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 IGNACE, ONTARIO

APM-REP-06144-0011

NOVEMBER 2013

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

November 2013

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

Township of Ignace, Ontario

Submitted to:

Nuclear Waste Management Organization
22 St. Clair Avenue East, 6th Floor
Toronto, Ontario
M4T 2S3

REPORT

Report No: 12-1152-0026 (3000)
NWMO Report No: APM-REP-06144-0011

Distribution:

PDF copy - NWMO

PDF copy - Golder Associates Ltd.

Golder Associates

Executive Summary

In November 2011, the Township of Ignace, 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 Ignace 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, 2013).

This report presents the results of a desktop geoscientific preliminary assessment to determine whether the Ignace 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 Ignace and its periphery, which are referred to as the "Ignace 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 desktop geoscientific 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 desktop geoscientific preliminary assessment showed that the Ignace area contains at least four general areas that have the potential to satisfy NWMO's site evaluation factors. Two of these areas are within the Indian Lake batholith. The two other areas are within the Revell and the Basket Lake batholiths, respectively.

The Revell, Basket Lake and Indian Lake batholiths hosting the four identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They are estimated to have sufficient depth and extend over large areas. The potentially suitable areas within these batholiths appear to be, for the most part, lithologically homogeneous and are far from major regional

structural features such as faults, shear zones and geological subprovince boundaries. All four areas have low potential for natural resources; are generally accessible; and are amenable to site characterization.

While the Ignace area appears to contain general areas with favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. Main uncertainties include the low resolution of available geophysical data over most of the potentially suitable areas and significant overburden cover in some areas.

Should the community of Ignace be selected by the NWMO to advance to Phase 2 study and remain interested in continuing with the site selection process, several years of progressively more detailed geoscientific studies would be required to confirm and demonstrate whether the Ignace area contains sites that can safely contain and isolate used nuclear fuel. This would include the acquisition and interpretation of higher resolution airborne geophysical surveys, detailed field geological mapping and the drilling of deep boreholes.

Table of Contents

TABLES

FIGURES (IN ORDER FOLLOWING TEXT)

APPENDICES

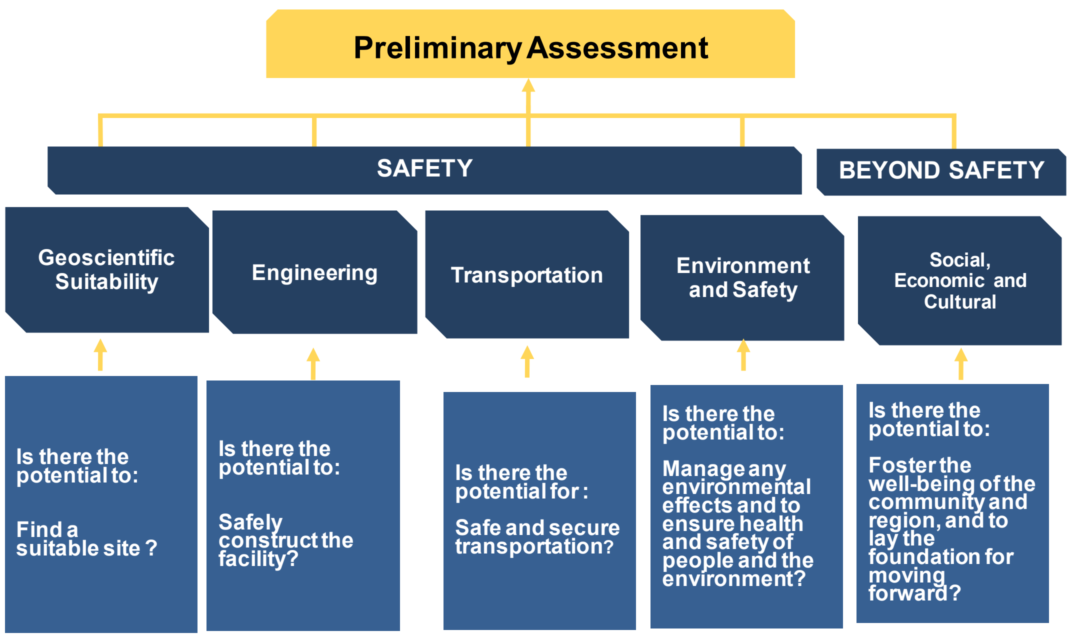
SUPPORTING DOCUMENTS

1.0 INTRODUCTION

1.1 Background

In November 2011, the Township of Ignace, Ontario, expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Ignace area for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process (Golder, 2011a).

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 findings of the preliminary assessment are documented in an integrated preliminary assessment report (NWMO, 2013).



The objective of the geoscientific preliminary assessment is to assess whether the Ignace area contains general areas that have the potential to meet 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 include 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 desktop preliminary assessment considering both technical and community well-being factors presented in the above diagram.

This report presents the results of a desktop geoscientific preliminary assessment of potential suitability (Phase 1), conducted by Golder Associates Ltd.

1.2 Desktop Geoscientific Preliminary Assessment Approach

The objective of the Phase 1 desktop geoscientific preliminary assessment is to assess whether the Ignace area contains general areas that have the potential to satisfy the geoscientific evaluation factors outlined in the site selection process document (NWMO, 2010). The location and extent of identified potentially suitable areas would be confirmed during subsequent site evaluation stages.

The desktop preliminary geoscientific assessment built on the work previously conducted for the initial screening (Golder, 2011a) and focused on the Township of Ignace and its periphery, which are referred to as the "Ignace area" (Figure 1.1). The boundaries of the Ignace area have been defined to encompass the main geological features within the Township of Ignace and its surroundings. The Phase 1 Desktop Geoscientific 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 details of these various studies are documented in three supporting documents: terrain analysis (JDMA, 2013a); geophysical interpretation (PGW, 2013); and lineament interpretation (JDMA, 2013b). 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 Ignace area using key geoscientific characteristics that can realistically be assessed at this stage of the assessment 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 Ignace 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 Ignace area. Key geoscientific information sources are summarized in this section, with a complete listing provided in Appendix B.

1.4.1 Satellite Imagery and Airborne Geophysics

The digital elevation model data for the Ignace area is the Canadian Digital Elevation Data (CDED), a 1:50,000 scale, 20 m resolution, elevation model constructed by Natural Resources Canada (NRCan) using provincial data created through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (MNR) (Table 1.1; GeoBase, 2011a). SPOT multispectral (20 m resolution) and panchromatic (10 m resolution) orthoimagery were available for the Ignace area (Table 1.1; GeoBase, 2011b). Six SPOT images (scenes) provided complete coverage for the Ignace area (Table 1.1). The scenes are from the SPOT 5 satellite with three images acquired in May 2006 and three in October 2007.

Aeromagnetic, gravity and radiometric data was obtained from various sources (Table 1.1). The majority of the Ignace area is covered by low-resolution aeromagnetic data published by the Geological Survey of Canada (GSC) and downloaded from their Geoscience Data Repository for Geophysical and Geochemical Data (GSC, 2012). This data was acquired at a flight line spacing of 805 m and a sensor height at 305 m.

Three higher resolution aeromagnetic and electromagnetic surveys were available from the Ontario Geological Survey (OGS). These include the Sturgeon Lake-Savant Lake survey (OGS, 2003) that covers the extreme northeastern corner of the Ignace area with a flight line spacing of 200 m and a sensor height of 45 m, the Lumby-Finlayson Lakes survey (OGS, 2009) that covers the extreme southeastern corner of the Ignace area with a flight line spacing of 200 m and a sensor height of 81 m, and the Stormy Lake dataset (OGS, 2011a) that covers much of the western half of the Ignace area with a flight line spacing of 200 m and sensor height of 73 m (PGW, 2013; Figure 1.2, Table 1.1).

High-resolution aeromagnetic and radiometric data are also available from a survey flown for Takara Resources over the southeastern part of the Basket Lake batholith (PGW, 2013). In this area, airborne geophysical data are available on 100 m line spacings (Figure 1.2; Table 1.1).

Table 1.1: Summary of Satellite and Geophysical Source Data Information for the Ignace Area

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	20 m	Entire Ignace area	1978 - 1995	Hillshaded and slope rasters used for mapping
Satellite Imagery	Spot 5; Orthoimage, multispectral/ panchromatic	Geobase	10 m (panchromatic) 20 m (multispectral)	Entire Ignace area	2006 (west) 2007 (east)	
Geophysics	Gravity Coverage	Geological Survey of Canada	5-15 km / surface	Entire Ignace area	1946-1974	Station locations were sparsely distributed
	Detailed Gravity Coverage	Szewczyk (1974)	1.5 km invervals along roads and lakeshores	Basket Lake Batholith, northern part of Indian Lake Batholith	1974	A total of 226 gravity stations are located within the Ignace area
	Radiometric Coverage	Geological Survey of Canada	5000 m / 120m	Entire Ignace area	1975 1979 1996	Data includes potassium, uranium, and thorium measurements

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
Geophysics (cont)	Regional Magnetic Compilation	Geological Survey of Canada	805 m line spacing Sensor height 305 m	Entire Ignace area	1965	Lowest resolution dataset Includes aeromagnetic and gravity data
	Sturgeon Lake-Savant Lake Survey (GDS1033)	Ontario Geological Survey	200 m line spacing Sensor height 45 m	Covers 48.1 km^2 in northeast corner of Ignace area	1990	Aeromagnetic Limited usefulness due to minimal coverage in Ignace area
	Lumby-Finlayson Lakes Survey (GDS1060)	Ontario Geological Survey	200 m line spacing Sensor Height 81 m	Covers 40.3 km^2 in southeast corner of Ignace area	2009	Aeromagnetic Limited usefulness due to minimal coverage in Ignace area
	Stormy Lake Survey (GDS1107)	Ontario Geological Survey	200 m line spacing Sensor Height 73 m	Covers 2,050.7 km^2 in western part of Ignace area	2001	Aeromagnetic Covers the entire Revell Batholith
	Takara Resources Survey (AFRI 20000003895)	Ontario Geological Survey	100 m line spacing Sensor Height 60 m	Covers 300 km^2 in northwestern corner of Ignace area	2008	Aeromagnetic Useful for detailed understanding

1.4.2 Geology

Geological mapping of the Ignace area began in the 19th century coinciding with increased prospecting and mining activity. Most of the early geological work was regional in scale and focussed on the metavolcanic rock assemblages, owing to their mineral potential. More detailed mapping was initiated in the 1930s by the Ontario Department of Mines and has continued to the present. Tanton (1938) produced a regional compilation map of the central part of the Wabigoon Subprovince, while Satterly (1960) mapped the Dyment area including most of the Revell batholith. Sage et al. (1974) mapped portions of the Ignace area and characterized the various felsic plutonic rocks, including the White Otter Lake and Revell batholiths, and Jackson (1985) mapped greenstones and felsic intrusives in the Lumby Lake area.

In recent years, the Ignace area has been subject to more detailed geological analysis (Figure 1.2) on a local scale (e.g., Stone et al., 1998; 2007ab; Stone and Halle, 1999; Stone, 2009a; Stone, 2010a; and Stone et al., 2011a; 2011b; 2011c), and a regional scale (e.g., Schwerdtner et al., 1978 and 1985; Blackburn et al.,1991; Sage, 1998; Percival, 2004; Stone and Davis, 2006; Percival and Easton, 2007; Beakhouse, 2009; Stone, 2010b; and Beakhouse et al., 2011). Additional work on geochronology (e.g., Larbi et al., 1998; Corfu and Davis, 1992; Stone, 2010a; and Stone et al., 2010) and structural geology (e.g., Card and Ciesielski, 1986; Card, 1990; Kamineni et al., 1990; Sanborn-Barrie, 1991; Percival et al., 2002; Tomlinson et al., 2004; Sanborn-Barrie et al., 2002 and 2006; Stone and Davis, 2006) have also been conducted. Geophysical gravity modelling (Szewcyk and West, 1976) and building stone assessments (Storey, 1986; Gerow and Bellinger, 1990; and Farrow, 1996) have also been conducted.

Geological mapping coverage is good and generally current throughout most of the Ignace area, with the notable exception of the northern portion (Figure 1.2). Only regional-scale mapping at a 1:250 000 scale (OGS, 2011) is available for the northern part of the Indian Lake batholith and in the area of the Basket Lake batholith. Figure 1.2 shows a summary of available geological map coverage and geophysical data for the Ignace area.

National seismicity data sources were reviewed to provide an indication of seismicity in the Ignace area (Hajnal et al., 1983; Hayek et al., 2009; NRCan, 2012).

1.4.3 Hydrogeology and Hydrogeochemistry

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

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

1.4.4 Natural Resources – Economic Geology

Information regarding the mineral resource potential for the Ignace area has been obtained from a variety of sources including general syntheses of mineralization in the Canadian Shield Region (Blackburn et al., 1991; Fyon et al., 1992; Breaks and Bond, 1993; and Stone and Halle, 1999), studies within the Ignace area (Satterly, 1960; Woolverton, 1960; Sage et al., 1974; Jackson, 1985; Breaks, 1993; Stone et al., 1998; and Stone, 2009ab, 2010ab), economic geology studies and reports such as Shklanka, 1968; Vos et al., 1982; Storey, 1986; Berger, 1988; Parker, 1989; Gerow and Bellinger, 1990; Breaks, 1993; Farrow, 1996; Hinz et al., 1994; Blackburn and Hinz, 1996; and Vaillancourt et al., 2003, as well as MNDM Mineral Deposit Inventories (MDI), Assessment Files (AFRI) and publications by industry (in particular NI 43-101 reports).

The availability of information is good throughout the Ignace area with the most detailed information available for areas having some mineral potential, such as greenstone belts and the margins of intrusive bodies. Limited data are available for the interior portions of the intrusive bodies and the northern portion of the Ignace area.

1.4.5 Geomechanical Properties

Little information is available regarding the rock geomechanical properties apart from compressive strength data for quarry sites in the Indian Lake and Revell batholiths (Storey, 1986; Farrow, 1996). As such, inferences have been made from geomechanical information derived from similar sites 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 research area in Ontario (Brown and Rey, 1989; Brown et al., 1989; Stone et al., 1989).

2.0 PHYSICAL GEOGRAPHY

2.1 Location

The Township of Ignace is approximately 100 km² in size and is located within the District of Kenora in northwestern Ontario. The settlement area of Ignace is shown on Figure 1.1, and is situated along the north shore of Lake Agimak, approximately 250 km northwest of Thunder Bay and 110 km southeast of Dryden. The Township of Ignace and its periphery, referred to in this report as the "Ignace area", is approximately 6,200 km^2 in size, as shown on Figure 1.1. Satellite imagery for the Ignace area (SPOT panchromatic, taken in 2006 and 2007) is presented on Figure 2.1.

The background image on Figure 2.1 is a colour composite of SPOT-5 satellite imagery taken in 2006. The composite image was created by assigning a primary colour (red, green and blue) to three of the SPOT-5 multispectral bands. Different materials reflect and absorb solar radiation differently at different wavelengths and therefore have varying intensities within each of the SPOT bands. When combined into a single image, the chosen colour scheme approaches a "natural" representation, where, for example, vegetation appears in shades of green.

2.2 Topography and Landforms

A detailed terrain analysis was completed as part of the preliminary assessment of potential suitability for the Ignace area (JDMA, 2013a). This section presents a summary of this analysis.

The Ignace area lies in the Severn Uplands physiographic region of Ontario (Thurston, 1991), a broadly rolling surface of Canadian Shield bedrock that occupies most of northwestern Ontario. The bedrock throughout the area is either exposed at surface or covered by a generally thin blanket of Quaternary glacial deposits. Terrains in the Severn Uplands contain numerous lakes (Thurston, 1991) and the terrain of the Ignace area is typical in that regard.

The topography of the Ignace area is presented on Figure 2.2. The land surface elevation in the Ignace area ranges in elevation from about 368 to 554 metres above sea level (masl), with this amount of relief being expressed over a lateral distance of about 80 km. There is considerable relief between the lakes in most areas. Topographic highs generally correspond to bedrock outcrops, whereas topographic lows are generally areas of thicker overburden. An exception to this generalization is found in two prominent moraine ridges: the Hartman and Lac Seul moraines, which form northwesterly-trending linear features that can be traced for more than 200 km across northwestern Ontario.

The major topographic high in the Ignace area is a bedrock ridge about 20 km wide and 85 km long extending northwest from the southeast corner of the Ignace area (Figure 2.3). For convenience within this report, this feature is termed the Revell-Gulliver highland (JDMA, 2013a). The local summits within this feature increase in height toward the southeast, with typical elevations of about 460 m in the northwest and 520 to 550 m in the southeast. The surface of this highland area is associated with bedrock terrain as shown on Figure 2.3 and is either exposed bedrock or is covered by a thin veneer of drift. Areas of relatively lower elevation surrounding this ridge are generally in the order of 400 masl. The location of the Hartman moraine along the northeast margin of this broad ridge suggests that the ridge may have formed a late-glacial topographic barrier to ice flow.

The Revell-Gulliver highland is split into separate blocks by distinct, cross-cutting, topographic lows clearly defined by the 460 m elevation contour, as seen on Figure 2.2, where these breaks have been termed for the convenience of this report as the Balmoral, Campus, Doan and Little Turtle lows (JDMA, 2013a). Geological control on the topographic lows that break the Revell-Gulliver highland is illustrated by the coincidence of the Balmoral low with the mapped extent of a thin belt of metasedimentary rocks extending along the northern margin of the White Otter Lake batholith, and the fact that the Little Turtle low represents the surface expression of the Finlayson-Marmion fault (see Section 3.1.3). The Campus low, located north of Elsie Lake, is a major topographic low within the northern part of the White Otter Lake batholith that extends into the broad ridge from the south. This trench-like low contains a major wetland.

The northwest-trending end moraines are the highest relief Quaternary landforms in the Ignace area. From southwest to northeast, these moraines are termed the Eagle-Finlayson, the Hartman and the Lac Seul moraines. They are topographically well expressed in some areas, but only faintly discernible in the digital elevation model in other areas.

The major topographic lows in the Ignace area are the outlets associated with the main rivers that drain away from the Revell-Gulliver highland to the northeast, west and southwest and labelled as the English, Wabigoon and Turtle lows respectively (inset of Figure 2.2). The Bending Lake low, located to the west of the highland and characterized by long narrow ridges and lakes, is the surface expression of the Bending Lake greenstone belt that divides the Revell batholith from the Islet pluton. A low-relief, northwest-trending trough, termed the Ilsley-Gulliver trough (JDMA, 2013a), forms a local topographic low between the Hartman moraine on the northeast side and the Revell-Gulliver highland along the southwest side. These topographic lows are frequently associated with the organic and/or glaciolacustrine deposits as shown on Figure 2.3.

Bedrock knobs and ridges typically extend 90 to 100 m above the large lakes in the Basket Lake, Indian Lake and White Otter Lake batholiths. For example, most of the large lakes north of the Revell-Gulliver highland are at an elevation of about 400 masl, with knobs and ridges extending to elevations up to 500 masl. These topographic features are well illustrated in the terrain report (JDMA, 2013a). Mollard and Mollard (1980) suggested that the bedrock-controlled relief in the Ignace area is knobby where intrusive rocks predominate and ridged where metavolcanic or metasedimentary rocks underlie the surficial deposits. This is illustrated by the characteristic knobby terrain of the Revell batholith, as compared to the long narrow ridges displayed in the Bending Lake greenstone belt. Many of the knobs in the Basket Lake batholith and some in Indian Lake and White Otter Lake batholiths exhibit a northeast-oriented, 'drumlinoid' elongation, suggesting a greater degree of glacial modification of the topography when compared with the more blocky appearance of knobs on the surface of the Revell-Gulliver highland (JDMA, 2013a).

Areas of steep slopes form the margins of many of the rugged landforms in the Ignace area, such as ridges and knobs. As steep slopes are often associated with bedrock topography, with some notable exceptions (e.g., end moraines, kames, drumlins, melt water channels), it is assumed that the presence of steep slopes in this landscape is most likely indicative of bedrock exposure.

2.3 Watersheds and Surface Water Features

The Ignace area is drained by the English, Wabigoon and Turtle rivers, which in turn make up part of the Nelson drainage system, which flows into Hudson Bay through the Nelson River. The Nelson River drains an area of 1,148,350 km^2, which includes the southern parts of Alberta, Saskatchewan and Manitoba, and smaller parts of North Dakota, Minnesota and northwestern Ontario, making it the single largest contributor of freshwater to Hudson Bay.

The English River drains the part of the Ignace area northeast of the Hartman moraine, while the Wabigoon River drains part of the Revell batholith and the areas around Stormy Lake and Raleigh Lake (Figure 2.2). Flow through the English and Wabigoon rivers passes through Lac Seul, located approximately 110 km northwest of the settlement area of Ignace, before emptying into the Winnipeg River. The Turtle River drains most of the area south of the Revell-Gulliver highland. Flow along the Turtle River feeds into the Rainy River, which forms the international border, located approximately 120 km southwest of the settlement area of Ignace, and eventually passes through Lake of the Woods before emptying into the Winnipeg River. The Winnipeg River passes through Lac du Bonnet before emptying into Lake Winnipeg, which drains to Hudson Bay via the Nelson River. As part of their terrain analysis, JDMA (2013a) carried out a drainage basin analysis in order to confirm and, where possible, partition the most detailed available mapping of watersheds by the MNR. The resulting mapping is shown on Figure 2.4, which includes the divides that delineate the three tertiary-scale watersheds associated with the three main river systems in the Ignace area, as well as several quaternary-scale watersheds that further compartmentalize surface drainage. The Revell-Gulliver highland has a strong topographic influence on the location of the drainage divide between the Turtle River and English River tertiary watersheds. Conversely, only portions of the Hartman and Eagle-Finlayson moraines coincide with quaternary-scale watershed divides, which is an indication of their occasional subdued topography in the Ignace area.

The Ignace area contains a large number of lakes of various sizes, 27 of which are larger than 10 km^2 and ten of which are larger than 20 km^2, with about 18% (1,115 km^2) of the total surface area occupied by water bodies. The larger lakes are sufficient in size to conceal geological structures up to about 10 km in length. Clusters of small lakes have additional potential to conceal structures, especially when the lakes are located in areas where geological structures are already largely masked by overburden cover. In general, the lakes on the Revell-Gulliver highland tend to be smaller (<20 km^2) than those located further to the north and south. Table 2.1 summarizes depth and surface area information for the larger lakes in the Ignace area.

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

Lake	Area (km^2)	Volume (km^3)	Max depth (m)	Mean depth (m)
Abamategwia Lake	13.1	0.13	33	9
Agimak Lake	12.5	0.04	16	3
Barrel Lake	30.4	...	...	...
Basket Lake	42.9	0.25	20	6
Bending Lake	11.3	...	...	...
Cecil Lake	15.7	0.2	24	13
Clearwater West Lake	36.1	0.98	73	27
Dibble Lake	10.7	...	...	...
Indian Lake	40.2	0.37	36	9
Kukukus Lake	41.9	0.21	20	5
Long Lake	18.4	...	...	...
Mameigwess Lake	52.7	0.86	50	16
Paguchi Lake	24.9	0.22	30	9
Pekagoning Lake	11.6	...	...	...

Lake	Area (km^2)	Volume (km^3)	Max depth (m)	Mean depth (m)
Raleigh Lake	17.3	0.18	29	10
Sandbar Lake	13	0.06	14	5
Sandford Lake	29.3	...	...	...
Sowden Lake	37.6	...	...	...
Stormy Lake	34.7	...	...	...
White Otter Lake	84.6	...	...	...
Wintering Lake	16.6	0.09	16	5

...information not available

Information on the depth of lakes in the Ignace area was obtained from bathymetry surveys conducted by the MNR in the late 1960s and early 1970s (see, for example, inset map in Figure 2.4). Except for Raleigh Lake, survey data exist only for lakes north of the Revell-Gulliver highland. The greatest known lake depth in the Ignace area is 50 m, which was measured in Mameigwess Lake (JDMA, 2013a), with the maximum depth of the other lakes ranging from 8 to 36 m. It is unknown whether the lakes south of the Revell-Gulliver highland are deeper than those to the north. The closest lake with a depth survey south of this highland is Clearwater West Lake, located immediately south of White Otter Lake (6 km south of the southern boundary of the Ignace area). This lake has a maximum depth of 73 m.

2.4 Land Use and Protected Areas

Figure 2.5 shows a summary of land disposition and ownership within the Ignace area, including known protected areas.

2.4.1 Land Use

Forestry is a major industry in the area and the largest single land use. The Ignace area has more than 75% productive forest, and a number of private timber companies are currently managing forestry operations. The Township of Ignace lies in the southwestern limit of the English River Forestry Management Unit (FMU) in the Dryden District, which extends towards the northeast of the settlement area of Ignace and is managed by Abitibi Bowater. West of the Township of Ignace, the Wabigoon and Dryden forests, also part of the Dryden District, are managed by Weyerhaeuser Company Inc. and the Dryden Forest Management Company, respectively. Other FMUs near Ignace are the Sapawe, Dog River-Matawin and Spruce River forests to the south, southeast and east of the Ignace area (Golder, 2011a).

2.4.2 Parks and Reserves

There are four provincial parks and eight conservation reserves in the Ignace area (Figure 2.5). The Sandbar Lake Provincial Park is 80 km^2 in size. Its southern tip occupies part of the northeast corner of the Township of Ignace. The park offers day use and overnight camping (Ontario Parks, 2010). The Turtle River-White Otter Lake Provincial Park lies south and southwest of the Township of Ignace and covers approximately 400 km^2 (Ontario Parks, 2010). Turtle River-White Otter Provincial Park offers no facilities and is accessible by water only. The southernmost portions of the East English River Provincial Park (approximately 170 km^2) and Bonheur River Kame Provincial Park (approximately 8 km^2) lie about 17 km north and 26 km east of the Township of

Ignace, respectively (Figure 2.5). Bonheur River Kame Provincial Park is classed as a nature reserve. It is fly-in access only and provides no facilities for visitors (Ontario Parks, 2010).

There are also eight conservation reserves in the Ignace area (LIO, 2012). Those closest to the Township of Ignace include the Campus Lake (194 km^2) and Gulliver River (27 km^2) Conservation Reserves, approximately 8 km and 15 km south and southeast of the Township, respectively. The Stormy Lake, Upper English River, Adair, Melgund, Pyatt Lake and Side Lake Conservation Reserves are also located within the Ignace area (LIO, 2012).

2.4.3 Heritage Sites

The cultural heritage screening examined known archaeological and historic sites in the Ignace area, using the Ontario Archaeological Sites Database, the Ontario Heritage Trust Database and the National Historic sites Database. There are 45 known archaeological sites in the Ignace area (von Bitter, 2010) but no National or Provincial Historic Sites (Ontario Heritage Trust, 2012; Parks Canada, 2010).

Seven of the archaeological sites are located within the Township of Ignace. Six of these sites are located on islands within Agimak Lake or on its shore and one site is located north of Agimak Lake close to the existing railway line. The latter is a historic Euro-Canadian storage structure probably related to the construction of the railway in the last half of the 19th century. Three of the sites on Agimak Lake are pre-contact Aboriginal sites including two Late Woodland period sites dating between 500 and 1,000 years ago and one other site is a 19th century Euro-Canadian logging camp with evidence for a historic Ojibwa component. Oral tradition indicates First Nations use on the lake during the 19th century. For the other two sites on Agimak Lake, aside from their location, no information is contained in the database (e.g., time period or cultural affiliation is not provided). The potential for archaeological and historical sites around Agimak Lake is considered to be high given the sites already documented within and around the lake.

The other 38 archaeological sites are at the periphery of the Township of Ignace. Eighteen of these are pictographs, or rock paintings. These paintings can be found along the shores of Mooseland Lake, Owl Lake and Mameigwess Lake. Those paintings found along the shores of Mameigwess Lake are of particular consideration as it is likely that they were painted entirely from the water (Dewdney and Kidd, 1967). Ten of the sites at the periphery of the Township are pre-contact Aboriginal campsites or habitation sites, with seven identified as either Middle or Late Woodland. Of the remaining ten known archaeological sites, one is a small Hudson’s Bay Company post, one is a fishing station, two are isolated finds and the remaining six are undetermined.

Local archaeologists have documented a number of sites in the Ignace area with archaeological potential (Smyk, 1990). Archaeological potential is established by determining the likelihood that archaeological resources may be present on a subject property. In archaeological potential modelling, a distance to water criterion of 300 m is generally employed for primary water courses, including lakeshores, rivers and large creeks, while a criterion of 200 m is applied to secondary water sources, including swamps and small creeks (Government of Ontario, 1997). The presence of local heritage sites would need to be further confirmed in discussion with the community and Aboriginal peoples in the area, if the community is selected by the NWMO, and remains interested in continuing with the site selection process.

3.0 GEOLOGY

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

The Ignace area is underlain by approximately 3 to 2.6 billion year old bedrock of the Superior Province 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 (Figure 3.1). The Canadian Shield forms the stable core of the North American continent.

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 has been divided into various regionally extensive east-northeast-trending subprovinces based on lithology, age and metamorphism (Figure 3.1). The Superior Province has been subdivided in recent years into lithotectonic terranes and domains (Percival and Easton, 2007; Stott et al., 2010). Terranes are defined as tectonically bounded regions with characteristics distinct from adjacent regions prior to their accretion into the Superior Province, while domains refer to lithologically distinct portions within a terrane (Stott et al., 2010).

The Ignace area is situated in the central part of the Wabigoon Subprovince (Figure 3.1). The Wabigoon Subprovince is about 900 km long and 150 km wide and bounded by the Winnipeg River Subprovince to the northwest, the English River Subprovince to the northeast, and the Quetico Subprovince to the south (Blackburn et al., 1991). The Wabigoon Subprovince in the Ignace area includes portions of three lithotectonic terranes: the granitoid Marmion Terrane, the predominantly volcanic Western Wabigoon Terrane and the plutonic Winnipeg River Terrane (Figure 3.2). The boundary between the Western Wabigoon Terrane and the Winnipeg River Terrane, as defined by Tomlinson et al. (2003; 2004) using the isotopic signature of granitoid bodies and volcanic rocks, passes north-south through the Township of Ignace bisecting the Indian Lake batholith. This boundary has been adopted by provincial-scale revisions of Percival and Easton (2007) and Stott et al. (2010). The boundaries between lithotectonic terranes are not sharply defined due to the emplacement of younger plutonic rocks at places along the inferred terrane boundaries (Stone, 2010a).

Figure 3.3 shows the bedrock geology of the central and western portions of the Wabigoon Subprovince, as well as their main structural features. The central Wabigoon Subprovince extends 30 to 270 km west of Thunder Bay and is underlain by thin, branched and anastomosed greenstone belts intruded by large felsic plutonic bodies (Stone, 2009a). Greenstone belts in the region are mostly composed of mafic metavolcanic rocks with lesser components of ultramafic, intermediate, and felsic metavolcanic rocks, gabbro and metasedimentary rocks. Some of these minor greenstone belts are restricted to the central Wabigoon Subprovince, while others represent extensions of greenstone belts of the adjacent regions.

Greenstone belts in the Wabigoon Subprovince often contain long, subconcordant, sinuous shear zones that exhibit complex histories of ductile and brittle deformation. Also, indications of repeated units and layer parallel shearing support the theory that supracrustal assemblages have been tectonically stacked (Blackburn et al., 1991).

Intrusive rocks in the central Wabigoon Subprovince vary in age. Among the oldest plutonic rocks are biotite tonalite-gneissic intrusions such as the approximately 3 billion year old Marmion batholith (Blackburn et al., 1991). A small percentage of intrusive rocks in the region are scattered oval to elongated masses of tonalite to granodiorite, and small units of granite within the greenstone belts. Late post-volcanic intrusions are the most common rock in the region and occur as massive biotite granite dykes, stocks and batholiths (e.g., White Otter Lake and Indian Lake batholiths). Other younger rocks are found to a lesser extent (10%) as sanukitoid (high-Mg granitoids) heterogeneous plutons (Stone and Davis, 2006). There are a number of regional faults in both the central and western Wabigoon subprovinces. The closest regional faults to the Township of Ignace are the northeast-trending Finlayson-Marmion fault zone and the east-west trending Washeibemaga Lake fault, approximately 34 km southeast and 45 km west of the Township, respectively (Figure 3.3).

3.1.2 Geological History

The oldest rocks in the Ignace area and surrounding region are biotite tonalite-gneisses of the ca. 3.002 billion year old Marmion batholith (Tomlinson et al., 2003) and ca. 2.989 billion year old gneissic rocks of the Raven Gneiss Complex (Tomlinson et al., 2003), located within the northeast corner of the White Otter Lake batholith in the vicinity of the Phyllis Lake greenstone belt (Figure 3.3). These granitoid rocks served as a basement for the younger supracrustal rocks of the ca. 2.956 billion year old Phyllis Lake greenstone belt (Tomlinson et al., 2003) as well as the other greenstone belts to the south of the Ignace area, which formed during a period of volcanism between ca. 2.96 and 2.90 billion years ago (Tomlinson et al., 2004).

The Ignace area preserves vestiges of three Archean terranes – the Winnipeg River, Marmion and Western Wabigoon Terranes (Figure 3.2). From as early as ca. 3.4 and 3.0 billion years ago, the terranes evolved through a complex history of magmatism, deformation and metamorphism ending with the collision of the Marmion and Winnipeg River Terranes approximately 2.93 to 2.87 billion years ago (Tomlinson et al., 2004). After this collision, all gneissic and metavolcanic rocks in the Ignace area became part of the composite Winnipeg River-Marmion Terrane (Tomlinson et al., 2004). Approximately 2.71 to 2.70 billion years ago, a possible arc-collision between this composite terrane and the Western Wabigoon Terrane occurred (Sanborn-Barrie and Skulski, 2006). In this model, pre-accrectionary structures would have been largely obliterated in the Ignace area by subsequent deformation and metamorphic events as well as intense plutonic activity that took place in the new amalgamated collage.

A simplified geological history for the Ignace area and surrounding region is provided below.

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

Time Period (billion years ago)	Geological Event
ca. 3.0	Assemblage of the oldest rocks in the Ignace area comprising the Marmion Terrane – essentially a micro-continent comprising tonalite basement rocks dominated by the Marmion batholith which occurs immediately south of the Ignace area.
ca. 3.0 to 2.74	Progressive growth of the Marmion Terrane through the additions of magmatic and crustal material in continental arcs and through accretion of allocthonous crustal fragments. This growth included the emplacement of the Phyllis Lake gneisses and tonalites ca. 2.955 to 2.989 billion years ago and amalgamation of the Winnipeg River and Marmion terranes by approximately 2.93 to 2.87 billion years ago (Tomlinson et al. 2004; Percival and Easton, 2007).

Time Period (billion years ago)	Geological Event
ca. 2.745 to 2.711	A major period of volcanism, derived from subduction, occurred in the Winnipeg River-Marmion Terrane (Blackburn et al., 1991). The result of this volcanic period is the Raleigh Lake and Bending Lake greenstone belts (Stone, 2010a). Sedimentation within the greenstone belts was largely synvolcanic, although sediment deposition in the Bending Lake area may have continued past the volcanic period (Stone, 2009b; Stone, 2010b). Synvolcanic to post-volcanic plutonism in the Ignace area included minor mafic intrusions (possibly flow centres) of gabbroic composition and the intrusion of tonalitic phases of the Revell batholith, approximately 2.737 to 2.732 billion years ago (Larbi et al., 1998; Buse et al., 2010). D_1-D_2 (Percival, 2004).
ca. 2.71	Collision of the Winnipeg River-Marmion Terrane and a northern superterrane (Uchian Orogeny) (Corfu et al., 1995).
ca. 2.70 to 2.67	Collision of the volcanic island arc (Western Wabigoon Terrane) against the superterrane (Central Superior Orogeny) (Percival et al., 2006; Stone, 2010a). The central Superior Orogeny was accompanied by widespread regional plutonism. In the Ignace area, this resulted in emplacement of intrusive rocks including the major batholiths of interest in this assessment. Specific dates include: ▪ Ca. 2.694 billion years ago: Crystallization age of the youngest phase of the Revell batholith; ▪ Ca. 2.685 billion years ago: Crystallization age of the White Otter Lake batholith; ▪ Ca. 2.671 billion years ago: Crystallization age of the Indian Lake batholith; and ▪ Ca. 2.697 to 2.684 billion years ago: an interval of sanukitoid magmatism (Stone, 2010a), which is expressed in the Ignace area by the emplacement of small plutons, such as the Islet pluton (Stone, 2009a). D_3 and D_4 (Percival, 2004).
ca. 2.6 to 2.4	Regional faulting and brittle fracturing (Kamineni et al., 1990).
ca. 2.12	Emplacement of the northwest-trending Kenora-Fort Frances dyke swarm (Southwick and Halls, 1987).
ca. 1.947	Brittle reactivation of regional-scale faults (Peterman and Day, 1989).
ca. 1.9	Emplacement of the west-northwest trending Wabigoon dyke swarm (Fahrig and West, 1986; Osmani, 1991).
ca. 1.13 to 1.14	Emplacement of the northwest-trending dykes of Eye–Dashwa swarm (Kamineni and Stone, 1983).
Post-1.13	A complex interval of erosion, brittle fracture, repeated cycles of burial and exhumation, and glaciations, particularly from the latest Miocene to the present.

Little information is available for the geological history of the Ignace area for the period following the emplacement of the Wabigoon dykes ca. 1.9 billion years ago. Other areas of the Superior Province provide evidence of past events including multiple generations of dyke emplacement between ca. 2.5 and 1.0 billion years ago (Osmani, 1991), and a major period of volcanism between ca. 1.1 and 1.0 billion years ago associated with the emplacement of the Logan sills in the Thunder Bay – Nipigon area and the alkali complexes extending from the north shore of Lake Superior to the northeast as far as the James Bay Lowlands. This period of volcanism is interpreted to be related to the Midcontinent Rift event in the Lake Superior Basin (Sutcliffe, 1991; Easton et al., 2007). Proterozoic sedimentation in the northwest Superior Province includes the Animkie and Sibley Groups of the Thunder Bay – Nipigon area which formerly extended further to the west than their present distribution. The reviewed literature, however, provides no evidence that such Paleoproterozoic sedimentation extended to the Ignace area.

During the Paleozoic Era, much of the Superior Province was inundated by shallow seas and Paleozoic strata dating from the Ordovician to Devonian are preserved within the Hudson Bay Basin and Michigan Basins. The presence of a small outlier of Paleozoic strata known as the Temiskaming outlier in the New Liskeard area indicates that Paleozoic cover was formerly much more extensive and much of the present surface of the Canadian Shield lies close to an exhumed paleoplain interpreted to be of Ordovician age (Brown et al., 1995). However no evidence exists that Paleozoic strata were present in the Ignace area (Johnson et al., 1992).

While there is a restricted area of Mesozoic strata within the Moose River Basin and there is evidence of Mesozoic-age emplacement of kimberlitic pipes and dykes elsewhere in northern Ontario, no post-Precambrian rocks are known to be present within the Ignace area. The contact between bedrock and the overlying unconsolidated Quaternary sediments represents an unconformity exceeding one billion years.

3.1.3 Regional Structural History

Direct information on the geological and structural history of the Ignace area is limited. The geological and structural history summarized below integrates the results from studies undertaken elsewhere throughout and proximal to the regional area shown on Figure 3.3. It is understood that there are potential problems in regional correlation of specific structural events within a D_x numbering system and in the application of such a system to the local geological history. This summary represents an initial preliminary interpretation for the Ignace area, which would need to be reviewed through detailed site-specific field studies.

Neoarchean-Proterozoic deformation in the Central Wabigoon Subprovince is interpreted to have occurred in multiple deformation events (Stone, 2010a). Although the sequence of events has not yet been established in the Ignace area, Percival et al. (2002) interpreted that the earliest deformation in the northern central Wabigoon Subprovince occurred between 2.913 and 2.835 billion years ago and that late shearing occurred about 2.677 billion years ago. Sanborn-Barrie et al. (2002) and Bethune et al. (2006) defined three deformation events in the western Wabigoon Subprovince, while Kamineni et al. (1990) recognized four major phases of deformation common to the west-central Superior Province and up to ten regional structural events.

As a general summary, at least five episodes of penetrative strain (D_1 to D_5) are understood to have affected the central portion of the Wabigoon Subprovince, where the Ignace area is located (Kamineni et al., 1990; Percival, 2004). It is also acknowledged, as indicated above, that some poorly understood pre-D_1 deformation events are preserved within the oldest gneissic tonalites in the area (Bethune et al., 2006). In addition, the D_5 event may have spanned the transition between ductile and brittle deformation, and was followed by a poorly constrained and protracted series of events characterized by multiple episodes of localized brittle deformation collectively termed D_6 herein (e.g., Peterman and Day, 1989; Kamineni et al., 1990).

While earlier deformation events are recognized (e.g., Bethune et al., 2006), the first two episodes of deformation identified by Percival (2004), D_1-D_2, produced and subsequently modified an S_1 gneissic layering through the progressive development and overprinting of this foliation by tight to isoclinal F_2 folds. The geometric and kinematic character of D_1-D_2 is cryptic as a result of the subsequent stages of magmatic and structural overprinting. D_1-D_2 structures are primarily confined to the gneissic tonalites throughout the central part of the Wabigoon Subprovince. The D_1-D_2 episode is estimated to have occurred between ca. 2.725 and 2.713 billion years ago (Percival, 2004).

The D_3 episode produced northwest-trending F_3 folds and an associated northwest-striking axial planar cleavage (S_3) that affected the gneissic tonalites and the supracrustal assemblages. In the Raleigh Lake and Bending Lake greenstone belts D_3 structures may be indicated by a strong northwest-striking magnetic grain observed within the first-vertical derivative magnetic data. The D_4 episode is characterized by the development of a moderately to well-developed, steeply-dipping, schistosity (S_4) that is axial planar to 050°-070° trending, steeply-plunging, F_4 folds. It should be noted that locally, the D_3 and D_4 events are interpreted as D_1 and D_2 where the earlier episodes are not recognized (e.g., Sanborn-Barrie and Skulski, 2006). The D_3 and D_4 events are interpreted to have occurred prior to ca. 2.698 billion years ago (Percival, 2004).

The D_5 episode is characterized by the activation of major ductile-brittle shear zones across the central portion of the Wabigoon Subprovince (Percival, 2004). The D_5 shear zones are interpreted to have undergone significant sinistral strike-slip displacement along northeast-trending structures, and dextral strike-slip displacement along easterly-trending structures (Bethune et al., 2006). D_5 is interpreted to have overprinted all main bedrock lithologies in the Ignace area, including the large batholiths. Regionally, the timing of D_5 shear movement has been constrained to between ca. 2.690 and 2.687 billion years ago (Davis, 1989; Brown, 2002). One example of a possible D_5 structure is the Finlayson-Marmion fault zone, which trends northeasterly and transects the southeastern corner of the Ignace area. As noted above, the recognition that this fault cuts the eastern extension of the ca. 2.671 billion years old Indian Lake batholith suggests that D_5 continued longer than has been documented. This is consistent with the interpretation by Kamineni et al. (1990) that suggests regional east-oriented dextral movement occurred along major terrane bounding shear zones between 2.685 and 2.500 billion years ago, including the regional-scale Quetico fault. In addition, Hanes and Archibald (1998) suggest that ca. 2.400 billion years old regional differential uplift was associated with movement along major fault zones throughout the Superior Province. Therefore, the D_5 episode is considered to have been a protracted event of shear zone activation and re-activation that occurred between ca. 2.690 and 2.400 billion years ago.

