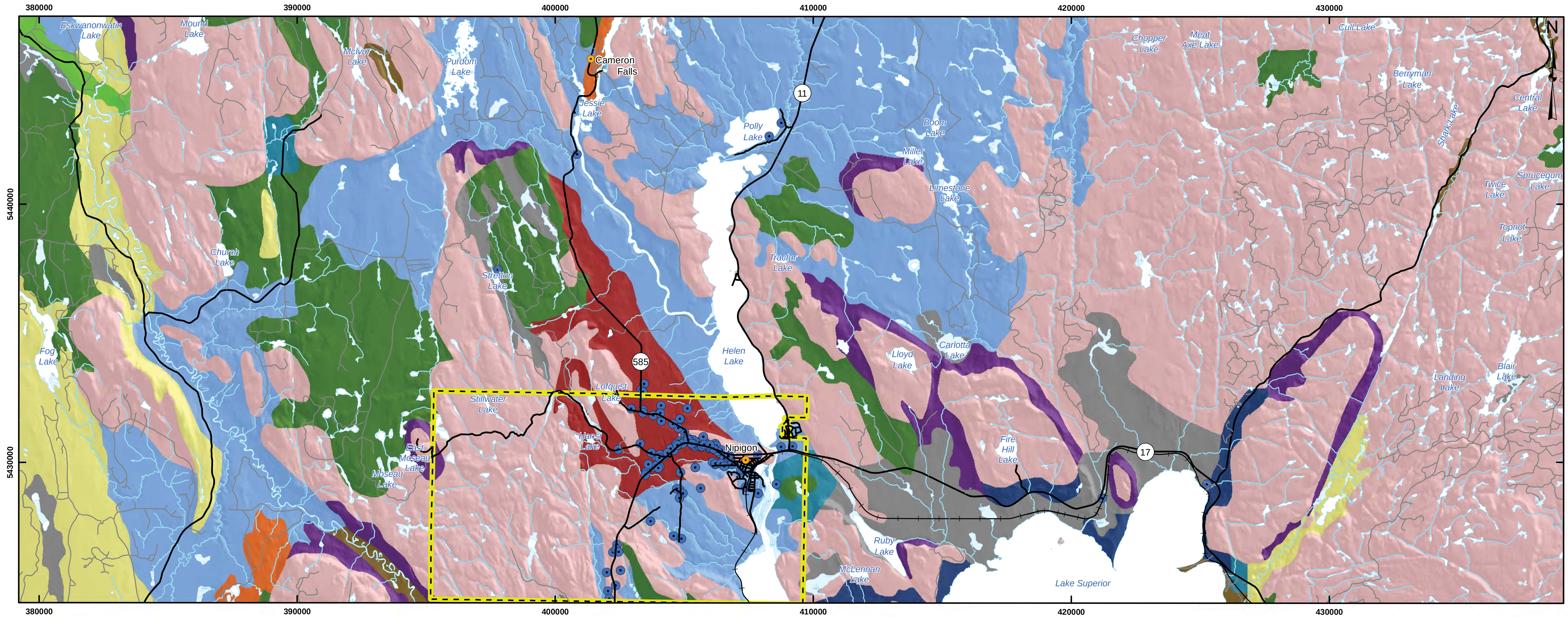
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Historical Earthquake Records of the Nipigon Area 1985-2013

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013	FIGURE: 3.19	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		



LEGEND

Municipal Boundary (Township of Nipigon)
Community
Main Road
Local Road
Railway
Watercourse
Waterbody
Wetland
MOE Water Well

Landform

- Man Made
- Ground Moraine
- End Moraine
- Glaciofluvial Kame
- Glaciofluvial Esker
- Glaciofluvial Outwash
- Glaciolacustrine Delta
- Glaciolacustrine Plain
- Glaciolacustrine Beach
- Colluvium
- Alluvial
- Organics
- Bedrock