Further episodes of brittle deformation, collectively termed D_6 herein, are interpreted to have re-activated some pre-existing faults/fractures in the region (Kamineni et al., 1990). Some evidence for this reactivation is based on the occurrence of approximately 1.947 billion year old pseudotachylite, a product of friction melting, observed along the Quetico fault (Peterman and Day, 1989). The recognition that the approximately 1.900 billion year old Wabigoon dykes are straight and continuous across the Ignace area (Figure 3.4), and that one dyke cuts across the Finlayson-Marmion fault zone without apparent offset, suggests that only limited fault movement, if any, has occurred in the Ignace area since the emplacement of the Wabigoon dykes.

Brittle lineaments are observed to cross-cut the Wabigoon dykes in the Revell batholith where good outcrop exposure allows crosscutting relationships to be observed (Section 3.2.3). These crosscutting relationships indicate that some of the brittle structural fabric in the Ignace area postdates ca. 1.9 billion years ago. Other evidence for a meso-proterozoic or younger age for the brittle lineaments exists in other areas of the Northwestern Superior Province where similar brittle lineament orientations and densities may be observed in the Nipigon sills, the Port Coldwell alkalic complex, and in the approximately 1.0 to 1.1 billion years old metavolcanic and metasedimentary rocks of the Keweenawan Supergroup. This indicates that the D_6 brittle lineaments may largely post-date the Archean Eon.

3.1.4 Mapped Regional Structure

Figure 3.3 shows the location and extent of regional-scale faults that have been mapped in the Ignace area straddling the central and western Wabigoon subprovinces. The geological structure in the Ignace area and surrounding region generally follows an easterly to northeasterly trend parallel to the boundary between the Wabigoon, Quetico and Winnipeg River subprovinces. Ductile deformation in the Wabigoon Subprovince is evidenced by the sinuous and anastomosing nature of the greenstone belts, at both the regional and local scale, which are now preserved in synforms and homoclinal panels between the voluminous masses of plutonic rock (Figure 3.3).

The closest mapped faults and shear zones to the Township of Ignace include: a fault running along the contact between metasedimentary and metavolcanic rocks about 4 km southwest of the Township of Ignace, and a northwest-trending shear zone along the edge of the Raleigh Lake greenstone belt about 30 km northwest of the Township of Ignace (Parker, 1989; Stone et al., 1998). It is likely that additional unmapped faults exist within the metasedimentary and metavolcanic rocks of the Raleigh and Bending Lake greenstone belts.

The only regional-scale faults that have been mapped within the Ignace area are the northeast-trending Finlayson-Marmion fault zone and the Washeibemaga Lake fault (referred as “Bending Lake fault” by Stone (2009b), approximately 34 km southeast and 28 km west of the Township of Ignace, respectively (Figure 3.3). The larger subprovince-bounding, east-trending Quetico fault lies about 40 km to the south of the Ignace area and is characterized as a dextral-sense strike-slip structure (e.g., Kameneni et al., 1990).

The northeast-trending Finlayson-Marmion fault zone occurs as a broad zone of strike-slip ductile to ductile-brittle deformation (Stone and Halle, 1999) and in the eastern sector of the Ignace area it transects the Indian Lake batholith (Figure 3.4). The fault is a complex braided structure with a surface topographic expression and strong aeromagnetic contrast showing bifurcations and splays occurring in both the horizontal and vertical planes (Figure 3.5). The fault zone exhibits shallow to moderately plunging south-southwesterly oriented slickenside lineations but the overall movement history is poorly constrained (Stone, 2010a). Woolverton (1960) reports near-vertically dipping schists and between 100 m and 1 km of dextral movement at Lumby Lake, in the southeastern part of the Ignace area (Figure 3.3). Stone (2010a) reports that the Finlayson-Marmion fault zone does not cut the Steep Rock Lake belt to the south of the Ignace area, and therefore may have ceased to move ca. 2.780 billion years ago. However, the cross-cutting relationship between the fault and the ca. 2.671 billion year old Indian Lake batholith indicates that the temporal constraints are poorly defined.

The Washeibemaga Lake fault is described by Stone (2009b) as a deep-seated structure curving from an easterly to southeasterly trend through the Bending Lake greenstone belt in the Stormy Lake area (Figure 3.4). Any surface or geophysical expression of the fault is masked by the layered stratigraphy in the Ignace area but the fault is inferred to follow the axis of the Bending Lake greenstone belt south of the Revell batholith (Stone, 2009b). One published account suggests that movement across the Washeibemaga Lake fault involved south-directed thrusting, and that the western extension of the fault is offset sinistrally by a northeast-trending fault (Beakhouse et al., 1996).

No evidence of post-Archean ductile shear-type deformation along the Finlayson-Marmion fault zone and the Washeibemaga Lake fault has been reported in the available literature, although there is evidence suggesting that brittle reactivation took place during the Proterozoic (Kameneni et al., 1990; Stone, 2009a).

Greenstone belts in the Wabigoon Subprovince often contain long, subconcordant, sinuous shear zones that exhibit complex histories of ductile and brittle deformation. In the Ignace area, the metavolcanic rocks of the greenstone belts show intense planar fabrics of tectonic origin with complex curved trajectories that parallel geologic contacts (Stone et al., 1998; Stone, 2010a).

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 a symposium proceedings (Fraser and Heywood, 1978), and issues of The Canadian Mineralogist in 1997 and 2000 (e.g., Kraus and Menard, 1997; Menard and Gordon, 1997; Berman et al., 2000; Easton, 2000a and 2000b) and Berman et al. (2005). The thermochronologic record for major parts of the Canadian Shield are given in a number of studies supported by government surveys and represented by Berman et al. (2005), Bleeker and Hall (2007), Corrigan et al. (2007), and Pease et al. (2008).

In general, there is limited local preservation of pre-Neoarchean metamorphism within the Canadian Shield (e.g., Breaks and Bartlett, 1991; and Percival and Skulski, 2000). 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 Archean crust by Paleoproterozoic deformation and typically amphibolite facies metamorphism across the Churchill Province through northernmost Ontario under the northern Hudson Bay lowland, western Manitoba, northern Saskatchewan and Nunavut (e.g., Skulski et al., 2002 and Berman et al., 2005). The Paleoproterozoic volcanic, sedimentary and plutonic rocks of the Trans-Hudson Orogen experienced metamorphism at moderate to high temperatures and low to moderate pressures at episodes from ca. 1.84 to 1.8 billion years ago, culminating with collisional convergence of the bounding Archean Hearne domain and Superior Province, at ca. 1.8 billion years ago (Kraus and Menard, 1997; Menard and Gordon, 1997; Corrigan et al., 2007).

In the Archean Superior Province, the relative timing and grade of regional metamorphism corresponds to the type of lithologic composition of the subprovinces (Easton, 2000a; Percival et al., 2006). Granite-greenstone subprovinces contain the oldest, Neoarchean 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, and dominantly plutonic and orthogneissic subprovinces, such as the Winnipeg River, display younger, syntectonic middle amphibolite to granulite facies metamorphism (Breaks and Bond, 1993; Corfu et al., 1995).

Sub-greenschist facies metamorphism in the Superior Province is restricted to limited areas, notably within the central Abitibi greenstone belt (e.g., Jolly, 1978; Powell et al., 1993). Most late orogenic shear zones in the Superior Province and Trans-Hudson Orogen experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through $^{40}Ar/^{39}Ar$ dating to ca. 2.500 billion years ago, the value of which remains unclear (Powell et al., 1995). The distribution of contrasting grades of metamorphism is a consequence of relative uplift, block rotation and erosion from Neoarchean orogenesis and subsequent local Proterozoic orogenic events and broader epeirogeny during Proterozoic and Phanerozoic Eons. In northwestern Ontario, the concurrent post-Archean effects, including the Trans-Hudson Orogen, are limited to poorly documented reactivation along faulted Archean terrane boundaries (e.g., Kamineni et al., 1990 and references therein).

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 of Paleoproterozoic age around the Superior Province and culminating at the end of the Grenville orogeny circa 950 Ma.

Metamorphism in the Central part of the Wabigoon Subprovince, where the Ignace area is located, occurred in late Neoarchean time, from approximately 2.722 to 2.657 billion years ago (Stone, 2010a), and it peaked ca. 2.701 billion years ago (Easton, 2000a, b). The collision of the Western Wabigoon Terrane with the Winnipeg River-Marmion Terrane approximately 2.70 billion years ago (Percival et al., 2006) may have been the cause of the peak regional metamorphism. Older, pre-Neoarchean metamorphic events may have also affected the region, but evidence of their occurrence has been obscured by the later metamorphic stages (Stone, 2010a). Metamorphism is generally restricted to greenschist facies but increases locally to middle-amphibolite facies in some rocks of the greenstone belts (Sage et al., 1974; Blackburn et al., 1991; Easton, 2000a; Sanborn-Barrie et al., 2002). Very high-grade (i.e., granulite facies) or very low-grade (e.g., zeolite facies) metamorphism is largely absent from the central Wabigoon (Stone, 2010a).

Low to medium grade metamorphism in the Ignace area is mainly recognized within the rocks of the Raleigh Lake and Bending Lake greenstone belts and within marginal zones of the Revell batholith. High metamorphic grade rocks are generally absent. In the Raleigh Lake greenstone belt, greenschist facies metamorphism varies to amphibolite facies. Presence of the mineral assemblage garnet+amphibole+feldspar+biotite is widespread in the rocks of the greenstone belt (Blackburn and Hinz, 1996; Stone et al., 1998). In the Balmoral Lake area, southwest of the Township of Ignace, metasedimentary sequences are extensively migmatized (Blackburn and Hinz, 1996; Stone et al., 1998), possibly due to contact metamorphism with the White Otter Lake batholith. In the Bending Lake greenstone belt, mineral assemblages are indicative of significantly variable metamorphic grade, up to amphibolite facies. Rocks at the margins and in thin extensions of the greenstone belt, exhibit higher metamorphic grade than rocks in the core of the belt, implying a degree of contact metamorphism adjacent to the surrounding intrusive bodies (Stone, 2009a). Satterly (1960) identified amphibolite facies metamorphism within metavolcanic rocks near the contact with the Revell batholith, implying a contact metamorphic aureole associated with the emplacement of the batholith. Stone (2010a) reports that average crystallization pressures remained approximately constant at about 6 kilobars from ca. 3.0 to about 2.72 billion years ago, based on Al-in hornblende geobarometry, after which the average crystallization pressure decreased rapidly to 4 kilobars for late plutonic intrusions (such as the Revell and Indian Lake batholiths) at about 2.690 billion years ago.

3.1.6 Erosion

There is no site-specific information on erosion rates for the Ignace area. Past studies reported by Hallet (2011) and McMurry et al. (2003) provide general information on erosion rates for the Canadian Shield. The average erosion rate from wind and water on the Canadian Shield is reported to be about 2 m per 100,000 years (Merrett and Gillespie, 1983). Higher erosion rates are associated with glaciation. The depth of glacial erosion depends on several regionally specific factors, such as the ice geometry, 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 accomplished only a few tens of feet of erosion 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 of 120 m over 3 million years. Bell and Laine (1985) consider this to be a minimum value, although they make no allowance for non-glacial erosion or the role of rock weathering on erosion rates during the initial glacial advances in the late Pilocene. Hay et al. (1989), contending that in the Gulf of Mexico the depth of sediment of Laurentide provenance is greatly overestimated by Bell and Laine (1985), reduced this estimate of regional erosion to 80 m over the same time period.

3.2 Local Bedrock and Quaternary Geology

Information on local bedrock geology for the Ignace area was obtained from the various published reports for the area, geological maps (Section 1.5.1) and the geophysical interpretation of the area conducted as part of this preliminary assessment (PGW, 2013). Findings from the geophysical, lineament and terrain analysis studies carried out as part of the preliminary assessment of the Ignace area (JDMA, 2013a; JDMA, 2013b; and PGW, 2013) are integrated in this report to provide insight on the lithological variability, structures and extent of the overburden cover for each of the large granitic intrusions in the Ignace area.

Geophysical data quality is good within the western portion of the Ignace area surrounding and including the Revell batholith (i.e., the Stormy Lake area) (PGW, 2013). In this area, airborne geophysical data are available on 200 m line spacings. High quality geophysical data are also available from a survey flown for Takara Resources over the southeastern part of the Basket Lake batholith (PGW, 2013). In this area, airborne geophysical data are available on 100 m line spacings. For the balance of the Ignace area, the geophysical data are regional, on 800 m line spacings.

3.2.1 Bedrock Geology

The bedrock geology of the Ignace area is shown on Figures 3.3 and 3.4. The total magnetic field and the first vertical derivative of the residual magnetic field over the Ignace area are shown on Figures 3.5 and 3.6. The regional Bouguer gravity data are shown on Figure 3.7.

The geology of the Ignace area is dominated by large granitic intrusions and associated tonalitic units, including the Indian Lake, Revell, White Otter Lake and Basket Lake batholiths, as well as a number of smaller felsic to intermediate plutons. These Neoarchean intrusions were emplaced into the older Raleigh Lake and Bending Lake greenstone belts. A description of the granitic intrusions, tonalitic units and the greenstone belts is provided in the following subsections.

3.2.1.1 Indian Lake Batholith

The Indian Lake batholith is a large granitic intrusion approximately 2.671 billion years old (Tomlinson et al., 2004) that underlies the Township of Ignace and extends well beyond the Township boundaries mostly to the north and east. The easternmost edge of the batholith extends beyond the Ignace area. The intrusion covers a total area of approximately 1,600 km^2; based on available geological mapping, the batholith extends in the Ignace area approximately 55 km and 25 km in the east-west and north-south directions, respectively. The Indian Lake batholith is bordered on the west and south by the Raleigh Lake and Phyllis Lake greenstone belts and to the north and east by tonalitic gneiss of uncertain affinity (Figure 3.4).

Figure 3.4 shows that the boundaries of the Indian Lake batholith are not always well-defined from magnetic data, largely due to the low resolution of available magnetic data, and the resulting relatively subdued texture exhibited in the magnetic image (Figure 3.5; PGW, 2013). The southern contact of the Indian Lake batholith, however, appears as a transitional change into the foliated tonalite suite (Unit 12). The magnetic response dissipates to the north and northwest, perhaps indicating that the batholith thins in that direction or transitions into foliated tonalites at depth (Figure 3.5; PGW, 2013).

The majority of the Indian Lake batholith is mapped as a compositionally uniform intrusion composed of massive granodiorite to granite. In the southern portion of the Township of Ignace and extending southward, there is an inclusion mapped as foliated tonalite (Figure 3.4). More detailed mapping (Stone et al., 2007b) identifies additional foliated tonalite, and muscovite-bearing granitic inclusions, as well as small inclusions of greenstone rocks, mostly along the southern edge of the batholith (Figure 3.4).

The low resolution of the regional aeromagnetic data (800 m line spacing) over the Indian Lake batholith does not allow for the identification of local-scale compositional/phase changes and inclusions of remnant volcanics, and the occurrence of later-stage dykes (Figures 3.5 and 3.6; PGW, 2013).

The Indian Lake batholith has been described as light grey-white to pale pink biotite granite, typically medium to coarse grained, inequigranular, leucocratic and massive to weakly foliated. The granite usually contains a small percentage of biotite (3-5%) and subequal proportions of quartz, plagioclase and potassium feldspar (Stone et al., 1998). The composition of this intrusion at the Butler Quarry (located approximately 8 km west of the Township of Ignace and north of the Trans-Canada Highway) is about 40% plagioclase, 29% quartz, 28% potassium feldspar, 3% biotite, and traces of magnetite, rare epidote and chlorite (Brisbin et al., 2005). Mineral foliation within the Indian Lake batholith is limited, and only weakly developed magmatic foliations have been recognized (Stone et al., 1998). These non-tectonic foliations are defined by the alignment of igneous minerals that delineate concentric patterns in the granite (Stone et al., 1998).

The Indian Lake batholith contains an enclave of biotite-hornblende tonalite to granite, approximately 35 km^2 in area, which extends from the southern portion of the Township of Ignace southward beyond its boundaries. The tonalite-granite enclave is usually coarse, granular and mesocratic and, when hornblende granite is present, it is characterized by large potassium feldspar megacrystals that are 1 to 5 cm in size (Stone et al., 1998). It is not known whether this tonalitic body is a separate intrusive body, the product of different phases of magmatic injection, or compositional zoning.

The northern portion of the Indian Lake batholith possesses a subdued negative gravity anomaly, possibly indicating a limited depth extent of this granodiorite-to-granite intrusion (Figure 3.7). Szewczyk and West (1976) estimate the thickness of the Indian Lake batholith to be about 2 km based both on gravity data, and forward modelling using an average density of 2.68 g/cm^3 or greater. The authors note the absence of a strong gravity response beneath the western margin of the batholith in the Ignace area, and infer either the presence of a denser rock mass beneath the batholith or the thinning of the intrusion in this area. Szewczyk and West (1976) provide a possible explanation for denser rock unit as the presence of mixed greenstone belts incorporated into the gneiss formation. More recent studies (Everitt, 1999) describe the Indian Lake batholith as a sheet-like intrusion less than 2 km thick. Brisbin et al. (2005) reported with rock densities of 2.6 g/cm^3 for the Indian Lake batholith granite as well as compressive strength values in the range of 180 MPa, and water contents of 0.28%.

3.2.1.2 Revell Batholith

The Revell batholith is an approximately 2.732 to 2.694 billion year old intrusion (Larbi et al., 1998; Buse et al., 2010), located approximately 23 km west of the Township of Ignace. It extends 40 km northwesterly and about 15 km in the northeast-southwest direction. The Revell batholith is surrounded by the Raleigh Lake and Bending Lake greenstone belts (Figure 3.4).

The Revell batholith is mapped by OGS (2011) as generally compositionally uniform (mostly massive granodiorite to granite) at the regional scale. Recent mapping by Stone et al. (2011a; 2011b; 2011c) at the detailed scale of 1:20,000 (Figure 3.4), and geophysical interpretation carried out as part of this preliminary assessment (Figure 3.5; PGW, 2013), indicates that the batholith is more lithologically complex.

As shown on Figure 3.4, detailed mapping in the central and southern portions of the batholith (Stone et al. 2011a; 2011b; 2011c) identified three distinct intrusive phases within the mapped extent of the batholith: a biotite tonalite exposed primarily along the western margin of the batholith and in its southern portion; a gneissic hornblende tonalite along the western margin; and a phase of mesocratic to leucocratic biotite granodiorite to granite that extends over most of the surface extent of the intrusion. Interpretation of magnetic data for the Ignace area as part of this preliminary assessment is largely consistent with these three mapped phases and it provides lithological information where detailed mapping is not available (see Figure 19 in PGW, 2013).

Age dating has interpreted the oldest biotite tonalite phase of the Revell batholith to be approximately 2.734 billion years old while the gneissic hornblende tonalite is interpreted as being ca. 2.732 billion years old (Stone et al., 2010). Aeromagnetic geophysical data identifies a 47 km^2 oval-shaped distinct magnetic signature within the youngest mapped phase of granodiorite to granite that coincides directly with the area mapped by Stone et al. (2011a) as a potassium feldspar (K)-megacrystic granite (Figure 3.4, 3.5, PGW, 2013). A sample of this K-megacrystic granite facies yielded a U-Pb age of ca. 2.694 billion years old for the youngest phase of the intrusion (Buse et al., 2010), while Larbi et al. (1998) obtained a date of ca. 2.737 billion years old using the Sm/Nd method for this same phase of the batholith. Given that the Sm/Nd method has several limitations (Zachariah et al., 1997) compared to the U/Pb method for dating of rocks, the age of ca. 2.694 billion years obtained by Stone et al. (2010) is retained in this preliminary assessment.

The tonalitic units present in the western-southwestern portion of the batholith likely originated from synvolcanic magmatism associated with the widespread volcanic activity in the Wabigoon Subprovince between the approximate period of 2.75 to 2.72 billion years ago (Buse et al., 2010). The early tonalite phase is medium-grained, foliated mesocratic biotite tonalite (Stone, 2009a), whereas the intermediate tonalite phase is coarse-grained mesocratic hornblende tonalite (Stone et al., 2010). Foliation in the tonalitic phases is likely a consequence of deformation events during the ca. 2.7 billion year old Central Superior Orogeny (Section 3.1.2; Percival et al., 2006).

The Revell batholith produces a pronounced gravity low between the two greenstone belts (Figure 3.7). Although this anomaly is defined by a small number of gravity stations, the amplitude of the gravity low is greater towards the northwest, indicating a lower density in that part of the batholith and/or a thickening or root of the batholith (PGW, 2013). Szewczyk and West (1976) interpret the Revell batholith (referred to as the Hodgson intrusion by the authors) to be a sheet-like intrusion approximately 1.6 km in thickness, based on a model with an average density of 2.60 g/cm^3 determined from five tested rock samples.

3.2.1.3 White Otter Lake Batholith

The ca. 2.685 billion year old (Buse et al., 2010) White Otter Lake batholith extends south and southwest of the Township of Ignace. The White Otter Lake batholith is about 80 km long and 30 km wide with an approximate surface area of 2,000 km^2, of which approximately 940 km^2 falls within the Ignace area (Figure 3.4). The northern limit of the White Otter Lake batholith extends to within approximately 7 km of the southern boundary of the Township of Ignace. The White Otter Lake batholith is separated from the Indian Lake batholith on its northern border by slivers of the Raleigh Lake greenstone belt. To the south it is bordered by gneissic terrain of the Marmion Terrane (not seen on Figure 3.4), while to the east it is truncated by the Finlayson-Marmion fault zone. The northwest margin of the White Otter Lake batholith is sharply defined against the greenstone belts, whereas to the northeast it appears more gradational into the foliated and gneissic tonalite suites (PGW, 2013).

The White Otter Lake batholith is typically composed of light grey-white to pink, biotite granite to granodiorite containing less than 6% biotite (Stone et al., 2007a; Stone, 2010a). Available geological mapping of this batholith (Figure 3.4) suggests that the majority of the body is compositionally homogeneous (McWilliams, 1998; Stone et al., 2007a), although portions of the northeastern part of the batholith have been mapped as quartz monzonite (Sage et al., 1974). Quartz monzonite as used in 1974 may overlap with a number of fields in the IUGS classification.

A large area of biotite-hornblende tonalite to granite, mapped as the Adele Lake pluton by Sage et al. (1974), is present in the northeastern part of the batholith, southeast of the Township of Ignace (Figure 3.4). The predominant phase is biotite tonalite to granodiorite, which is locally gneissic (ca. 2.989 billion years old; Tomlinson et al., 2001). Additional phases include tonalite to granodiorite gneiss and hornblende tonalite (ca. 2.721 billion years old; Tomlinson et al., 2003). The age of the oldest gneissic phases indicate that this part of the batholith is contemporaneous with the Marmion batholith to the south of the Ignace area, and therefore distinct from the White Otter Lake batholith.

Outcrop descriptions of the White Otter Lake batholith have reported some foliation at surface (Sage et al., 1974). Orientations suggest that these are largely non-tectonic magmatic foliations, however no detailed descriptions have been found in the available literature. George Armstrong Co. Limited (1981) drilled a test drillhole to a depth of 97 m in the South Grey Trout Lake area of the White Otter Lake batholith and described the lithology in this area as coarse grained grey-white massive granite.

Aeromagnetic surveys (Figures 3.5 and 3.6) indicate a relatively consistent magnetic response over the White Otter Lake batholith. The regional aeromagnetic data reveals little detail within the batholith, and thus it is not possible to interpret local-scale compositional/phase changes and inclusions of remnant volcanics, and the occurrence of later-stage dykes within the intrusion. This is most likely due to the overall low resolution of the regional aeromagnetic data.

No information was found in the available literature regarding the thickness of the White Otter Lake batholith. Some conclusions, however, can be drawn from the gravity surveys (Figure 3.7). The gravity response over the White Otter Lake batholith, particularly to the east of Half Moon Lake, exhibits a marked gravity low of roughly 20 mGal amplitude. This gravity response trends in an easterly direction and extends into the Kay Lake foliated tonalite suite. The similar gravity response suggests that the maximum depth extent of the White Otter Lake batholith may be comparable to the Basket Lake batholith (8 km) (PGW, 2013).

3.2.1.4 Basket Lake Batholith

The Basket Lake batholith occurs in the northwestern corner of the Ignace area, approximately 27 km northwest of settlement area of Ignace. It is about 35 km long and 10 to 15 km wide with an approximate surface area of 420 km^2, but approximately half of this intrusion is outside of the Ignace area. The Basket Lake batholith is separated from the Indian Lake batholith by a zone of tonalitic rock and from the Revell batholith by the Raleigh Lake greenstone belt. The batholith contacts are typically poorly defined by aeromagnetic data due to the low resolution of the data (PGW, 2013).

Although no direct age determination is available for this batholith, Szewczyk and West (1976) interpret the existence of a weak foliation defined by aligned biotite and a fine- to medium-grained character to suggest that it experienced some degree of ductile deformation. This suggests that the Basket Lake batholith pre-dates the intrusion of the White Otter Lake and Indian Lake batholiths, as well as the late phase of the Revell batholith. Berger (1988), reports that granitic rocks of dioritic to quartz dioritic composition have partially assimilated mafic metavolcanic amphibolites of the greenstones along the southwest contact of the batholith, suggesting either a late synvolcanic or post-volcanic emplacement age.

Detailed mapping of the eastern portion of the Basket Lake batholith by Sage et al. (1974) describes the lithology as hornblende-biotite quartz-diorite to tonalite. The western-northwestern portion of the batholith, mapped by Berger (1988), consists mainly of leucocratic biotite-rich granodiorite, which varies to granite with subordinate tonalite, quartz monzonite, quartz diorite and a mixed hybrid zone locally developed near the contact with rocks of the Bending Lake and Raleigh Lake greenstone belts. The contact zone contains white tonalite dykes which cross-cut the granite and granodiorite facies of the intrusion, as well as the adjacent metavolcanics. These dykes are interpreted by Berger (1988) to be a late phase of the Basket Lake batholith. The rock is commonly foliated, and biotite is the major mafic mineral typically comprising less than 10% of the rock (Berger, 1988). A small swarm of Wabigoon dykes cut across the southern margin of the batholith while two mapped Kenora-Fort Frances dykes occur immediately to the southeast (Figure 3.4).

Aeromagnetic surveys (Figures 3.5 and 3.6) indicate a relatively consistent magnetic response over most of the Basket Lake batholith. Where there is low resolution magnetic data, it is not possible to identify local-scale compositional/phase changes and inclusions of remnant volcanics (Figure 3.5; PGW, 2013). A small area of high resolution aeromagnetic data (Evans, 2008) over the southeastern part of the Basket Lake batholith (Figure 3.5) shows an oval-shaped magnetic anomaly measuring 11 by 9 km and centred between Mameigwess Lake and the southern portion of the Basket Lake batholith. It is located within an area mapped as foliated tonalite but is interpreted to reflect a separate intrusive phase (PGW, 2013).

The gravity data over the Basket Lake batholith exhibits a large negative gravity anomaly, compared to the local gravity field measurements, of over 20 mGal amplitude, suggesting that it may be the thickest of the batholiths in the Ignace area (Figure 3.7; PGW, 2013). Szewczyk and West (1976) estimated the thickness of the northern side of the Basket Lake batholith to be at least 8 km and thinning progressively to 0.5 km to the southeast forming a tongue-like extension of the main batholith body. The modelling was performed using an average density of 2.61 g/cm^3 based on 10 tested rock samples.

3.2.1.5 Tonalite Gneiss

Tonalite gneiss is present over much of the Ignace area, particularly bordering the northern plutonic rocks of the Indian and Basket Lake batholiths (Figure 3.4) where the rock has been mapped as compositionally heterogeneous tonalitic gneiss and foliated tonalite. Throughout the Wabigoon Subprovince these gneisses yield a broad range of ages (ca. 3.009 to 2.673 billion years old; Buse et al., 2010) and appear to exhibit an episodic history of development. Overall, the tonalitic gneiss or gneissic suite is texturally and compositionally heterogeneous with individual layers varying compositionally from leucocratic tonalite and granodiorite through mesocratic tonalite and granodiorite to diorite and amphibolites (Stone, 2010a). The tonalitic gneisses exhibit boudinage, folding and development of strongly foliated to mylonitic zones as well as being cut by deformed dykes of tonalite, granodiorite and amphibolite and may contain xenoliths of amphibolites. Stone (2010a) reports that mafic tonalite gneisses locally grade to amphibole gneisses of volcanic origin or migmatites of sedimentary origin. The tonalites commonly show strongly foliated to mylonitic textures and belts of gneisses are spatially associated with zones of high strain such as the margins of large batholiths. Although mapped as distinct plutonic units, the Paddy Lake and Adele Lake plutons are a subset of this complexly deformed and poorly defined suite of crystalline rocks. Little information is available regarding the metamorphic condition of the tonalites or their state of recrystallization.

The tonalitic rocks in the Ignace area are discussed along with the batholiths or pluton with which they are associated, due to the generally limited information regarding the tonalites, and the fact that the mapped batholith contacts with the adjacent tonalites are sometimes approximate (i.e., inferred to be where granodiorite begins to dominate over tonalite).

3.2.1.6 Minor Plutons

In addition to the major plutonic bodies described above, the Ignace area contains a number of smaller felsic to intermediate intrusions, including the Raleigh Lake intrusions, the Paddy Lake, Norway Lake and Islet plutons, and the Melgund Lake stock (Figure 3.4).

The largest of these intrusions is the Islet pluton, which covers an area of approximately 140 km^2 in the southwest part of the Ignace area, at the southern boundary of the Revell batholith (Figure 3.4). The Islet pluton has a sanukitoid affinity, is coarse-grained, grey to pink, generally massive to weakly foliated, and is heterogeneous in composition, ranging from biotite-hornblende syenodiorite to diorite, to monzodiorite to monzonite, with local mafic phases of coarse-grained, grey to black gabbro and hornblendite (Stone, 2009a). No direct age determinations have been documented for the Islet pluton. However plutons having sanukitoid composition cross-cut most other lithologies and show a narrow range of ages from ca. 2.697 to 2.684 billion years old (Stone, 2010a). The Islet pluton is, therefore, interpreted to be a post-volcanic intrusion, an interpretation supported by the presence of inclusions of metavolcanic rocks into the magmatic fabric (McWilliams, 1998).

The oval-shaped Paddy Lake pluton extends for approximately 50 km^2 adjacently to the Islet pluton, at the southern boundary of the Bending Lake greenstone belt (Figure 3.4). This intrusion is composed of coarse-grained biotite tonalite bounded on its western side by tonalitic gneiss of uncertain origin (Stone, 2009b). No direct age determinations have been documented for the Paddy Lake pluton.

The Melgund Lake stock is located to the northeast of the Township of Ignace covering an approximate area of 20 km^2 within the Raleigh Lake-Bending Lake greenstone belts. This intrusion is white to orange, equigranular to porphyritic, and generally massive; it ranges compositionally from a hornblende-bearing diorite to a granodiorite, with quartz monzonite comprising over 80% of the intrusion (Berger et al., 1987).

The Raleigh Lake intrusions comprise three granitic stocks enclosed within the metavolcanic rocks of the Raleigh Lake greenstone belt. Foliation is weak to absent and the stocks are associated with a number of felsic dykes which are generally concordant to the contact with the metavolcanics, and which are reported to increase in size and frequency toward the stock (Sage et al., 1974).

The easternmost portion of the Entwine Lake stock extends about 10 km into the southwestern corner of the Ignace area. This intrusion is weakly foliated to massive, as well as sanukitoid and heterogeneous in composition. From older to younger phases, it consists of medium to coarse grained, massive to weakly foliated syenodiorite, biotite-augite diorite, porphyritic biotite-hornblende monzonite and hornblende peridotite (McWilliams, 1998).

The Norway Lake pluton covers approximately 40 km^2 in the southeast corner of the Ignace area, adjacent to the eastern side of the Finlayson-Marmion fault zone. This sanukitoid intrusion is medium to coarse-grained, inequigranular, contains hornblende and magnetite, and it is heterogeneous in composition, ranging from diorite to quartz diorite, monzonite to quartz monzonite, syenogranite and granodiorite (Buse et al., 2010).

All of these minor intrusions in the Ignace area are clearly defined in the magnetic data (Figure 3.5), typically by the following (PGW, 2013):

- Moderate to highly increased amplitude in the pole-reduced magnetic field relative to surrounding rocks (mainly mafic to intermediate metavolcanics (Unit 5, Figure 3.4) and/or foliated tonalite (Unit 12, Figure 3.4));
- Concentric pattern of magnetic highs visible in the various derivative maps (less developed over the Norway Lake pluton); and
- Contrast in magnetic texture visible in the various derivative maps (i.e., less linear than the metavolcanics).

3.2.1.7 Greenstone Belts

The greenstone belts in the Ignace area were not considered as potentially suitable for hosting a deep geological repository in the initial screening due to their composition, structural complexity and resource potential (Golder, 2011a). However, they are described here for completeness and context.

There are three greenstone belts within the Ignace area: the Raleigh Lake and Bending Lake greenstone belts extending around the Revell batholith, and the smaller Phyllis Lake greenstone belt northeast of the White Otter Lake batholith (Figure 3.4). The Raleigh Lake and Bending Lake greenstone belts have been interpreted as extensions of the Neoarchean greenstone sequences of the Kakagi Lake – Savant Lake volcanic belt in the western part of the Wabigoon Subprovince (Stone, 2009a), while the smaller Phyllis Lake greenstone belt is restricted to the area of the Adele Lake pluton in the northeast portion of the White Otter Lake batholith. These greenstone sequences are interpreted to have developed about 2.745 to 2.712 billion years ago. A metavolcanic rock sample from the Raleigh Lake greenstone belt has an age of ca. 2.73 billion years (Stone, 2010a). Stone (2009b) suggests that these greenstone units extend to approximately 3 km depth.

Raleigh Lake Greenstone Belt

The Raleigh Lake greenstone belt stretches in a northwest-trending direction in the area between the Indian Lake, White Otter Lake and Revell batholiths, to a width of 10 km west of the Township of Ignace. A narrow arm of the belt runs south of the Township of Ignace (Figure 3.4) and extends eastwards to the Bonheur area.

The most abundant rocks in the Raleigh Lake greenstone belt are mafic metavolcanic rocks, usually present as fine-grained, dark green to black pillow lavas commonly associated with pyritic iron formation units. In the mafic parts of the greenstone belt, gabbroic sills and stocks are present at scattered locations. Intermediate to felsic metavolcanic rocks exist as dacitic to rhyolitic flows, tuffs and breccias, the latter being mostly concentrated west of Raleigh Lake. These rocks show gneissic textures due to moderate levels of strain south and southeast of Raleigh Lake. The more intensely developed foliation in intermediate-felsic metavolcanics may imply that these rocks could be older than the mafic metavolcanic units (Stone, 2009a). Both mafic and intermediate-felsic metavolcanic rocks are intruded by biotite tonalite, which is typically coarse-grained, grey and moderately foliated. Metasedimentary units are concentrated at Balmoral Lake, just south of the Township of Ignace. Although migmatization has obliterated most of the original sedimentary structures, these metasedimentary units are interpreted by Stone (2009b) as turbiditic sandstone-siltstone sequences.

Bending Lake Greenstone Belt

The southwest-trending Bending Lake greenstone belt runs south of the Revell batholith (Figure 3.4). This belt is mostly composed of mafic metavolcanic rocks, gabbro, intermediate volcanic rocks and clastic metasedimentary rocks that occur in units of up to at least 2 km thick extending for almost the full length of the belt. Mapping in the Stormy Lake area by Stone (2010b) has extended lithological assemblages in the Kawashegamuk Lake and Manitou Lakes area to the Bending Lake area south of the Revell batholith. In order of stratigraphic succession these are: the Wapageisi Lake Group, the Stormy Lake Group, the Boyer Lake Group and the Kawashegamuk Lake Group. The Kawashegamuk Group consists largely of volcanic rocks ranging from pillowed mafic flows to intermediate breccias with related intrusive phases and sedimentary zones. Radiometric dating (Stone, 2010b) indicates an age of ca. 2.734 billion years. The Kawashegamuk Group is overlain by massive to pillowed mafic flows and gabbro intrusions of the Boyer Lake Group which is, in turn, overlain by similar lithologies of the ca. 2.727 billion year old Wapageisi Lake Group and formations of conglomerate, sandstone, iron formation and minor volcanic flows of the Stormy Lake Group (Stone, 2010b).

Numerous small shear zones and fractures are reported by Stone (2010b) within the Bending Lake greenstone belt. As discussed in Section 3.1.4, the larger scale Washeibemega Lake/Bending Lake fault is interpreted to follow the axis of the Bending Lake greenstone belt (Stone, 2009b). The timing and sense of displacement of the fault in the Stormy Lake-Bending Lake area is not known, though Stone (2009b) indicates that at least part of the faulting postdates the deposition of turbiditic sediments in the Kawashegamuk Group.

The Bending Lake greenstone belt is interpreted by Thompson (2008) to represent a broad, overturned, northeast facing, southwest dipping, synformal structure bounded on the northeast by younger granitic rocks of the Revell batholith. This interpretation is generally consistent with structural measurements made by Stone (2010b), although limited exposure leaves the structural interpretation unresolved.

Phyllis Lake Greenstone Belt

The northeasterly-striking Phyllis Lake greenstone belt is preserved as a sliver of supracrustal rocks between the Adele Lake pluton and the White Otter Lake batholith. The belt has a maximum width of a few kilometres and extends for about 30 km in length towards the edge of the Ignace area (Figure 3.4).

The Phyllis Lake greenstone belt is composed of mafic metavolcanic rocks exhibiting amphibolite-facies metamorphism that has locally transformed some of the metavolcanic rocks to amphibole gneiss (Stone, 2010a). The Phyllis Lake greenstone belt unconformably overlies biotite tonalite along the northwest side of the belt. U-Pb dating gives an age of ca. 2.955 billion years old for metavolcanic flows in the centre of the Phyllis Lake greenstone belt, compared to an age of ca. 2.989 billion years for the underlying tonalites in the northwest part of the belt. Younger ages were obtained for tonalite gneisses to the southeast of the belt, where Stone (2010a) obtained a U-Pb zircon age of ca. 2.817 billion years old.

3.2.1.8 Mafic Dykes

The youngest Precambrian rocks in the Ignace area are a series of widely spaced mafic dykes (the Fort Frances, Wabigoon and Eye-Dashwa dyke swarms) that cross–cut all earlier rock types. Mafic dykes are widespread throughout the Superior Province including multiple generations of dyke emplacement between ca. 2.5 and 1.0 billion years ago, (Osmani, 1991). Within the Ignace area, early dyke emplacement, typically in a northwesterly orientation, occurred between approximately 2.20 and 1.9 billion years ago, represented by the Fort Frances and Wabigoon dyke swarms, and a late stage of emplacement represented by the Eye-Dashwa dyke swarm. The most prominent are the Wabigoon dykes which extend in a northwest orientation for at least 70 km from Ignace to Lac des Mille Lacs and are not offset along any terrane boundaries. Within the Ignace area, the Wabigoon dykes are typically a few metres to 200 metres in width. Fahrig and West (1986) give a K/Ar age of ca. 1.9 billion years old for the Wabigoon dykes.

The northwest-trending Kenora-Fort Frances dyke swarm contains hundreds of dykes up to 100 km long and 120 m wide, covering an area of 90,000 km^2 (Osmani, 1991). Within the Ignace area, Kenora-Fort Frances dykes occurs in two clusters within the Ignace area: in the Meglund Lake area to the northwest of the Revell batholith, and in the Mameigwess Lake area between the Basket and Indian Lake batholiths. The Kenora-Fort Frances dykes are composed of variable amounts of plagioclase, pyroxene, quartz, hornblende with varying degrees of alteration. Southwick and Halls (1987) report a Rb-Sr age of ca. 2.120 billion years old.

The emplacement of the Kenora-Fort Frances and Wabigoon dykes was followed by pulses of brittle deformation and fault reactivation, concurrent with the Penokean Orogeny. Following these deformation stages, late dyke emplacement and presumably fault-joint reactivation associated with Midcontinent Rift magmatism occurred at ca. 1.150 to 1.130 billion years ago (Easton et al., 2007). Kamineni and Stone (1983) give K/Ar ages of ca. 1.132 and ca. 1.143 billion years old for dykes of the Eye–Dashwa swarm which are considered by Stone (2010a) to pre-date the main phase of rifting and intrusion associated with Midcontinent Rift magmatism at ca. 1.150 to 1.130 billion years ago (Heaman and Easton, 2006; Easton et al., 2007).

3.2.2 Quaternary Geology

Overburden deposits within the Ignace area were mapped as part of the Northern Ontario Engineering Terrain Study (NOEGTS), a program undertaken between 1977 and 1980. These studies divided the landscape into a set of distinct terrain units within which the engineering characteristics are broadly predictable. In many areas of northern Ontario, including the Ignace area, maps produced from these programs currently represent the best level of detail available for surficial geology mapping and descriptions of terrain conditions (JDMA, 2013a). Major landforms mapped by the NOEGTS program are shown on Figure 2.3.

The Quaternary cover in the Ignace area mostly comprises different types of glacial deposits that accumulated with the progressive retreat of the ice sheet during the end of the Wisconsinan glaciations (Figure 2.3; JDMA, 2013a). This period of glaciation began approximately 115,000 years ago and peaked about 21,000 years before present, at which time the glacial ice front extended south of Ontario into what is now Ohio and Indiana (Barnett et al., 1991).

The earliest known Quaternary deposits in the Ignace area are thin basal till deposits laid down during the advance of the Laurentide Ice Sheet from the northeast. A thin veneer of till may be present in areas mapped as bedrock terrain, while thicker accumulations are mapped as morainal terrain on Figure 2.3. While earlier glacial and interstadial deposits are encountered in a few locations in northern Ontario (e.g., the interstadial or interglacial Missinaibi Beds of the Moose River drainage or the interstadial Owl Creek Beds of the Timmins area), none are known in the Ignace area. It is likely that any earlier deposits have been largely or entirely removed by glacial erosion which stripped away the pre-existing overburden and eroded the crystalline bedrock in the Ignace area.