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

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Landform - OGS, MNDMines, and Northeast Science and Information Section, MNR 2005. Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release - Data 160
Wells - Ministry of the Environment, last accessed September, 2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Groundwater Wells within the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Aug. 2013	FIGURE: 4.1	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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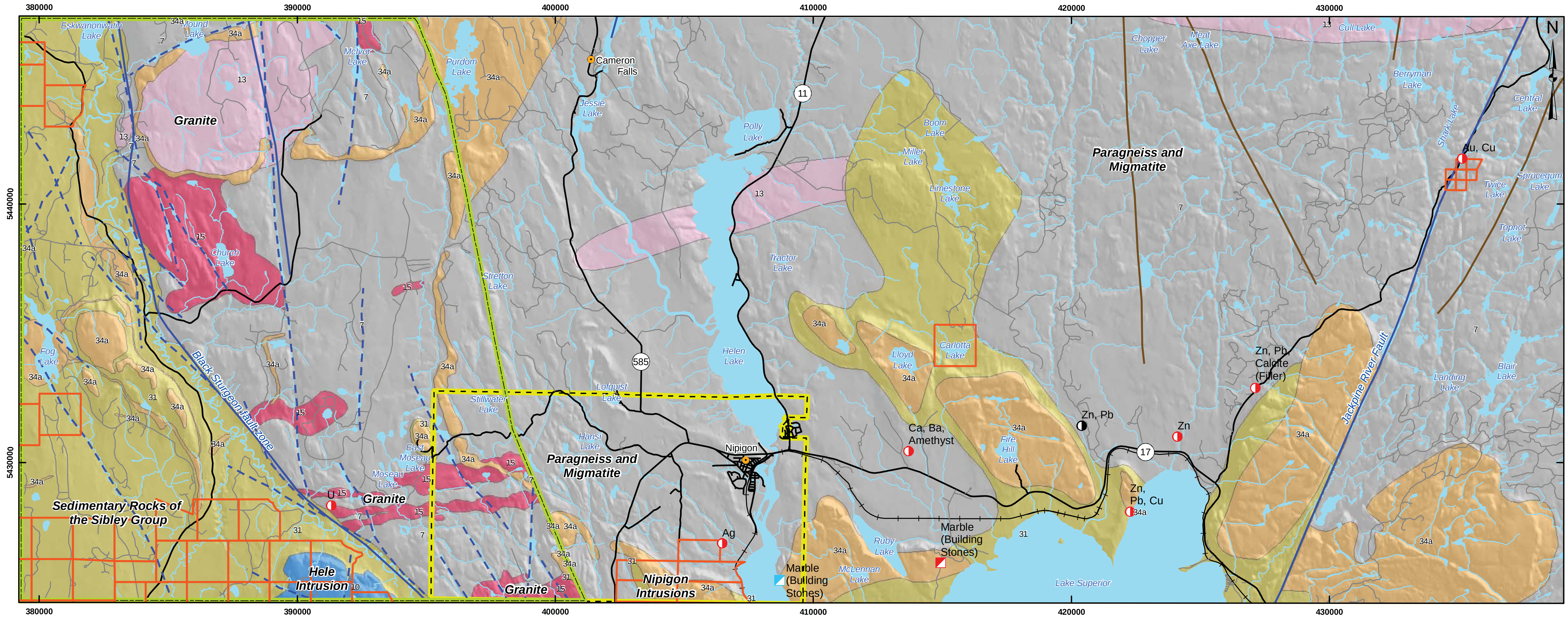

LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Discretionary Mineral Occurrence
- Mineral Occurrence
- Past Producing Mine With Reserves
- Past Producing Mine Without Reserves
- Mapped Fault
- Lineament / Fault (Hart, 2005)
- Mapped Dyke
- Active Mining Claim
- Revised Mapping (Hart, 2005)

Bedrock Geology

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

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

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)
Claims - Ministry of Northern Mines and Development October 4, 2013
Mineral Inventory - Mineral Deposit Inventory - 2013; Ontario Geological Survey
Hillshade - CDED slope raster: GeoBase.ca (1:50,000)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Mineral Showings and Dispositions of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013		
GIS	PM/JB	30 Jul. 2014		
CHECK	CWM	30 Jul. 2014		
REVIEW	GWS	30 Jul. 2014		

FIGURE: 5.1

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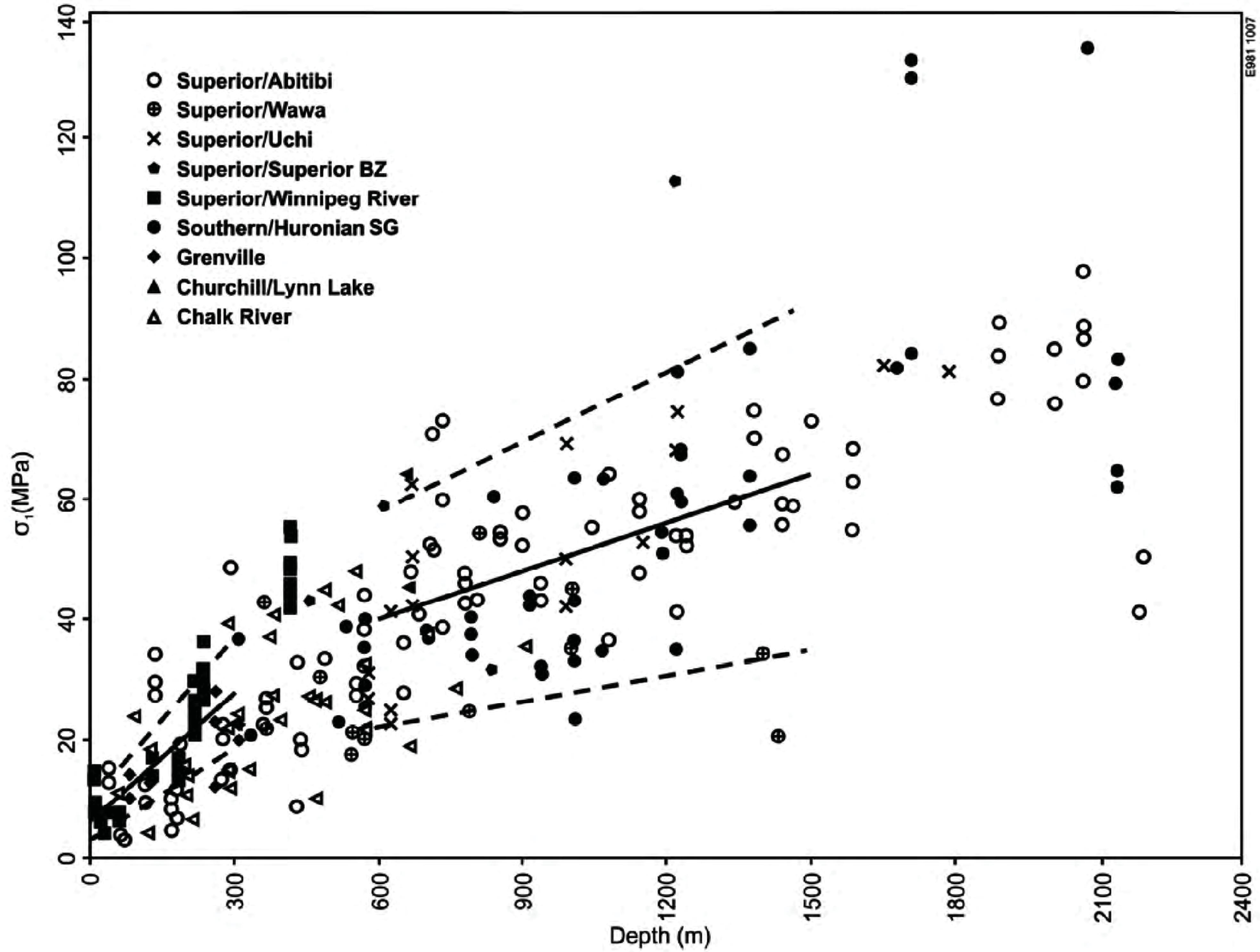