The northward retreat of the ice sheet in the Ignace area started approximately 12,000 years ago and the Ignace area became ice-free approximately 10,500 years ago (Dyke et al., 2003). During this period, significant deposition of glaciofluvial outwash occurred. In the Ignace area, these deposits are mapped generally to the northeast of the Trans-Canada Highway (Figure 2.3). The progressive retreat of the ice sheet is also recorded in the deposition of the Eagle-Finlayson, Hartmann and Lac Seul moraines, successively from south to north (Figure 2.3). These major end moraines, generally consisting of cross-stratified gravelly sand or sandy gravel of deltaic ice-contact origin (JDMA, 2013a), form northwesterly-trending linear features that can be traced for more than 200 km across northwestern Ontario. During the waning of the Wisconsinan glaciation, drainage was blocked from flowing northward by the residual ice mass still remaining over the Hudson Bay Basin. This created a large ice-dam lake, known as Lake Agassiz, which covered much of northwestern Ontario and the majority of the Ignace area. Lake Agassiz was the largest of several glacial lakes that bordered the southern margin of the retreating ice sheet during the late Wisconsinan glaciations covering a maximum area of approximately 1 million km^2 (Bajc et al., 2000). Clays and silts were laid down as Lake Agassiz gradually inundated the area ca. 9,900 years ago and these fine-textured glaciolacustrine deposits are mapped in the Ignace area, primarily to the north of the Lac Seul moraine.

Southwest of the Trans-Canada Highway in the Ignace area, the bedrock is generally either exposed at surface or covered by a thin layer of Quaternary sediments. A notable glacial feature in the Ignace area is associated with the Bonheur River Kame Provincial Nature Reserve Park, located 26 km east of the Township of Ignace (Figure 1.1). This park features a moulin kame that rises over 80 m above a peat-covered plain. A moulin kame is a cone-shaped hill of gravel and small boulders deposited by glacial meltwaters falling through a hole in the glacial ice (Ontario Parks, 2010). This glacial feature is evident as a localized topographic high in the digital elevation model (DEM), approximately 10 km south of Sowden Lake (Figure 2.2; JDMA, 2013a).

Following the disappearance of the ice sheets and the gradual draining of glacial lakes, modern streams have developed alluvial flood plains and organic deposits have accumulated in wet depressions (Figure 2.3; JDMA, 2013a). Many of the organic deposits in the area are located within the trough formed between the south flank of the Hartman moraine and the sub-parallel Revell-Gulliver highland to the southwest (Figure 2.2).

Information on the thickness of Quaternary deposits within the Ignace area is largely derived from terrain evaluation (JDMA, 2013a). Measured thicknesses are limited to a small number of water well records for rural residential properties, typically along the Trans-Canada Highway and to diamond drill holes concentrated in the greenstone belts (Figure 2.3). A detailed accounting of recorded depths to bedrock in the Ignace area is provided by JDMA (2013a), and depths generally range from 0 to 15 m, although greater thicknesses have been recorded in a few locations. The 124 diamond drill holes with reliable information on overburden thickness in the Ignace area are mostly located within the Raleigh Lake and Bending Lake greenstone belts (Figure 2.3; JDMA, 2013a). The maximum depth to bedrock recorded in the Ignace area is about 32 m, with an average of 3.7 m. Twenty-six drill holes (or 20%) record depths greater than 5 m, and only three drill holes record depths exceeding 20 m. An examination of the distribution of the drill holes indicates that it is common to see variations of 10 to 15 m or more in drift thickness within a ground distance of a kilometre or less. The thickest overburden is inferred to occur along the Eagle-Finlayson, Hartman and Lac Seul moraines where depth to bedrock can be many 10's of metres (JDMA, 2013a). These observations provide an indication of the typical values and variability in drift thicknesses that can be expected within the bedrock terrain in the Ignace area (JDMA, 2013a).

The Indian Lake batholith is partially covered by overburden in the Ignace area. Terrain analysis carried out as part of the desktop geoscientific preliminary assessment of the Ignace area (JDMA, 2013a) indicates that less than 20% of the surface of the Indian Lake batholith consists of exposed bedrock and that this exposure is predominantly along the southern margins of the batholith. Thicker overburden deposits mapped within the northern portion of the Indian Lake batholith result in sparse to absent bedrock outcrop exposures in the northern portion of the batholith.

The Revell batholith is partially covered by overburden. Terrain analysis carried out as part of the desktop geoscientific preliminary assessment of the Ignace area (JDMA, 2013a) indicates that approximately 70% of the surface of the Revell Lake batholith consists of exposed bedrock or bedrock covered by only a thin mantle of unconsolidated Quaternary sediments.

Outcrop exposure is good over the majority of the White Otter Lake batholith with apparent large barren areas (Sage et al., 1974). Terrain analysis carried out as part of the desktop geoscientific preliminary assessment of the Ignace area (JDMA, 2013a) indicates that more than 70% of the surface of the White Otter Lake batholith consists of exposed bedrock or bedrock with only a thin veneer of Quaternary sediments.

Terrain analysis carried out as part of the desktop geoscientific preliminary assessment of the Ignace area (JDMA, 2013a) indicates that a substantial portion of the Basket Lake batholith is covered by overburden deposits, and a relatively high percentage of the southeast portion of the batholith is covered by lakes.

3.2.3 Lineament Investigation

A detailed lineament investigation was conducted for the Ignace area using multiple datasets that included satellite imagery (SPOT), digital elevation model data (CDED) and geophysical (aeromagnetic) survey data (JDMA, 2013b). Lineaments are linear features that can be observed on remote sensing and geophysical data and 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 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 Ignace 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 (2013b) 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 desktop 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. These features are included to provide context to our understanding of the tectonic history of the Ignace area, but were not included in the merged lineament sets or statistical analyses.
- **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 (described below).
- **Dyke lineaments**: For this preliminary desktop interpretation, any features which were interpreted, on the basis of their distinct character, e.g., scale and composition of fracture in-fill, orientation, geophysical signature and topographic expression, were classified as dykes. Dyke interpretation is largely made using the aeromagnetic data set, and is often combined with pre-existing knowledge of the bedrock geology of the Ignace area.

The desktop interpretation of remotely-sensed datasets necessarily includes a component of uncertainty as a result of data quality; scale of Ignace area; expert judgement; and to a certain extent, the quality of the pre-existing knowledge of the bedrock geology of the Ignace area. Therefore, the ductile, brittle or dyke categorization of each identified feature, as described herein, is preliminary, and would need to be confirmed during future stages of the site evaluation process.

For each dataset, brittle lineaments and dykes were interpreted by two independent experts using a number of attributes, including Certainty and Reproducibility (JDMA, 2013b). 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 datasets used.

In addition, ductile lineaments were identified from the geophysical dataset by a single expert interpreter. These ductile lineaments are included to provide context to our understanding of the tectonic history of the Ignace area, but were not included in the merged lineament sets or statistical analyses.

The SPOT and CDED datasets (Figures 2.2 and 2.3, respectively) were used to identify surficial lineaments expressed in the topography, drainage and vegetation. The SPOT dataset has a uniform resolution of 10 m (panchromatic) and 20 m (multispectral) over the entire Ignace area (JDMA, 2013a, b). The CDED dataset is at a 1:50,000 scale, with a uniform 20 m resolution over the entire Ignace area (JDMA, 2013a, b). The resolution of the SPOT and CDED datasets allowed for the identification of surficial lineaments as short as a few hundred metres in length and provided sufficient detail to reveal surficial structural patterns (JDMA, 2013b). Aeromagnetic datasets (Figures 3.5 and 3.6) were used to identify linear geophysical anomalies indicative of bedrock structures. Regional low resolution data (at 800 m line spacing) is available for the entire Ignace area (Figure 1.2). High resolution data (at 200 m line spacing) is available for the western portion of the Ignace area and for the Revell batholith. High resolution data (at 100 m line spacing) is also available from a survey flown for Takara Resources over the southeastern part of the Basket Lake batholith (Evans, 2008). Although the digital geophysical data were not available for the Takara Resources surveys, the magnetic and radiometric data were incorporated into this assessment in the form of raster maps that were extracted from the report and georeferenced (PGW, 2013). The high resolution geophysical coverage allowed for the identification of geophysical lineaments on the order of 500 m or longer in length, while the regional geophysical coverage limited the resolution of geophysical lineaments to features on the order of 2 km or longer in length.

Figure 3.8 shows the combined surficial lineaments (SPOT and CDED). The SPOT dataset yielded a total of 1,084 surficial lineaments, ranging from 225 m to 38.5 km in length, with a mean length of 2.3 km, while the CDED dataset yielded a total of 659 lineaments, ranging from 659 to 46.5 km long, with a mean length of 4.2 km. The density and distribution of surficial lineaments was seen to be influenced by the more than 40% overburden coverage in the area, which masked and truncated the surface continuity of some lineaments. This is particularly evident in the northeast part of the Ignace area, where thick overburden cover dominates and the density of surficial lineaments is low. Both the SPOT and CDED data sets offered advantages to characterize the surficial lineaments. The higher resolution of the SPOT imagery allowed for finer structures to be identified that were not resolved by the CDED data, but the CDED data often revealed subtle trends masked by the surficial cover captured in the SPOT imagery.

The aeromagnetic dataset yielded a total of 764 lineaments (Figure 3.9), 677 interpreted as brittle faults and 87 interpreted as dykes. Ductile lineaments are not shown. The length of the geophysical lineaments ranged from 100 m to 47.3 km, with a geometric mean length of 4.7 km. The density and distribution of geophysical lineaments is influenced by the resolution of the geophysical coverage. The density of geophysical lineaments is higher in areas of high resolution such as in the Revell batholith and the southern part of the Basket Lake batholith. This observation suggests that the Indian Lake, Basket Lake and central part of the White Otter Lake batholiths may have a similar geophysical lineament density to other intrusions in the area where high resolution aeromagnetic data are available. In addition, shorter lineaments could be present in areas other than those covered by high resolution aeromagnetic data, but remain undetectable due to the low resolution aeromagnetic coverage. The length-weighted lineament trends for the geophysical lineaments interpreted as brittle features exhibit a dominant orientation to the north-northwest at 340º. Other prominent orientations include a westerly trend at 285º and a northeasterly trend at 067º.

The 87 lineaments identified as dykes (Figure 3.9), which includes smaller segments of the same dyke, belong to the northwest trending (295º to 310º) suite of Wabigoon dykes. The distribution of these dykes appears clustered within a narrow linear trend toward the northwest that passes roughly through the middle of the Ignace area and cuts the northern portion of the Adele Lake pluton, the southern extent of the Indian Lake batholith, and the northernmost portion of the Revell batholith. The more steeply northwest trending Kenora-Fort Frances dykes identified in the OGS mapping between the Basket Lake and Indian Lake batholiths were generally not discernible in the aeromagnetic data due to the low resolution coverage.

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 greenstone belts and the “wrapping” of the greenstone ductile features around the younger Revell batholith, Paddy Lake pluton and the Raleigh and Meglund Lake stocks is clearly visible on Figure 3.10. It should be noted that the density of these features is also 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 Ignace area, classified by length. The merged lineament dataset yielded a total of 1,998 lineaments, ranging from 100 m to 46.5 km in length, with a mean length of 3.2 km. There are three dominant lineament trends observed in the merged lineament dataset based on length-weighted frequency, they are north-northwest (340º to 005º), northeast (045º to 067º) and west-northwest (285º to 310º). Lineament orientation trends for the individual intrusive geological units in the Ignace area (i.e., Basket Lake batholith, Indian Lake batholith, Revell batholith, White Otter Lake batholith, Paddy Lake pluton, Adele Lake pluton and Islet pluton) are presented on Figure 3.12 and further discussed in the geologic unit-specific sub sections below.

JDMA (2013b) noted the following trends in the final merged lineament dataset:

- Longer lineaments generally have higher certainty and reproducibility.
- There is a much greater coincidence between surficial lineaments (20% of the total merged lineaments are interpreted from both CDED and SPOT) than between geophysical lineaments and surficial lineaments (2.2% of the total merged lineaments are observed in geophysical data and at least one of the surficial data sets), presumably since surficial lineaments interpreted from CDED and SPOT are expressions of the same bedrock feature.
- The low 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 800 m flight line spacing, small features or features in the aeromagnetic dataset oriented at a low angle to the flight lines 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 Ignace area when lineaments are progressively “filtered” by length (i.e., plots showing only lineaments longer than 1 km, >5 km and >10 km). 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 greatly increases the spacing between lineaments, including those areas having exposed bedrock and higher resolution aeromagnetic surveys. For example, Figure 3.16 shows that the Revell batholith contains 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 lineaments density. For example, the Revell batholith with well-exposed bedrock and high resolution aeromagnetic surveys exhibits very high lineament densities 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 data sets (i.e., mapped regional faults, brittle lineaments, dykes and ductile lineaments), which helps provide a structural understanding of the Ignace area. The mapped regional faults include the Finlayson-Marmion fault zone, which has coincident geophysical and surficial lineaments, and the Washeibemaga Lake fault, whose surficial and geophysical expression, if present, is masked in the Ignace area by concordant stratigraphy within the Bending Lake greenstone belt. As these mapped faults are interpreted to have originated as D_5 structures (Section 3.1.3), their origin is thought to largely pre-date the structural fabric defined by the various brittle lineament sets. The lineament orientations, therefore, do not appear to be directly influenced by the orientation of the regional mapped faults, though both may ultimately reflect regional stress conditions and 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 intrusive bodies in the area, as well as the relative age of the lineaments identified in the Ignace area.

3.2.3.1 Indian Lake Batholith

A total of 322 lineaments were mapped over the Indian Lake batholith (Figure 3.11). Many of the long interpreted lineaments extend beyond the batholith into the metavolcanic rocks of the Raleigh Lake greenstone belt.

Interpreted surficial lineaments (Figure 3.8) range in length from approximately 1.5 to 25 km, and are distributed in two main orientations, trending east-southeast and northeast to east-northeast (Figure 3.12). The surficial lineament density is uniformly low across the entire batholith (Figure 3.8). This is likely due to the extensive overburden cover present in the northeastern half of the Ignace area. Interpreted geophysical lineaments (Figure 3.9) range in length from approximately 2 to 46 km, and show three main orientations, trending west-northwest (280º to 305º), north-northwest (340º to 005º) and northeast (045º to 065º). The geophysical lineament density is generally low (Figure 3.9). However, lineament density shows a marked increase where the higher resolution datasets overlap the northwestern and southwestern margins of the Indian Lake batholith (Figures 3.9 and3.13). The density variation is primarily a result of the variable aeromagnetic data resolution and it is therefore likely that a similar density of lineaments exists across the entire Indian Lake batholith.

Data from two quarries in the Indian Lake batholith reveal the existence of joint systems with varied orientations and spacing either on the surface or at shallow depths (Storey, 1986; Hinz et al., 1994). It is unknown how deep such joint systems extend. The predominant joint set in the Indian Lake batholith at the Butler Quarry (approximately 2.5 km northwest of the Township of Ignace) is widely spaced (5 m or more) and oriented 110º with lesser sets at 045º and 070º having average spacings 1 to 2 m apart (Storey, 1986). In the Gummeson Quarry within the Indian Lake batholith (approximately 10 km west of the settlement area of Ignace), the outcrop rock presents incipient horizontal fracturing spaced from 0.3 to 2.5 m apart. A roughly vertical, nearly orthogonal joint system exists, containing joint sets trending westerly and northerly. Spacing of the west-trending set measures 2 m, while spacing of the north-trending set measures 5 to 7 m. The eastern portion of the Indian Lake batholith (east of the Ignace area) is transected by the Finlayson-Marmion fault zone, and a number of Wabigoon dykes are interpreted to cross the southern margin of the batholith. In addition, several dykes from the Fort Francis suite cut the northwest portion of the Indian Lake batholith. The mapped Finlayson-Marmion fault zone coincides with interpreted surficial and geophysical lineaments while the Wabigoon dykes coincide with interpreted geophysical lineaments. The Kenora-Fort Frances dykes are not readily discernible in the low resolution geophysical coverage.

3.2.3.2 Revell Batholith

As shown on Figure 3.11, brittle lineaments interpreted in the Revell batholith (JDMA, 2013b) extend beyond the batholith into the metavolcanic rocks of the Bending Lake and Raleigh Lake greenstone belts. The Revell batholith has good bedrock exposure and high resolution aeromagnetic survey coverage relative to most of the Ignace area. This in part explains the relatively high density of lineaments in this intrusion; 306 lineaments were interpreted over an area of approximately 455 km^2 along with a number of prominent dykes of the Wabigoon dyke swarm stepping en echelon in the north portion of the batholith.

Figure 3.8 shows the surficial lineament distribution over the Revell batholith. These lineaments range in length from approximately 1 to 29 km. The surficial lineament density is variable across the batholith (Figure 3.8). The northwestern and southeastern areas of the batholith show a slightly higher density than the central part of the batholith. The overburden cover over the Revell batholith is uniformly low, and so the variation in interpreted surficial lineament density is possibly due to lithological variation, as the Revell batholith is characterized by several phases of intrusion (Section 3.2.1.2).

Figure 3.9 shows the geophysical lineament distribution over the Revell batholith. These lineaments range in length from approximately 1 to 34 km. The geophysical lineament density across the Revell batholith is relatively high compared to the other batholiths in the Ignace area, which is the result of the high resolution aeromagnetic data coverage over the entire batholith (Figure 3.9). Within the batholith, the density of geophysical lineaments appears to be lower in the northern part than in the southern part of the batholith, possibly reflecting a lower magnetic mineral content within the granodiorite of this part of the batholith compared to the magnetite-bearing central megacrystic facies. The dominant orientation of the lineaments in the Revell batholith is west-northwest (270º to 285º); much less dominant are the northwest (315º to 340º) and east-northeast (067º) trends (Figure 3.12). Several geophysical lineaments that traverse the northern and central portions of the Revell batholith and the adjacent greenstones do not appear to extend into the southern portion of the intrusion.

3.2.3.3 White Otter Lake Batholith

A total of 455 lineaments were identified within the portion of the White Otter Lake batholith included within the Ignace area (Figure 3.11). Some of these lineaments extend beyond the batholith into the gneissic terrane to the south and into the metavolcanic rocks of the Raleigh Lake greenstone belt to the north. As with the other intrusions, the density of lineaments identified from the White Otter Lake batholith appears to be closely related to the extent of overburden cover and the low resolution of the available aeromagnetic data.

Figure 3.8 shows the surficial lineament distribution over the White Otter Lake batholith. These lineaments range in length from approximately 1 to 38 km. The surficial lineament density is variable across the batholith. The western and central portions show a much lower density of surficial lineaments than the eastern extension of the batholith in the Ignace area. Figure 3.9 shows the geophysical lineament distribution over the White Otter Lake batholith. These lineaments range in length from 1.5 to more than 45 km. The geophysical lineament density across the White Otter Lake batholith is uniformly low, and similar to that of most of the Indian Lake batholith. This is likely due to the low resolution aeromagnetic data available for most of the batholith. Only a thin sliver of higher geophysical lineament density occurs along the extreme northwestern margin of the White Otter Lake batholith where there is coverage by the Stormy Lake high resolution dataset.

Lineament orientations for the White Otter Lake batholith (Figure 3.12) show main trends to the west-northwest (295º), to the north-northwest (340º to 355º), and to the northeast (035º to 050º). The northeastern trend is the most dominant trend observed followed closely by the north-northwestern trend.

3.2.3.4 Basket Lake Batholith

A total of 200 lineaments were identified over an area of approximately 430 km^2 of the Basket Lake batholith (Figure 3.11). Overall, lineament density is relatively low compared to the Revell and White Otter Lake batholiths (Figure 3.13).

Figure 3.8 shows the surficial lineament distribution over the Basket Lake batholith. These lineaments range in length from approximately 2 to 15 km. The surficial lineament density is uniformly moderate to low across the batholith, and slightly higher than that of the Indian Lake batholith. The overburden cover over the Basket Lake batholith is relatively extensive. Figure 3.9 shows the geophysical lineament distribution over the Basket Lake batholith. These lineaments range in length from 2 to more than 30 km. The geophysical lineament density across the Basket Lake batholith is highly variable. A high density of lineaments was interpreted in the southeastern corner of the batholith where high resolution geophysical data are available. In contrast, the remainder of the batholith has a relatively low density of geophysical lineaments.

The density of geophysical lineaments in the southern part of the Basket Lake batholith covered by high resolution survey coverage (Takara Resources, 100 m line spacing) is higher than the density of geophysical lineaments in the Revell batholith reflecting the greater resolution of the geophysical survey coverage (200 m line spacing for the Stormy Lake survey which covers the Revell batholith). This greater geophysical lineament density is the result of increased recognition of short lineaments and much of the apparent increase in geophysical lineament density is lost when the lineaments are filtered by length (e.g., >5 km as shown on Figure 3.15).

As is the case for other batholiths in the Ignace area where only low resolution geophysical data are available, it is possible that the higher density of geophysical lineaments present in the southeast portion of the Basket Lake batholith could be representative of the lineament density for the entire batholith.

Orientation data for the Basket Lake batholith (Figure 3.12) indicate strong trends to the north-northwest (340º to 350º) and northeasterly trends (055º to 065º). Weakly defined trends to the northwest and east-west are also observed in the Basket Lake batholith.

3.2.3.5 Minor Plutons

A total of 82 lineaments were identified on the Islet pluton, which covers an area of 144 km^2 (Figure 3.11). Azimuth data for all the lineaments indicate a range of orientations, with the two strongest trends observed to the northeast (060º to 065º) and to the northwest (310º), as shown on Figure 3.12. Both of these trends, and in particular the northwest trend, appear to be strongly influenced by the geophysical lineaments. The southern half of this pluton has a higher density of interpreted surficial lineaments than the northern half; presumably due to variable distribution of overburden cover (Figure 3.8). In contrast, there is a higher density of geophysical lineaments in the northern half of the Islet pluton, which coincides with high resolution geophysical data coverage (Figure 3.9).

The Paddy Lake pluton covers an area of 115 km^2, where a total of 101 lineaments were mapped. The rose diagram for these lineaments appears very similar to that for the neighbouring Islet Lake pluton (Figure 3.12). The strongest trend is observed to the northeast (060º to 065º). Two strong north-northwesterly trends are also observed at 290º and 310º. Both the surficial and aeromagnetic datasets show a relatively low density of interpreted lineaments (Figures 3.8 and 3.9).

The Adele Lake pluton covers an area of approximately 375 km^2 from which a total of 197 lineaments were mapped. The orientations of these lineaments appear to follow three major trends (Figure 3.11). The most prominent orientation is northwest (295º to 300º), with secondary trends at north-northwest (345º to 350º) and northeast (060º to 065º). A very high density of surficial lineaments was interpreted for the Adele Lake pluton (Figure 3.8). In contrast, a low density of geophysical lineaments was recognized for the Adele Lake pluton (Figure 3.9), similar to the density recognized within the areas of low data resolution coverage of the Indian Lake and White Otter Lake batholiths.

3.2.3.6 Relative Age Relationships of Lineaments

The identified surficial lineaments in the Ignace area are interpreted to represent cross-cutting brittle deformation features (Figure 3.8; JDMA, 2013b) or traces of stratigraphic contacts. The latter are identified primarily within the greenstone belts. Their formation is therefore attributed to deformation processes associated with the D_5 and later episodes of regional deformation as described in Section 3.1.3. At the desktop stage of preliminary assessment, it is still uncertain whether or not each interpreted lineament is in fact an actual brittle geological feature, or whether or not it has a significant expression at depth. Nor are the three dimensional orientations of such features discernible at the desktop stage and shallow dipping features cannot reliably be differentiated from steeply dipping features. The interpreted geophysical lineaments are less affected by overburden cover and more likely represent bedrock features across the whole of the Ignace area (Figure 3.9). At this stage in the mapping process, it is generally not possible to conclusively assign a particular geophysical lineament to the ductile or brittle regime, and many observed geophysical lineaments will likely prove to be transitional with both brittle and ductile components.

The geophysical lineament interpretation (Figure 3.9) yields three diffusely distributed lineament sets in west-northwest, north-northwest and east-northeast orientations (Figure 3.9 inset). In all cases, there is a spread in orientation of approximately 25–30° within sets. Examination of the surficial and geophysical lineament interpretation indicates that there are no obvious and consistent cross-cutting relationships between the different sets (Figure 3.11). There are examples where the west-northwest trending geophysical lineaments appear to offset the other two geophysical lineament sets with both sinistral and dextral movements (Figure 3.9). There are also examples where the west-northwest trending features are shown to be offset by lineaments of both the north-northwest and east-northeast sets. This may be due to the coarse resolution of the geophysical dataset across much of the Ignace area, which does not provide the necessary detail to discern such structural relationships.

A detailed examination of the interpretation across the small high-resolution area of the Takara Resources survey on Figure 3.9 shows a high-density mosaic pattern that again indicates no clearly consistent cross-cutting relationship between the lineament sets. In addition, the surficial lineaments observed in the Ignace area generally exhibit intersecting sets of lineaments without visibly discernible offsets (JDMA, 2013b). The orientations observed for the combined set of interpreted brittle lineaments (Figure 3.12) include strong trends to the west-northwest (280º to 305º), north-northwest (340º to 005º), and northeast (045º to 065º) with some minor variation within the individual plutonic bodies. The principal lineament orientations in the Ignace area are essentially common to all the major late plutonic bodies (i.e., the Indian Lake, White Otter Lake, Revell and Basket Lake batholiths; Figure 3.12). This suggests that the tectonic events related to the various brittle lineament sets all post-date the emplacement of the plutonic bodies at approximately 2.734 to 2.671 billion years ago.

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

The Ignace area lies within the Superior Proivince of the Canadian Shield, where large parts have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). 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 2010; no seismic events exceeding a magnitude m_N of 6 are recorded within 1,000 km of the Ignace area. Although Hayek et al. (2011) indicate that the general Western Superior Province has experienced a number of low magnitude, shallow seismic events (generally 5 km focal depth), all recorded earthquakes in the region since 1985 had a Nuttli magnitude m_N of less than 4. Figure 3.19 shows the locations and magnitudes of seismic events recorded in the National Earthquake Database (NEDB) for the period between 1985 and 2011 in the Ignace area (NRCan, 2012). Over this time period, all recorded seismic events in the area had magnitudes ranging from less than 1 to 3.

Ma et al. (2008) have recently pointed out the existence of small swarms of microseismic activity in the physiographic Severn Highlands of northwestern Ontario, which roughly extends west and north-northwest of Lake Nipigon. The closest of such occurrences is the Dryden swarm, which occurred in 2002-2003 just north of the Town of Dryden and northwest of the Ignace area, with a total of 22 events recorded, the largest having a Nuttli magnitude m_N of 3.2. These events may be related to post-glacial rebound and appear to correlate to a particularly thick and cold lithospheric root beneath the Severn Highlands.

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

3.3.2 Neotectonic Activity

Neotectonics refers to deformation, stress and displacement 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 Ignace area is typical of many areas of the Canadian Shield, which has been subjected to numerous glacial cycles during the last million years. The continental scale tectonic movements are therefore overprinted by 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 Ignace area would be of a somewhat greater magnitude, due to its closer proximity to the main centre 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). The vertical velocity contours developed from the lake water level data sets compared well with the postglacial rebound models, which in turn indicated that present day rebound rates in the Ignace area should be well below 10 mm/yr, likely between 2 and 4 mm/yr. As a result of the glacial unloading, acting along with tectonic stresses, principal stress magnitudes and orientations are changed. Seismic events could be associated with these post-glacial stress changes as a result of reactivation of existing fracture zones. In addition, natural stress release features can include elongated compressional ridges or pop-ups such as those described by McFall (1993) and Karrow and White (2002).

No neotectonic structural features are known to occur within the Ignace area. It is therefore useful to review the findings of previous field studies involving fracture characterization and evolution as it pertains 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 in western Ontario. These various studies found that fractures below a depth of several hundred metres in the plutonic rock were 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, 2013a). Existence of such features can be used to extend the seismic record for a region well into the past. As shown on Figure 2.4, glaciolacustrine terrain in the Ignace area is generally located northeast of the Lac Seul moraine and along the northern boundary of the Revell batholith. Some road and water access is available to both of these regions, which may allow for the investigation of the presence of neotectonic features.

4.0 HYDROGEOLOGY AND HYDROGEOCHEMISTRY

4.1 Groundwater Use

Information regarding groundwater use in the Ignace area was obtained from the Ontario Ministry of the Environment (MOE) Water Well Record (WWR) database (MOE, 2012). The location of known water wells is shown on Figure 4.1. Until recently, the Township of Ignace obtained its municipal water supply from two overburden water wells which supplied the normal demands of the municipality and a third well which provided fire flows. The municipality has recently constructed an upgraded water supply system, sourcing water from a new surface water intake structure. A number of scattered wells serving individual private residences exist mostly along the shores of Agimak Lake.

Water wells in the Ignace area obtain water from the overburden or the shallow bedrock. The MOE water well database contains 120 water well records in the Ignace area, 85 of which provided useful information regarding aquifer, yield and other parameters noted in Table 4.1.

Table 4.1: Water Well Record Summary for the Ignace Area

Water Well Type	Number of Wells	Total Well Depth (m)	Median Well Depth (m)	Static Water Level (mbgs)	Tested Well Yield (L/min)	Depth to Top of Bedrock (m)
Overburden[1]	48	4.5 to 42	16.9	0 to 12	4.5 to 930	N/A
Bedrock	37	5.5 to 154	46.3	0 to 22.5	0 to 206	0 to 80.5

N/A = not applicable

[1]inferred for some records which were lacking stratigraphic descriptions

4.2 Overburden Aquifers

There are 48 water well records in the area of Ignace that can be confidently assigned to the overburden aquifer. These wells generally are 4.5 to 42 m deep and have pumping rates of 4.5 L/min to 930 L/min. These well yields 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. The highest yields recorded in the area are for municipal test wells sited and constructed to maximize yields. Tested yields reflect the short term hydraulic performance of the wells and may not be sustainable over long periods.

The limited number of well records and their concentration along the main roadways and Agimak Lake limits the available information regarding the extent and characteristics of the overburden aquifers in the Ignace area. However, as several of these water wells are located within glaciofluvial terrain, it is likely that similar terrain mapped in the Ignace area (Figure 2.4) will also host shallow overburden aquifers.

4.3 Bedrock Aquifers

No information was found on deep bedrock groundwater conditions in the Ignace area at a typical repository depth of approximately 500 m. In the Ignace area, there are 37 well records that can be confidently assigned to the shallow bedrock aquifer. These wells range from 5.5 to 154 m in depth, with most wells between 20 and 40 m deep. The anomalously deep well extending to 154 m has coordinates that place it along the shore of Sandbar Lake to the north of Ignace. The well record contains little stratigraphic information but its accuracy cannot be discounted given its location in an area known to contain thick overburden of the Lac Seul moraine.

Measured pumping rates in the bedrock wells are variable and range from 0 to 206 L/min, with yields typically between 30 and 40 L/min. These well yields 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 shallow bedrock 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 WWRs indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Ignace area or anywhere else in Northern 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 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. However, 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 Ignace area shown on Figure 2.5, it is inferred that the Revell-Gulliver highland will tend to act as a regional divide between groundwater flow tending towards the English River watershed to the north and towards the Seine/Turtle River watershed to the south. In the northwest portion of the Ignace area, where the highland is absent, regional flow can be assumed to be influenced by the Wabigoon River watershed and would therefore tend towards the northwest. 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 2.5. 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 Ignace 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 Ignace 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 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, 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). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan 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.

There is no site-specific information on the hydraulic characteristics of the dykes interpreted for the Ignace 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; Svensson and Rhén, 2010; Gupta et al., 2012; Holland, 2012).

The orientation of fracture networks relative to the orientation of the maximum horizontal compressive stress may also influence permeability. In this case, a lower effective hydraulic conductivity would be predicted for fractures oriented at a high angle to the maximum compressive stress axis compared to otherwise identical low angle fractures. 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 predominantly in the west-southwest direction. This is generally consistent with the World Stress Map; however, anomalous stress orientations are known to exist in a small portion of the northwest Superior Province that includes the Ignace area (Brown et al., 1995). A 90° change in azimuth of the maximum compressive stress axis was identified in the near surface in the Whiteshell area of Manitoba (Brown et al., 1995) while a roughly north-south orientation of maximum horizontal compressive stress was found for the Sioux Falls Quartzite in South Dakota (Haimson, 1990). In view of the general paucity of data and the anomalous stress orientations in mid-continent, caution is warranted in extrapolating a west-southwest stress orientation to the Ignace area without site-specific data. The exact nature of deep groundwater flow systems in the Ignace area would need to be evaluated at later stages of the site evaluation process, through the collection of site-specific information.

4.5 Hydrogeochemistry

No information on groundwater hydrogeochemistry was found for the Ignace 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). Such conditions would need to be evaluated during subsequent site evaluation stages.

5.0 NATURAL RESOURCES — ECONOMIC GEOLOGY

Information regarding the mineral resource potential for the Ignace area has been obtained from a variety of sources including general syntheses of mineralization in the Canadian Shield Region (Blackburn et al., 1991; Fyon et al., 1992; Breaks and Bond, 1993; and Stone and Halle, 1999), studies within the Ignace area (Satterly, 1960; Woolverton, 1960; Sage et al., 1974; Jackson, 1985; Breaks, 1993; Stone et al., 1998; and Stone, 2009ab, and 2010ab), economic geology studies and reports (for example: Shklanka,1968; Vos et al., 1982; Storey, 1986; Berger, 1988; Parker, 1989; Gerow and Bellinger, 1990; Breaks, 1993; Farrow, 1996; Hinz et al., 1994; Blackburn and Hinz, 1996; and Vaillancourt et al., 2003), as well as Ontario Ministry of Northern Development and Mines Mineral Deposit Inventories and Assessment Files and publications by industry.

Resource development and ongoing exploration in the Ignace area is focused on minerals associated with the greenstone belts, regional shear zones and the contact halos with the surrounding plutonic rocks. The economic mineral potential is considered low within the core regions of the major felsic plutonic bodies in the Ignace area. Figure 5.1 shows the areas of active exploration interest based on active mining claims, as well as known mineral occurrences identified in the OGS's Mineral Deposit Inventory Version 2 (OGS, 2004).

5.1 Metallic Mineral Resources

Past production of metallic resources and exploration potential for different metals has been recognized in the Ignace area. The Ignace area is part of the Kenora Mining District, where mining history is closely related to the exploration for gold, which was produced in the past at a number of mines. Active mining claims as well as known mineral occurrences identified in the OGS's Mineral Deposit Inventory Version 2 (OGS, 2004) are shown on Figure 5.1.

Metallic mineralization occurrences in the Ignace area include: gold and Platinum Group Elements (PGE); copper-nickel and copper-zinc; iron formation, and rare metals and radioactive element-enriched pegmatites (Figure 5.1). There are currently no producing mines in the Ignace area.

Base Metals

Base metals include copper, nickel, lead, zinc, tungsten, molybdenum and cobalt, which are often found in characteristic associations: volcanogenic massive sulphide mineralizations dominated by Cu-Zn (with accessory gold) or by Cu-Zn-Pb (with accessory silver and minor gold); magmatic deposits dominated by Cu-Ni (often with accessory gold and PGE), and porphyry type deposits that may include one or more of Mo-Cu-Ag-W-Au in varying proportion.

In the Ignace area, the Raleigh and Bending Lake greenstone belts have the potential to host such base metal deposits. In the Bending Lake area, a large iron deposit is currently under development by the Bending Lake Iron Group Ltd., which has also identified five mineral showings (Cu, Zn or Au) related to volcanogenic massive sulphides (VMS) on the property (Stone, 2009a) (Figure 5.1). Base metal potential exists in the volcanic rocks elsewhere in the Bending Lake area, where a garnet-bearing alteration zone with characteristics typical of volcanogenic massive sulphide environments has been identified (Stone, 2010b). In the 1990s Noranda Ltd. carried out extensive exploration for base metals in the area (Stone, 2010b).

Base metals and molybdenum occurrences have been reported in the thin greenstone belts south of Agimak Lake and exploration efforts in the area continue today (Figure 5.1).

Gold

Gold exploration activities in the Ignace area date from the late 1800's and have continued sporadically to date, with most exploration efforts focusing on the Raleigh Lake and Bending Lake greenstone belts. A number of small gold mines operated during the late 1800s including the Hammond and Sawbill Mines in the Atikokan area, and the Sakoose and Tabor Mines within the current Ignace area. The Sakoose Mine, located 45 km northwest of the Township of Ignace, intermittently produced gold and associated base metals from 1899 to 1947 to a total depth of approximately 60 m. Gold was produced from a quartz vein system at a contact between a mafic volcanic and a metasedimentary rock, intruded by a felsic dyke. During this period, the mine produced a total of 3,669 ounces of gold, at an average grade of 0.41 ounces/ton (Titan Resources International Corporation, 2010).

In 1935, minor gold and silver production also occurred at the Tabor Lake Mine (45 km northwest of the Township of Ignace), which contains non NI 43-101 compliant indicated reserves of 50,000 tons at 0.50 ounces Au/ton (Norontex Exploration Ltd., 1983). These gold deposits are found in the metavolcanic rocks along the northwestern contact of the Revell batholith. Gold-bearing quartz veins here are controlled by northeast-trending shear and fracture zones associated with a major northeast-trending deformation zone that extends across Melgund Township (Parker, 1989). Exploration efforts have intensified in recent years and a 2008 drilling program by King's Bay Gold identified new gold zones below and to the east of the old Sakoose Mine. Exploration by companies, such as Titan Resources International and Laurentian Goldfields, continues along this mineralized shear zone in the greenstone belt.

As shown on Figure 5.1, numerous gold occurrences are present within the Raleigh and Bending Lake greenstone belts bordering the Revell batholith. Gold deposits are also associated with the main Finlayson-Marmion fault zone and associated splays. Gold potential is considered high within the Raleigh and Bending Lake greenstone belts and this environment continues to be the focus of exploration effort. In 2008, Amador Gold Corp. acquired eight exploration claims in the Revell and Hyndman Townships about 30 to 35 km northwest of the Township of Ignace, to assess the gold and base metal potential of the area (Amador Gold Corp., 2008). Greenschist alteration mineralized with gold is characteristic of the Marmion fault in the Atikokan area. In the Bonheur area, the extension of this same fault is a new exploration target for gold (Stone and Halle, 1999).

The exploration potential of the late granitic intrusions is considered low, although granite-hosted gold deposits are seeing increased exploration effort following the development of the large-tonnage granite-hosted Hammond Reef and Côté Lake gold deposits. While these large tonnage low-grade deposits are hosted within granitic intrusions, the mineralized zones are intensely fractured and silicified or brecciated (Golder, 2011b; Roscoe and Cook, 2012).

Iron

There is a long history of iron mining within the central part of the Wabigoon Subprovince. Past producers include the Atikokan Iron Mine and the Steep Rock and Caland Mines near Atikokan, which produced iron from 1944 to 1979.

The Bending Lake iron deposit, located within the Bending Lake greenstone belt to the west of the Revell batholith, is the largest undeveloped iron deposit in the central Wabigoon Subprovince area (Stone, 2010a). The deposit is composed of magnetite interbedded with chert with NI 43-101 compliant reserves of

245,000,000 tonnes with 25.08% recoverable iron (Thompson, 2008). Apart from the Bending Lake deposit, the potential for economically exploitable iron deposits is considered low within the Ignace area (Stone, 2010a).

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 (Stone, 2010a).

Rare metals mineralization has been reported in the pegmatitic dykes of the Raleigh Lake pegmatite field, 15 km west of the Township of Ignace (Pedersen, 1999). Previous exploration in the area by Breaks and Bond (1993) led to findings of spodumene and beryl. Abaddon Resources Inc. is currently actively exploring for lithium and rare metals pegmatite dykes in the volcanic rocks flanking the Raleigh Lake granite intrusion; where previous and current drilling work on the property has confirmed the existence and extension of the mineralization. Other companies, such as King's Bay Gold Corp. and Mainstream Minerals Corp., are also exploring pegmatite dykes in the Raleigh Lake area. Additionally, two-mica granite on the northeast side of the Revell batholith and the metasedimentary rocks at Balmoral Lake provide favourable environments for rare metals and REE mineralization (Stone et al., 1998).

Uranium

No economic deposits of uranium have been identified in the Ignace area.

Platinum Group Elements (PGE)

PGE have not been reported in the Ignace area in the literature to date. However, elevated copper, nickel and PGE are present in gabbros and diorites in the Entwine Lake area immediately beyond the southwest corner of the Ignace area. Here, a reef-like horizon known as the Campbell Zone is exposed at surface for approximately 1,200 m. Assays show consistent precious and base metal grades of 1 g/T Au+Pd+Pt and 0.5% Cu+Ni (McCracken and Karrei, 2011). Potential for similar mineralization exists within portions of the Entwine Lake intrusion that extends slightly into the Ignace area, and within lithologically similar phases of the Islet pluton, as well as the gabbroic phases of the Bending Lake greenstone belt in the Stormy Lake area.

5.2 Non-metallic Mineral Resources

Known non-metallic mineral resources in the Ignace area include sand and gravel, stone and peat as described below.

Sand, Stone and Gravel

Sand and gravel deposits exist in the northern portion of the Ignace area associated with reworked sediments of the Hartman moraine (Zoltai, 1965). Sand and gravel deposits have been locally exploited for construction of forest access roads in the Melgund Lake area (Berger, 1988) and similar potential exists elsewhere along the Hartman, Lac Seul and Eagle-Finlayson moraines as well as the coarser facies of Lake Aggasiz deposits (Figure 2.4).

The Indian Lake batholith has been the site of periodic extraction of ornamental stone at four quarries from 1888 until 1952. The Bannerman & Horne Quarry, the Gummeson deposit and the Horne Granite Quarries extracted granite along the Trans-Canada Highway within or near to the Township of Ignace. In the Bonheur area, 22 km southeast of the Township of Ignace, the Bonheur Quarry operated prior to 1932. In the Revell batholith, a small quarry of unknown history exists at the intersection of Highway 17 and Basket Lake Road. Potential was also recognized in the Twin River Road prospect, 55 km west of the Township of Ignace, but no production is known from it (Storey, 1986; Gerow and Bellinger, 1990; Hinz et al., 1994, and Farrow, 1996; Brisbin et al., 2005).

Peat

In 1984 the Proctor and Redfern Group Ltd., on behalf of the OGS, carried out an evaluation of a number of peatlands in the Ignace area. Some of the examined peatlands showed potential for supporting conventional peat operations, with peat quality excellent for horticultural applications. Despite the commercial potential of some of these deposits in the Ignace area, no peat extraction is known to have occurred (Proctor and Redfern Group Ltd., 1984).

Diamonds

No kimberlites or lamproites that could be diamond-bearing have been identified in the Ignace 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. An investigation of kimberlite indicator minerals (KIM) including pyrope garnet, eclogitic garnet, chrome diopside, ilmenite and chromite was carried out for the central Wabigoon area by Stone (2010a) who reports that results appear to indicate a low potential for diamonds compared to other areas of northern Ontario.

Industrial Minerals

No industrial mineral deposits have been identified within the Ignace area.

5.3 Petroleum Resources

The Township of Ignace is located in a crystalline rock geological setting where the potential for petroleum resources is negligible and where no hydrocarbon production or exploration activities are known to occur.