REFERENCE

Maximum Horizonal In Situ Stresses Measured in the Canadian Shield: After Maloney, Kaiser, and Vorauer, 2006.

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Maximum Horizontal In Situ Stress Typically Encountered in Crystalline Rock of the Canadian Shield

Golder Associates

Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013	FIGURE: 6.1	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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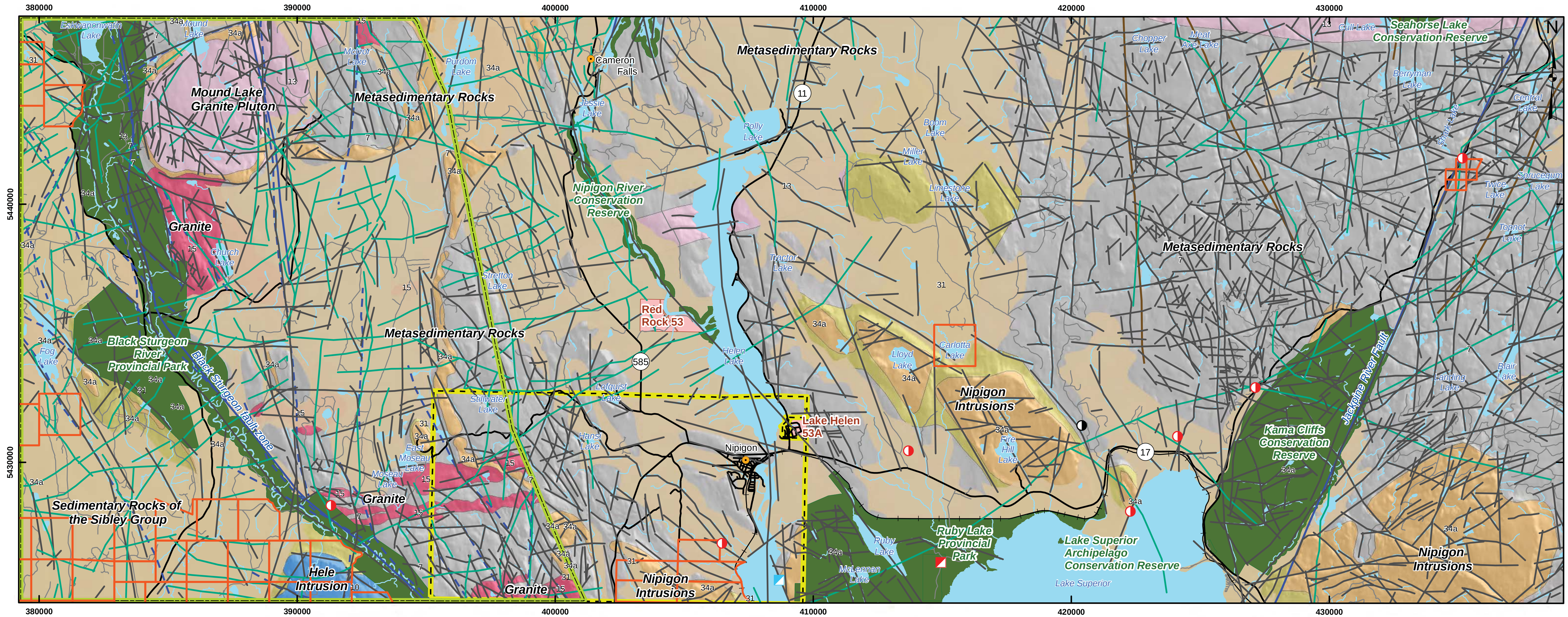

LEGEND

- Municipal Boundary (Township of Nipigon)
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Protected Area
- Federal Land - Indian Reserve
- Discretionary Mineral Occurrence
- Mineral Occurrence
- Past Producing Mine With Reserves
- Past Producing Mine Without Reserves
- Mapped Fault
- Lineament / Fault (Hart, 2005)
- Mapped Dyke
- Geophysical Lineament
- Surficial Lineament
- Active Mining Claim
- Overburden Cover
- Revised Mapping (Hart, 2005)

Bedrock Geology

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

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Claims - Ministry of Northern Mines and Development October 4, 2013
Geology - Modified 1:250 000 Scale MRD126-Bedrock Geology of Ontario, 2011 - incorporating detailed mapping published by Hart (2005)
Lineaments - Lineament interpretation - Township of Nipigon (JDMA, 2014)
Mineral Inventory - Mineral Deposit Inventory - 2013; Ontario Geological Survey 2013
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR 2005. Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Approximate Size of Repository Footprint

3 km

2 km

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Key Geoscientific Characteristics of the Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013		
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

FIGURE: 7.1

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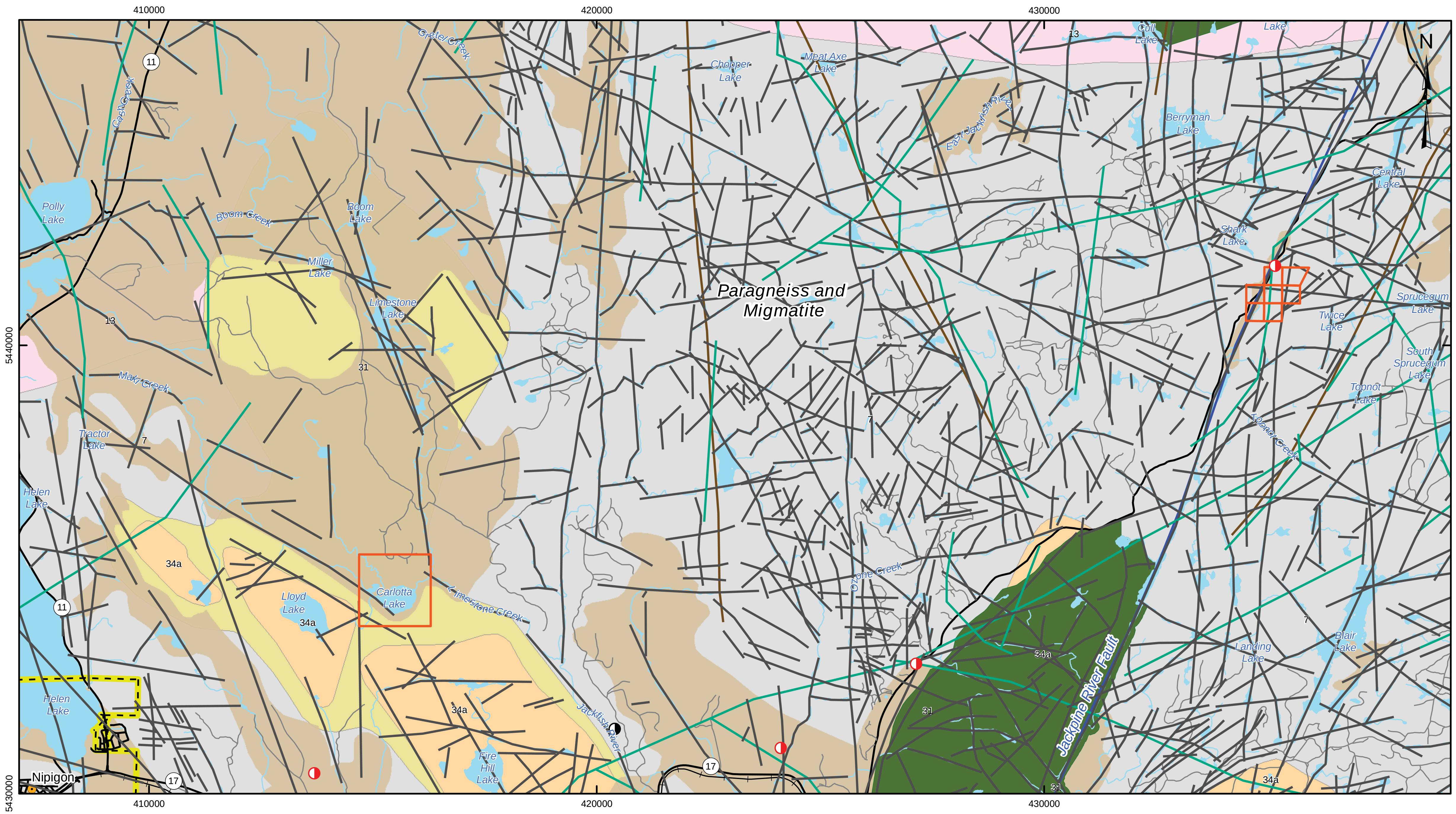