6.0 GEOMECHANICAL AND THERMAL PROPERTIES

Geomechanical information including intact rock properties, rock mass properties and *in situ* stresses 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 limited geomechanical information on the granitic intrusions in the Ignace area. Table 6.1 summarizes all available geomechanical information from the granitic intrusions in the Ignace area, and from sites elsewhere in the Canadian Shield with rock types similar to those of interest in the Ignace area. These sites are the Lac du Bonnet granite at AECL's Underground Research Laboratory (URL) in Manitoba and the Eye-Dashwa granite near Atikokan, Ontario. The majority of the geomechanical characterization work for the URL in Pinawa, Manitoba 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 basic 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, and *in situ* stress determination. Limited information on intact rock properties is available for the Indian Lake, Basket Lake and Revell batholiths, and no specific information is available for the White Otter Lake batholith and the minor plutons within the Ignace area. The felsic plutonic rocks of the Ignace area share a similar age, tectonic setting and mineralogical composition to the comparatively well-studied Lac du Bonnet batholith and Eye-Dashwa pluton. At this early stage of the site evaluation process, it is reasonable to assume that the geomechanical properties of intact rock in the Ignace area may resemble those of the Lac du Bonnet batholith and Eye-Dashwa pluton, and similar rock types elsewhere in the northwestern Superior Province. The rock property values presented in Table 6.1 are consistent with the values selected for numerical modeling studies conducted to evaluate the performance of hypothetical repository designs in a similar crystalline rock environment (SNC-Lavalin Nuclear Inc., 2011; Golder, 2012a, b).

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

Property	Lac du Bonnet Granite	Eye-Dashwa Granite	Indian Lake Batholith Granite	Revell Batholith Granite	Basket Lake Batholith Granite
Uniaxial Compressive Strength (MPa)	185 ± 24[b]	212 ± 26[c]	180[a]	NA	NA
Split Tension Strength (Brazilian) (MPa)	4 to 9[d]	NA	NA	NA	NA
Porosity (%)	0.35[b]	0.33[b]	NA	NA	NA
P-wave velocity (km/s)	NA	NA	NA	NA	NA

Property	Lac du Bonnet Granite	Eye-Dashwa Granite	Indian Lake Batholith Granite	Revell Batholith Granite	Basket Lake Batholith Granite
S-wave velocity (km/s)	NA	NA	NA	NA	NA
Density (Mg/m^3)	2.65[b]	2.65[b]	2.6[c]	2.6[c]	2.61[c]
Young's Modulus (GPa)	66.8[b]	73.9[b]	NA	NA	NA
Poisson's Ratio	0.27[b]	0.26[b]	NA	NA	NA
Thermal Conductivity (W/(mK))	3.4[b]	3.3[b]	NA	NA	NA
Coef. Thermal Expansion ($x10^{-6}/^{o}C$)	6.6[b]	15[b]	NA	NA	NA

NA = Not Available

[a]Brisbin et al., 2005
[b]Stone et al., 1989
[c]Szewcyk and West, 1976
[d]Annor et al., 1979

The limited data available for the Indian Lake and Revell batholiths (e.g., Brisbin et al., 2005; Farrow, 1996; and Storey, 1986) are indicative of high compressive strength (180 MPa), widely spaced near-surface joints and bulk densities in keeping with the generally granitic character of the rock. Site specific geotechnical assessments would need to be conducted during later stages of site evaluation process.

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 information available on rock mass properties of the granitic intrusions in the Ignace area is a brief description of joint orientation and spacing described from quarry exposures of the Indian Lake batholith (Storey, 1986; Hinz et al., 1994). This provides a general understanding of fractures likely to be encountered in the Ignace area.

In general, there will be a downward decreasing fracture density from highly fractured rocks in shallow horizons (ca. < 300 metres below ground surface) to sparsely fractured intact rock at greater depths as experienced at other Canadian 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 Canadian Shield sites (e.g., Everitt, 2002) and stress measurement data (e.g., Maloney et al. 2006), one could infer that a shallowly-dipping to sub-horizontal fracture set may exist as a result of either strain releasing 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.

Rock mass properties for the Ignace area would need to be determined at later stages of the assessment through the collection of site-specific information.

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.

No site-specific information is available regarding the *in situ* stress conditions within the Ignace area. The nearest *in situ* stress measurements were taken at the Campbell Mine (Superior Province/Uchi Sub-province) located approximately 230 km to the northwest of Ignace. The minimum principal stress data available from the Campbell Mine yields an average value of 8 MPa, dipping at an average angle of 46° at depths ranging from 580 m to 670 m. As a check, vertical *in situ* stresses may also be estimated using the unit weight of the rock measured on intact core specimens. Assuming a rock density of 2.8 Mg/m^3, and a corresponding unit weight of 27.5 kN/m^3, the approximate magnitude of the *in situ* vertical stress at a depth of 500 m at the Campbell Mine is 14 MPa.

Horizontal stress conditions are more difficult to estimate; however, 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). This data is presented on Figure 6.1. A review of the data available for the Campbell Mine area indicates that the maximum principal stress in that area is 34 MPa (on average) and oriented predominantly in the west-southwest direction. This is generally consistent with the World Stress Map. However, a significant number of measurements (4/11) indicated a maximum principal stress direction approximately 90° to the dominant trend.

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 southwest orientation for the maximum horizontal stress, which is consistent with the World Stress Map, although anomalous stress orientations have been identified 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). In addition, a roughly north-south orientation of maximum horizontal compressive stress was 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 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 a 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) (Zoback, 1992). 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 55-60 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 modelling activities. Due to wide scatter in the data (Figure 6.1), site-specific measurements would be needed to 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 Ignace area. The mineralogy of the Indian Lake, White Otter Lake, Revell and Basket Lake batholiths are described in Section 3.1.2. Available information indicates that the compositions of these batholiths range from granite to granodiorite to tonalite. The quartz mineral content of these rock types can range from approximately 20% to 60% by volume (Streckeisen, 1976). The range of measured thermal conductivity values for these 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] Fernández et al. 1986; [h]de Lima Gomes and Mannathal Hamza 2005; [i]Posiva 2007

Although no thermal conductivity values are available for the Ignace 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%. In addition, the Eye-Dashwa pluton has been described as being similar in age and composition to several plutons and batholiths in the nearby Ignace area (Schwerdtner et al, 1979; Stone, 1984). 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 is 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. However, actual values would need to be determined at later stages of the assessment.

7.0 POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE IGNACE AREA

7.1 Approach

The objective of the Phase 1 desktop geoscientific preliminary assessment is to assess whether the Ignace 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 location and extent of general potentially suitable areas would be refined during the second phase of the preliminary assessment through more detailed assessments and field evaluations.

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 x 550 m for the main buildings and about 100 x 100 m for the ventilation exhaust shaft (NWMO, 2013). 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 is assumed that the repository would require a footprint in the order of 2 x 3 km.

The geoscientific assessment of 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). 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, 2011a) were not considered. Such areas include the Raleigh Lake, Bending Lake and Phyllis Lake greenstone belts, which were considered not suitable due to their lithological heterogeneity, structural complexity and mineral potential. Plutons that are too small to be a viable host (such as the Norway and Paddy Lake plutons) were also not considered. Potentially suitable geological units in the Ignace area include the Indian Lake, Revell, White Otter Lake and Basket Lake batholiths, as well as their respective flanking tonalites, and the Islet pluton (Figure 3.4).

- ***Structural Geology:*** Areas within or immediately adjacent to regional faults and shear zones were not considered. This was applied to the Finlayson-Marmion fault zone that transects the Indian Lake batholith in the eastern sector of the Ignace area (Figure 3.4). The thickness of potentially suitable units was also considered when identifying potentially suitable areas. All of the large granitic intrusions in the Ignace area are estimated to have sufficient thickness for the purpose of siting a deep geological repository.

- ***Lineament Analysis:*** In the search for potentially suitable areas, there is a preference to select areas that have a relatively low density of lineaments, particularly a low density of longer lineaments, as they are more likely to extend to greater depth than shorter lineaments. For the purpose of this assessment, all interpreted lineaments (fractures and dykes) we 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 is an important site characteristic to consider when assessing amenability to site characterization of an area. For practical reasons, it is 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. Finland; Posiva, 2007). At this stage of the assessment preference was given to areas with greater mapped bedrock exposures. The extent of bedrock exposure in the Ignace area is shown on Figure 2.3. Areas mapped as bedrock terrain are assumed to be covered, at most, with a thin veneer of overburden and are therefore considered amenable to geological mapping.

- ***Protected Areas:*** All provincial parks, conservation reserves and provincial nature reserves in the Ignace area were excluded from consideration. The largest protected areas in the Ignace area include the Turtle River-White Otter Lake Provincial Park (368 km^2) and the Campus Lake Conservation Reserve (194 km^2), both overlying a significant portion of the White Otter Lake batholith (Figure 1.1). Other protected areas include the Sandbar Lake and East English River Provincial Parks and the Bonheur River Kame Provinvial Nature Reserve, which cover relatively small portions of the Indian Lake batholith.

- ***Natural Resources:*** The potential for natural resources in the Ignace area is shown on Figure 5.1. Areas with known potential for exploitable natural resources such as the rocks of the greenstone belts were excluded from further consideration. All granitic intrusions in the Ignace area have low potential for economically exploitable natural resources. At this stage of the assessment, areas of active mining claims located in geologic environments judged to have low mineral resource potential were not systematically excluded.

- ***Surface Constraints:*** Areas of obvious topographic constraints (density of steep slopes), large water bodies (wetlands, lakes), and accessibility were considered for the identification of potentially suitable areas. While areas with such constraints were not explicitly excluded at this stage of the assessment, they are considered less preferable, all other factors being equal. Distribution of large lakes in the Ignace area is variable (Figure 1.1). Certain portions of the Indian Lake, Basket Lake and White Otter Lake batholiths have extensive lake cover. Topography in the Ignace area is generally relatively flat, although considerable relief is observed between lakes in most areas (Figure 2.2). The majority of the Ignace area is accessible by existing logging roads, with the exception of some portions of the White Otter Lake batholith.

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the above key geoscientific characteristics revealed that the Ignace area contains general areas where there is a potential to find suitable sites for hosting a deep geological repository. These general areas are located within the Revell, Basket Lake, and Indian Lake batholiths. Figure 7.1 shows features illustrating some of the key geoscientific characteristics and constraints used to identify general potentially suitable areas, including: bedrock geology; protected areas; areas of thick overburden cover; surficial and geophysical lineaments, existing road network, the potential for natural resources and mining claims. Zoomed-in views of the Revell, Basket Lake and Indian Lake batholiths are shown on Figures 7.2 to 7.4. The legend of each figure includes a 2 km by 3 km box to illustrate the approximate extent of potentially suitable rock that would be needed to host a repository.

The following sections provide a summary of how the key geoscientific characteristics discussed above were applied to the various geological units within the Ignace area to assess whether they contain general potentially suitable areas. At this early stage of the assessment, the boundaries of these general areas are not yet defined. The location and extent of general potentially suitable areas would be further refined during subsequent site evaluation stages.

7.2.1 Revell Batholith

As discussed in Section 3.2.1, the Revell batholith is a multi-phase intrusion that was emplaced approximately 2.734 to 2.694 billion years ago. It extends for about 455 km^2 and has an estimated thickness of approximately 1.6 km. Detailed geologic mapping and interpretation of geophysical data identify a number of compositionally variable intrusive phases within the batholith, the youngest of which includes a distinct oval-shaped signature in the aeromagnetic data. There are no faults mapped within the Revell batholith, and there are only two dykes mapped in the northern part of the intrusion.

Most of the Revell batholith has extensive bedrock exposure, low potential for natural resources, is far from major regional geological features such as faults, shear zones and geological subprovince boundaries, and is free of protected areas and surface constraints (i.e., topography and large water bodies). Therefore, the main constraining factors used for finding potentially suitable areas within the Revell batholith were geology, structural geology and lineament density.

The north-central portion of the Revell batholith appears to have a number of favourable geoscientific characteristics for hosting a repository. It encompasses what is likely the youngest phase of the batholith, suggesting a shorter deformation history compared to the other phases within the intrusion. Also, the magnetic signature in the identified north-central portion of the batholith is relatively quiescent when compared to the southern half of the Revell batholith, where the magnetic pattern suggests the potential presence of metavolcanic contamination from the surrounding greenstone belts (PGW, 2013).

The potential of the Revell batholith to host mineral resources is considered low, and no active mining claims exist in the north-central portion of the intrusion. Land in the southern portion of the batholith was staked in 2011 for mining exploration purposes (MNDM, 2012), as shown on Figures 5.1 and 7.2. Since these claims are of short tenure and located in a geological environment judged to have low mineral resource potential, they were not considered to impact the potential suitability of the Revell batholith. However, while the batholith itself has very low potential for natural resources, it is fairly close to rock units with known mineral potential (i.e. the surrounding greenstone belts). It is likely that exploration claims over the southern portion of the intrusion are associated to exploration activities in the neighbouring greenstone belts.

Figures 3.9 and 7.2 show that geophysical lineament density over the Revell batholith is moderately high compared to other areas within the Ignace area, likely reflecting the uniformly higher resolution aeromagnetic data over the entire batholith. However, the spacing between shorter geophysical lineaments in the north-central portion of the Revell batholith is generally on the order of 2 to 3 km, suggesting a good potential for identifying suitable volumes of rock for siting a repository.

Figures 3.8 and 7.2 show that the surficial lineament density is generally moderate to high throughout the Revell batholith due to the extensive bedrock exposure, which makes surficial lineaments readily mappable. At the desktop stage of the assessment it is uncertain if surficial lineaments represent real bedrock structures and how far they extend to depth, particularly the shorter lineaments.

The distribution of lineament density as a function of lineament length over the Revell batholith 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 batholith as shorter lineaments are filtered out.

The north-central portion of the Revell batholith is predominantly Crown land (Figure 2.6), and is outside of protected areas. Access is good throughout the area via an extensive network of logging roads from either the Trans-Canada Highway or Highway 622 which transects the central portion of the batholith from northeast to southwest. The north-central portion of the batholith is well drained and of moderate relief with numerous granitic knobs and domes characterizing the terrain.

7.2.2 Basket Lake Batholith

As discussed in Section 3.2.1, the Basket Lake batholith is an approximately 420 km^2 granitic intrusion. Only about half of the batholith lies within the Ignace area. There is no direct information on the age of the Basket batholith, but Szewczyk and West (1976) suggest that it was emplaced before the White Otter and Indian Lake batholiths. Modelling of gravity data (Szewczyk and West, 1976) suggests a thickness of up to 8 km for the northern portion of the batholith, with a thinning of the intrusion towards its southeastern edge.

The portion of the Basket Lake batholith within the Ignace area appears to have a number of favourable geoscientific characteristics for hosting a repository (Figures 7.2 and 7.2). Approximately 60% of the bedrock in this area of the batholith is exposed, surface constraints are limited to a small number of relatively large lakes, and the area is free of protected areas. The Basket Lake batholith, including the portion identified in the Ignace area, lies away from major regional structures and shear zones, such as the Finlayson-Marmion and Wawasheimaga Lake faults (Figure 7.1).

Bedrock in the Basket Lake batholith is mapped as granite to granodiorite. Where there is low resolution magnetic data it was not possible to identify local-scale compositional variations within the intrusion. Interpretation of high resolution geophysical data, however, recognized potential lithology changes towards the southeastern tip of the intrusion. The lithological homogeneity of the area of the Basket Lake batholith identified as potentially suitable would need to be further assessed in futures stages of the evaluation.

The potential for mineral potential of the Basket Lake is considered low, and most of the southern portion of the intrusion lies away from areas with mineral resources potential (i.e. greenston belts). There are no mineral occurrences or active mining claims in the area of the Baket Lake batholith identified as potentially suitable.

Figures 3.9 and 7.3 show that geophysical lineament density over the Basket Lake batholith is moderate to low, except for the southeastern tip of the batholith, where high resolution geophysical data are available. It is possible that the geophysical lineament density interpreted for the area with high resolution data is representative of the entire batholith. Nonetheless, the spacing between shorter geophysical lineaments in the area with high resolution data is generally on the order of 1 to 3 km, suggesting that there is a potential for there to be sufficient volumes of structurally bounded rock at typical repository depth.

Figures 3.8 and 7.3 show a low density of surficial lineaments within this portion of the batholith despite the fairly good bedrock exposure. The apparent low density of surficial lineaments within the portion of the Basket Lake batholith in the Ignace area may reflect a genuine difference in brittle structure.

The distribution of lineament density as a function of lineament length over the Basket Lake batholith 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 batholith as shorter lineaments are filtered out. The portion of the batholith within the Ignace area exhibits low lineament density for all length classifications. The spacing between longer lineaments (i.e., those longer than 10 km) is typically on the order of 5 km.

The portion of the batholith within the Ignace area is Crown land, and is readily accessible via logging roads from the Trans-Canada Highway. Drainage is good throughout the area, and topography is generally favourable, although areas of rugged terrain exist locally in the southern portion of the Basket Lake batholith.

7.2.3 Indian Lake Batholith

The Indian Lake batholith is an approximately 2.671 billion years old, large granitic intrusion that extends for about 1,366 km^2 within the Ignace area. It has been interpreted to be up to approximately 2 km thick, although the batholith may thin towards its western margin. Detailed geological mapping available for portions of the Indian Lake batholith suggest that the majority of the intrusion is compositionally uniform. While the regional Finlayson-Marmion fault transects the Indian Lake batholith along its eastern margin, most of the intrusion lies away from this regional shear zone. This batholith is characterized by having low metallic mineral resource potential, and is mostly free of protected areas. Lithology within the intrusion is mapped as being fairly homogeneous and interpretation of geophysical data did not allow for the identification of distinct compositional variations. The the main differentiating factors for identifying potentially suitable areas within the Indian Lake batholith were bedrock exposure, surface constraints (i.e., topography and large water bodies), and lineament density.

There are two general areas in the Indian Lake batholith that appear to have a number of favourable geoscientific characteristics for hosting a repository. One of the areas is in the western edge of the batholith, west of Indian Lake. The other potentially suitable area is in the vicinity of Cecil Lake, northeast of the Township, between Sandbar Lake Provincial Park and Sowden Lake (Figures 7.1 and 7.4).

Bedrock in the western general area has fairly good exposure. Overburden cover in the north-eastern general area is more extensive, but bedrock outcrop is considered to be sufficient for site characterization activities. This, however, would need to be confirmed during subsequent site evaluation stages. These two potentially suitable areas include large lakes (e.g., Mameigwess Lake, Cecil Lake), but contain sufficient land to host the repository facilities and allow for site characterization activities (Figures 7.1 and 7.4).

Figures 3.8, 3.9 and 7.4 show that the density of geophysical lineaments is low throughout the Indian Lake batholith in general, including the two identified potentially suitable areas. The low density of geophysical lineaments, however, is presumably due in a large part to the low resolution of the available aeromagnetic data rather than the absence of brittle structures. It is possible that the actual lineament density in the Indian Lake batholith is similar to that observed in areas of high resolution aeromagnetic coverage in the Revell and Basket Lake batholiths, allowing the same conclusions to be drawn with regard to the potential of finding sufficient volumes of structurally favourable rock at typical repository depth.

The density of surficial lineaments is also low throughout the Indian Lake batholith (Figure 7.4). Such low density of surficial lineaments is likely due to the fairly large extent of overburden cover across the baholith. Added insight into the fracture characteristics at surface is provided by information from the Butler quarry, located just north of the Trans-Canada Highway west of the Township (Figures 5.1 and 7.4), where the rock has been described as sparsely fractured on the outcrop scale. This provides an additional indication that there is a potential for finding structurally favourable volumes of rock at depth within the Indian Lake batholith. This would have to be confirmed during subsequent stages of the site evaluation process.

The distribution of lineament density as a function of lineament length over the Indian Lake batholith 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 batholith as shorter lineaments are filtered out. The western and northeastern portions of the batholith are regions of the batholith that exhibit a combination of low lineament density and somewhat better bedrock exposure.

The metallic mineral potential of the Indian Lake batholith is considered low, and no active mining claims exist in the northeastern portion of the intrusion. As shown on Figures 5.1 and 7.4, part of the western portion of the batholith was staked in 2011 (MNDM, 2012) for mining exploration purposes. Since these claims are of short tenure and located in a geological environment judged to have low mineral resource potential, they were not considered to impact the potential suitability of the western portion of the Indian Lake batholith. It is worth mentioning, however, that while the batholith itself has very low potential for natural resources, its western portion is fairly close to rock units with known mineral potential (i.e. the surrounding greenstone belts).

The potentially suitable western and northeastern areas of the Indian Lake batholith are predominantly Crown land, with small areas of privately owned lands bordering the Trans-Canada Highway, as shown on Figure 2.5. They are free of protected areas, and are characterized by moderate to low relief and good access via a network of logging roads from the Trans-Canada Highway. Drainage is good over much of the areas.

7.2.4 Other Areas

No general potentially suitable areas were identified within the Islet pluton or the White Otter Lake batholith. The Islet pluton is characterized by moderate lineament density, active mining claims of long tenure, and extensive overburden cover, making it less desirable than areas within the Revell, Basket Lake and Indian Lake batholiths.

Much of the White Otter Lake batholith is covered by the Turtle River/White Otter Lake Provincial Park and the Campus Lake Conservation Reserve (Figure 7.1). The balance of the batholith has limited suitability for a potential repository because of extensive lake cover (especially in the south part of the batholith), poor access, rugged topography and high lineament density. A small area was identified as potentially suitable from a geological perspective between the Turtle River/White Otter Lake Provincial Park and the Campus Lake Conservation Reserve. However, the proximity of this area to protected lands is a concern for site access and site characterization activities.

Given the very large geographic extent of the Ignace area, it may be possible to identify other general potentially suitable areas. However, the four general areas identified in the Revell, Basket Lake and Indian Lake batholiths are those judged to best meet the preferred geoscientififc characteristics outlined in Section 7.1, based on available information.

7.2.5 Summary of Geoscientific Characteristics of the General Potentially Suitable Areas

Table 7.1 provides a summary of the key geoscientific characteristics of the potentially suitable general areas in the Revell, Basket Lake and Indian Lake batholiths in the Ignace area.

Table 7.1: Summary of Geoscientific Characteristics of the Potentially Suitable Areas in the Revell, Basket Lake and Indian Lake batholiths – Ignace

Geoscientific Descriptive Characteristic	General Area		
	Revell Batholith (north-central region)	**Basket Lake Batholith (south-eastern region)**	**Indian Lake Batholith (western and north-eastern regions)**
Rock Type	Granite to granodiorite	Predominantly granodiorite	Predominantly granodiorite
Age	ca. 2.694 billion years old for the youngest phase	Unknown but believed to be late (i.e., post volcanic, ca. 2.73-2.68 billion years old)	ca. 2.684 billion years old
Inferred host rock thickness	Approximately 1.6 km	6 to 12 km	1.5 to 2 km
Extent of rock unit within the Ignace area	Revell batholith: 455 km^2	Basket Lake batholith: 429 km^2	Indian Lake batholith: 1,366 km^2
Relative proximity to mapped geological features (fault zones, shear zones, geological sub-province boundaries, etc.)	Finlayson-Marmion fault-approx 70 km Northern fault – approx. 40 km Quetico fault – approx. 80 km Nearest mapped fault – approx. 10 - 20 km	Finlayson-Marmion fault-approx. 70 km Northern fault – approx. 30 km Quetico fault – approx. 100 km Nearest mapped fault – approx. 20 - 30 km	Finlayson-Marmion fault - approx 30 - 50 km Northern fault – approx. 50 - 60 km Quetico fault – approx. 80 km Nearest mapped fault – approx. 40 km
Structure: faults, foliation, dykes, joints	Moderate apparent surface lineament density Moderate apparent geophysical lineament density	Low apparent surface lineament density Low to high apparent geophysical lineament density	Low apparent surface lineament density Low apparent geophysical lineament density
Aeromagnetic characteristics and resolution	Moderately noisy to quiescent, high resolution	Moderately noisy, mostly low resolution except the very southeast corner of the batholith where resolution is high	Moderately noisy, low resolution
Terrain: topography, vegetation	Moderate relief	Moderate relief	Moderate to low relief
Access	Good access throughout via logging roads	Good access throughout via logging roads	Good access throughout via logging roads
Resource Potential	Low	Low	Low
Bedrock exposure	Generally high	Generally high to moderate	Generally moderate to low
Drainage	Generally good	Generally good	Generally good

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

This section provides a brief description of how the identified potentially suitable areas were evaluated to verify if 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?
- ***Long-term resilience to future geological processes and climate change*** Are the rock formations beneath the siting area adequate, such that they will not be substantially altered by natural geological disturbances and events such as earthquakes and climate change?
- ***Safe construction, operation and closure of the repository*** Are rock 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 natural resource exploration or extraction?
- ***Amenable to site characterization and data interpretation activities*** Can the geologic conditions that are important for demonstrating long-term safety at the site be practically studied and described?

The evaluation factors under each safety function are listed in Appendix A. At this early stage of the site evaluation process, where limited data at repository depth exist, the intent is to assess whether there are any obvious conditions within the identified potentially suitable areas that would fail to satisfy the safety functions.

An evaluation of the four general potentially suitable areas in the Ignace area in the Revell, Basket Lake and Indian Lake batholiths 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 information and the geophysical interpretation conducted as part of this preliminary assessment indicate that the estimated thicknesses of the Indian Lake, Revell and Basket Lake batholiths are between 0.5 and 8 km. Therefore, the rock in the four general areas identified in these batholiths (Section 7.2) is likely to extend well below typical repository depths (approximately 500 m), which would contribute to the isolation the repository from human activities and natural surface events.

Analysis of lineaments interpreted during this preliminary assessment (Section 3.2.3) indicates that the four general areas in the Ignace 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 strongly influenced by the amount of exposed bedrock and the resolution of available geophysical data. By classifying the lineaments according to length, this local bias is greatly reduced and the spacing between lineaments increases as shorter lineaments are filtered out. Longer lineaments are more likely to extend to greater depth than shorter lineaments. All four general areas exhibit lineament spacing between short brittle lineaments on the order of less than 0.5 km to 3 km, and spacing between longer lineaments (i.e., those longer than 10 km) on the order of 3 to 5 km. All four general potentially suitable areas are located away from regional faults within the Ignace area, such as the Finlayson-Marmion and the Washeibemaga Lake faults.

As discussed in Section 4.4, there is limited information on the hydrogeologic properties of the deep bedrock in the Ignace 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 four identified 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). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan 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 400-500 m. Also, experience from other areas in the Canadian Shield indicates that ancient faults, similar to those in the Ignace 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 in the Ignace area would need to be investigated at later stages of the site evaluation process.

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, the thermal and geomechanical properties of the rock is limited for the Ignace 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 granitic plutonic rocks characterizing the four general potentially suitable areas identified within the Ignace area (Sections 4 and 7.2). Site specific mineralogical and hydrogeochemical characteristics, including pH, eH and salinity, would need to be assessed during subsequent site evaluation stages. Similarly, it is expected that the geomechanical and thermal characteristics of the granitic intrusions within the Ignace area may resemble those of the Lac du Bonnet batholith and Eye-Dashwa pluton, and similar rock types elsewhere in the northwestern Superior Province (Section 6.0) with no obvious unfavourable conditions known at present. These characteristics would need to be assessed during subsequent site evaluation stages.

In summary, the review of available geoscientific information, including completion of a lineament analysis for the Ignace area, did not reveal any obvious conditions that would fail the four identified potentially suitable areas to satisfy the containment and isolation functions. Potential suitability of these areas would need to be further assessed during subsequent stages of the site evaluation process.

7.3.2 Long-term Resilience to Future Geological Processes 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 these processes 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 four general potentially suitable areas identified in the Ignace area. The remainder of this section provides a summary of the factors listed above.

The Ignace area is located in the Superior Province of the Canadian Shield, where large portions of land have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). Although a number of low magnitude seismic events have been recorded in the Ignace area over the past 25 years, there are no recorded earthquakes of magnitude greater than 3 occurring in the Ignace area (Section 3.3). As discussed in Sections 3.1 and 3.2, fault zones have been identified in the Ignace area including the regional Finlayson-Marmion fault zone and the Washeibemaga Lake fault; however, there is no evidence to suggest these faults have been tectonically active within the past billion years. The four identified general areas are far away from these fault zones.

The geology of the Ignace area is typical of many areas of the Canadian Shield, which has been subjected to numerous glacial cycles during the last million years. Glaciation is a significant past perturbation that could occur again in the future. 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 300 m shallow groundwater zone has 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 western Ontario. These various studies found that fractures below a depth of several hundred metres in the plutonic rock were ancient features. Subsequent geological processes such as plate movement and continental glaciation have typically caused reactivation of existing zones of weakness rather than the formation of large new zones of fractures.

Land in the Ignace area is still experiencing isostatic rebound following the end of the Winsonsinan glaciations (Section 3.3.2). 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. Lake level records (Mainville and Craymer, 2005) indicate that present day rebound rates in the Ignace 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 Ignace 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 potentially suitable areas in the Ignace area have the potential to satisfy the long-term stability function. The review did not identify any obvious conditions that would cause the performance of a repository to be substantially altered by future geological and climate change processes. The long-term stability of the Ignace area would need to be further assessed through detailed multidisciplinary site-specific geoscientific and climate change site investigations.

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 four general potentially suitable areas identified in the Ignace area. The areas are characterized by moderate topographic 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 potentially suitable geologic units in the Ignace area. However, there is abundant information at other locations of the Canadian Shield that could provide insight into what might be expected for the Ignace area in general. As discussed in Section 6, available information suggests that granitic and gneissic crystalline rocks 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, describes 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 area in the north-central portion of the Revell batholith has very good bedrock exposure, while the area in the southern portion of the Basket Lake batholith and the two areas in the Indian Lake batholith have more extensive overburden cover. Information on the measured thickness of overburden deposits within the Ignace area is limited to a small number of water well records mostly within the Township and to diamond drill holes concentrated in the greenstone belts. Overburden thickness is highly variable with variations of 10 to 15 m or more in drift thickness encountered within a ground distance of a kilometre or less (JDMA, 2013a). At this stage of the site evaluation process, it is not possible to accurately determine the thickness of the overburden deposits in these areas due to the low resolution of available data. However, it is anticipated that overburden cover is not a limiting factor in any of the identified general areasrepository..

In summary, the four identified general potentially suitable areas in the Ignace area have good potential to satisfy the safe construction, operation and closure function.

7.3.4 Isolation of Used Fuel from Future Human Activities

A suitable site must 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 formations 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 formations containing groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.

The mineral potential in the Ignace area is mainly limited to the greenstone belts and no known economic mineralization has been identified to date within the granitic batholiths in the Ignace area (Section 5). Active mining claims exist in the western portion of the Indian Lake batholith and south of the north-central portion of the Revell batholith. However, these claims are of short tenure and no related exploration activity has been reported in MNDM assessment files (MNDM, 2012).

The review of available information did not identify any groundwater resources at repository depth for the Ignace area. As discussed in Section 4.0, the MOE Water Well Records database shows that all water wells known in the Ignace area obtain water from overburden or shallow bedrock sources ranging from 4.5 to 154 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 (Singer and Cheng, 2002). MOE WWRs indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Ignace 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 the containment and isolation functions of a repository in the Ignace area to be disrupted by future human activities is low.

7.3.5 Amenability to Site Characterization and Data Interpretation Activities

In order to support the case for demonstrating long-term safety, the geoscientific conditions at a potential site must be predictable and 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.

As described in Section 3, the Indian Lake and Basket Lake batholiths are mapped as relatively homogeneous. Detailed mapping of the Revell batholith (Figure 3.4) and the interpretation of geophysical data (PGW, 2013) identified multiple intrusive phases within this instrusion. It is uncertain if multiple intrusive phases exist in the Basket Lake and Indian Lake batholiths, where there is limited detailed mapping and geophysical data is of lower resolution. However, at this stage of the assessment, such uncertainties are not expected to greatly affect site characterization.

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.), and the underlying resolution of the data used for the mapping. In the Ignace area, orientations of interpreted geophysical lineaments are fairly well defined (Figure 3.9), which facilitates the mapping and interpretation of these features. The degree of structural complexity associated with the orientation of lineament features in three dimensions would need to be further assessed through detailed site investigations in future phases of the site selection process.

The identification and field mapping of structures is strongly influenced by the extent of overburden cover and the presence of large water bodies. The four identified potentially suitable areas differ with respect to their amount of bedrock terrain (i.e., exposed bedrock outcrop or bedrock covered by a thin mantle of unconsolidated material). The north-central portion of the Revell batholith has excellent bedrock exposure. Overburden cover and large water bodies in the potentially suitable general areas within the Basket Lake and Indian Lake batholiths are more extensinve, but they contain sufficient areas with good bedrock exposure and limited surface water bodies to allow for surface bedrock mapping as part of detailed site characterization.

The four identified general potentially suitable areas in the Ignace area are all accessible using existing logging road networks, although some regions are more than 20 km from a main road, and have less extensive road networks.

In summary, the review of available information did not indicate any obvious conditions which would make the rock mass in the four identified general areas unusually difficult to characterize.

8.0 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

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

The preliminary geoscientific assessment built on the work previously conducted for the initial screening (Golder, 2011a) and focused on the Township of Ignace and its periphery, which are referred to as the "Ignace area" (Figure 1.1). 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. Where information for the Ignace area was limited or not available, the assessment drew on information and experience from other areas with similar geological settings on the Canadian Shield. The desktop geoscientific 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 desktop geoscientific preliminary assessment showed that the Ignace area contains at least four general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. Two of these areas are within the Indian Lake batholith. The two other areas are within the Revell and the Basket Lake batholiths, respectively.

The Revell, Basket Lake and Indian Lake batholiths hosting the four identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They are estimated to have sufficient depth and extend over large areas. The potentially suitable areas within these batholiths appear to be, for the most part, lithologically homogeneous and are far from major regional structural features such as faults, shear zones, and geological subprovince boundaries. All four areas have low potential for natural resources; are generally accessible; and are amenable to site characterisation.

While the Ignace area appears to contain general areas with favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. Main uncertainties include the low resolution of available geophysical data over most of the potentially suitable areas and significant overburden cover in some areas.

Interpreted lineaments suggest that the four identified general areas have the potential to contain structurally bounded rock volumes of sufficient size to host a deep geological repository. However, this would need to be confirmed during subsequent stages of the site evaluation process. Except for the Revell batholith, where good bedrock exposure and high resolution data is available, the moderately low geophysical and surficial lineament density observed in the other areas is likely due the low resolution of available geophysical data and the presence of significant overburden cover over certain areas.

Should the community of Ignace be selected by the NWMO to advance to Phase 2 study and remain interested in continuing with the site selection process, several years of progressively more detailed geoscientific studies would be required to confirm and demonstrate whether the Ignace area contains sites that can safely contain and isolate used nuclear fuel. This would include the acquisition and interpretation of higher resolution airborne geophysical surveys, detailed field geological mapping and the drilling of deep boreholes.

9.0 REFERENCES

Amador Gold Corp. 2008. Press release April 30, 2008.
URL: http://www.amadorgoldcorp.com/s/NewsReleases.asp?ReportID=298590&_Type= News-Releases& Title=Revell-and-Norberg-Properties-Acquired.

Annor, A., G. Larocque and P. Chernis, P. 1979. Uniaxial compression tests, Brazilian tensile tests and dilatational velocity measurements on rock specimens from Pinawa and Chalk River. CANMET Report No. MRP/MRL 79-60 (TR).

Arjang, B. and G. Herget, 1997. *In situ* ground stresses in the Canadian hardrock mines: An update. International Journal of Rock Mechanics and Mining Science Vol 34. Issue 3-4. pp. 15.e1-15.e16.

Baird, A. and S.D. McKinnon, 2007. Linking stress field deflection to basement structures in southern Ontario: results from numerical modeling, Tectonophysics 432, 89, 100, 2007.

Bajc, A.F., D.P. Schwert, B.G. Warner and N.E. Williams, 2000. A reconstruction of Moorhead and Emerson Phase environments along the eastern margin of glacial Lake Agassiz, Rainy River basin, northwestern Ontario, Canadian Journal of Earth Science 37: 1335–1353

Barnett, P.J., A.P. Henry and D. Babuin, 1991. Quaternary geology of Ontario, west-central sheet; Ontario Geological Survey, Map 2554, scale 1:1,000,000.

Barnett, P.J., 1992. Quaternary Geology of Ontario in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, pp.1010–1088.

Beakhouse, G.P., G.M. Stott, C.E. Blackburn, F.W. Breaks, J. Ayer, D. Stone and F. Corfu, 1996. Western Superior Province, Field Trip Guidebook A5/B6; Geological Association of Canada /Mineralogical Association of Canada Annual Meeting, Winnipeg, Manitoba, May 27-29, 1996.

Beakhouse, G.P., 2009. Western Wabigoon Subprovince Synthesis Project; in Summary of Field Work and Other Activities 2009, Ontario Geological Survey, Open File Report 6240, pp.12-1 to 12-6.

Beakhouse, G.P., J.L. Webb, D.R.B. Rainsford, D. Stone and S.D. Josey, 2011. Western Wabigoon GIS synthesis–2011, Ontario Geological Survey, Miscellaneous Release–Data 280.

Bell, M. and E.P. Laine, 1985. Erosion of the Laurentide region of North America by glacial and glaciofluvial processes. Quaternary Research 23, 154-175.

Berger, B.R., 1988. Geology of the Melgund Lake Area, District of Kenora; Ontario Geological Survey, Open File Report 5680, 184p., 24 figures, 10 tables, 9 photographs and maps P.3068, P.3069, and P.3070 in the back pocket.

Berger, B.R., D. MacMillan and G. Butler, 1987. Precambrian Geology of the Melgund Lake Area, Avery Township, Kenora District: Ontario Geological Survey, Map P.3070

Berman, R.G., M. Sanborn-Barrie, R.A. Stern and C.J. Carson, 2005. Tectonometamorphism at ca. 2.35 and 1.85 Ga in the Rae Domain, western Churchill Province, Nunavut, Canada: Insights from structural, metamorphic and *IN SITU* geochronological analysis of the southwestern Committee Bay Belt; The Canadian Mineralogist, v. 43, p. 409-442

Berman, R.G., R.M. Easton and L. Nadeau, 2000. A New Tectonometamorphic Map of the Canadian Shield: Introduction; The Canadian Mineralogist, v. 38, p. 277-285.

Bethune, K.M., H.H. Helmstaedt and V.J. McNicoll, 2006. Structural analysis of the Miniss River and related faults, western Superior Province: post-collisional displacement initiated at terrane boundaries; Can. J. Earth Sci. 43:p. 1031–1054

Blackburn, C.E. and P. Hinz, 1996. Gold and Base Metal Potential of the Northwest Part of the Raleigh Lake greenstone belt, Northwestern Ontario-Kenora Resident Geologist's District; in Summary of Field Work and Other Activities 1996, Ontario Geological Survey, Miscellaneous Paper 166, pp.113-115.

Blackburn, C.E., G.W. Johns, J.W. Ayer and D.W. Davis, 1991. Wabigoon Subprovince; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, pp. 303-382.

Bleeker, W. and B. Hall, 2007. The Slave Craton: Geology and metallogenic evolution; in Goodfellow, W.D., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 849-879.

Breaks, F.W., 1993. Granite-related mineralization in northwestern Ontario: 1. Raleigh Lake and Separation Rapids (English River) rare-element pegmatite fields; in Summary of Field Work and Other Activities 1993, Ontario Geological Survey, Miscellaneous Paper 162, p. 104-110.

Breaks, F.W. and W.D. Bond, 1993. The English River Subprovince-An Archean Gneiss Belt: Geology, Geochemistry and associated mineralization; Ontario Geological Survey, Open File Report 5846, v.1, pp.1-483, 884p.

Breaks, F.W. and J.R. Bartlett, 1991. Geology of the Eyapamikama Lake Area; Ontario Geological Survey, Open File Report 5792, 132p.

Brevic, E.C. and J.R. Reid, 1999. Uplift-based limits to the thickness of ice in the Lake Agassiz basin of North Dakota during the Late Wisconsinan; Geomorphology 32 2000. pp.161–169

Brisbin, W.C., G. Young and J. Young, 2005. Geology of the Parliament Buildings 5: Geology of the Manitoba Legislative Building; in Geoscience Canada, v. 32, numb 4, pp.177-193.

Brown, J.L., 2002. Neoarchean evolution of the western—central Wabigoon boundary zone, Brightsand Forest area, Ontario. Unpublished M.Sc. thesis, University of Ottawa, Ottawa.

Brown, P.A. and N.A.C. Rey, 1989. Statistical analysis of the geological-hydrogeological conditions within part of the Eye-Dashawa Pluton, Atikokan, northwestern Ontario. Can. J. Earth Sci. Vol. 26, p. 345-356.

Brown A., N.M. Soonawala, R.A. Everitt and D.C. Kamineni, 1989. Geology and geophysics of the Underground Research Laboratory Site, Lac du Bonnet batholith, Manitoba. Can. J. Earth Sci. 26, 404-425.

Brown, A., R.A. Everitt, C.D. Martin and C.C. Davison, 1995. Past and Future Fracturing In AECL Research Areas in the Superior Province of the Canadian Precambrian Shield, with Emphasis on The Lac Du Bonnet Batholith; Whiteshell Laboratories, Pinawa, Manitoba

Buse, S., D. Stone, D. Lewis, D. Davis and M.A. Hamilton, 2010. U/Pb Geochronology Results for the Atikokan Mineral Development Initiative; Ontario Geological Survey, Miscellaneous Release—Data 275.

Card, K.D. and A. Ciesielski, 1986. Subdivisions of the Superior Province of the Canadian Shield; Geoscience Canada, v.13, p.5-13.

Card, K.D., 1990. A review of the Superior Province of the Canadian Shield, a product of Archaean accretion; Precambrian Research, v.48, p.99-156.

Chandler, N., R. Guo and R. Read (Eds), 2004. Special issue: Rock Mechanics Results from the Underground Research Laboratory, Canada. International Journal of Rock Mechanics and Mining Science. Vol 41. Issue 8. pp. 1221-1458.

Clauser, C. and E.Huenges, 1995. Thermal conductivity of rocks and minerals. - In: Ahrens, T. J. (Eds.), Rock Physics & Phase Relations: A Handbook of Physical Constants, American Geophysical Union, 105-126.

Corrigan, D., A.G. Galley and S. Pehrsson, 2007. Tectonic evolution and metallogeny of the southwestern Trans-Hudson Orogen, in Goodfellow, W.D., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 881-902.

Corfu, F., G.M. Stott and F.W. Breaks, 1995. U-Pb geochronology and evolution of the English River Subprovince, an Archean low P – high T metasedimentary belt in the Superior Province; Tectonics, v.14, p.1220-1233.

Corfu, F. and D.W. Davis, 1992. A U/Pb geochronological framework for the western Superior Province, Ontario; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part II, p.1335-1348.

Davis, D.W., 1989. Final report for the Ontario Geological Survey on precise U–Pb age constraints on the tectonic evolution of the western Wabigoon subprovince, Superior Province, Ontario. Earth Science Department, Royal Ontario Museum, 30 pp.

de Lima Gomes, A. J. and V. Mannathal Hamza, 2005. Geothermal Gradient and Heat Flow in the State of Rio de Janeiro. Revista Brasileira de Geofísica 23, 325-347.