LEGEND

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- Local Road
- Railway
- Watercourse
- Waterbody
- Discretionary Mineral Occurrence
- Mineral Occurrence
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- Overburden Cover

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- 34 Mafic and related intrusive rocks (Keweenawan age)
- 34a Logan and Nipigon sills
- 31 Sibley Gp.
- 13 Muscovite-bearing granitic rock
- 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)
Claims - Ministry of Northern Mines and Development October 4 6, 2013; Mineral Inventory - Mineral Deposit Inventory - 2013; Ontario Geological Survey
Lineaments - Lineament interpretation - City of Nipigon (JDMA, 2013)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Approximate Size of Repository Footprint

3 km

2 km

2 1 0 2 4 6

SCALE 1:100,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Key Geoscientific Characteristics of Metasedimentary Rocks of the Quetico Subprovince - Eastern Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013		
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

FIGURE: 7.2

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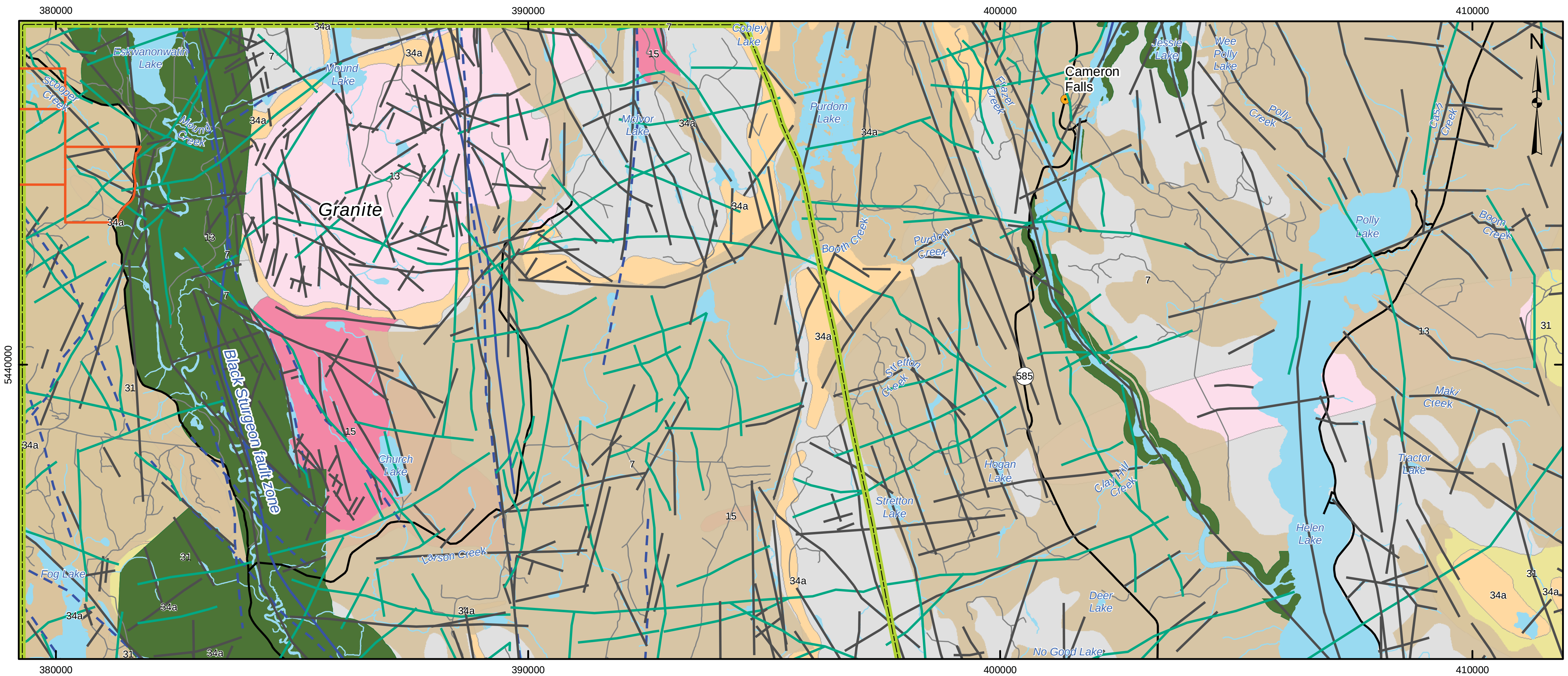

LEGEND

- Community
- Main Road
- Local Road
- Watercourse
- Waterbody
- Protected Area
- Discretionary Mineral Occurrence
- Mineral Occurrence
- Past Producing Mine With Reserves
- Past Producing Mine Without Reserves
- Mapped Fault
- Lineament / Fault (Hart, 2005)
- Geophysical Lineament
- Surficial Lineament
- Active Mining Claim
- Revised Mapping (Hart, 2005)
- Overburden Cover

Bedrock Geology

- 34 Mafic and related intrusive rocks (Keweenawan age)
- 34a Logan and Nipigon sills
- 31 Sibley Gp.
- 15 Massive granodiorite to granite
- 13 Muscovite-bearing granitic rock
- 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)
Claims - Ministry of Northern Mines and Development October 4 6, 2013; Mineral Inventory - Mineral Deposit Inventory - 2013; Ontario Geological Survey
Lineaments - Lineament interpretation - City of Nipigon (JDMA, 2013)
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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 16N

Approximate Size of Repository Footprint

3 km

2 km

2 1 0 2 4 6

SCALE 1:100,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Key Geoscientific Characteristics of Mound Lake Pluton and Surrounding Metasedimentary Rocks - Western Nipigon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Aug. 2013	FIGURE: 7.3	
GIS	PM/JB	2 Jun. 2014		
CHECK	CWM	2 Jun. 2014		
REVIEW	GWS	2 Jun. 2014		

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APPENDIX A

Geoscientific Factors

Table A-1: Safety Factors, Performance Objectives and Geoscientific Factors

Safety Factors	Performance Objectives	Evaluation Factors to be Considered
Containment and isolation characteristics of the host rock	**1.** The geological, hydrogeological and chemical and mechanical characteristics of the site should: ■ Promote long-term isolation of used nuclear fuel from humans, the environment and surface disturbances; ■ Promote long-term containment of used nuclear fuel within the repository; and ■ Restrict groundwater movement and retard the movement of any released radioactive material.	**1.1** The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events. **1.2** The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities. **1.3** The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multi-barrier system. **1.4** The hydrogeological regime within the host rock should exhibit low groundwater velocities. **1.5** The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement. **1.6** The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.
Long-term stability of the site	**2.** The containment and isolation functions of the repository should not be unacceptably affected by future geological processes and climate changes.	**2.1** Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long term. **2.2** The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository. **2.3** The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository. **2.4** The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.

Safety Factors	Performance Objectives	Evaluation Factors to be Considered
Repository construction, operation and closure	**3.** The surface and underground characteristics of the site should be favourable to the safe construction, operation, closure and long-term performance of the repository.	**3.1** The strength of the host rock and *in situ* stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities. **3.2** The soil cover depth over the host rock should not adversely impact repository construction activities. **3.3** The available surface area should be sufficient to accommodate surface facilities and associated infrastructure.
Human intrusion	**4.** The site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities.	**4.1** The repository should not be located within rock formations containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today. **4.2** The repository should not be located within geological formations containing exploitable groundwater resources (aquifers) at repository depth.
Site characterization	**5.** The characteristics of the site should be amenable to site characterization and site data interpretation activities.	**5.1** The host rock geometry and structure should be predictable and amenable to site characterization and site data interpretation.

APPENDIX B

Geoscientific Data Sources

Table B-1: Summary of Geological Mapping Sources for the Nipigon Area

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
M5052	Northern Ontario engineering geology terrain study, data base map, Frazer Lake, NTS 52H/SE	Mollard, D.G.	OGS	1:100 000	1979	partial	
M5079	Roslyn Lake, NTS 42E/SE, data base map, northern Ontario engineering geology terrain study	Gartner, J.F.	OGS	1:100 000	1980	partial	
M5092	Schreiber, NTS 42D/NW, data base map, northern Ontario engineering geology terrain study	Gartner, J.F.	OGS	1:100 000	1980	partial	
M5046	Black Bay, NTS 52A/E, data base map, northern Ontario engineering geology terrain study	Mollard, D.G.	OGS	1:100 000	1979	partial	
P0357	Red Rock-Pine Portage sheet, District of Thunder Bay, geological compilation series	E.G. Pye	OGS	1:126 720	1966	partial	
M2232	Nipigon-Schreiber, geological compilation series, Thunder Bay District	M.W. Carter, W.H. McIlwaine, P.A. Wisbey	OGS	1:253 440	1973	partial	
M2137	Nipigon-Schreiber sheet, geological compilation series, Thunder Bay District	E.G. Pye	OGS	1:253 440	1968	partial	
P1819	Fort William sheet and part of Nipigon sheet, sample location map, District of Thunder Bay [GSC open file 507] Water	Geological Survey of Canada, Ontario Geological Survey	OGS	1:250 000	1978	partial	Water and sediment geochemistry