Dewdney, S. and K.E. Kidd, 1967. Indian Rock Paintings of the Great Lakes. Quetico Foundation series. 1967. University of Toronto Press

Dyke, A.S., A. Moore and L. Robertson, 2003. Deglaciation of North America, Geological Survey of Canada Open File 1574.

Easton, R.M., 2000a. Metamorphism of the Canadian Shield, Ontario, Canada. I. The Superior Province; The Canadian Mineralogist, v. 38, p. 287-317.

Easton, R.M., 2000b. Metamorphism of the Canadian Shield, Ontario, Canada. II. Proterozoic metamorphic history; The Canadian Mineralogist, v. 38, p. 319-344.

Easton, R. M., T. R. Hart, P. Hollings, Heaman, L.M., C. A. MacDonald, and M. Smyk, 2007. Further refinement of the timing of Mesoproterozoic magmatism, Lake Nipigon region, Ontario; Canadian Journal of Earth Sciences,v.44, p.1055-186.

Everitt, R., J. McMurry, A. Brown and C.C. Davison, 1996. Geology of the Lac du Bonnet Batholith, inside and out: AECL's Underground Research Laboratory, southeastern Manitoba. Field Excursion B-5: Guidebook. Geological Association of Canada — Mineralogical Association of Canada, Joint Annual Meeting, 30 May 1996, Winnipeg, Man. 72p.

Everitt, R.A., 1999. Experience gained from the geological characterisation of the Lac du Bonnet batholith, and comparison with other sparsely fractured granite batholiths in the Ontario portion of the Canadian Shield. OPG Report 06819-REP-01200-0069-R00. OPG. Toronto. Canada.

Everitt, R.A., 2002. Geological model of the Moderately Fractured Rock Experiment. OPG Report No. 06819-REP-01300-10048-R00.

Evans, B., 2008. High resolution aeromagnetic survey (HRAM) logistical report, Basket Lake Project, Ignace, Ontario, for Takara Resources Inc., part of assessment file number 2.40559.

Fahrig, W.F. and T.D. West, 1986. Diabase dike swarms of the Canadian Shield; Geological Survey of Canada, Map 1627A

Farrow, D.G., 1996. Potential dimension stone quarry sites in the Kenora, Ignace and Rainy River areas of Northwestern Ontario; Ontario Geological Survey, Open File Report 5949, 139p.

Farvolden, R. N., O. Pfannkuck, R. Pearson, P. Fritz, 1988. Region 12, Precambrian Shield in The Geology of North America, Vol 0-2, Hydrogeology. Geological Society of America Special Volume.

Fernández, M., E. Banda and E. Rojas, 1986. Heat pulse line-source method to determine thermal conductivity of consolidated rocks. Rev. Sci. Instrum., 57, 2832-2836.

Flint, R. 1947. Glacial Geology and the Pleistocene Epoch, J. Wiley and Sons, New York.

Fountain, D.M., M.H. Salisbury and K.P. Furlong, 1987. Heat production and thermal conductivity of rocks from the Pikwitonei - Sachigo continental cross section, Central Manitoba: Implications for the thermal structure of Archean crust, Can. J. Earth Sci., 24, 1583-1594.

Frape, S.K., P. Fritz and R.H. McNutt, 1984. Water–Rock Interaction and Chemistry of Groundwaters from the Canadian Shield. Geochimica et Cosmochimica Acta, Volume 48, pp. 1617–1627.

Fraser, J.A. and W.W. Heywood (editors), 1978. Metamorphism in the Canadian Shield; Geological Survey of Canada, Paper 78-10, 367p.

Fyon, J.A., F.W. Breaks, K.B. Heather, S.L. Jackson, T.L. Muir, G.M. Stott and P.C. Thurston, 1992. Metallogeny of metallic mineral deposits in the Superior Province of Ontario; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.1091-1176.

Gascoyne, M., C.C. Davison, J.D. Ross and R. Pearson, 1987. Saline groundwaters and brines in plutons in the Canadian Shield; In Saline water and gases in crystalline rocks, Editors: Fritz, P., and Frape, S.K.

Gascoyne, M., 1994. Isotopic and geochemical evidence for old groundwaters in a granite on the Canadian Shield. Mineralogical Magazine 58A, pp. 319-320.

Gascoyne, M., 2000. Hydrogeochemistry of the Whiteshell Research Area. Ontario Power Generation, Nuclear Waste Management Division Report, 06819-REP-01200-10033-R00. Toronto, Canada.

Gascoyne, M., 2004. Hydrogeochemistry, groundwater ages and sources of salts in a granitic batholith on the Canadian Shield, southeastern Manitoba. Applied Geochemistry, 19: pp. 519-560.

George Armstrong Co. Limited, 1981. Diamond drilling log, Hole No. 151, Claim No. 475281, South Greytrout Lake, Ontario. Ontario Geological Survey AFRI number 52F01 SE0697.

GeoBase, 2011a. Canadian Digital Elevation Data: http://www.geobase.ca/

GeoBase, 2011b. GeoBase Orthoimage 2005-2010: http://www.geobase.ca/

Gerow, M.C. and J.A. Bellinger, 1990. Northwestern Region Industrial Minerals Program — 1989; in Report of Activities 1989 Resident Geologists, Ontario Geological Survey, Miscellaneous Paper 147, pp. 161-180.

Golder (Golder Associates Ltd.), 2011a. Initial screening for siting a deep geological repository for Canada's used nuclear fuel. The Corporation of the Township of Ignace, Ontario. Nuclear Waste Management Organization, March 2011, 31p.

Golder (Golder Associates Ltd.), 2011b. Project Description, for the Hammond Reef Project, Technical Report 10-1118-0020, 86 p.

Golder (Golder Associates Ltd.), 2012a. Thermo-mechanical Analysis of a Single Level Repository for Used Nuclear Fuel. Prepared by Golder Associates Ltd. for the Nuclear Waste Management Organization. APM-REP-00440-0010.

Golder (Golder Associates Ltd.), 2012b. Thermo-mechanical Analysis of a Multi-Level Repository for Used Nuclear Fuel. Prepared by Golder Associates Ltd. for the Nuclear Waste Management Organization. APM-REP-00440-0019.

Gordon, R.G. and D.M. Jurdy, 1986. Cenozoic global plate motions, J. Geophys. Res., 91, 12,389–12,406.

Government of Ontario, 1997. Conserving a Future for our Past: Archaeology, Land Use Planning & Development in Ontario.

GSC (Geological Survey of Canada), 2012. Geoscience Data Repository for Geophysical and Geochemical Data, gdr.nrcan.gc.ca. (data accessed 2012)

Gupta, G., Erram, V., Kumar, S. 2012. Temporal geoelectric behavior of dyke aquifers in northern Deccan Volcanic Province, India. J. Earth Syst. Sci. 121, No. 3, June 2012, pp. 723-732.

Haimson, B.C., 1990. Stress measurements in the Sioux Falls quartzite and the state of stress in the Midcontinent; The 31st U.S. Symposium on Rock Mechanics (USRMS), June 18 - 20, 1990, Golden, Colorado.

Hajnal, Z., M.R. Stauffer, M.S. King, P.F. Wallis, H.F. Wang and L.E.A. Jones, 1983. Seismic characteristics of a Precambrian pluton and its adjacent rocks. Geophysics, Vol. 48, No. 5, p. 569-581.

Hallet, B., 2011, Glacial Erosion Assessment, NWMO DGR-TR-2011-18

Hanes, J.A. and D.A. Archibald, 1998. Post-orogenic tectonothermal history of the Archean western Superior Province of the Canadian Shield by conventional and laser Ar-Ar dating. Abstracts with programs - Geological Society of America, vol. 30(7), p.110-110.

Hay, W.W., C.A. Shaw and C.N. Wold. 1989. Mass-balanced paleogeographic reconstructions. Geologishce Rundschau 78.

Hayek S.J., J.A. Drysdale, J. Adams, V. Peci, S. Halchuk and P. Street, 2011. Seismic Activity in the Northern Ontario Portion of the Canadian Shield: Annual Progress Report for the Period January 01 – December 31, 2010, NWMO TR-2011-26.

Hayek, S., J.A. Drysdale, V. Peci, S. Halchuk, J. Adams and P. Street, 2009. Seismic Activity in the Northern Ontario Portion of the Canadian Shield: Progress Report for the Period of January 01 to December 31, 2008; NWMO TR-2009-05, 30 p.

Heaman, L.M. and R. M. Easton, 2006. Preliminary U-Pb geochronology results from the Lake Nipigon Region Geoscience Initiative; Ontario Geological Survey, Miscellaneous Release—Data 191

Herget, G., 1980. Regional stresses in the Canadian Shield. In Proceedings 13th Canadian Rock Mechanics Symposium, CIM 22, 9-16, Can. Inst. Min. and Metall.

Hinz, P., R.M. Landry and M.C. Gerow, 1994. Dimension stone occurrences and deposits in northwestern Ontario; Ontario Geological Survey, Open File Report 5890, 191p.

Holland, M. 2012. Evaluation of factors influencing transmissivity in fractured hard-rock aquifers of the Limpopo Province. Water SA Vol. 38 No. 3 International Conference on Groundwater Special Edition 2012.

JDMA (J.D. Mollard and Associates Ltd.), 2013a. Phase 1 Geoscientific Desktop Preliminary Assessment, Terrain and Remote Sensing Study, Township of Ignace, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0012.

JDMA (J.D. Mollard and Associates Ltd.), 2013b. Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Interpretation, Township of Ignace, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0014.

Jackson, S.L., 1985. Geology of the Lumby Lake area, western part, districts of Kenora and Rainy River; Ontario Geological Survey, Open File Report 5534, 178p.

Johnson, M.D., D.K. Armstrong, B.V. Sanford, P.G. Telford and M.A. Rutka, 1992. Paleozoic and Mesozoic Geology of Ontario in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, pp.1010–1088.

Jolly, W.T., 1978. Metamorphic history of the Archean Abitibi Belt; in Metamorphism in the Canadian Shield; Geological Survey of Canada, Paper 78-10, p.63-78.

Kaiser, P. K. and S. Maloney, 2005. Review Of Ground Stress Database For The Canadian Shield Report No: 06819-Rep-01300-10107-R00, December 2005

Kamineni, D.C. and D. Stone, 1983. The ages of fractures in the Eye–Dashwa pluton, Atikokan, Canada; Contributions to Mineralogy and Petrology, v.83, p.237-246.

Kamineni, D.C., D. Stone and Z. E. Peterman, 1990. Early Proterozoic deformation in the western Superior province, Canadian Shield, Geological Society of America Bulletin 1990;102;1623-1634

Karrow, P.F. and O.L. White, 2002. A history of neotectonic studies in Ontario, Tectonophysics 353, 3-15.

Kraus, J. and T. Menard, 1997. A thermal gradient at constant pressure: Implications for low- to medium-pressure metamorphism in a compressional tectonic setting, Flin Flon and Kisseynew domains, Trans-Hudson Orogen, Central Canada; The Canadian Mineralogist, v. 35, p. 1117-1136.

Laine, E.P. 1980. New evidence from beneath western North Atlantic for the depth of glacial erosion in Greenland and North America. Quaternary Research 14, 188–198.

Laine, E.P. 1982. Reply to Andrew's comment. Quaternary Research 17, 125–127.

LIO (Land Information Ontario), 2012. Ontario Ministry of Natural Resources. http://www.mnr.gov.on.ca/en/Business/LIO/. Accessed March 2012.

Larbi, Y., R. Stevenson, F. Breaks, N. Machado and C. billion years agoriépy, 1998. Age and isotopic composition of late Archean leucogranites: implications for continental collision in the western Superior Province. Canadian Journal of Earth Sciences 36, pp.495-510.

Ma, S., D.W. Eaton and J. Adams, 2008. Intraplate Seismicity of a Recently Deglaciated Shield Terrane: A Case Study from Northern Ontario, Canada. Bulletin of the Seismological Society of America, Vol. 98, No. 6, pp. 2828–2848, December 2008.

Mainville A. and M.R. Craymer, 2005. Present-day tilting of the Great Lakes region based on water level gauges. GSA Bulletin, V. 117, no. 7/8, p. 1070-1080, July/August 2005.

Maloney, S.M., P.K. Kaiser and A. Vorauer, 2006. A re-assessment of *in situ* stresses in the Canadian Shield. In Proceedings of the 41st US Rock Mechanics Symposium, 50 Years of Rock Mechanics

Martino, J.B., P.M. Thompson, N.A. Chandler and R.S. Read, 1997. The *in situ* stress program at AECL's Underground Research Laboratory, 15 years of research (1982-1997). Ontario Hydro Report No. 06819-REP-01200-0053 R00.

McFall, G.H., 1993. "Structural Elements and Neotectonics of Prince Edward County, Southern Ontario"; Géographie physique et Quaternaire, vol. 47, n° 3, 1993, pp. 303-312.

McMurry, J., D.A. Dixon, J.D. Garroni, B.M. Ikeda, S. Stroes-Gascoyne, P. Baumgartner and T.W. Melnyk, 2003. Evolution of a Canadian deep geologic repository: Base scenario. Ontario Power Generation, Nuclear Waste Management Division Report 06819-REP-01200-10092-R00. Toronto, Canada.

McCracken, T. and L. Karrei, 2011. Technical Report on the Eagle Rock Project, Northwestern Ontario, National Instrument 43-101 Report prepared by Wardrop-Teratech for Champion Bear Resources Ltd./Canadian Platinum Corp, 71p.

McWilliams, G.M., 1998. Operation Ignace–Armstrong, Mine Centre–Entwine Lake area, Geology of Area IV; Ontario Geological Survey, Open File Report 5979, 34p.

Menard, T. and T.M. Gordon, 1997. Metamorphic P-T paths from the Eastern Flin Flon Belt and Kisseynew Domain, Snow Lake, Manitoba; The Canadian Mineralogist, v. 35, p. 1093-1115.

Merrett, G.J. and P.A. Gillespie. 1983. Nuclear fuel waste disposal: Long-term stability analysis. Atomic Energy of Canada Limited Report, AECL-6820. Pinawa, Canada.

MNDM (Ontario Ministry of Northern Development and Mines), 2012. Mining Claims Inventory (CLAIMaps) Mining Lands Section: Ontario Mining Land Tenure Spatial Data, 2012: Accessed August, 2012

MOE (Ontario Ministry of the Environment), 2012. Water Well Information System (WWIS) – Well Record Data (accessed October, 2012).

Mollard, D.G. and J.D. Mollard, 1980. Northern Ontario Engineering Geology Terrain Study, Terrain Conditions for General Construction, Gulliver River, NTS 52G/SW. Ontario Geological Survey, Map 5067, Scale 1:100,000.

NRCan (Natural Resources Canada), 2012. Earthquakes Canada Website. http://earthquakescanada.nrcan.gc.ca Accessed April 26, 2012

Norontex Exploration Ltd., 1983. Update on the Sakoose — Melgund Claim Group, Kenora Mining District, NW Ontario. Ministry of Northern Development, Mines and Forestry AFRI file 52F09NW0012.

NWMO, 2013. Preliminary Assesment for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel - Township of Ignace, Ontario - Findings from Phase One Studies. NWMO Report Number APM-REP-06144-0009.

NWMO, 2010. Moving Forward Together: Process for Selecting a Site for Canada's Deep Geological Repository for Used Nuclear Fuel, Nuclear Waste Management Organization. (Available at www.nwmo.ca)

OGS (Ontario Geological Survey), 2004 [shapefile]. Ontario Geological Survey: Mineral Deposit Inventory Version 2 (MDI2), October 2004 Release; Ontario Geological Survey. ISBN 0-7794-7002-8: last accessed August 2012

OGS (Ontario Geological Survey), 2003, Sturgeon Lake-Savant Lake Area, Ontario airborne magnetic and electromagnetic surveys, processed data and derived products, Geophysical Dataset 1033 - Revised.

OGS (Ontario Geological Survey), 2009, Airborne geophysical time domain electromagnetic and magnetic survey, Lumby-Finlayson Lakes Area, Geophysical Dataset 1060.

OGS (Ontario Geological Survey), 2011a. 1:250 000 scale bedrock geology of Ontario, Miscellaneous Release Data 126 - Revision 1.

OGS (Ontario Geological Survey), 2011b, Ontario airborne geophysical surveys, magnetic and electromagnetic data, Stormy Lake area, Geophysical Dataset 1107 - Revision 1.

Ontario Parks, 2010. Provincial Park Profiles. http://www.ontarioparks.com/. Accessed May 2012.

Ontario Heritage Trust, 2012. http://www.heritagetrust.on.ca/Home.aspx. Accessed March 26, 2012.

Ophori, D.U. and T. Chan, 1996. Regional Groundwater Flow in the Atikokan Research Area: Model Development and Calibration. AECL-11081, COG-94-183

Osmani, I.A., 1991. Proterozoic mafic dyke swarms in the Superior Province of Ontario; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.661-681.

Parker, J.R., 1989. Geology, Gold Mineralization and Property Visits in the Area Investigated by the Dryden-Ignace Economic Geologist, 1984-1987; Ontario Geological Survey, Open File Report 5723, 306p.

Parks Canada, 2010. National Historic Sites. http://www.pc.gc.ca/progs/lhn-nhs/index.aspx. Accessed November 2, 2010.

Pease, V., J. Percival, H. Smithies, G. Stevens and M. Van Kranendonk, 2008. When did plate tectonics begin? Evidence from the orogenic record; in Condie, K.C. and Pease, V., eds., When Did Plate Tectonics Begin on Earth?; Geological Society of America Special Paper 440, p.199-228.

Pedersen, J.C., 1999. Report on 1999 Exploration Program, Raleigh Lake Property for Assessment, Raleigh Lake Area G-2557, Balmoral Area G-2530, Kenora Mining Division, Ontario. Avalon Resources Ltd.

Peltier, W.R., 2002. On eustatic sea level history: Last Glacial Maximum to Holocene: Quaternary Science Reviews 21 (2002) pp. 377–396

Percival, J.A. and R.M. Easton, 2007. Geology of the Canadian Shield in Ontario: an update. Ontario Power Generation, Report No. 06819-REP-01200-10158-R00.

Percival, J.A., 2004. Insights on Archean continent—ocean assembly, western Superior Province, from new structural, geochemical and geochronological observations: introduction and summary: Precambrian Research 132 (2004) 209–212

Percival, J.A., J.B Whalen, K.Y. Tomlinson, V. McNicoll and G.M. Stott, 2002. Geology and tectonostratigraphic assemblages, north central Wabigoon Subprovince, Ontario; Geological Survey of Canada, Open File 4270; Ontario Geological Survey, Preliminary Map P.3447, scale 1:250 000.

Percival, J.A., M. Sanborn-Barrie, T. Skulski, G.M. Stott, H. Helmstaedt and D.J. White, 2006. Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies; Canadian Journal of Earth Sciences, v.43, p.1085-1117.

Percival, J.A. and T. Skulski, 2000. Tectonothermal evolution of the northern Minto block, Superior Province, Québec, Canada; The Canadian Mineralogist, v. 38, p. 345-378

Peterman, Z.E. and W. Day, 1989. Early Proterozoic activity on faults in the western Superior Province—evidence from pseudotachylite; Geology, v.17, p.1089-1092.

Petrov, V.A., V.V. Poluektov, A.V. Zharikov, R.M. Nasimov, N.I. Diaur, V.A. Terentiev, A.A. Burmistrov, G.I. Petrunin, V.G. Popov, V.G. Sibgatulin, E.N. Lind, A.A. Grafchikov and V.M. Shmonov, 2005. Microstructure, filtration, elastic and thermal properties of granite rock samples: implications for HLW disposal. Geological Society, London, Special Publications, 240:237-253.

PGW (Patterson, Grant and Watson Ltd.), 2013. Phase 1 Geoscientific Desktop Preliminary Assessment, Processing and Interpretation of Geophysical Data, Township of Ignace, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0013.

Posiva, 2007. Olkiluoto Site Description 2006. Technical Report 2007-03 by Andersson, J., H. Ahokas, J.A. Hudson, L. Koskinen, A. Luukkonen, J. Löfman, V. Keto, P. Pitkänen, J. Mattila, A. T.K. Ikonen, M. Ylä-Mella.

Powell, W.G., D.M. Carmichael and C.J. Hodgson, 1993. Thermobarometry in a subgreenschist to greenschist transition in metabasites of the Abitibi greenstone belt, Superior Province, Canada; J. Metamorphic Geology, v.11, p.165-178.

Powell, W.G., Hodgson, C.J., Hanes, J.A., Carmichael, D.M., McBride, S. and Farrar, E. 1995. 40Ar/39Ar geochronological evidence for multiple postmetamorphic hydrothermal events focused along faults in the southern Abitibi greenstone belt; Can. J. Earth Sciences, v.32, p. 768-786.

Proctor and Redfern Group Ltd., 1984. Peat and Peatland Evaluation of the Ignace area, Volume I of VI, Ontario Geological Survey, Open File Report 5487, 209p.

Raven, K.G., D.J. Bottomley, R.A. Sweezey, J.A. Smedley and T.J. Ruttan, 1985. Hydrogeological Characterization of the East Bull Lake Research Area. National Hydrology Research Institute Paper No. 31, Inland Water Directorate Scientific Series No. 160, Environment Canada, Ottawa. ISBN 0-662-15782-6.

Rivard, C., H. Vigneault, A. Piggott, M. Larocque and François Anctil, 2009. Groundwater Recharge Trends in Canada. Can. J. Earth Sci. 46: 841–854

Rona, P.A., and E.S. Richardson, 1978. Early Cenozoic Global Plate Reorganization, Earth Planet. Sci. Letters, 40: 1-11, 1978.

Roscoe, W.E. and R.B. Cook, 2012. NI 43-101 Report on the Côté Lake Resource Update, Chester Property, prepared for Trelawney Mining and Exploration Inc., 137 p.

Ryan, M. P., Pierce, H. A., Johnson, C. D., Sutphin, D. M., Daniels, D. L., Smoot, J. P., Costain, J. K., Çoruh, C., and Harlow, G. E. 2007. Reconnaissance borehole geophysical, geological and hydrological data from the proposed hydrodynamic compartments of the Culpeper Basin in Loudoun, Prince William, Culpeper, Orange and Fairfax Counties, Virginia. [Version 1.0]: U.S. Geological Survey Open File Report 2006-1203.

SKB, 2007. Thermal properties Site descriptive modelling Forsmark – Stage 2.2; Technical Report R-07-47 by Back, P-E., J. Wrafter, J. Sundberg, and L. Rosén

SNC-Lavalin Nuclear Inc. 2011. APM Conceptual Design and Cost Estimate Update – Deep Geological Repository Design Report – Crystalline Rock Environment – Copper Used Fuel Container. Prepared by SNC-Lavalin Nuclear Inc. for the Nuclear Waste Management Organization. APM-REP-00440-0001.

Sage, R. P., F.W. Breaks, G.M. Stott, G.M. McWilliams and S. Atkinson, 1974. Operation Ignace-Armstrong, Ignace-Graham Sheet, Districts of Thunder Bay, Kenora, and Rainy River; Ontario Division of Mines, Preliminary Map P. 964.

Sage, R.P.,1998. Operation Ignace–Armstrong, Obonga–Lac des Iles area, geology of Area II: Part 2 – granites: granite-supracrustal relationships; Ontario Geological Survey, Open File Report 5978, Parts 1 and 2, 443p.

Sanborn-Barrie, M., 1991. Structural Geology and Tectonic History of the Eastern Lake of the Woods greenstone belt, Kenora District, Northwestern Ontario, Ontario Geological Survey Open File Report 5773, 137p.

Sanborn-Barrie, M., T. Skulski, J.A. Percival, J.B. Whalen, J.L. Brown and V. McNicoll, 2002. Geology and tectonostratigraphic assemblages, western Wabigoon Subprovince, Ontario; Ontario Geological Survey, Preliminary Map P.3446, scale 1:250 000.

Sanborn-Barrie, M. and T. Skulski, 2006. Sedimentary and structural evidence for 2.7 billion years ago continental arc-oceanic arc collision in the Savant–Sturgeon greenstone belt, western Superior Province, Canada; Canadian Journal of Earth Sciences, v.43, p.995-1030.

Satterly, J., 1960. Geology of the Dyment Area. Ontario Department of Mines, Volume LXIX, Part 6, 30p.

Sbar, M.L. and L.R. Sykes, 1973. Contemporary compressive stress and seismicity in eastern North America: An example of intra-plate tectonics: Geol. Soc. America Bull., v. 84, p. 1861-1882.

Schwerdtner, W.M., D. Stone, J. Osadetz, A. Morgan and G.M. Stott, 1978. Granitoid complexes and the Archean tectonic record in the southern part of northwestern Ontario; Can. J. Earth Sci., 16, 1965-1977

Schwerdtner, W.M., D. Stone, K. Osadetz, J. Morgan and G.M. Stott, 1979. Granitoid complexes and the Archean tectonic record of the southern part of northwestern Ontario; Can. J. Earth Sci., v.16, p.1965-1977.

Schwerdtner, W.M., J. Morgan and G.M. Stott, 1985. Contacts between greenstone belts and gneiss complexes within the Wabigoon Subprovince, northwestern Ontario; in Evolution of Archean supracrustal sequences, Geological Association of Canada, Special Paper 28, p.117-124.

Sella, G.F., S. Stein, T.H. Dixon, M. Craymer, T.S. James, S. Mazzotti and R.K. Dokka, 2007. Observation of glacial isostatic adjustment in “stable” North America with GPS, Geophys. Res. Lett., 34, L02306, doi:10.1029/2006GL027081.

Skulski, T., H. Sandeman, M. Sanborn-Barrie, T. MacHattie, D. Hyde, S. Johnstone, D. Panagapko and D. Byrne, 2002. Contrasting crustal domains in the Committee Bay belt, Walker Lake – Arrowsmith River area, central Nunavut; Geological Survey of Canada, Current Research 2002-C11, 11p.

Shackleton, N.J., A. Berger and W.R. Peltier, 1990. An alternative astronomical calibration of the lower Pleistocene timescale based on ODP Site 677: Transactions of the Royal Society of Edinburgh: Earth Sciences, 81, pp. 251-261

Shklanka, R., 1968. Iron deposits of Ontario; Ontario Department of Mines, Mineral Resources Circular 11, 489p.

Singer, S.N. and C.K. Cheng, 2002. An Assessment of the Groundwater Resources of Northern Ontario, Ontario Ministry of the Environment.

Smyk, D., 1990. Pottery, Projectile Points, and Pictographs: a Look at Ignace's Prehistory. In First Annual Archaeological Report, Ontario. Volume 1 (New Series). Ed. Peter Storck. Ontario Heritage Foundation, Toronto. p. 17.

Southwick, D.L. and H. Halls, 1987. Compositional characteristics of the Kenora-Kabetogama dike swarm (Early Proterozoic), Minnesota and Ontario; Canadian Journal of Earth Sciences, v.24, p.2197-2205.

Stevenson, D.R., E.T. Kozak, C.C. Davison, M. Gascoyne, R.A. Broadfoot, 1996. Hydrogeologic characterization of domains of sparsely fractured rock in the granitic Lac du Bonnet Batholith, Southeastern Manitoba, Canada. Atomic Energy of Canada Limited Report, AECL-11558, COG-96-117. Pinawa, Canada.

Stone, D., 1984. Sub-surface fracture maps predicted from borehole data: an example from the Eye–Dashwa pluton, Atikokan, Canada; International Journal of Rock Mechanics and Mining Science, v.21, p.183-194.

Stone, D., 2009a. The Central Wabigoon Area; Ontario Geological Survey, poster, Northwest Ontario Mines and Minerals Symposium, Thunder Bay, Ontario, April 7-8, 2009.

Stone, D., 2009b. Geology of the Bending Lake Area, Northwestern Ontario; in Summary of Field Work and Other Activities 2009, Ontario Geological Survey, Open File Report 6240, pp.14-1 to 14-7.

Stone, D., 2010a. Precambrian geology of the central Wabigoon Subprovince area, northwestern Ontario; Ontario Geological Survey, Open File Report 5422, 130p.

Stone, D., 2010b. Geology of the Stormy Lake Area, Northwestern Ontario, Project Unit 09-003 in Summary of Field Work and Other Activities 2010, Ontario Geological Survey, Open File Report 6260, p.13-1 to 13-12.

Stone, D., B. Hellebrandt and M. Lange, 2011a. Precambrian geology of the Bending Lake area (north sheet); Ontario Geological Survey, Preliminary Map P.3623, scale 1:20 000.

Stone, D., B. Hellebrandt and M. Lange, 2011b. Precambrian geology of the Bending Lake area (south sheet); Ontario Geological Survey, Preliminary Map P.3624, scale 1:20 000.

Stone, D., G. Paju and E. Smyk, 2011c. Precambrian geology of the Stormy Lake area; Ontario Geological Survey, Preliminary Map P.2515, scale 1:20 000.

Stone, D., D.C. Kamineni, A., A. Brown and R. Everitt, 1989. A Comparison of Fracture Styles in Two Granite Bodies of the Superior Province, Canadian Journal of Earth Science. 26. 387-403

Stone, D. and D.W. Davis, 2006. Revised Tectonic Domains of the South-Central Wabigoon Subprovince; in Summary of Field Work and Other Activities 2006, Ontario Geological Survey, Open File Report 6192, pp.11-1 to 11-18.

Stone, D. and J. Halle, 1999. Geology of the Entwine Lake and Bonheur areas, South-Central Wabigoon Subprovince; in Summary of Field Work and Other Activities 1999, Ontario Geological Survey, Open File Report 6000, pp.21-1 to 21-8.

Stone, D., J. Halle and E. Chaloux, 1998. Geology of the Ignace and Pekagoning Lake Areas, Central Wabigoon Subprovince; in Summary of Field Work and Other Activities 1998, Ontario Geological Survey, Miscellaneous Paper 169, pp.127-136.

Stone, D., J. Carter, J. Halle, B. Lennox and P. Pufahl, 2007a. Precambrian geology, White Otter Lake area; Ontario Geological Survey, Preliminary Map P. 3364-Revised, scale 1:50,000.

Stone, D., J. Halle, M. Lange, B. Hellebrandt and E. Chaloux, 2007b. Precambrian Geology, Ignace Area; Ontario Geological Survey, Preliminary Map P.3360—Revised, scale 1:50 000

Stone, D., D.W. Davis, M.A. Hamilton and A. Falcon, 2010. Interpretation of 2009 Geochronology in the Central Wabigoon Subprovince and Bending Lake Areas, Northwestern Ontario, Project Unit 09-003. Summary of Field Work and Other Activities 2010, Ontario Geological Survey, Open File Report 6260, p.14-1 to 14-13.

Storey, C.C., 1986. Building and Ornamental Stone Inventory in the Districts of Kenora and Rainy River; Ontario Geological Survey, Mineral Deposits Circular 27, 150p.

Stott, G.M., M. T. Corkery, J. A. Percival, M. Simard and J. Goutier, J. 2010. A revised terrane subdivision of the Superior Province; in Summary of Field Work and Other Activities 2010, Ontario Geological Survey, Open File Report 6260, p.20-1 to 20-10.

Streckeisen, A. L., 1976. Classification of the common igneous rocks by means of their chemical composition: a provisional attempt. Neues Jahrbuch fr Mineralogie, Monatshefte, 1976, H. 1, 1-15.

Sutcliffe, R.H, 1991. Proterozoic Geology of the Lake Superior Area; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, pp. 627-658

Svensson, U., and Rhén, I. 2010. Groundwater flow modelling of the excavation and operational phases – Laxemar. SKB R-09-23, December, 2010.

Szewcyk, Z., J. and G.F. West, 1976. Gravity study of an Archean granitic area northwest of Ignace, Ontario Canadian Journal of Earth Sciences 13, pp. 1119-1130

Tanton, T. L., 1938. Ignace sheet, southwest quarter, Kenora District, Ontario; Geological Survey of Canada, Paper 38-13, 13p.

Thompson, M., 2008. Bending Lake Property, National Instrument 43-101 Report by Fladgate Exploration Consulting Corporation for the Bending Lake Iron Group Limited, 51 p.

Thurston, P.C., 1991. Geology of Ontario: Introduction; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, pp. 3-25

Titan Resources International Corporation, 2010. www.titan-resource.com.

Tomlinson, K.Y., D.W. Davis, D. Stone and T.R. Hart, 2003. U-Pb age and Nd isotopic evidence for Archean terrane development and crustal recycling in the south-central Wabigoon Subprovince, Canada; Contributions to Mineralogy and Petrology, v.144, p.684-702.

Tomlinson, K.Y., G.M. Stott, J.A. Percival and D. Stone, 2004. Basement terrane correlations and crustal recycling in the western Superior Province: Nd isotopic character of granitoid and felsic volcanic rocks in the Wabigoon subprovince, N. Ontario, Canada; in Precambrian Research, v. 132, pp. 245-274.

Vaillancourt, C., R.A. Sproule, C.A. MacDonald and C.M. Lesher, 2003. Investigation of mafic–ultramafic intrusions in Ontario and implications for platinum group element mineralization: Operation Treasure Hunt; Ontario Geological Survey, Open File Report 6102, 335p.

von Bitter, R., 2010. Personal Communication on October 29, 2010 re: Archaeological Sites Database. Ministry of Tourism, Culture, and Sport.

Vos, M.A., T. Abolins and V. Smith, 1982. Industrial Minerals of Northern Ontario-Supplement I, Ontario Geological Survey Open File Report 5388, 344 p.

White, W.A. 1972. Deep erosion by continental ice sheets. Geological Society of America Bulletin 83, 1037-1056.

Woolverton, R.S., 1960. Geology of the Lumby Lake Area. Ontario Department of Mines, Volume LXIX, Part 6, 49p.

Zachariah, J.K., S. Balakrishnan and V. Rajamani, 1997. Significance of Sm-Nd systematic in crustal genesis: a case study of archean metabasalts of the eastern Dharwar Craton; Proceedings of the Indian Academy of Sciences (Earth Planet Sci.), 106, No. 4, pp. 361-367

Zoback, M.L., 1992. First- and second-order patterns of stress in the lithosphere: the world stress map project; Journal of Geophysical. Research., 97, 11,703-11,728.

Zoltai, S.C., 1965. Kenora-Rainy River, Surficial Geology, Map S165. Ontario Department of Lands and Forests.

Report Signature Page

GOLDER ASSOCIATES LTD.

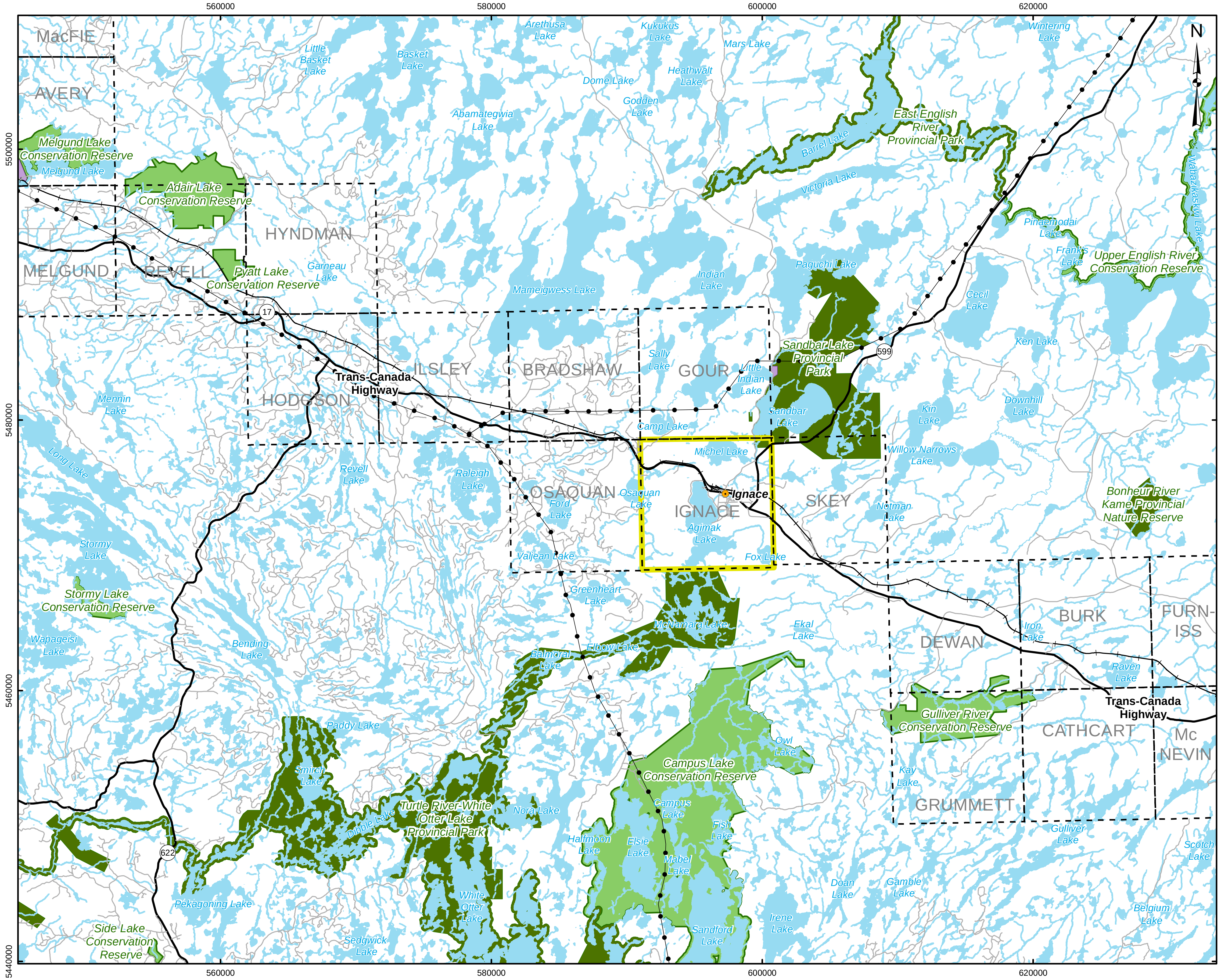
Charles Mitz, M.Eng., P.Geo.
Senior Geoscientist

George Schneider, M.Sc., P.Geo.
Senior Geoscientist, Principal

CWM/GWS/wlm

c:\gws-work\1 - active\12-1152-0026 nwmo feasibility gws files\3000 - ignace gws\16 final pdf main\apm-rep-06144-0011_12-1152-0026 3000 ignace_main_report_12nov2013_final.docx

FIGURES



LEGEND

- Municipal Boundary (Township of Ignace)
- Geographic Township
- Ignace
- Main Road
- Local Road
- Railway
- Transmission Line
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Forest Reserve
- Conservation Reserve
- Provincial Park

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

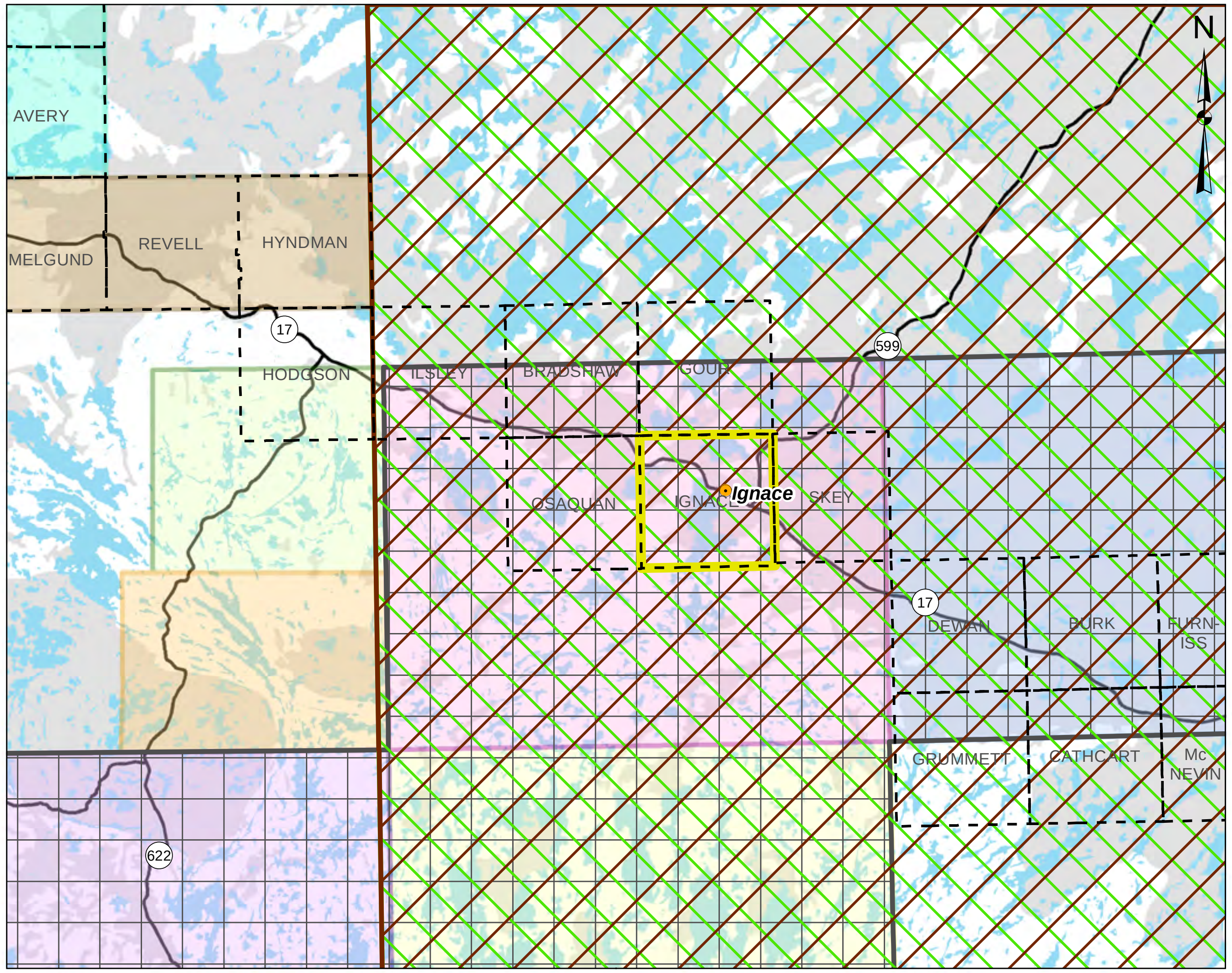
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Township of Ignace and Surrounding Area