	and sediment geochemistry						
P1805	Schreiber sheet and part of Longlac sheet, sample location map, District of Thunder Bay [GSC open file 506]	Geological Survey of Canada, Ontario Geological Survey	OGS	1:250 000	1978	partial	Water and sediment geochemistry
P0463	Black Sturgeon Lake area (east half), District of Thunder Bay	M.E. Coates	OGS	1:63,360	1968	partial	
P3539	Precambrian Geology of the Disraeli Lake Area, Nipigon Embayment, Northwestern Ontario	Hart, T.R., Préfontaine, S.	OGS	1:50 000	2004	partial	
P3540	Northern Black Sturgeon River Area Geological Cross-Sections, Nipigon Embayment, Northwestern Ontario	Magyarosi, Z., Hart, T.R., Fralick, P.W., Metsaranta, R., Heggie, G.J., Hollings, P., Richardson, A.J.	OGS	1:50 000	2004	partial	
M2665-RE	Precambrian Geology Compilation Series - Schreiber Sheet	Santaguida, F.	OGS	1:250 000	2002	partial	
M2667	Precambrian Geology Compilation Series - Longlac Sheet	Johns, G.W., McIlraith, S., Stott, G.M	OGS	1:250 000	2003	partial	Tags a strip along the east side
P3563	Southern Black Sturgeon River-Seagull Lake Area Geological Cross-Sections, Nipigon Embayment, Northwestern Ontario	Hart, T.R., Tolson, A	OGS	1:100 000	2005	partial	

Table B-2: Summary of Geophysical Mapping Sources for the Nipigon Area

Product	Source	Line Spacing/ Sensor Height	Coverage	Date	Additional Comments
Canadian Digital Elevation Data (CDED); 1:50,000	Geobase	20 m	Entire Nipigon area	1978 - 1995	Hillshade and slope rasters used for mapping
Spot 4/5; Orthoimage, multispectral/ panchromatic	Geobase	10 m (panchromatic) 20 m (multispectral)	Entire Nipigon area	2005 and 2008	Panchromatic mosaic used for mapping
LandSAT 7/5; Orthoimage, multiprectral/panchromatic	Geobase	15 m (panchromatic) 30 and 28.5 m (multispectral) 60 and 120 m (infrared)	Entire Nipigon area	2001 and 1988	Multispectral bands used for mapping outcrop and wetlands
GSC Regional Magnetic Compilation (Ontario #8)	Geological Survey of Canada	805 m line spacing Sensor height 305 m	Mainly east	1962	Lowest resolution dataset
GDS1047 Lake Nipigon Embayment	Ontario Geological Survey	150 m line spacing Sensor height 100 m	West and northwest	2003	High resolution dataset, includes radiometric data
Nipigon Bay (GDS1226)	Ontario Geological Survey	350 m line spacing Sensor height 39 m	Southeast	1994	Medium resolution, includes Geotem electromagnetic data
Georgia Lake	GSC, 2013	1,000 m/120 m	East 30%	1989	Medium resolution radiometric survey with VLF.
Thunder Bay Detail	GSC, 2013	1,000 m/130 m	West 20%	1979	Medium resolution radiometric survey.
Thunder Bay Reconnaissance	GSC, 2013	5,000 m/144 m	Central 50%	1979	Low resolution radiometric survey.
GDS1052 Lake Nipigon Embayment	OGS, 2004b	250 m-12 km	West half	2003-2004	High resolution gravity survey.
GSC Gravity Coverage	GSC, 2013	5-25 km	Entire Nipigon area	1952-1965	Relatively sparse GSC coverage.

Table B-3: Summary of Geoscientific Databases for the Nipigon Area

Database	Description	Scale (Regional/Local)	Used? (Yes/No)
AFRI	The AFRI database captures details on location, property ownership, type of work done and commodities sought for each Assessment File. It provides an index to the reports and maps that comprise the technical data as well as a link to complete digital images of that data. Spatial data is collected for each file in the form of polygons indicating property outlines.	Regional	Yes
AMIS (Abandoned Mines Information System Database)	AMIS is a database containing information on all known abandoned and inactive mine sites located on both Crown and privately held lands within the province of Ontario. There are currently 5,700 known abandoned mine sites scattered throughout the Province, which contain more than 16,400 mine features.	Regional	Yes
Bedrock Geology	Bedrock Geology contains information about the solid rock underlying the Province of Ontario at a compilation scale of 1:250000. Data includes: bedrock units, major faults, dike swarms, iron formations, kimberlites and interpretation of the Precambrian bedrock geology underlying the Hudson Bay and James Bay lowlands Phanerozoic cover.	Regional	Yes
(MRD 126)	Whole-rock and trace element analyses for 114 bedrock samples of mafic igneous rocks related to the Mesoproterozoic Midcontinent Rift. The release also includes a compilation of geochemical data for Midcontinent Rift–related rocks compiled from previously released digital data sets (Miscellaneous Release—Data (MRD) 114, 132, 133, 146, 147, 190, 194 and 261—Revised) totalling 2358 spatially referenced data points with geochemical analyses, in addition to the 114 new samples.	Local	Yes
MRD308	Includes digital products of three-dimensional (3D) inversion modelling carried out as part of this program. The contents of this release consist of data, images and reporting for 15 gravity areas and 23 magnetic areas in a region flanking the west shore of Lake Nipigon.	Local	Yes
MRD193	Preliminary results from the largest audiomagnetotelluric (AMT) survey conducted in Ontario. The survey was successful in imaging the contact between overlying Sibley Group sedimentary rocks and underlying Archean basement, as well as imaging individual Nipigon mafic sills.	Local	Yes
MRD192	Lake sediment and water geochemical data and lake water quality (limnological) data, including quality control data, collected from a survey of 2136 sites in the Nipigon to Beardmore area of northwestern Ontario.	Regional	No
RD243	Lithogeochemical data for 27 476 analyses for approximately 25 664 samples collected by Ontario Geological Survey geoscientists during mapping projects and 1812 laboratory duplicates.	Regional	No