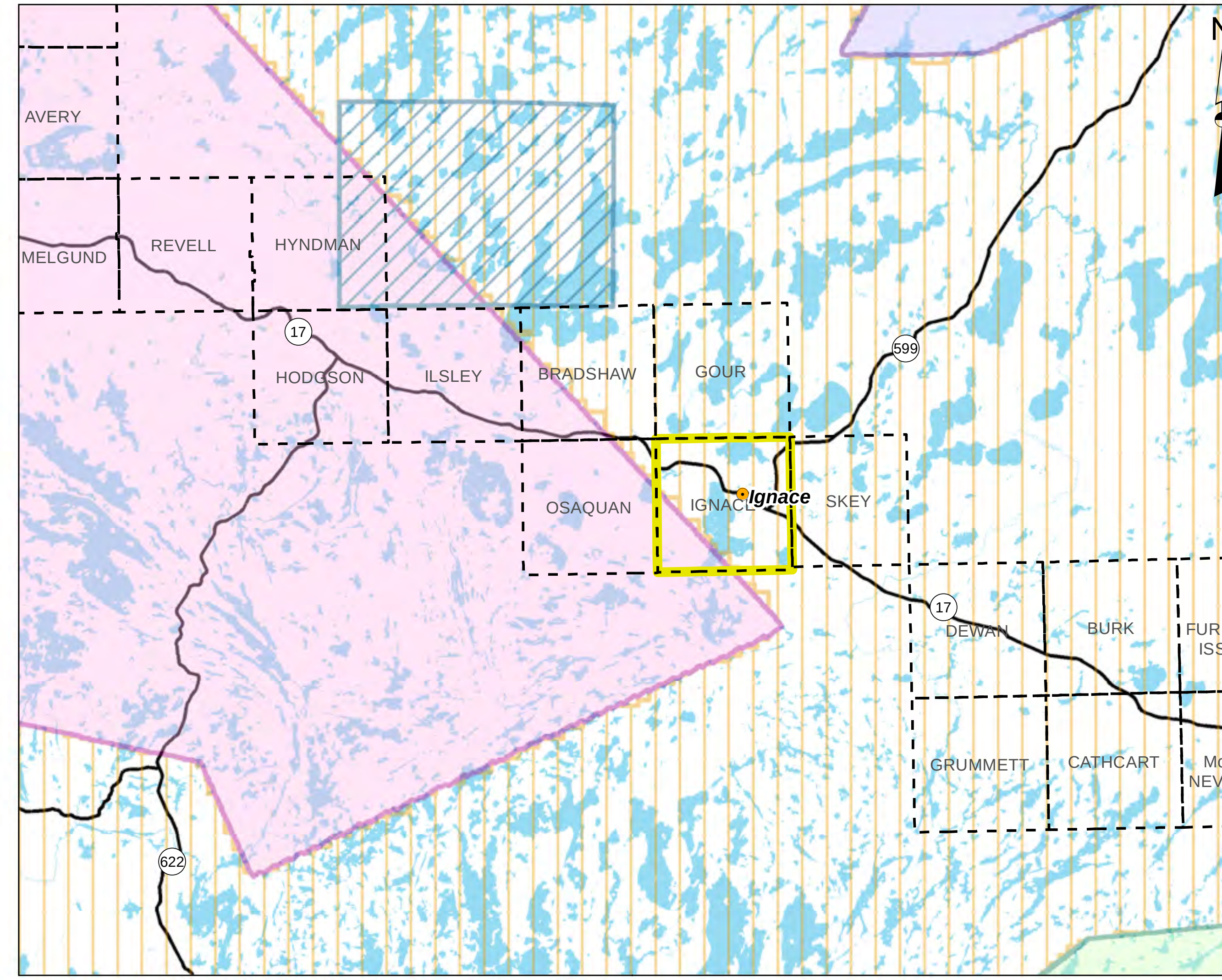
Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 1.1	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

Geology Mapping Coverage



Geophysics Mapping Coverage



LEGEND

- Ignace
- Main Road
- Water Area, Permanent
- Geographic Township
- Municipal Boundary (Township of Ignace)
- Overburden Cover

Detailed Geology Extent

- Satterly, 1960 (M1960H)
- Sage et al, 1974 (P.964)
- Berger et al, 1987 (P3068, P.3069, and P.3070)
- Stone 1998 (P3386)
- Stone et al. 2002 (P3448)
- Stone & Halle 2005 (P3401)
- Stone et al. 2007 (P3360)
- Stone et al. 2006 (P3364)
- Stone, D., 2010 (P2229)
- Stone 2011 (P3624)
- Stone 2011 (P3623)

Full Geology Coverage

Springer, 1978 (P1579)
OGS Quaternary Geology of Ontario (Data Set 14)
OGS Bedrock Geology of Ontario 2011 (MRD 126)

Full Geophysics Coverage

GSC Gravity 1946-1974
GSC Radiometric 1975, 1979, 1996

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

LEGEND

- Ignace
- Main Road
- Water Area, Permanent
- Geographic Township
- Municipal Boundary (Township of Ignace)

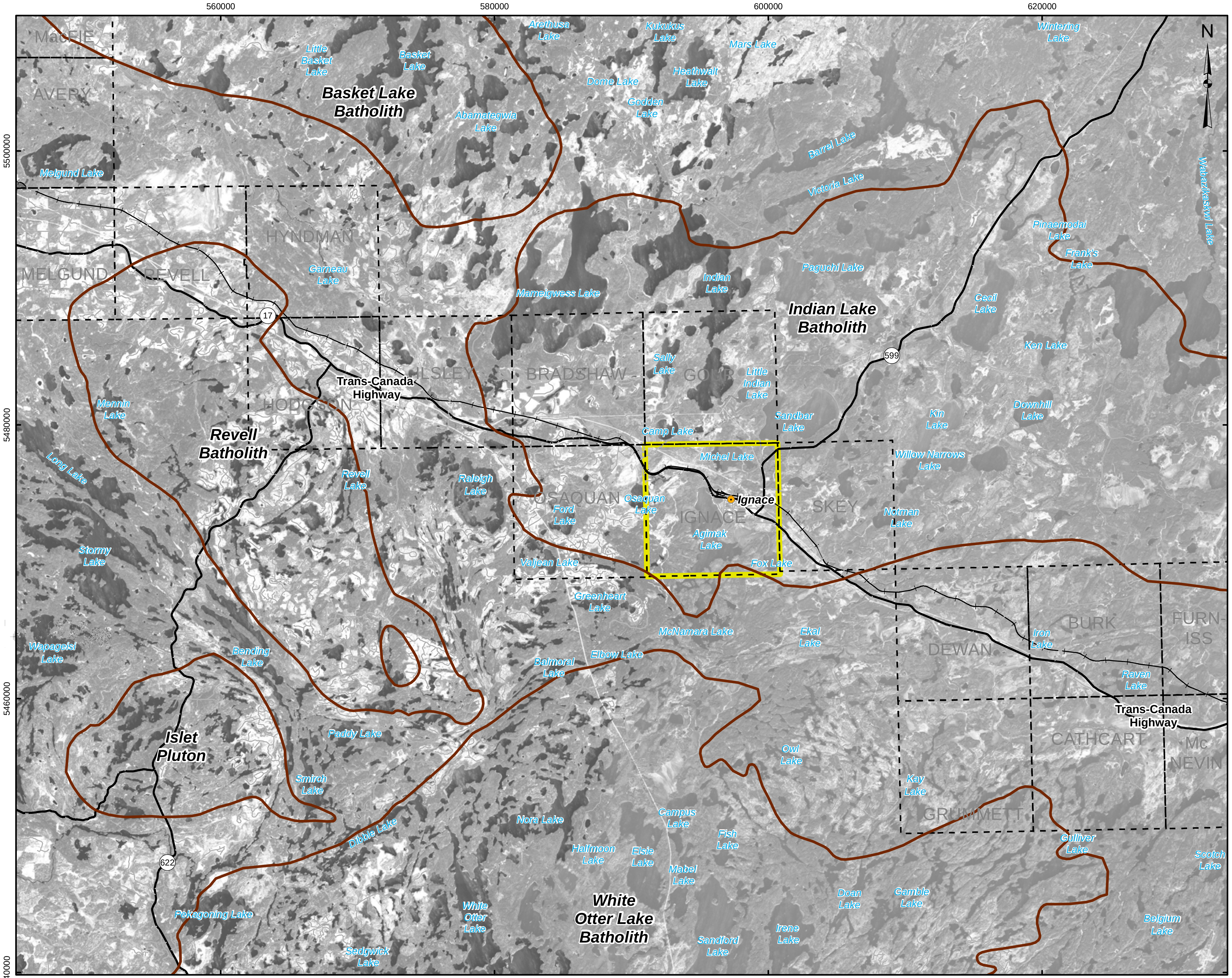
Geophysical Survey Extent

- Ontario #7 1965-1979
- Sturgeon Lake-Savant Lake 1990 (GDS1033)
- Stormy Lake 2001 (GDS1107)
- Lumby-Finlayson Lakes 2009 (GDS1060)
- Takara Resources (Assessment File No. 2.40559)

10 5 0 10 20 30
SCALE 1:500,000 KILOMETERS

PROJECT				
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY PHASE 1 DESKTOP STUDY				
TITLE: Geoscience Mapping and Geophysical Coverage of the Ignace Area				
Golder Associates, Mississauga, Ontario	PROJECT NO. 12-1152-0026		SCALE AS SHOWN	REV. 0.0
	DESIGN	PM	19 Oct. 2012	FIGURE: 1.2
	GIS	PM/JB	27 Aug. 2013	
	CHECK	CM	27 Aug. 2013	
	REVIEW	GWS	27 Aug. 2013	

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\GeoscienceMappingGeophysicalCoverageIgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Geographic Township
- Ignace
- Main Road
- Local Road
- Railway
- Outline of Major Batholith/Pluton

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Imagery - Spot 5, Obtained from Geobase (2006, 10m resolution)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

PROJECT

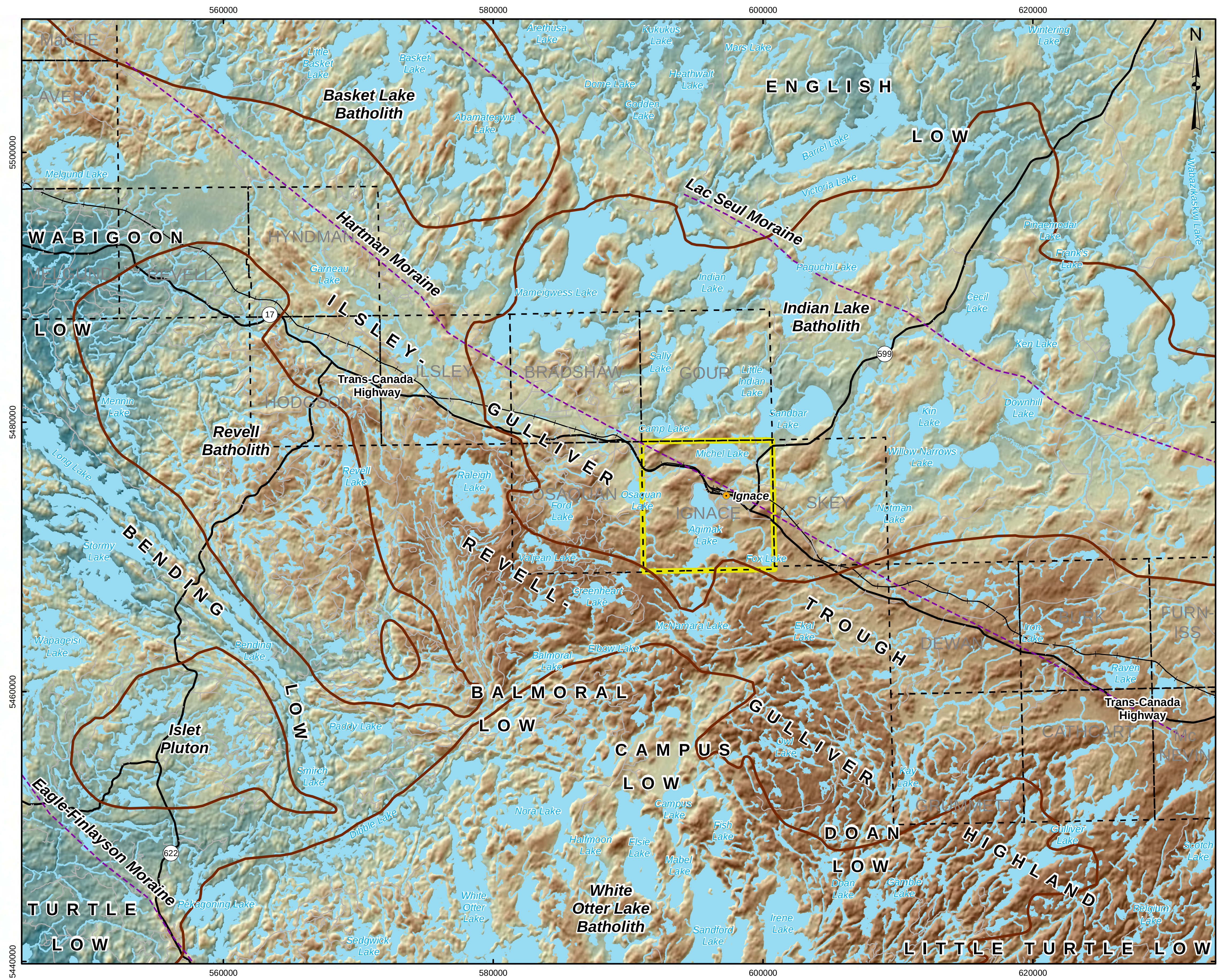
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Satellite Imagery of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 2.1	
GIS	PM/JB	12 Aug. 2013		
CHECK	CM	12 Aug. 2013		
REVIEW	GWS	12 Aug. 2013		



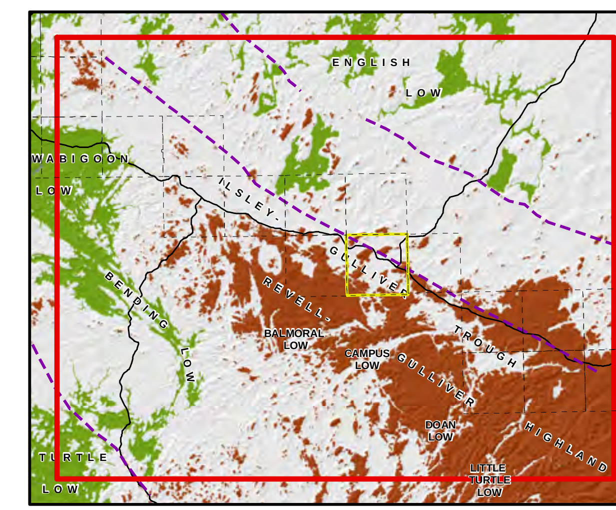
LEGEND

- Municipal Boundary (Township of Ignace)
- Geographic Township
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- End moraine
- Outline of Major Batholith/Pluton

Elevation (masl)

555
530
510
480
460
435
415
390
365

KEY TOPOGRAPHIC HIGHS AND LOWS



Elevation (m)

365 - 405 | 406 - 460 | 461 - 555

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Digital Elevation Model - CDED slope and elevation raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

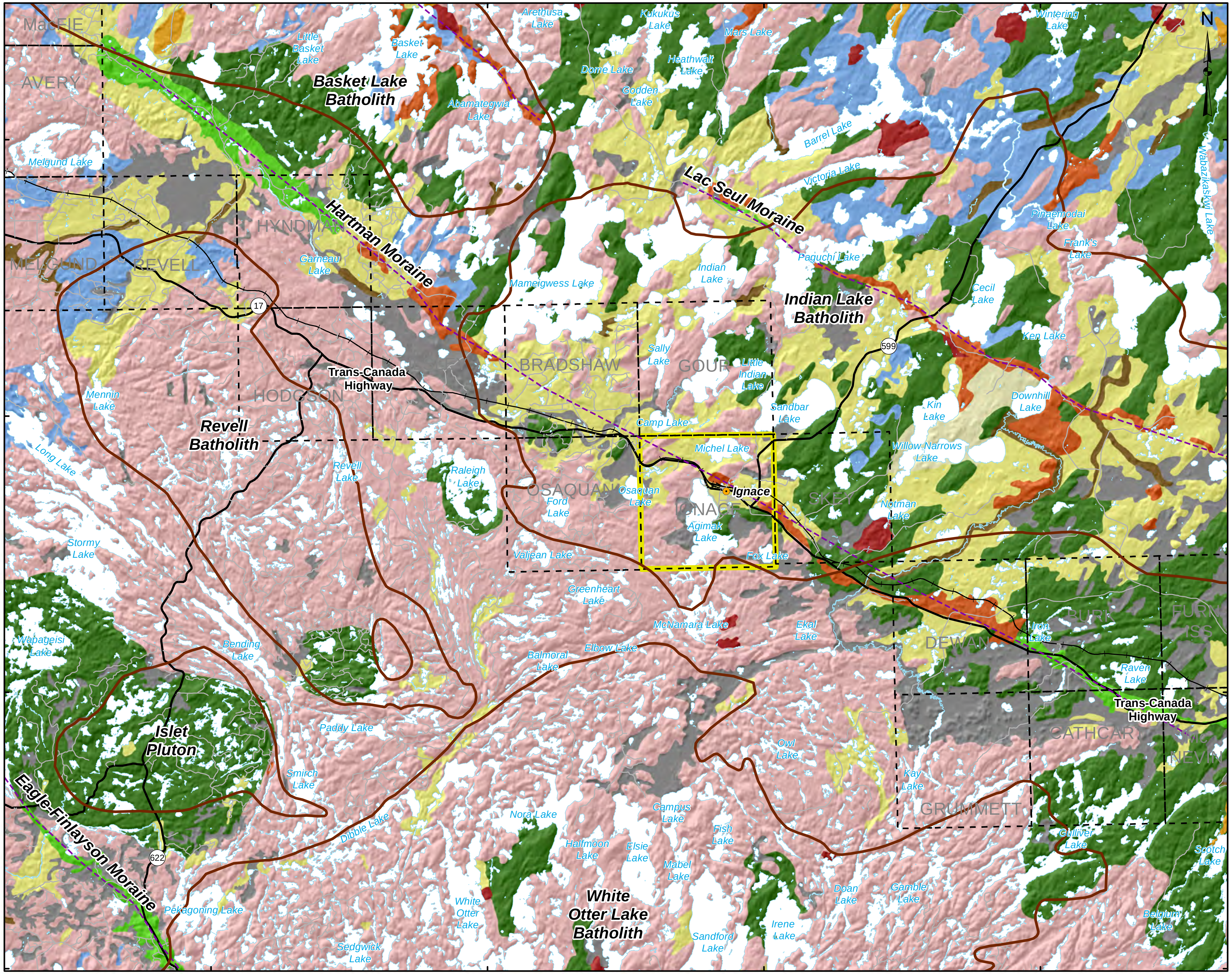
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Elevation and Major Topographic Features of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN / REV. 0.0
DESIGN	PM	17 May. 2012	
GIS	PM/JB	27 Aug. 2013	
CHECK	CM	27 Aug. 2013	
REVIEW	GWS	27 Aug. 2013	FIGURE: 2.2

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\ElevationMajorTopographicFeatures\IgnaceArea.mxd



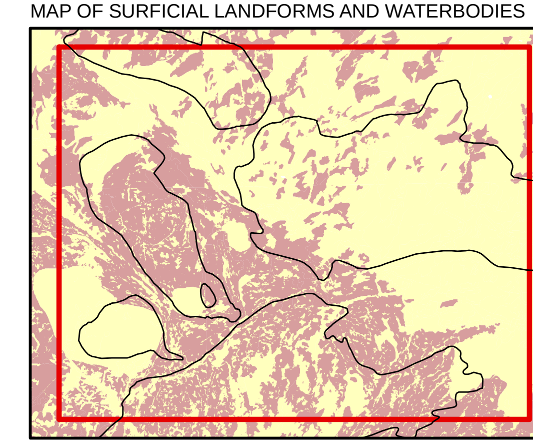
LEGEND

- Municipal Boundary (Township of Ignace)
- Geographic Township
- Ignace
- Main Road
- Local Road
- Railway
- Water Area, Permanent
- End moraine
- Outline of Major Batholith/Pluton

Landform

- Ground moraine
- End moraine
- Outwash
- Glaciolacustrine esker
- Kame
- Ice-contact delta
- Glaciolacustrine plain
- Alluvial plain
- Aeolian dune
- Organic terrain
- Bedrock terrain

MAP OF SURFICIAL LANDFORMS AND WATERBODIES



Batholith Surficial/water (62%) Bedrock terrain (38%)

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Landform - OGS, MND Mines, and Northeast Science and Information Section, MNR 2005
Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Geology - MRD126-Bedrock Geology of Ontario, 2011
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

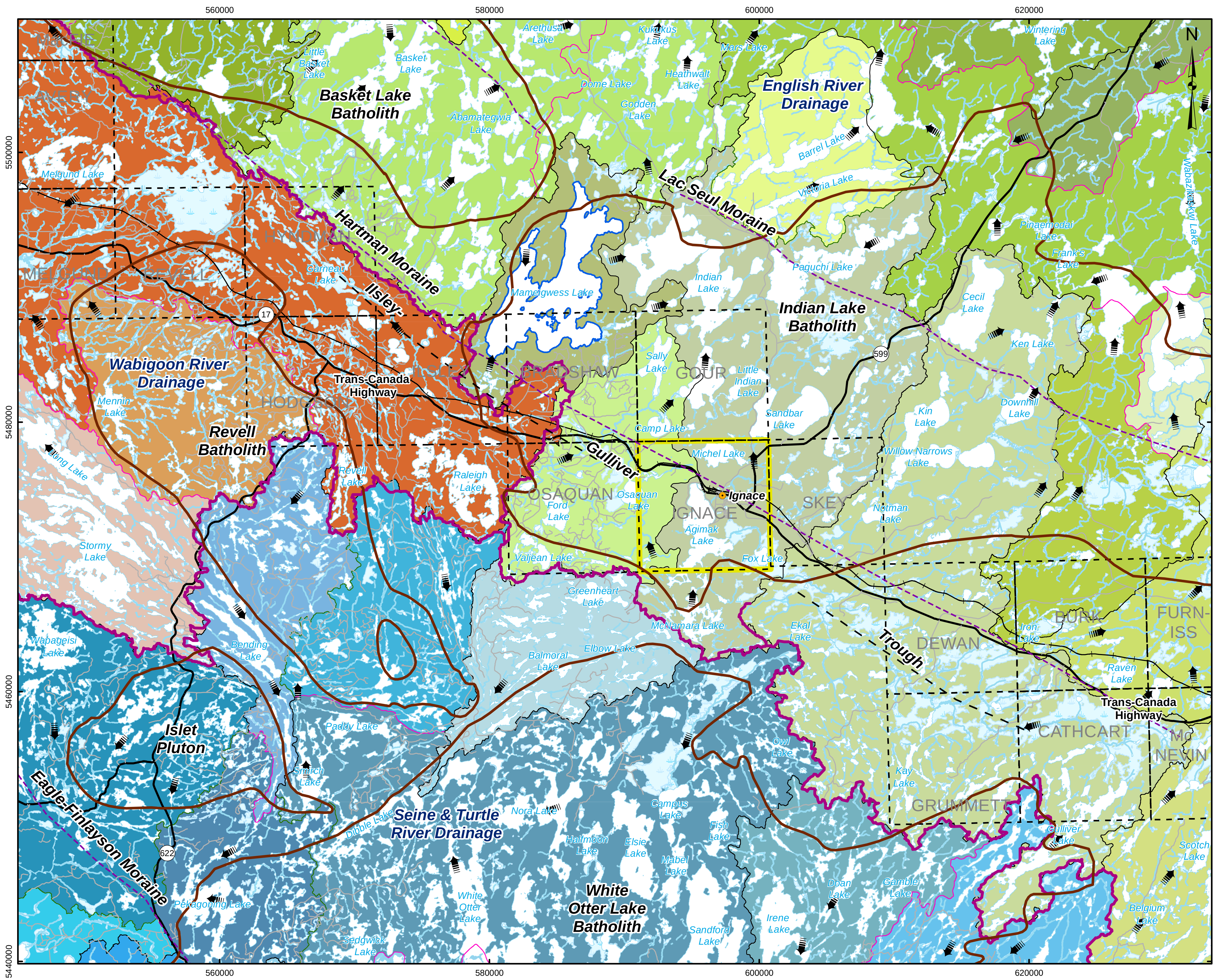
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Terrain Features of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 2.3	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\TerrainFeaturesIgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Geographic Township
- Ignace
- Main Road
- Local Road
- Railway
- Ilsley-Gulliver Trough
- End Moraine
- Outline of Major Batholith/Pluton
- Surface Water Flow Direction

Drainage Divide

- MNR/JDMA
- JDMA
- MNR
- Tertiary Watershed Boundary
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Wetland, Permanent
- Mameigwess Lake (Depth Survey shown in Inset Map)

MNR DEPTH SURVEY OF MAMEIGWESS LAKE

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Watershed - Terrain and Remote Sensing Study, Ignace area, Ontario (JDMA, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

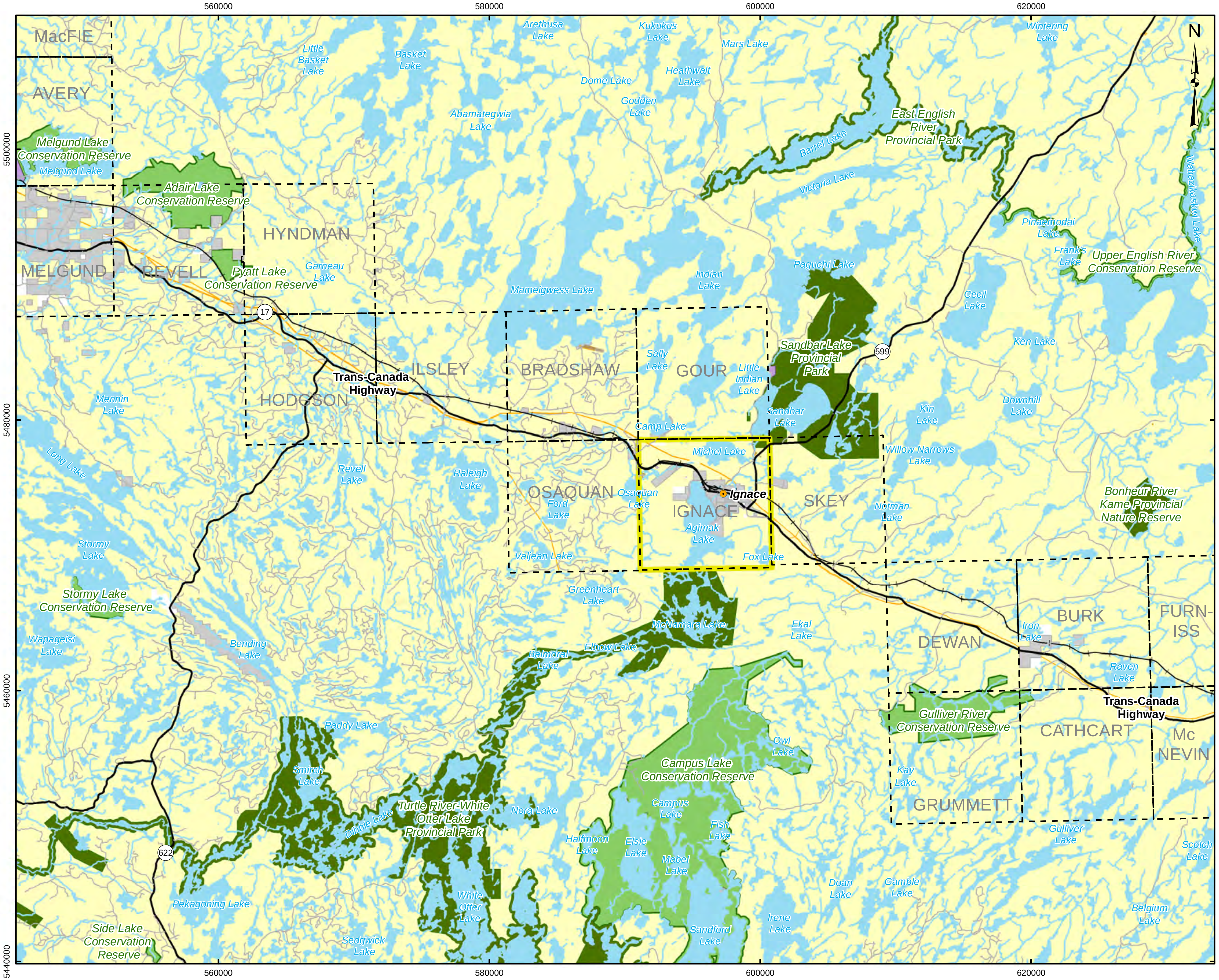
TITLE

Drainage Features of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012		
GIS	PM/JB	27 Aug. 2013	FIGURE: 2.4	
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\DrainageFeaturesIgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Geographic Township
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Forest Reserve
- Conservation Reserve
- Provincial Park
- Crown Leased Land
- Crown Land - Non-Freehold Dispositions Public
- Crown Land - Unpatented Public Land
- Private Land

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP V2006.4
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

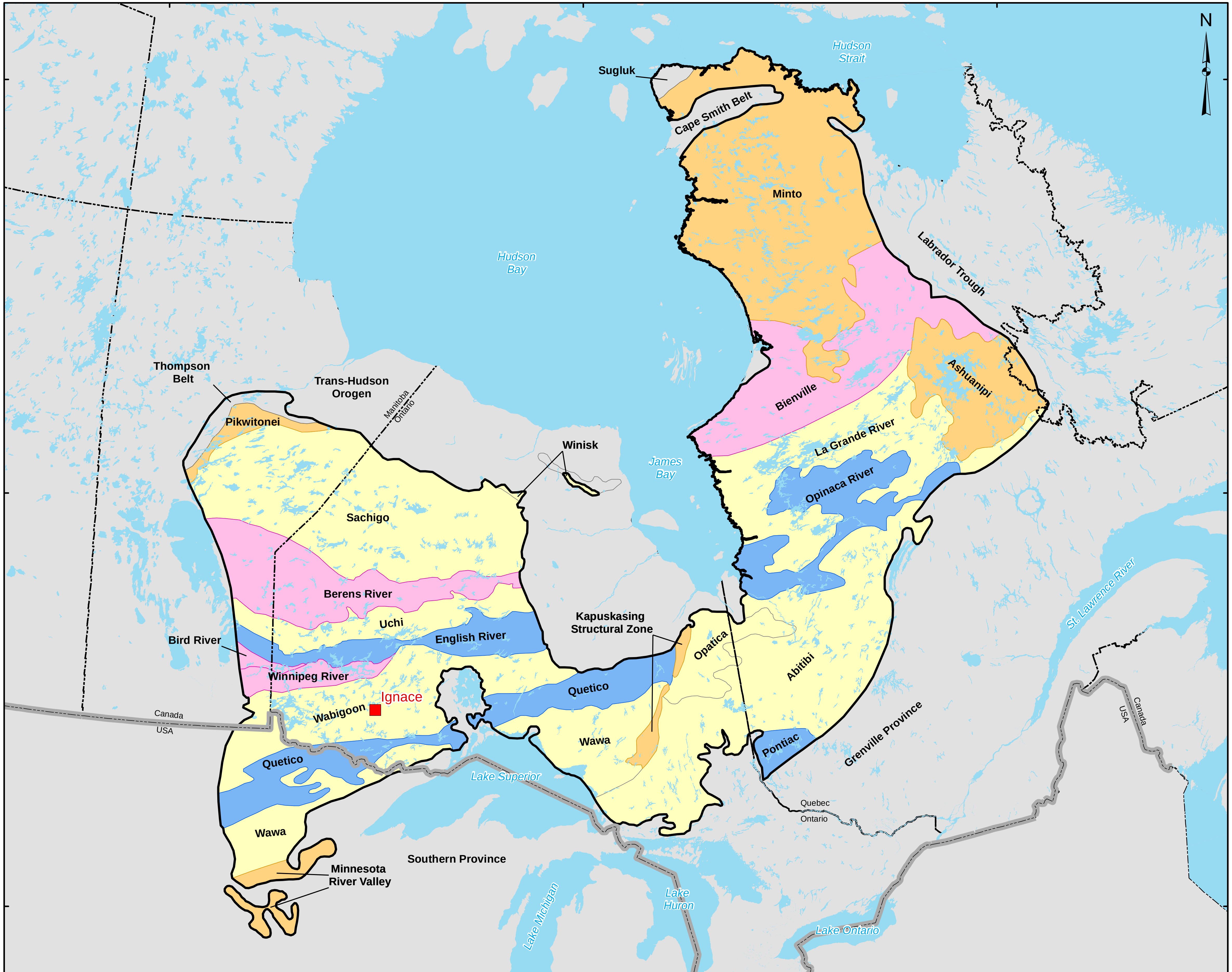
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Land Disposition and Ownership within the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT No. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 2.5	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_Phase1_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\LandDispositionOwnershipIgnaceArea.mxd

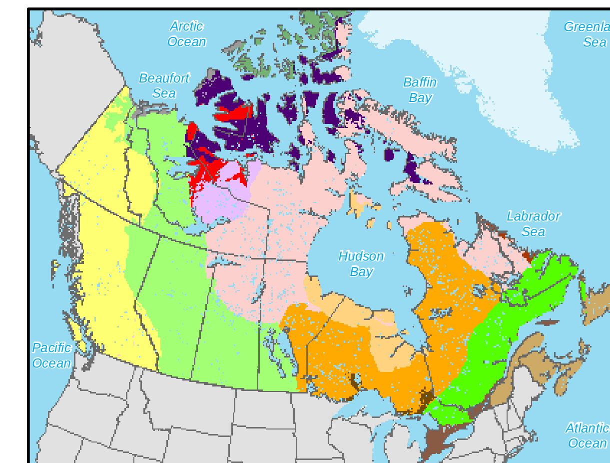


LEGEND

- Ignace
- 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	Cordilleran Orogen	Pacific Continental Shelf
Arctic Continental Shelf	Grenville Province	Slave Province
Arctic Platform	Hudson Bay Lowlands	Southern Province
Atlantic Continental Shelf	Innuitian Orogen	St. Lawrence Platform
Bear Province	Interior Platform	Superior Province
Churchill Province	Nain Province	Oceanic crust

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Physiographic Regions of Ontario - Thurston, P. C. 1991 Geology of Ontario: Introduction in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.26-57
Geology - Geological Map of Canada 1996, Map D1860A
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

200 100 0 200 400
SCALE 1:9,500,000 KILOMETRES

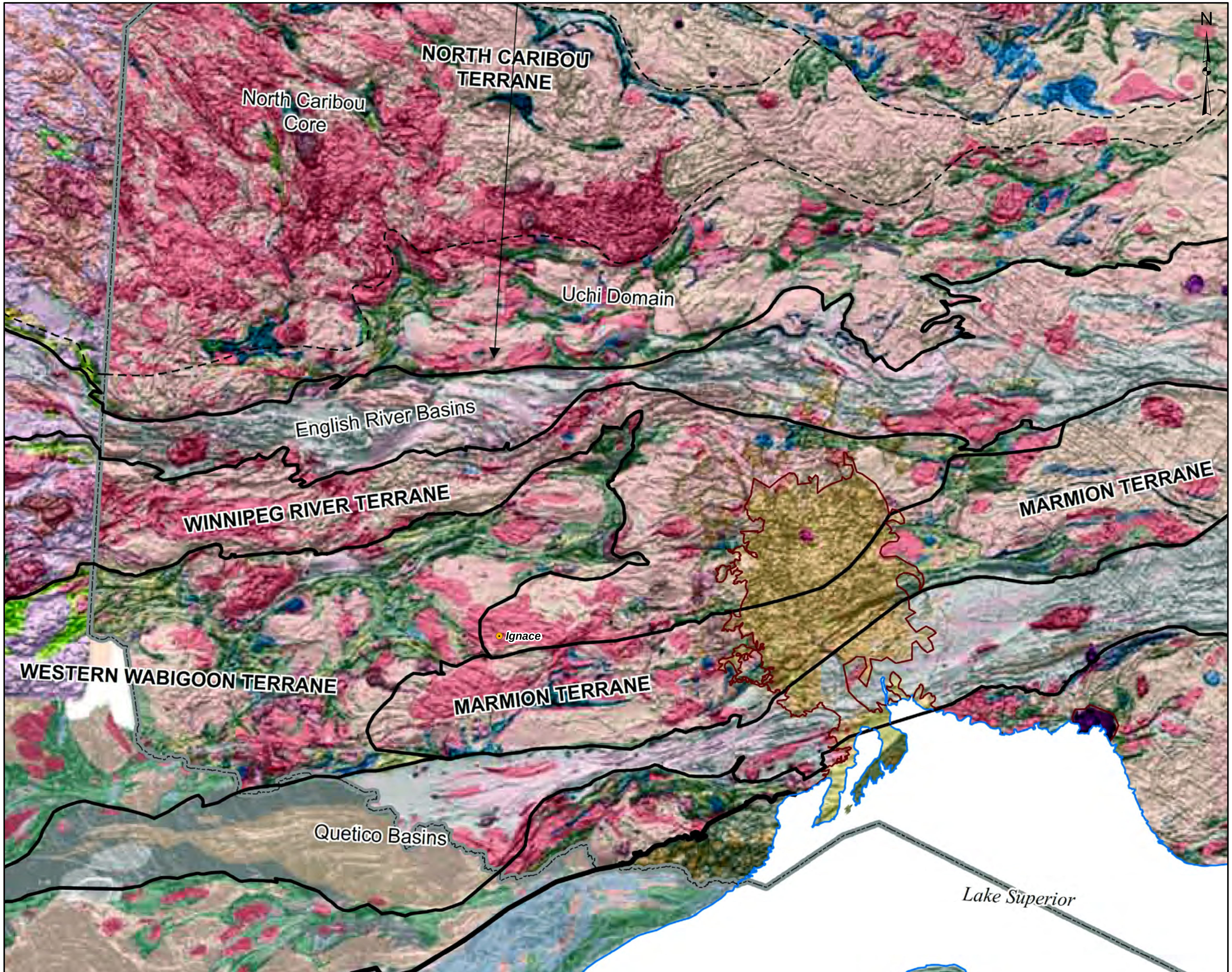
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Subdivision of the Superior Province of the Canadian Shield

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	27 May. 2012	FIGURE: 3.1	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_Phase1_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\SubdivisionSuperiorProvinceCanadianShield.mxd



LEGEND

- Ignace
- Provincial Boundary
- Domain Boundary
- Terrane Boundary
- Trans Hudson Orogen Extent

Bedrock Geology

- 31 Sibley Gp.
- 23 Mafic and related intrusive rocks
- 16 Hornblendite - nepheline syenite suite
- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 7 Metasedimentary rocks
- 7c Marble, chert, iron formation, minor metavolcanic rocks
- 7f Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 4 Mafic to ultramafic metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks
- 2 Felsic to intermediate metavolcanic rocks
- 1 Metasedimentary rocks and mafic to ultramafic metavolcanic rocks
- Nipigon Sills

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Stott, G., M.T. Corkery, J.A. Percival, M. Simard, J. Goutier 2010. A Revised Terrane Subdivision for the Superior Province; Ontario Geological Survey, poster, Northwest Ontario Mines and Minerals Symposium, December 07-09, 2010. Sudbury, Ontario, Canada
Geophysical underlay - Ontario #7, GSC, 800 m line spacing
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

50 25 0 50 100 150

SCALE 1:2,500,000 KILOMETRES

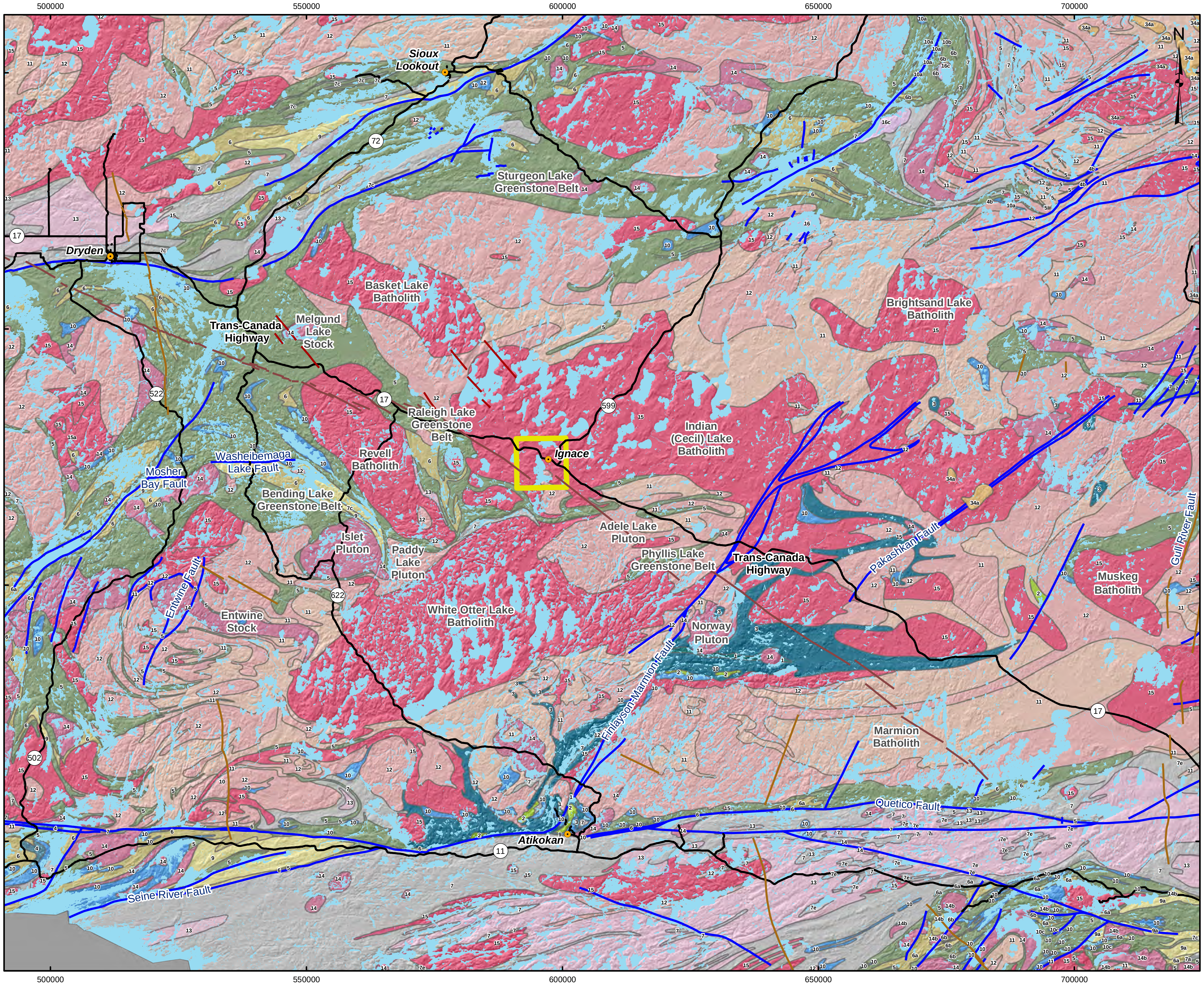
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Terrane Subdivision of the
Central Wabigoon Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	30 Apr. 2012	FIGURE: 3.2	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\TerraneSubdivisionCentralWabigoonArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Main Road
- Community
- Water Area, Permanent
- Mapped Fault

Mapped Dyke

- Kenora-Fort Frances Dyke
- Wabigoon Dyke
- Dyke (Other)

Bedrock Geology

- 34 Mafic and related intrusive rocks (Keweenawan age)
- 31 Sibley Gp.
- 24 Sedimentary Rocks (Animikie Group): wacke, shale, iron formation, limestone, minor volcanic rocks, conglomerate, taconite, aldal chert, carbonate rocks, argillite-tuff
- 16 Hornblendite - nepheline syenite suite
- 15 Massive granodiorite to granite
- 14 Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 7 Metasedimentary rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 4 Mafic to ultramafic metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks
- 2 Felsic to intermediate metavolcanic rocks
- 1 Metasedimentary rocks and mafic to ultramafic metavolcanic rocks

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Geology - 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 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

10 5 0 10 20 30 40
SCALE 1:750,000 KILOMETRES

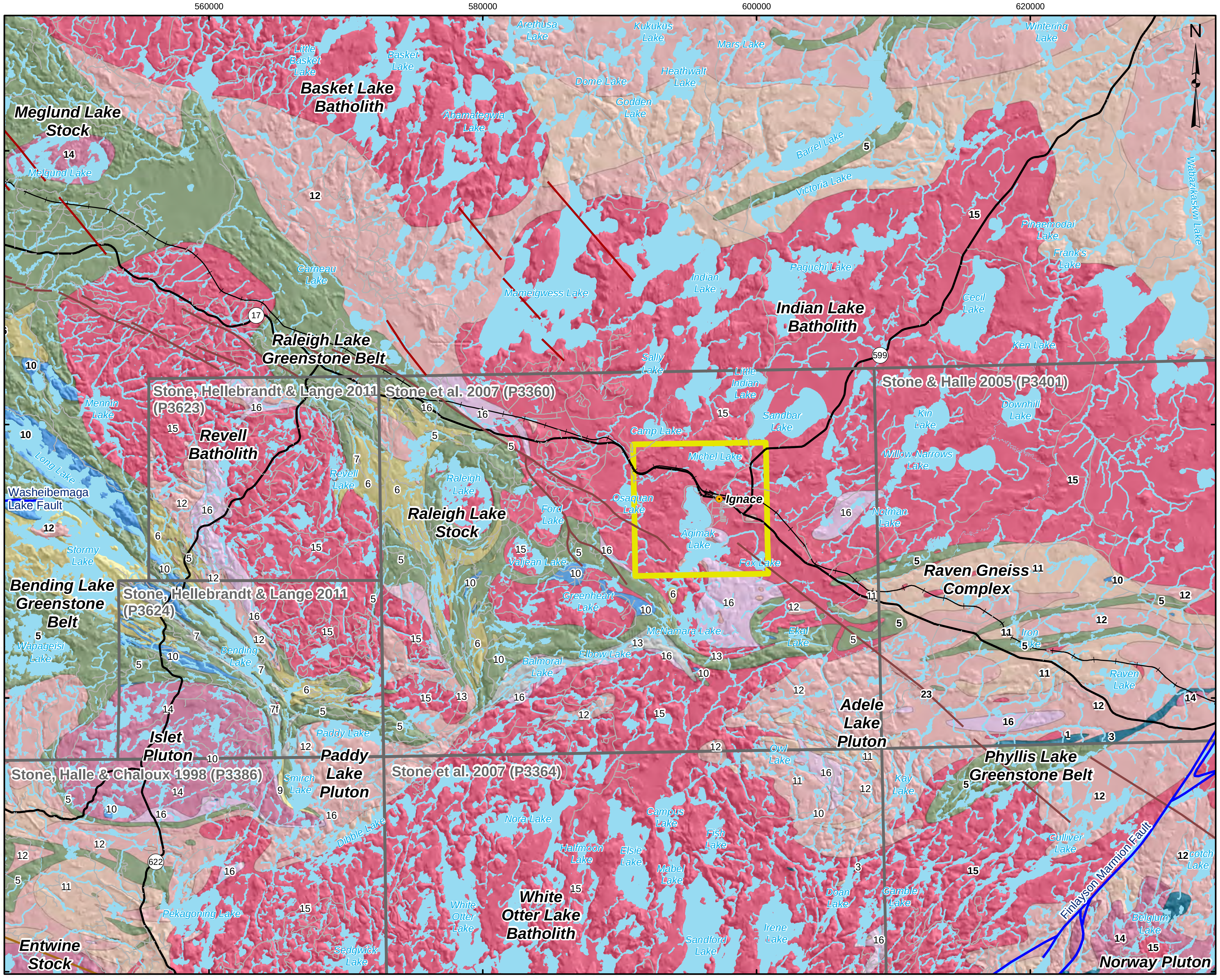
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Regional Geology of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.3	
GIS	PM/JB	18 Oct. 2013		
CHECK	CM	18 Oct. 2013		
REVIEW	GWS	18 Oct. 2013		

G:\Projects\2012\12-1152-0026_NWMO_Phase1_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\RegionalGeologyIgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault

Mapped Dyke

- Kenora-Fort Frances Dyke
- Wabigoon Dyke
- Dyke (Other)
- Detailed Geology Extent

Bedrock Geology

- 31 Sibley Gp.
- 23 Mafic and related intrusive rocks
- 16 Hornblendite - nepheline syenite suite
- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 7 Metasedimentary rocks
- 7c Marble, chert, iron formation, minor metavolcanic rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 4 Mafic to ultramafic metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks
- 1 Metasedimentary rocks and mafic to ultramafic metavolcanic rocks

Stone et al. 2007 (P3360)
Stone et al. 2007 (P3364)
Stone, Halle & Chaloux 1998 (P3386)
Stone, Hellebrandt & Lange 2011 (P3623)
Stone, Hellebrandt & Lange 2011 (P3624)
Stone & Halle 2005 (P3401)

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Geology - 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 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

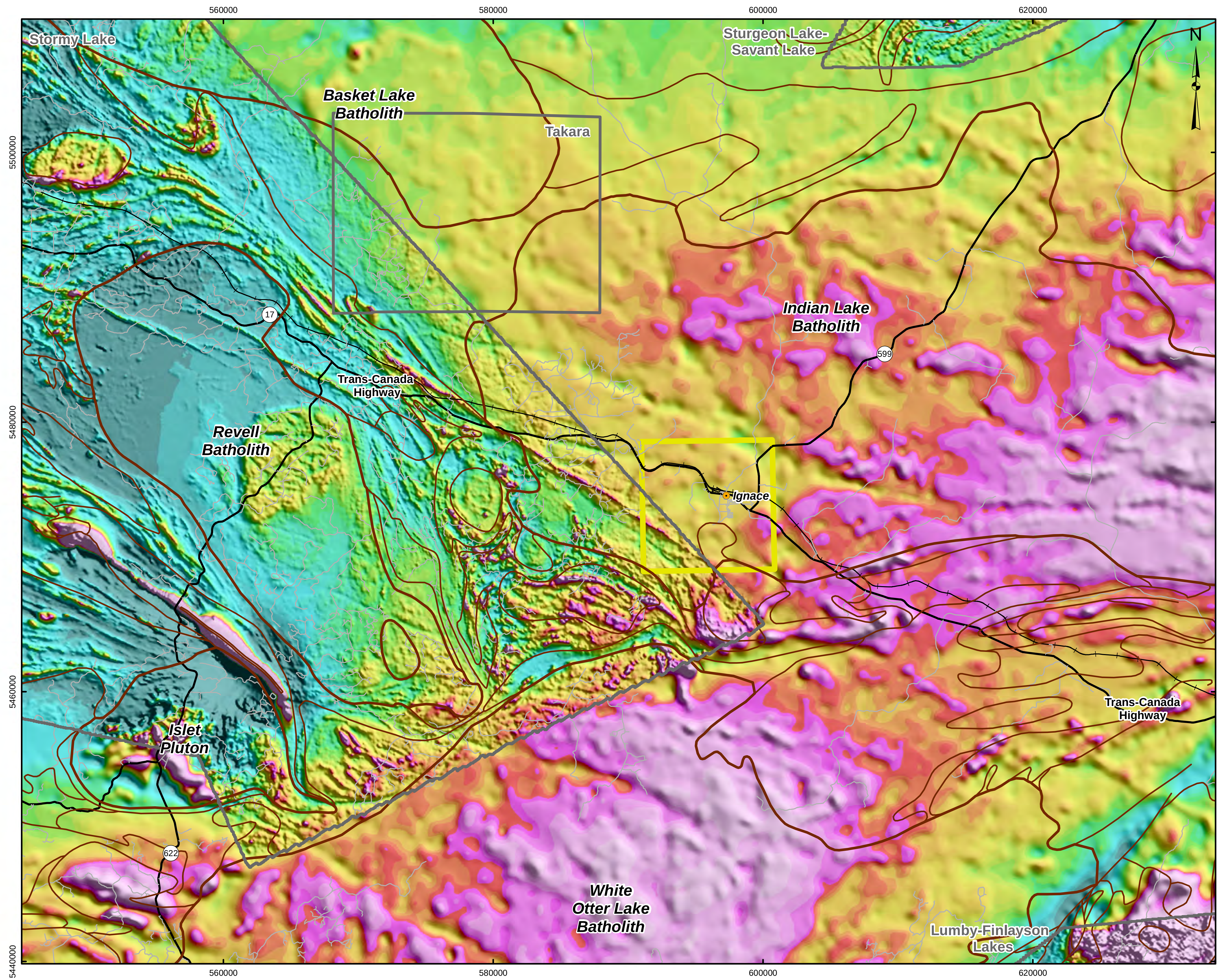
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Local Bedrock Geology of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.4	
GIS	PM/JB	22 Oct. 2013		
CHECK	CM	22 Oct. 2013		
REVIEW	GWS	22 Oct. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\LocalBedrockGeologyIgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Geological Contact
- Outline of Major Batholith/Pluton
- Higher Resolution Geophysical Surveys

Residual Total Magnetic Field (nT)

300
240
200
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-220
-240
-280

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Geophysics - GSC Canada - 200m - Magnetic - Residual Total Field, 2008;
Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada Division, Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

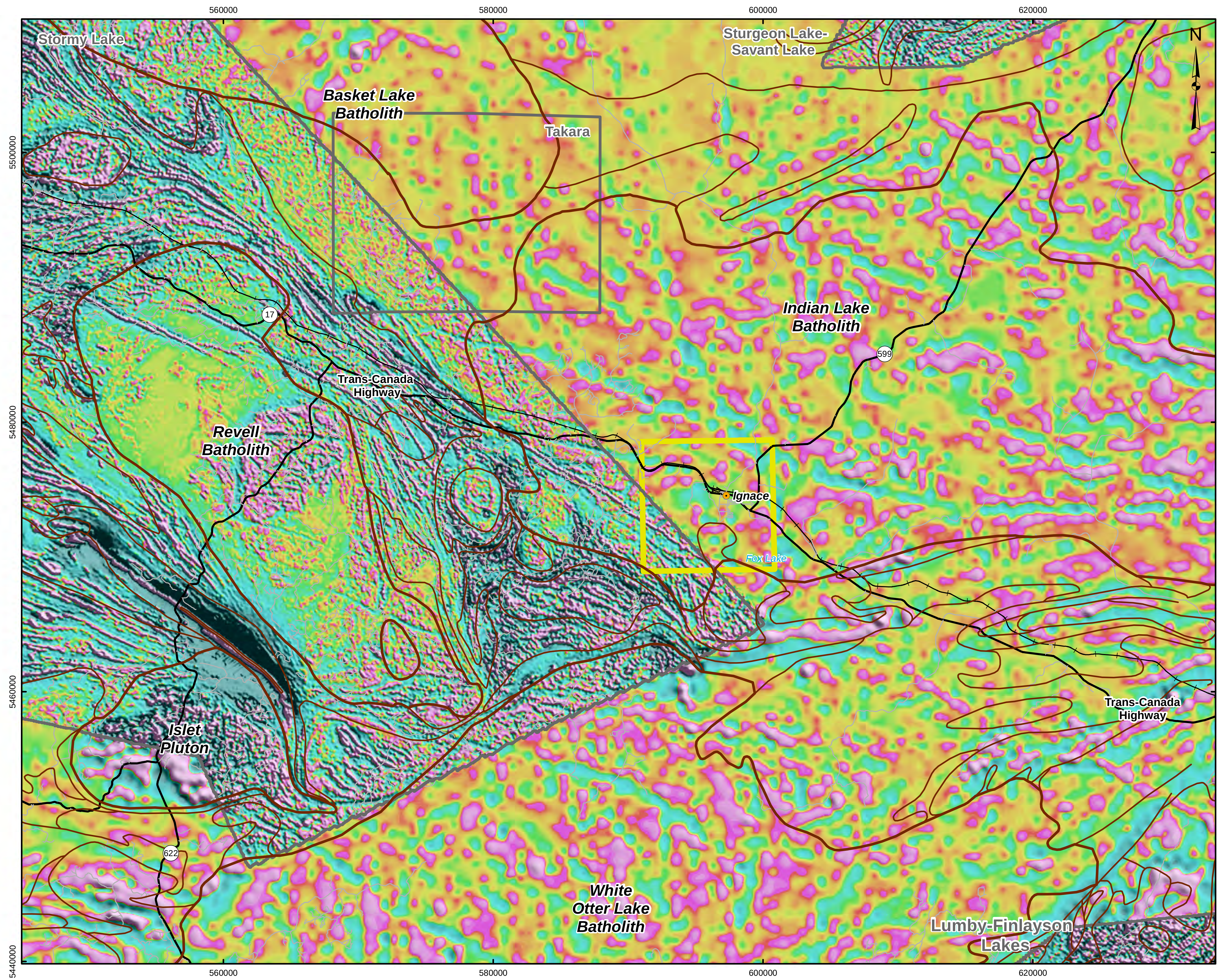
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Total Magnetic Field (Reduced to Pole) of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.5	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\TotalMagneticFieldReducedPoleIgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Geological Contact
- Outline of Major Batholith/Pluton
- Higher Resolution Geophysical Surveys

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

0.37
0.19
0.13
0.10
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.09
-0.11
-0.15
-0.20
-0.28
-0.47

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Geophysics - GSC Canada - 200m - Magnetic - Residual Total Field, 2008;
Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada
Division, Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

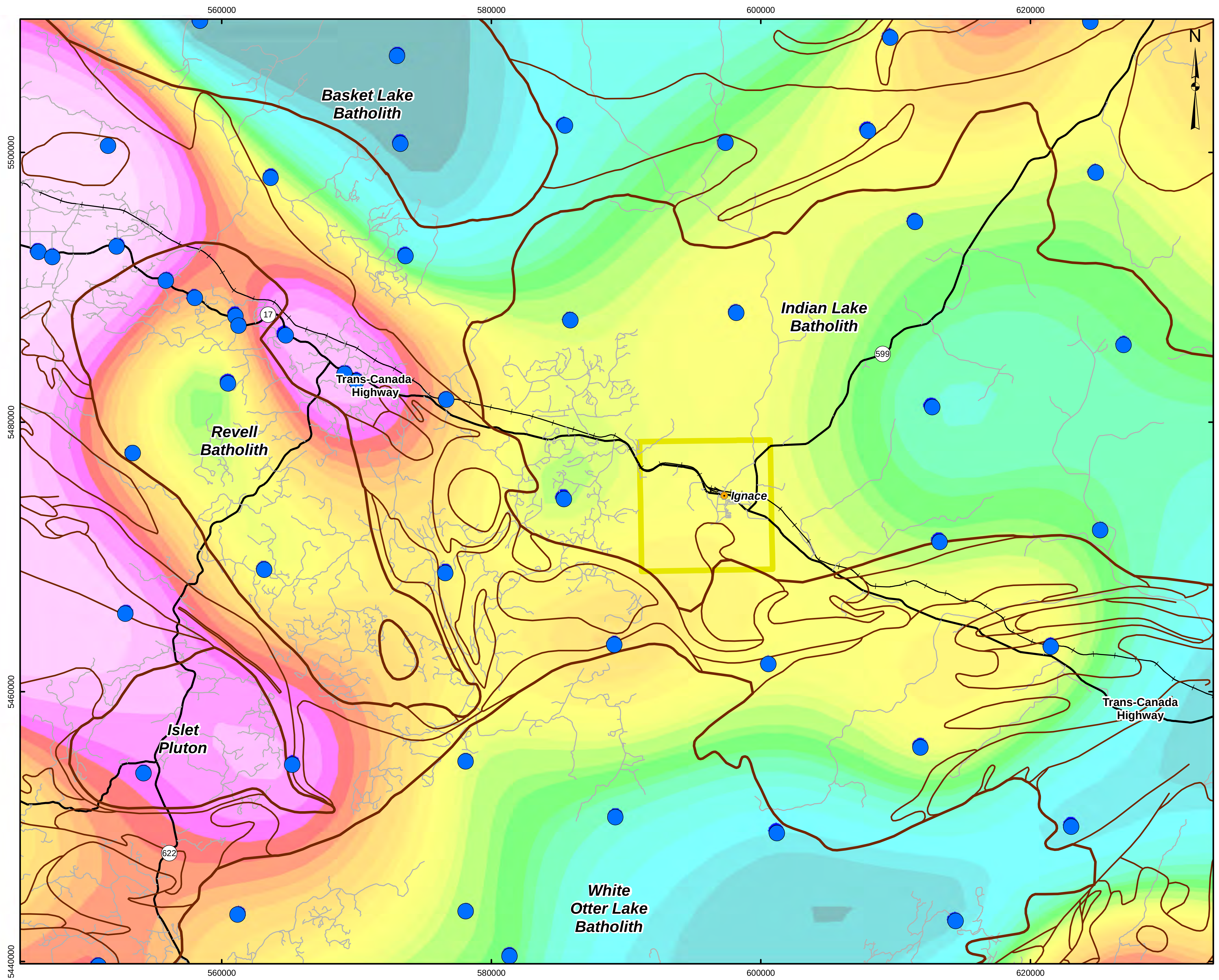
SCALE 1:300,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

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

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.6	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Gravity Station
- Geological Contact
- Outline of Major Batholith/Pluton

Gravity Anomaly (mGal)

-43.0, -48.5, -51.0, -53.5, -55.0, -56.5, -58.0, -59.0, -60.0, -61.5, -62.5, -63.0, -64.0, -64.5, -65.0, -65.5, -66.0, -66.5, -67.5, -68.0, -69.0, -69.5, -70.5, -71.5, -73.0, -74.5, -75.5, -77.0

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
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
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

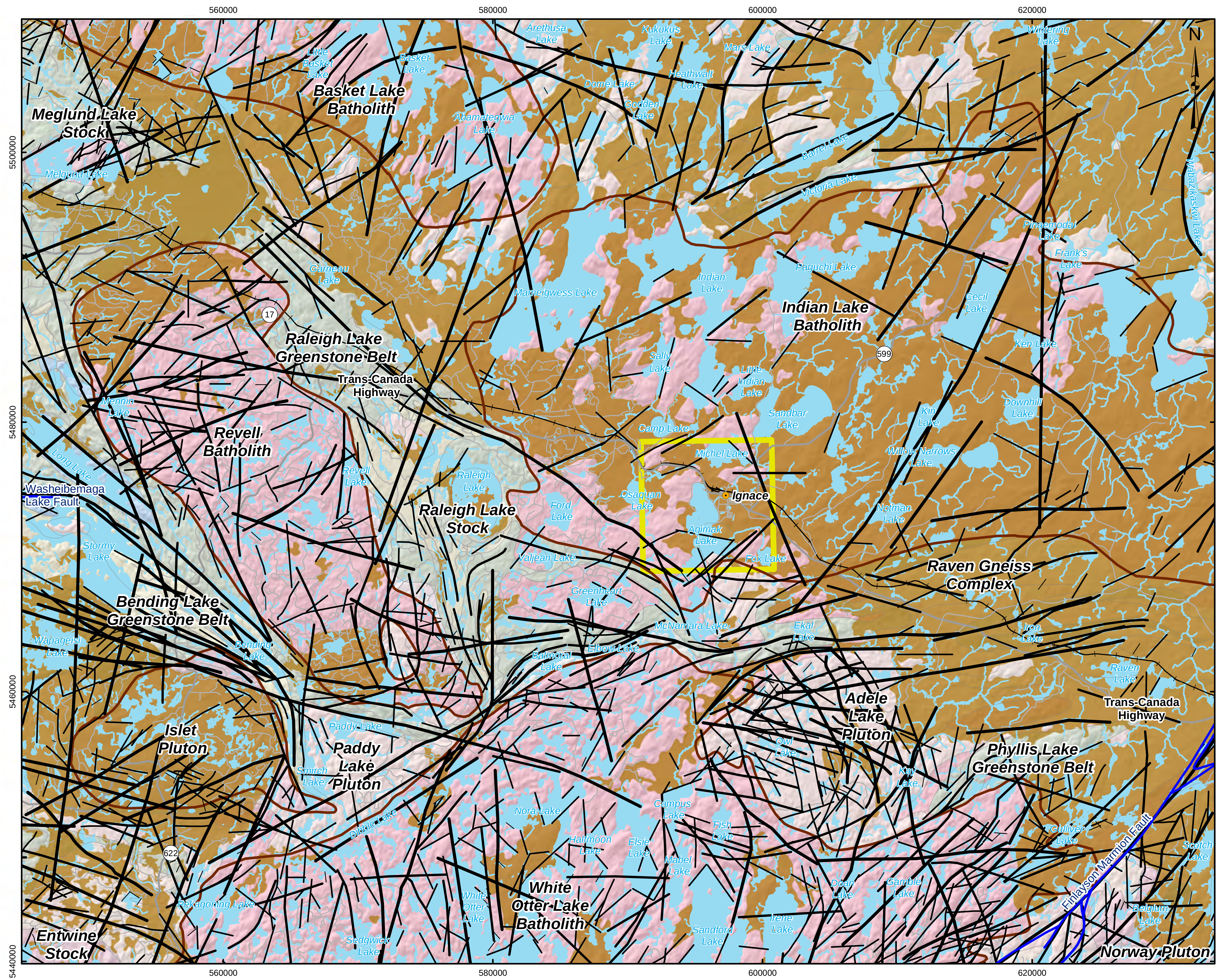
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Bouguer Gravity of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.7	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\BouguerGravity\IgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault
- Outline of Major Batholith/Pluton
- Overburden Cover

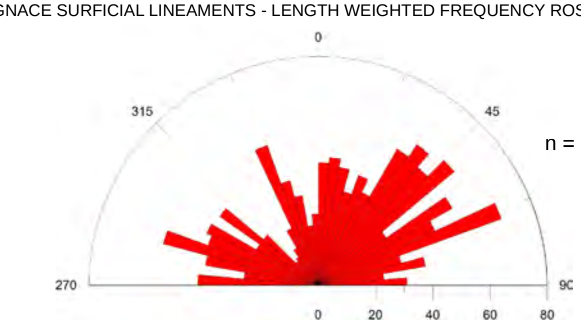
Surficial Lineament (SPOT and CDED)

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

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 7 Metasedimentary rocks
- 7c Marble, chert, iron formation, minor metavolcanic rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks

IGNACE SURFICIAL LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Landform - OGS, MND Mines, and Northeast Science and Information Section, MNR
2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - 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 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

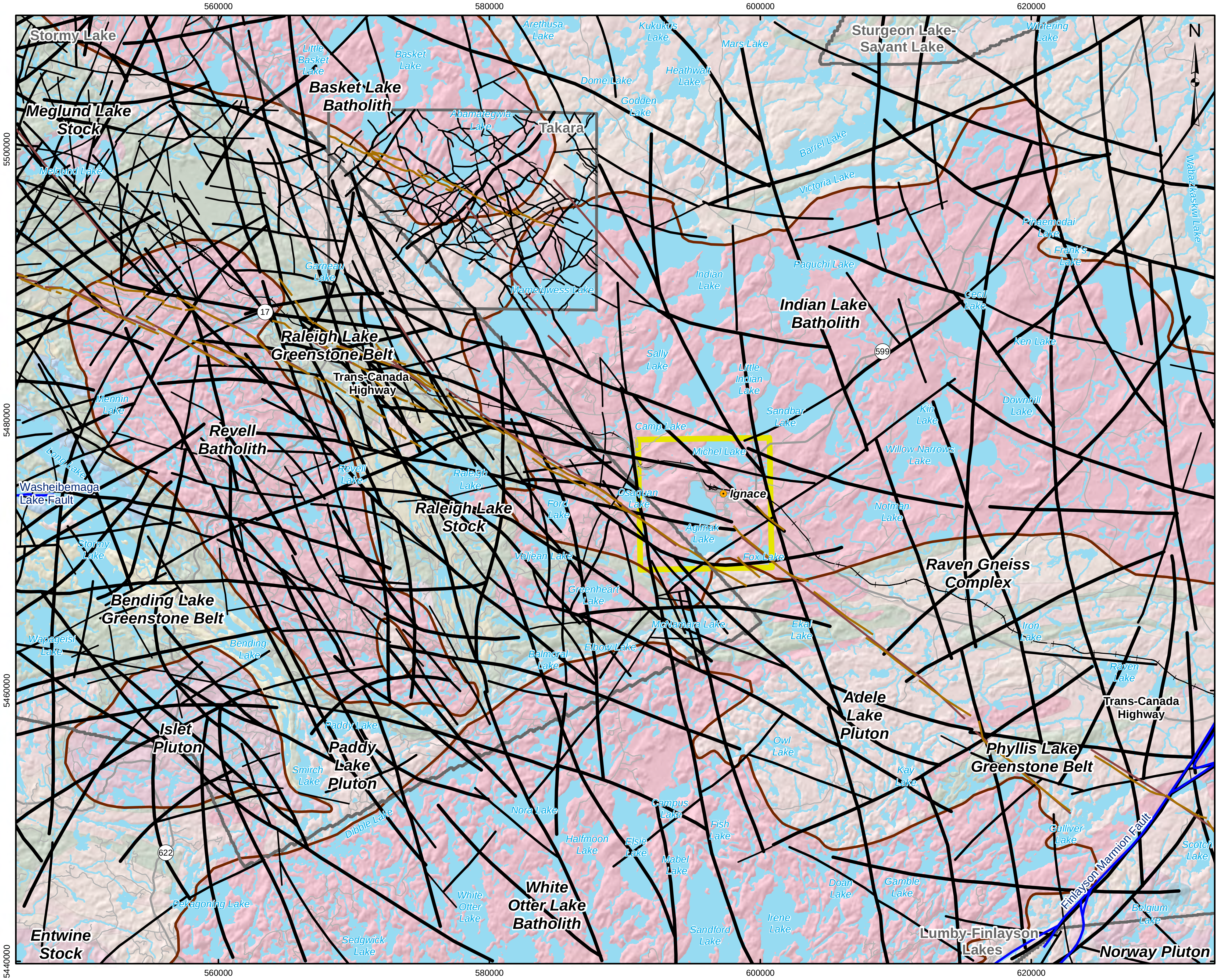
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Surficial Lineaments of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.8	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\SurficialLineamentsIgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault
- Mapped Dyke (MRD 126)
- Interpreted Dyke (PGW, 2012)
- Outline of Major Batholith/Pluton
- Higher Resolution Geophysical Surveys

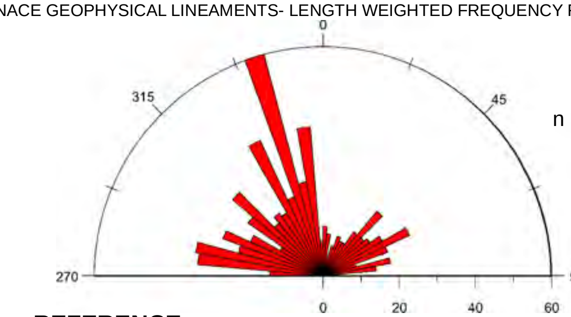
Geophysical Lineament

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

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 7 Metasedimentary rocks
  - 7c Marble, chert, iron formation, minor metavolcanic rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks

IGNACE GEOPHYSICAL LINEAMENTS- LENGTH WEIGHTED FREQUENCY ROSE PLOT



REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - 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 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

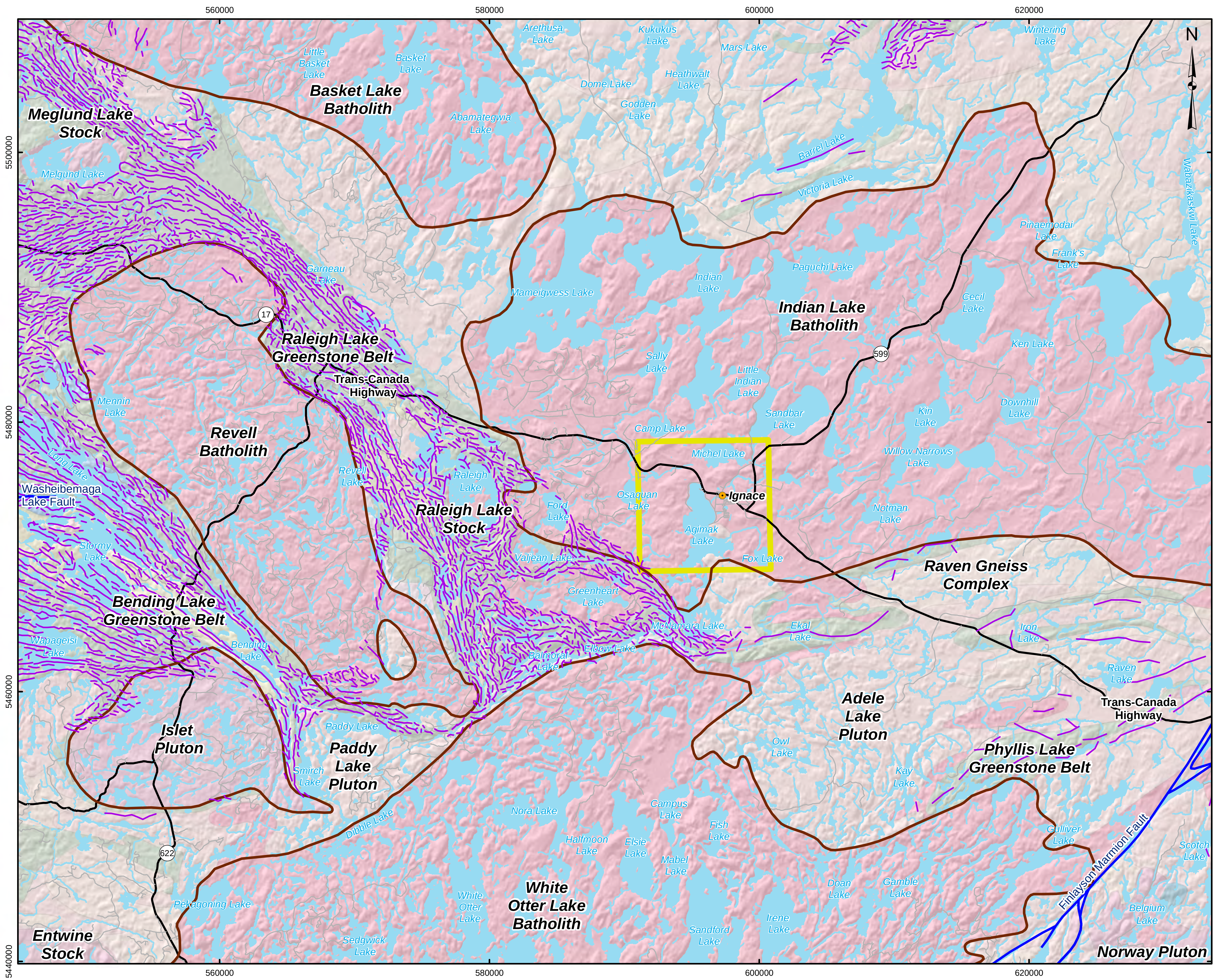
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geophysical Lineaments of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.9	
GIS	PM/JB	27 Aug. 2013		
CHECK	CM	27 Aug. 2013		
REVIEW	GWS	27 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\GeophysicalLineamentsIgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault
- Outline of Major Batholith/Pluton
- Ductile Lineaments

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 7 Metasedimentary rocks
- 7c Marble, chert, iron formation, minor metavolcanic rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Ductile Lineaments - Processing & Interpretation of Geophysical Data, Igance (PGW, 2012)
Geology- 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 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

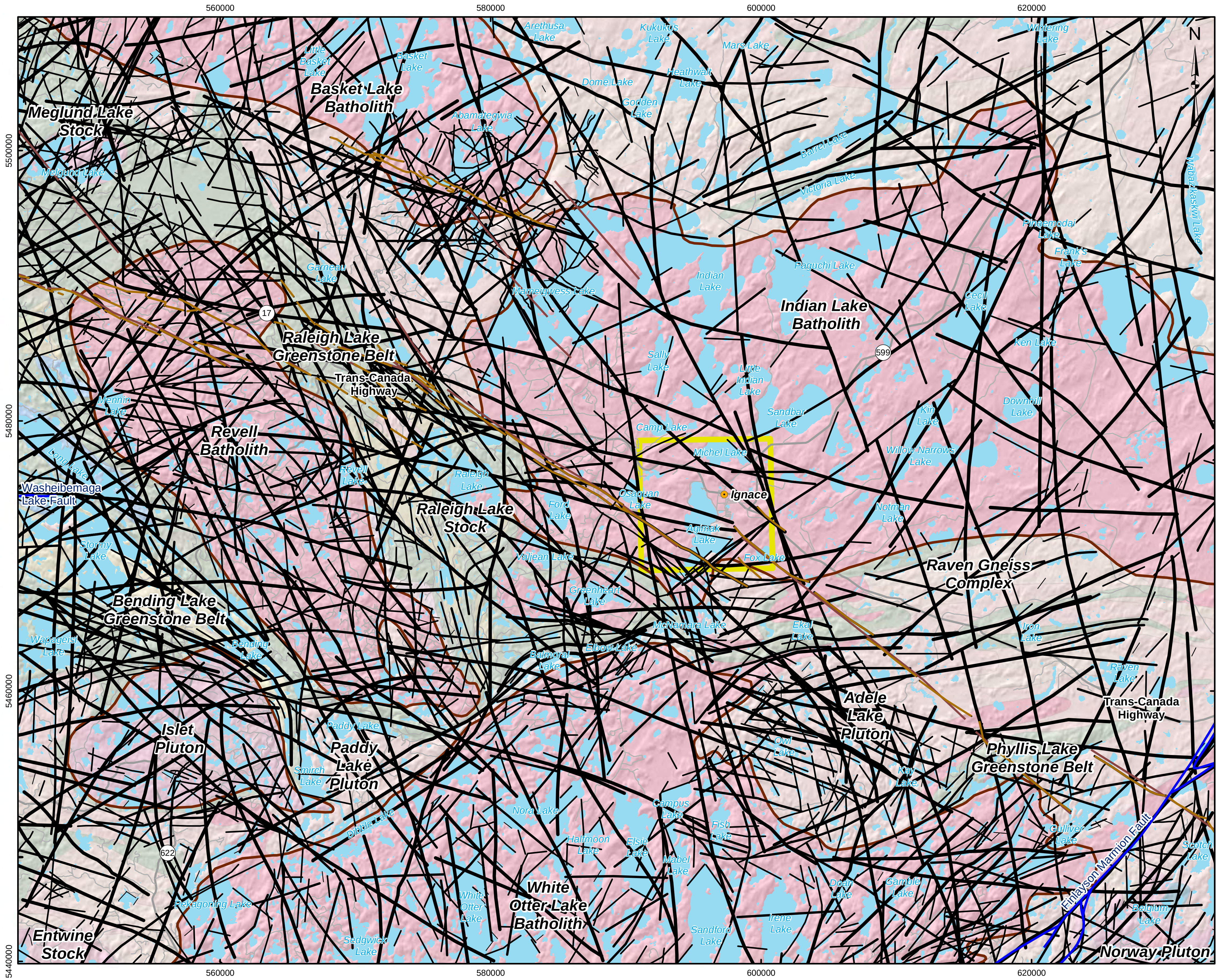
5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Ductile Lineaments of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.10	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Water Area, Permanent
- Mapped Fault
- Mapped Dyke (MRD 126)
- Interpreted Dyke (PGW, 2012)
- Outline of Major Batholith/Pluton

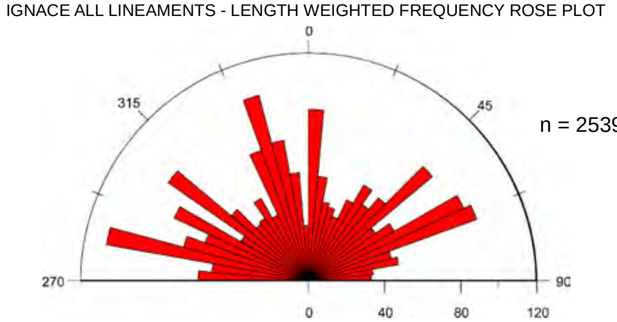
Brittle Lineaments (Surficial and Geophysical)

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

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 7 Metasedimentary rocks
  - 7c Marble, chert, iron formation, minor metavolcanic rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks

IGNACE ALL LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - 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 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

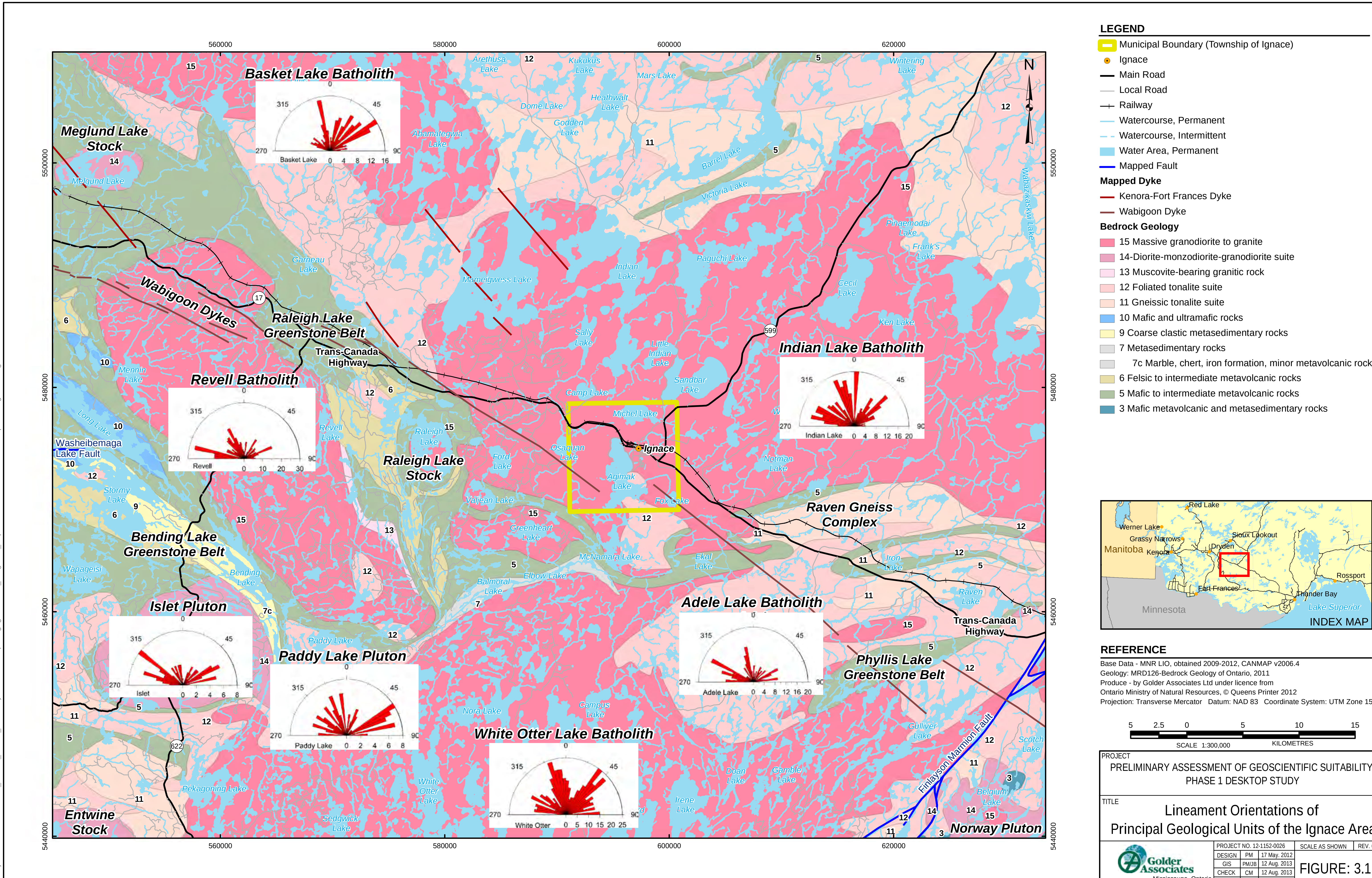
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Brittle Lineaments of the Ignace Area

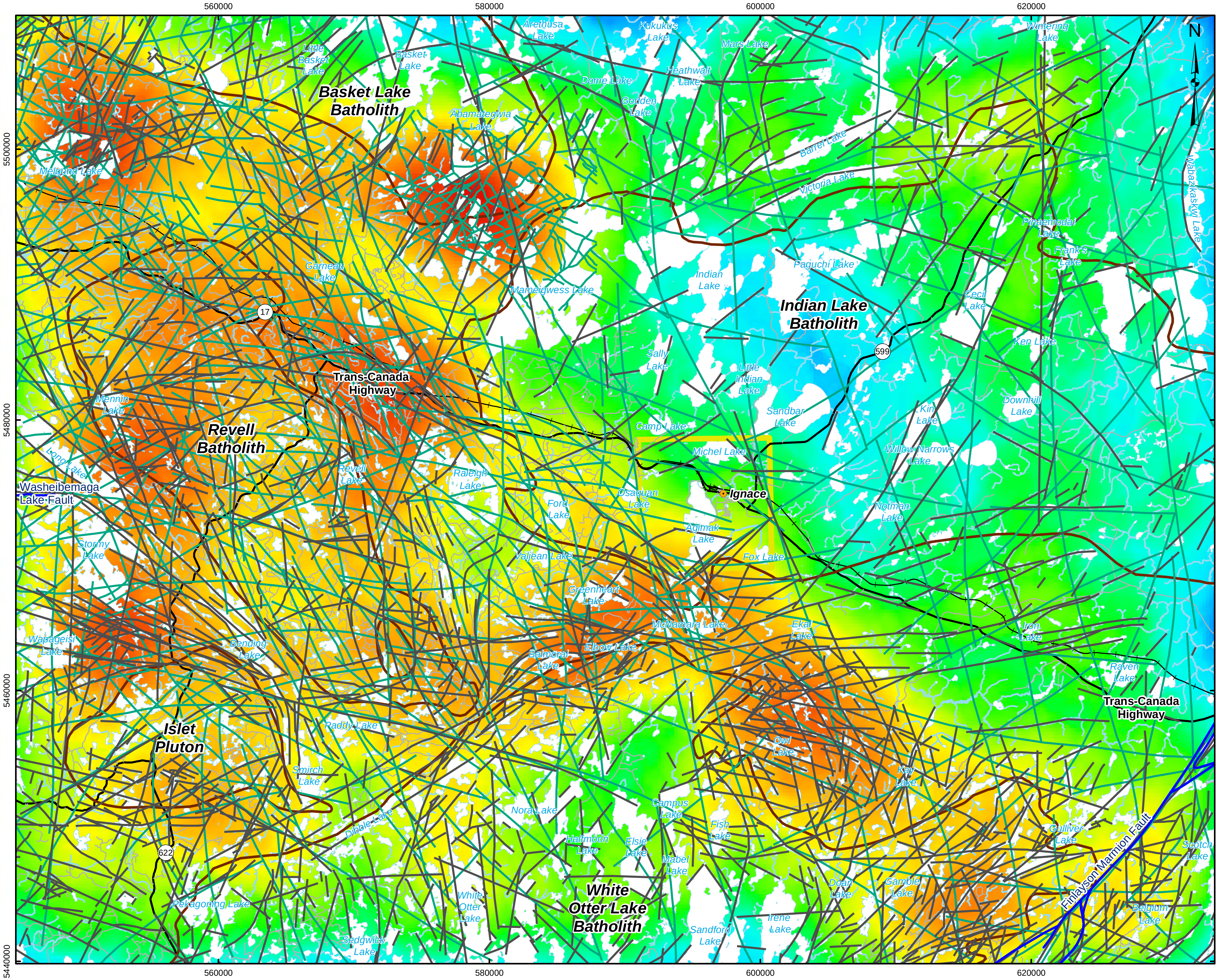
Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.11	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\BrittleLineaments\IgnaceArea.mxd