MRD250	Whole rock and trace element lithogeochemical data for samples collected in the mid-1980s in the Beardmore–Geraldton area.	Regional	No
Data to Accompany MRD264	Compositional data produced by a 2003 regional investigation of peraluminous, S-type granitic and pegmatitic granitic rocks and proximal rare-element pegmatites in the Georgia Lake area of the Quetico Subprovince. The data set comprises 2331 electron microprobe, 237 bulk rock and 126 bulk mineral (potassium feldspar, muscovite and beryl) compositions.	Local	Yes
MRD231	Data from tables and/or appendixes in Open File Report (OFR) 6174 (Stratigraphy and Sedimentology of the Mesoproterozoic Sibley Group and Related Igneous Intrusions, Northwestern Ontario: Lake Nipigon Region Geoscience Initiative), OFR 6175 (Geochemistry and Radiogenic Isotope Characteristics of the Sills of the Nipigon Embayment.	Regional	Yes
MRD190	Chemical analyses and diamond-drill hole information utilized in the geological interpretation presented on Preliminary Maps P.3562 and P.3563 as a result of mapping in the southern Black Sturgeon River to Seagull Lake area of the Nipigon Embayment.	Local	Yes
MRD147	Chemical analyses and diamond drill hole information utilized in the geological interpretation presented on preliminary maps P.3538 and P.3539 as a result of mapping in the northern Black Sturgeon River to Disraeli Lake area of the Nipigon Embayment.	Local	Yes
MRD133	Preliminary U/Pb Geochronology Results results from baddeleyite and/or zircon for 44 rock samples collected between 2003 and 2005. In addition to location information, descriptions of the dated minerals and concordia plots illustrating the U/Pb data are included in the report. Samples are mainly from Mesoproterozoic Nipigon diabase sills and Nipigon ultramafic intrusions; however, ages from Archean mafic intrusions, Paleoproterozoic and Mesoproterozoic sedimentary and volcanic rocks are also reported.	Local	Yes
MRD191	Assessment of Using 3D Large-Scale Visualization and Data Integration for the Lake Nipigon Region Geoscience Initiative	Local	No
MRD184	CLAIMaps contains active claims, alienations and dispositions. Data includes: links to further land tenure information.	Regional	Yes
CLAIMaps	Stott, G.M. and Josey, S.D. 2009. Post-Archean mafic (diabase) dikes and other intrusions of northwestern Ontario, north of latitude 49°30′; Ontario Geological Survey	Regional	Yes
Diabase Dykes	Drill Holes contains information on surface and underground drilling done as outlined by assessment files. Data includes: company name, company hole number, township and a link to the full drill hole record on Geology Ontario.	Regional	Yes
(MRD 241)	Geological Survey of Canada Earthquake Search (On-line Bulletin): http://www.earthquakescanada.nrcan.gc.ca/index-eng.php	Regional	Yes

Drill Holes	Geochronology Data for Ontario; Ontario Geological Survey. The compilation covers all isotopic ages greater than 10 Ma for Ontario, and adjacent areas of Manitoba, Michigan, Minnesota, New York and Quebec.	Regional	No (redundant)
Earthquakes Canada (NEDB)	Geotechnical Boreholes contains records of boreholes constructed during geotechnical investigations. Data includes: information on the Geological Stratum identified down each hole as well as the hole depth.	Regional	Yes
NOEGTS	Northern Ontario Engineering Geology and Terrain Study. Contains an evaluation of near-surface geological conditions such as material, landform, topography and drainage. Data includes: land form type, geomorphology, primary material, secondary material, topography and drainage condition, point features such as sand and gravel pits, sand dunes, drumlins, eskers, landslide scars and index maps to study areas.	Regional	Yes
Ontario Base Mapping	Land Information Ontario (LIO). Ontario Ministry of Natural Resources. Topography, roads, infrastructure, land cover and drainage. http://www.mnr.gov.on.ca/en/Business/LIO	Regional	Yes
Quaternary Geology (Data Set 14)	Ontario's Quaternary Geology at a compilation scale of 1:1000000. Ontario Geological Survey, 1997. Quaternary geology, seamless coverage of the province of Ontario: Ontario Geological Survey, Data Set 14. This layer includes Quaternary geology units, point features such as drumlins and glacial striae and line features such as eskers, shore bluffs and moraines.	Regional	Yes
WWIS (Water Wells)	Database containing water well records throughout Ontario from 1949 to present: http://www.ene.gov.on.ca/environment/en/mapping/index.htm	Regional	Yes

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Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

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