G:\Projects\2012\12-1152-0026_NWMO_Phase1_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\LineamentOrientationsPrincipalGeologicalUnits\IgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault
- Outline of Major Batholith/Pluton
- Geophysical Lineament
- Surficial Lineament

Lineament Density (km/km²)

High : 3.5

Low : 0

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

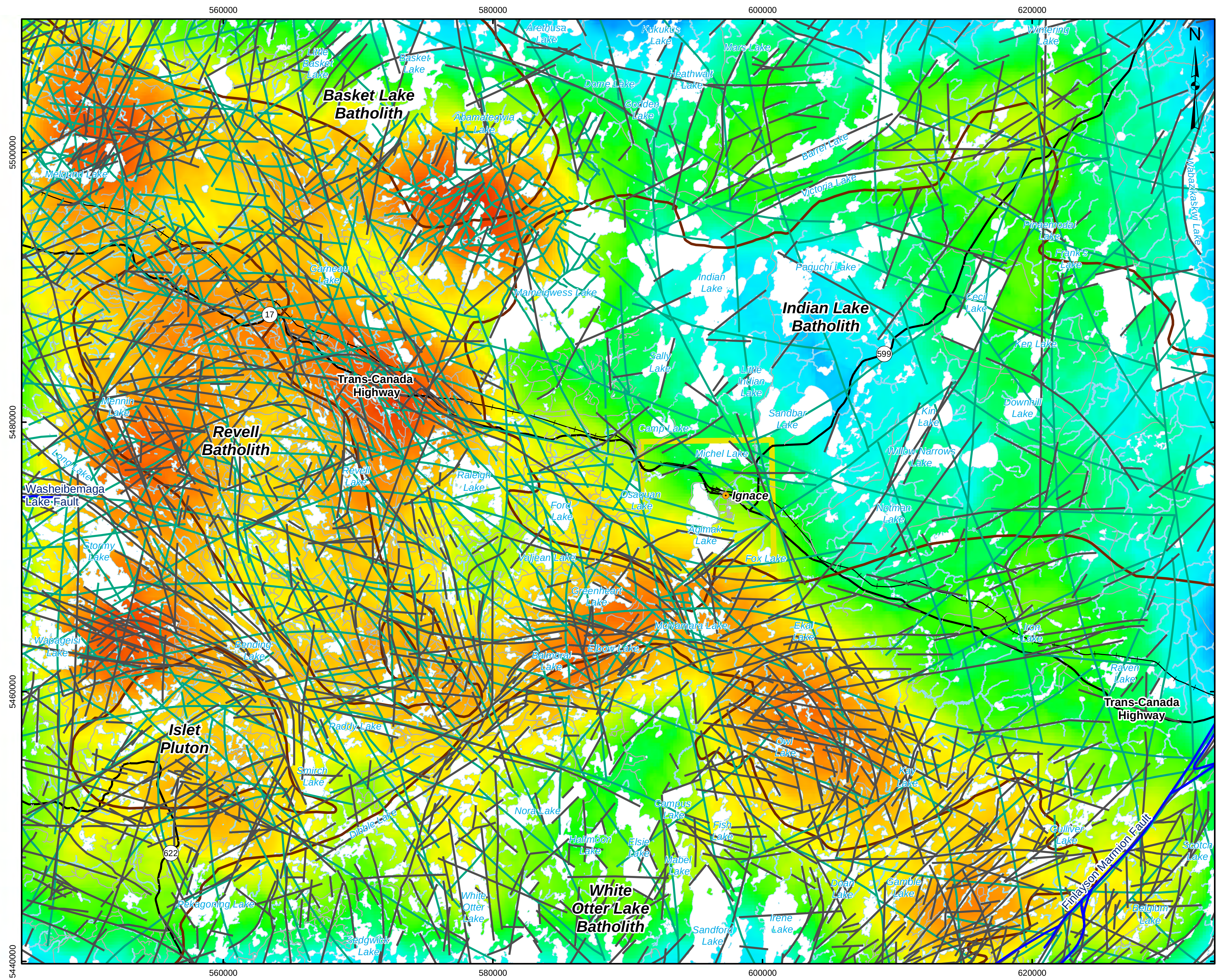
TITLE

Brittle Lineament Density Calculated for Lineaments in the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.13	
GIS	PM/JB	12 Aug. 2013		
CHECK	CM	12 Aug. 2013		
REVIEW	GWS	12 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\Ignace_Lineament_Density.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault
- Outline of Major Batholith/Pluton
- Geophysical Lineament (>1 km)
- Surficial Lineament (>1 km)

Lineament Density (km/km²)

High : 3.5

Low : 0

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES

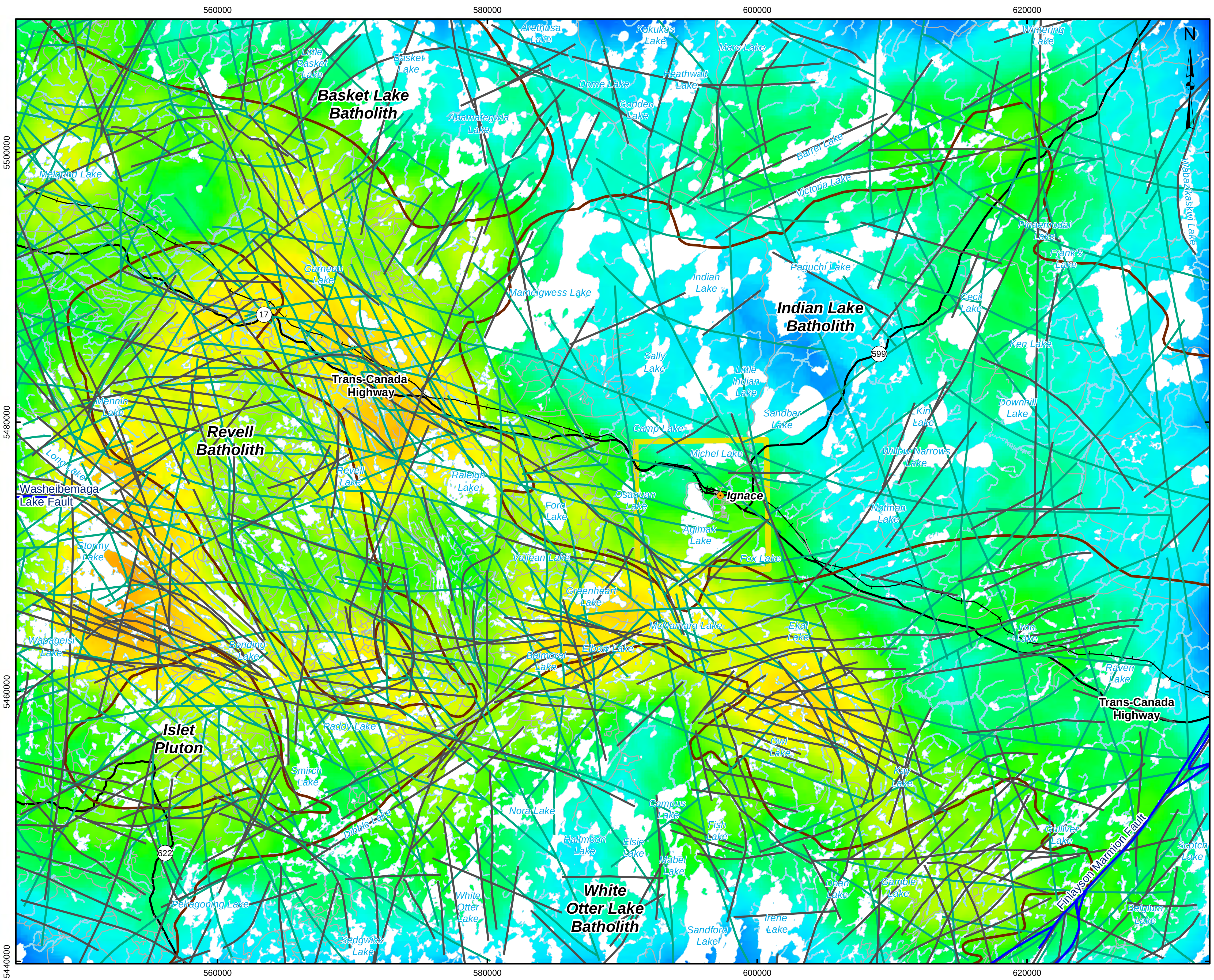
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Brittle Lineament Density Calculated for Lineaments >1 km in the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.14	
GIS	PM/JB	12 Aug. 2013		
CHECK	CM	12 Aug. 2013		
REVIEW	GWS	12 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\Ignace\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\Ignace_Lineament_Density_Greater1km.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault
- Outline of Major Batholith/Pluton
- Geophysical Lineament (>5 km)
- Surficial Lineament (>5 km)

Lineament Density (km/km²)

High : 3.5

Low : 0

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

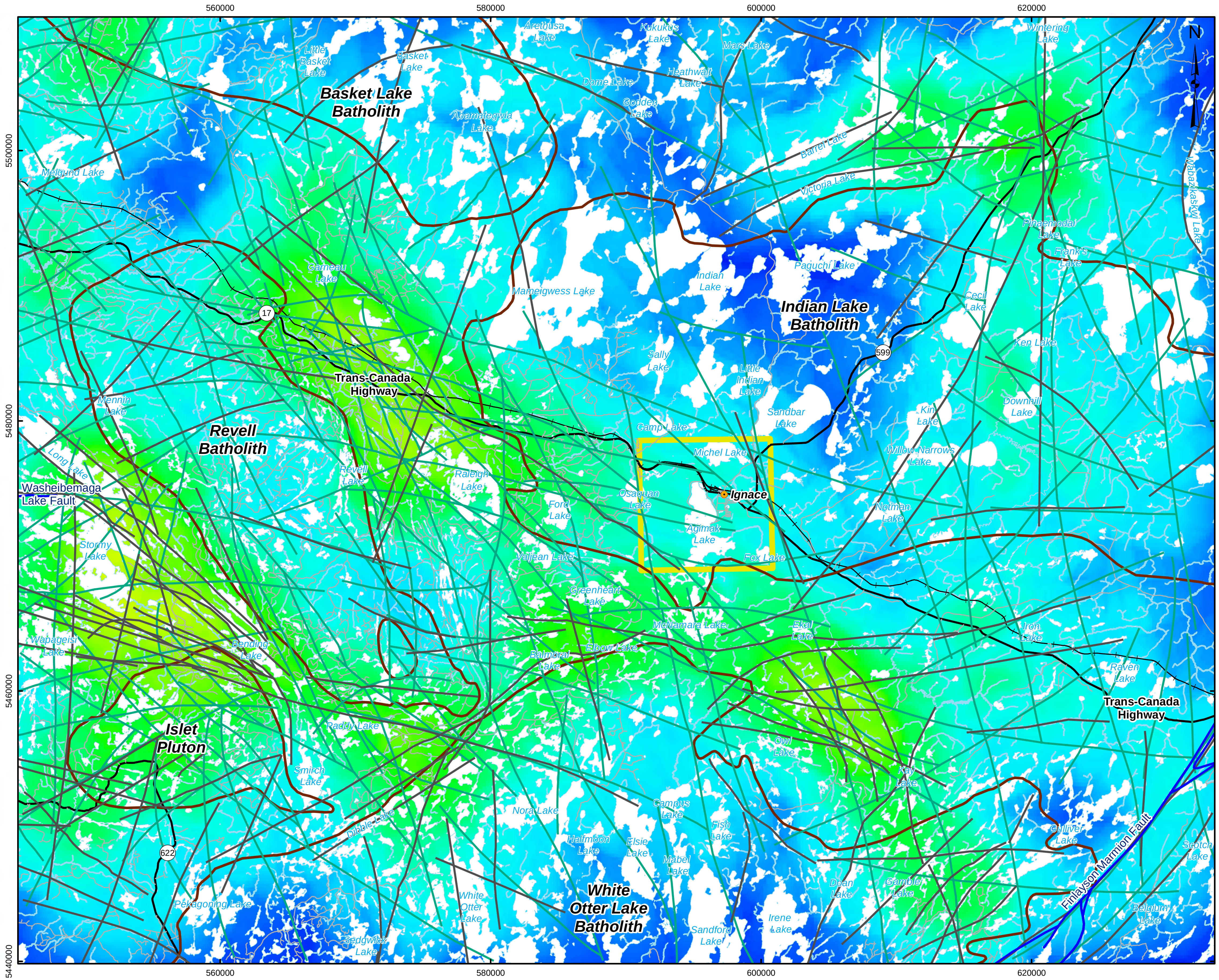
TITLE

Brittle Lineament Density Calculated for Lineaments >5 km in the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.15	
GIS	PM/JB	12 Aug. 2013		
CHECK	CM	12 Aug. 2013		
REVIEW	GWS	12 Aug. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\Ignace_Lineament_Density_Greater5km.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault
- Outline of Major Batholith/Pluton
- Geophysical Lineament (>10 km)
- Surficial Lineament (>10 km)

Lineament Density (km/km²)

High : 3.5

Low : 0

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Brittle Lineament Density Calculated for Lineaments >10 km in the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026		
DESIGN	PM	17 May. 2012
GIS	PM/JB	12 Aug. 2013
CHECK	CM	12 Aug. 2013
REVIEW	GWS	12 Aug. 2013

SCALE AS SHOWN REV. 0.0

FIGURE: 3.16

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\Ignace_Lineament_Density_Greater10km.mxd

LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent

Seismic Events (Magnitude)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- > 3.0
- Mapped Fault
- Mapped Dyke (MRD 126)
- Interpreted Dyke (PGW, 2012)
- Ductile Lineaments
- Brittle Lineament
- Outline of Major Batholith/Pluton

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 7 Metasedimentary rocks
- 7c Marble, chert, iron formation, minor metavolcanic rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Ductile Lineaments - Processing & Interpretation of Geophysical Data, Igance (PGW, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Seismic - Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), Nov. 2012
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

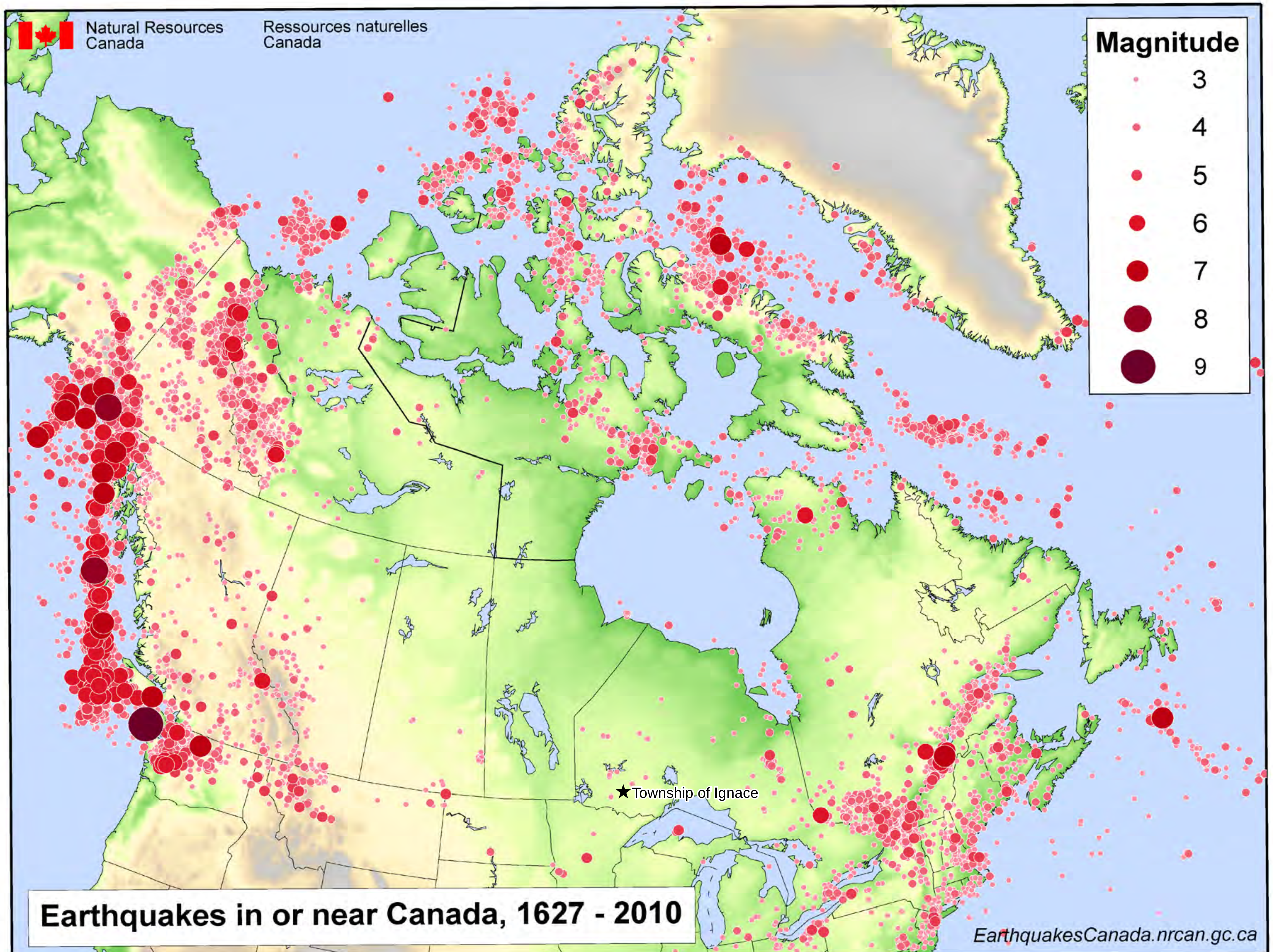
TITLE
Combined Structural Features of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012		
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		

FIGURE: 3.17

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\CombinedStructuralFeatures\Ignace Area.mxd



LEGEND

★ Township of Ignace

REFERENCE

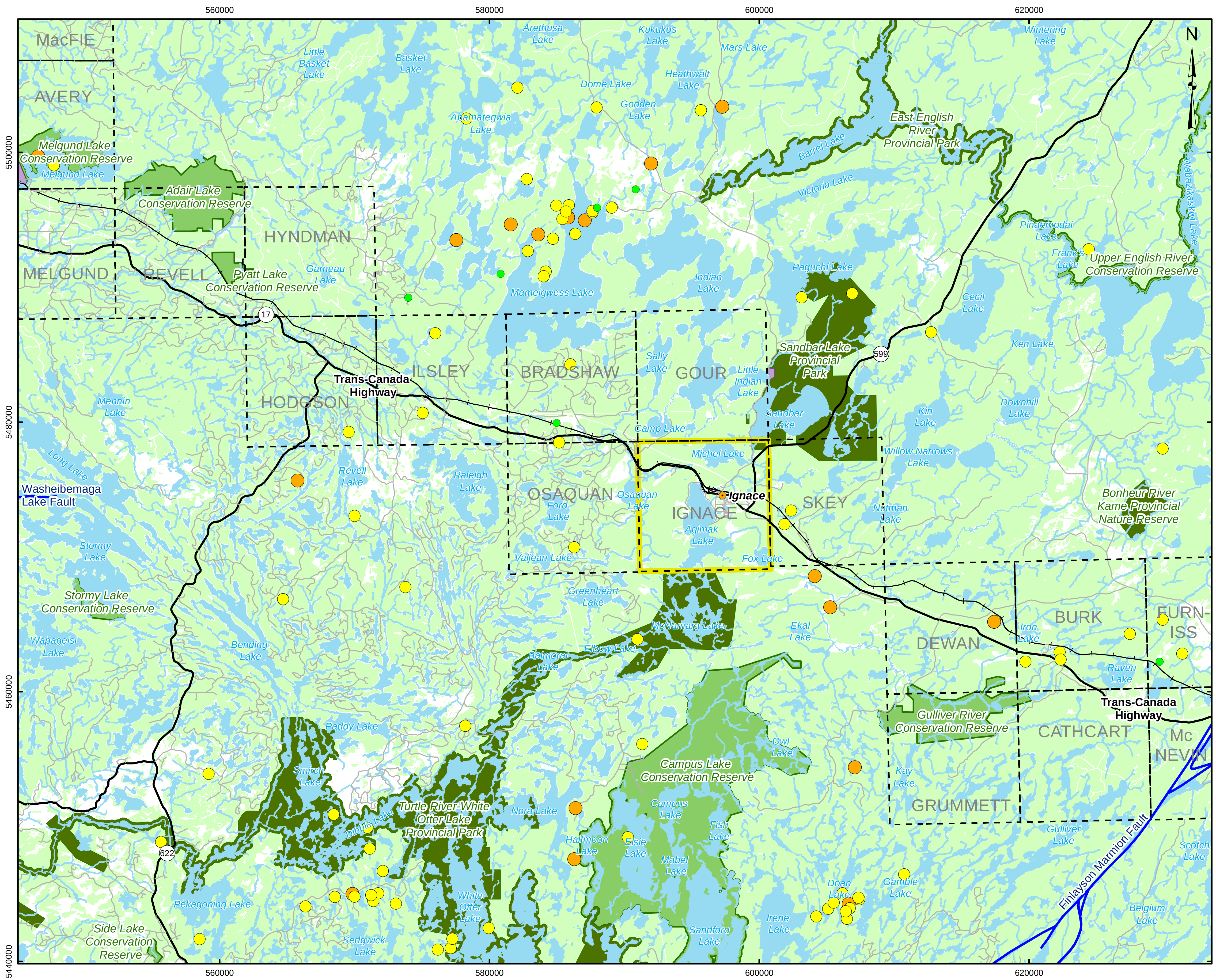
Seismic - Resources Canada (NRC). Earthquakes Canada Website. http://earthquakescanada.nrcan.gc.ca

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Earthquakes Map of Canada 1627-2010

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.18
GIS	PM/JB	12 Aug. 2013	
CHECK	CM	12 Aug. 2013	
REVIEW	GWS	12 Aug. 2013	



LEGEND

- Municipal Boundary (Township of Ignace)
- Geographic Township
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent

Seismic Events (Magnitude)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- > 3.0
- Mapped Fault
- Wooded Area
- Forest Reserve
- Conservation Reserve
- Provincial Park

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Seismic - Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), Nov. 2012
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

PROJECT

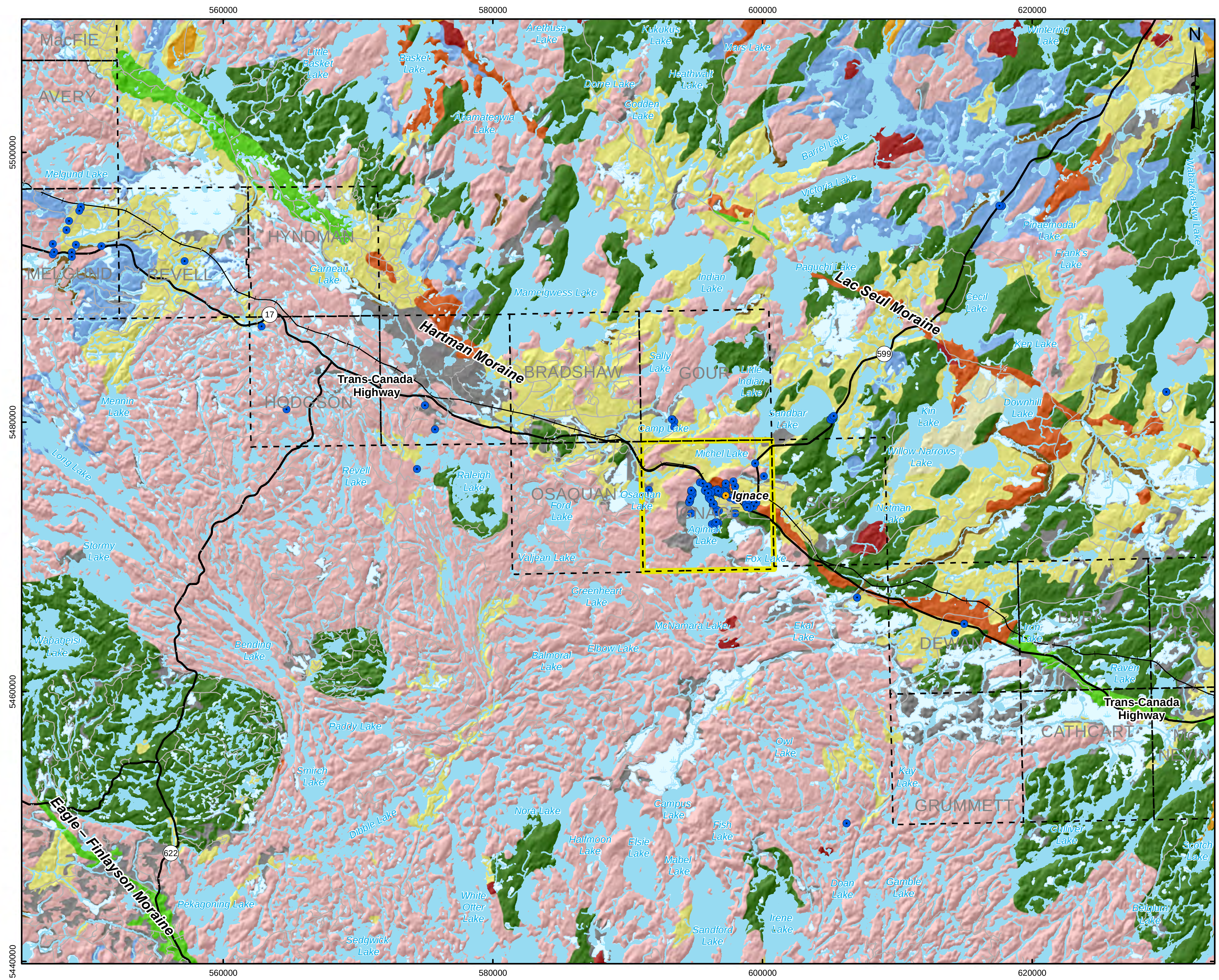
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Historical Earthquake Records of the Ignace Area 1985-2011

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN / REV. 0.0
DESIGN	PM	17 May. 2012	
GIS	PM/JB	12 Aug. 2013	
CHECK	CM	12 Aug. 2013	
REVIEW	GWS	12 Aug. 2013	FIGURE: 3.19



G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\GroundwaterWellsIgnaceArea.mxd

LEGEND

- Municipal Boundary (Township of Ignace)
- Geographic Township
- Ignace
- MOE Water Well
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Wetland, Permanent

Landform

- Ground moraine
- End moraine
- Outwash
- Glaciolacustrine esker
- Kame
- Ice-contact delta
- Glaciolacustrine plain
- Alluvial plain
- Aeolian dune
- Organic terrain
- Bedrock terrain

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Landform - OGS, MNDMines, and Northeast Science and Information Section, MNR 2005
Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release - Data 160.
Water Wells - Ministry of the Environment, last accessed October 18, 2012.
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

PROJECT

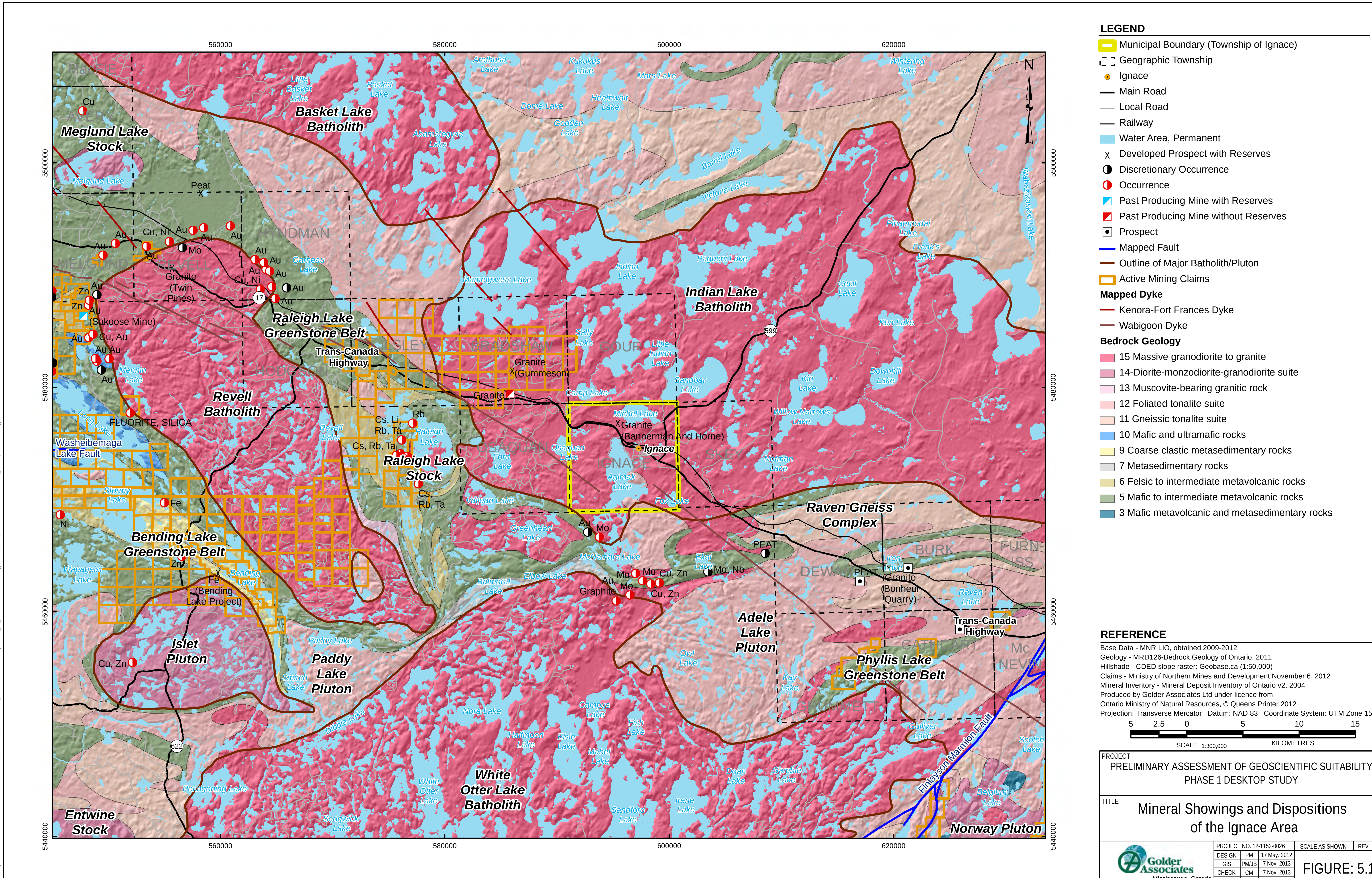
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

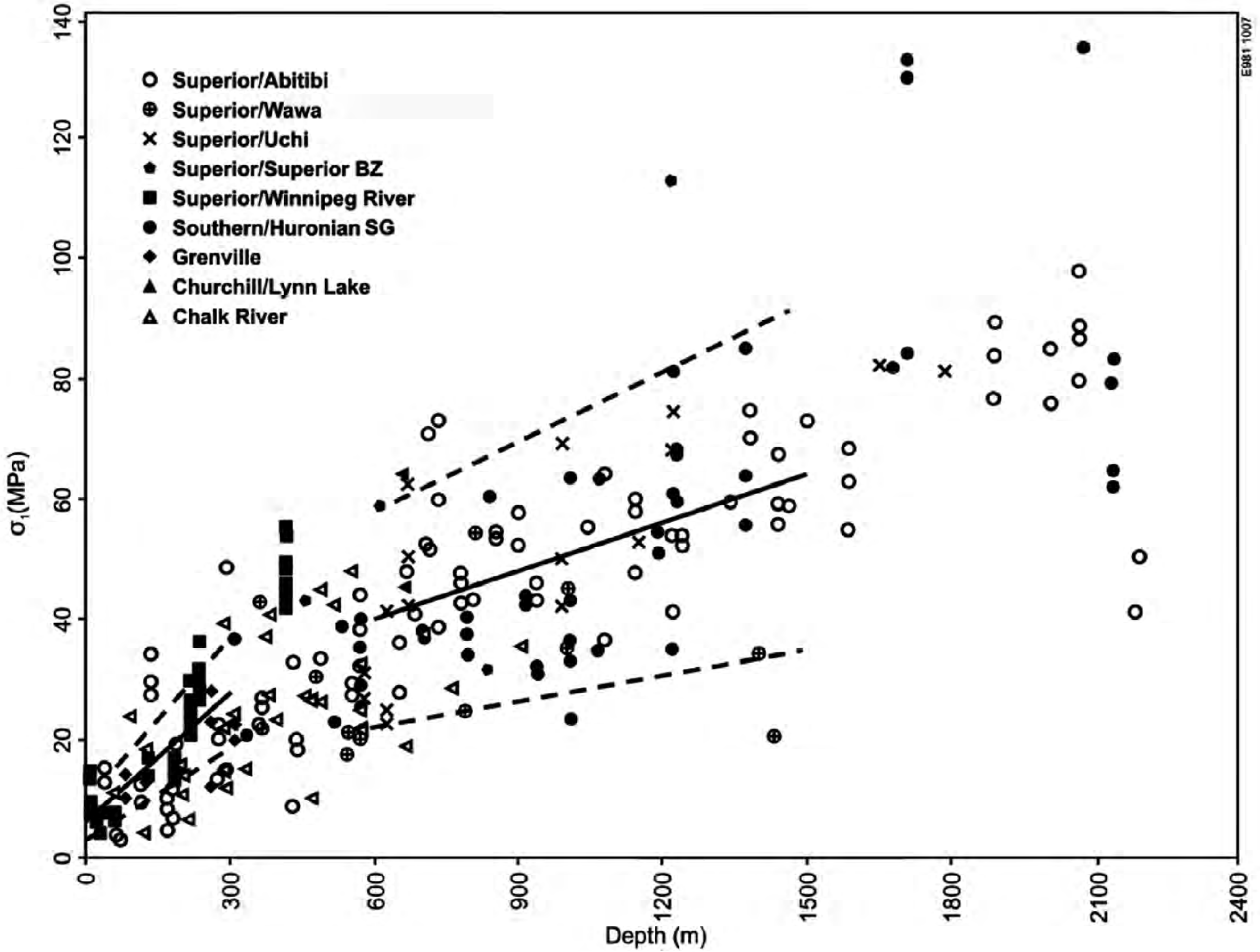
TITLE

Groundwater Wells within the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 4.1	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		


LEGEND
Municipal Boundary (Township of Ignace)
Geographic Township
Ignace
Main Road
Local Road
Railway
Water Area, Permanent
Developed Prospect with Reserves
Discretionary Occurrence
Occurrence
Past Producing Mine with Reserves
Past Producing Mine without Reserves
Prospect
Mapped Fault
Outline of Major Batholith/Pluton
Active Mining Claims
Mapped Dyke
Kenora-Fort Frances Dyke
Wabigoon Dyke
Bedrock Geology
15 Massive granodiorite to granite
14-Diorite-monzodiorite-granodiorite suite
13 Muscovite-bearing granitic rock
12 Foliated tonalite suite
11 Gneissic tonalite suite
10 Mafic and ultramafic rocks
9 Coarse clastic metasedimentary rocks
7 Metasedimentary rocks
6 Felsic to intermediate metavolcanic rocks
5 Mafic to intermediate metavolcanic rocks
3 Mafic metavolcanic and metasedimentary rocks
REFERENCE
Base Data - MNR LIO, obtained 2009-2012
Geology - MRD126-Bedrock Geology of Ontario, 2011
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Claims - Ministry of Northern Mines and Development November 6, 2012
Mineral Inventory - Mineral Deposit Inventory of Ontario v2, 2004
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N
5 2.5 0 5 10 15
SCALE 1:300,000 KILOMETRES
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY
TITLE
Mineral Showings and Dispositions
of the Ignace Area
Golder Associates
Mississauga, Ontario
PROJECT NO. 12-1152-0026
SCALE AS SHOWN
REV. 0.0
DESIGN PM 17 May. 2012
GIS PM/JB 7 Nov. 2013
CHECK CM 7 Nov. 2013
REVIEW GWS 7 Nov. 2013
FIGURE: 5.1
Meglund Lake Stock
Basket Lake Batholith
Indian Lake Batholith
Raleigh Lake Greenstone Belt
Revell Batholith
Raleigh Lake Stock
Raven Gneiss Complex
Bending Lake Greenstone Belt
Islet Pluton
Paddy Lake Pluton
Adele Lake Pluton
Phyllis Lake Greenstone Belt
White Otter Lake Batholith
Entwine Stock
Norway Pluton
Ignace
Trans-Canada Highway
Washeibemaga Lake Fault
Finlayson Marmion Fault
Granite (Twin Pines)
(Sakoose Mine)
Granite (Gummeson)
Granite (Bannerman And Horne)
Granite (Bonheur Quarry)
(Bending Lake Project)
FLUORITE, SILICA
560000
580000
600000
620000
5500000
5480000
5460000
5440000



PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

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

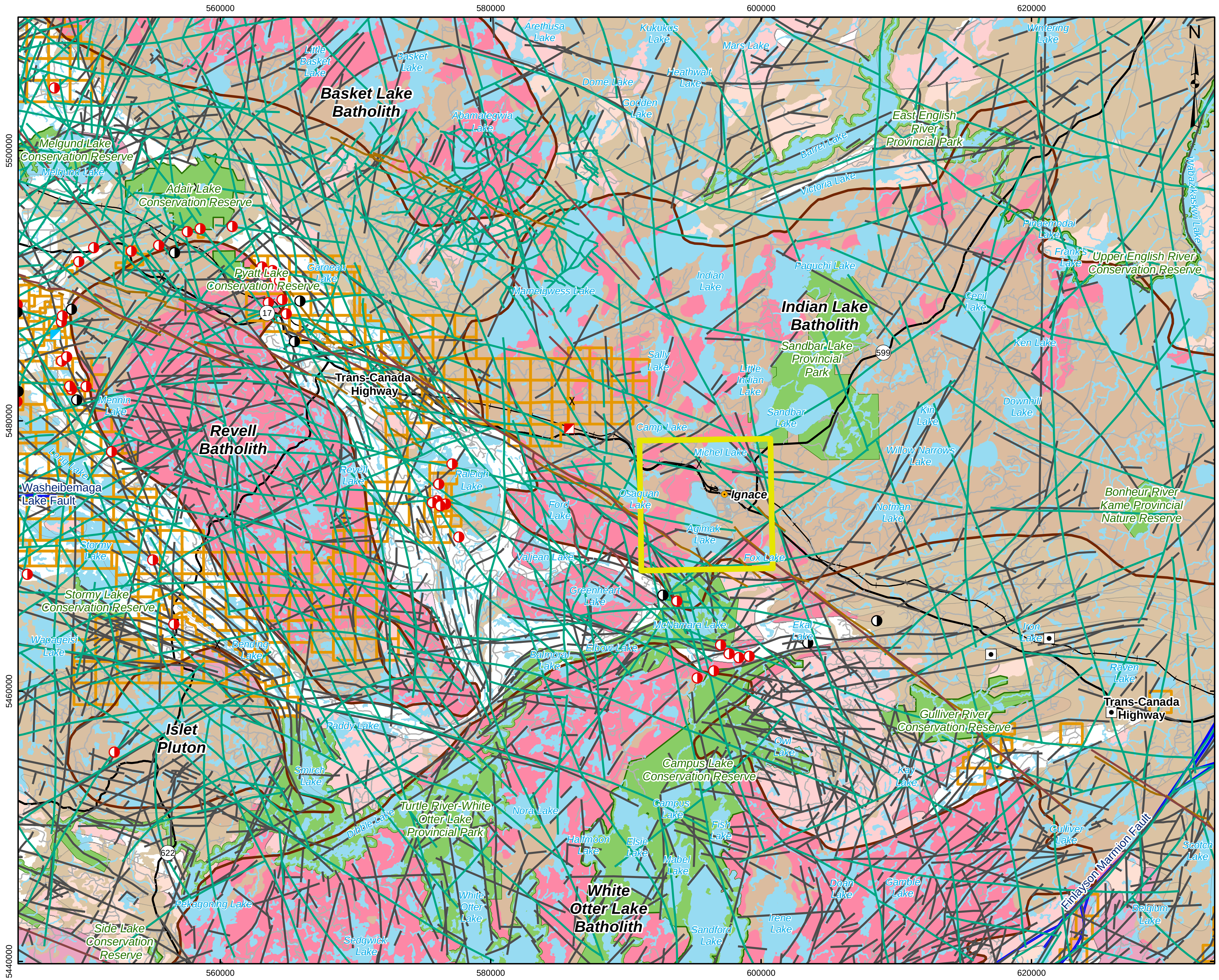
PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	6 Nov. 2012	FIGURE: 6.1	
GIS	PM/JB	12 Aug. 2013		
CHECK	CM	12 Aug. 2013		
REVIEW	GWS	12 Aug. 2013		

Golder Associates
Mississauga, Ontario

REFERENCE

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

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\MaximumHorizontalInSituStressesCanadianShield.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- X Developed Prospect with Reserves
- Discretionary Occurrence
- Occurrence
- Past Producing Mine with Reserves
- Past Producing Mine without Reserves
- Prospect
- Mapped Fault
- Mapped Dyke (MRD 126)
- Interpreted Dyke (PGW, 2012)
- Geophysical Lineament
- Surficial Lineament
- Outline of Major Batholith/Pluton
- Protected Area
- Active Mining Claims
- Overburden Cover

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- Unfavourable Geology

Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development, May 8, 2013
Mineral Inventory - Mineral Deposit Inventory of Ontario v2, 2004
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR 2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:300,000 KILOMETRES

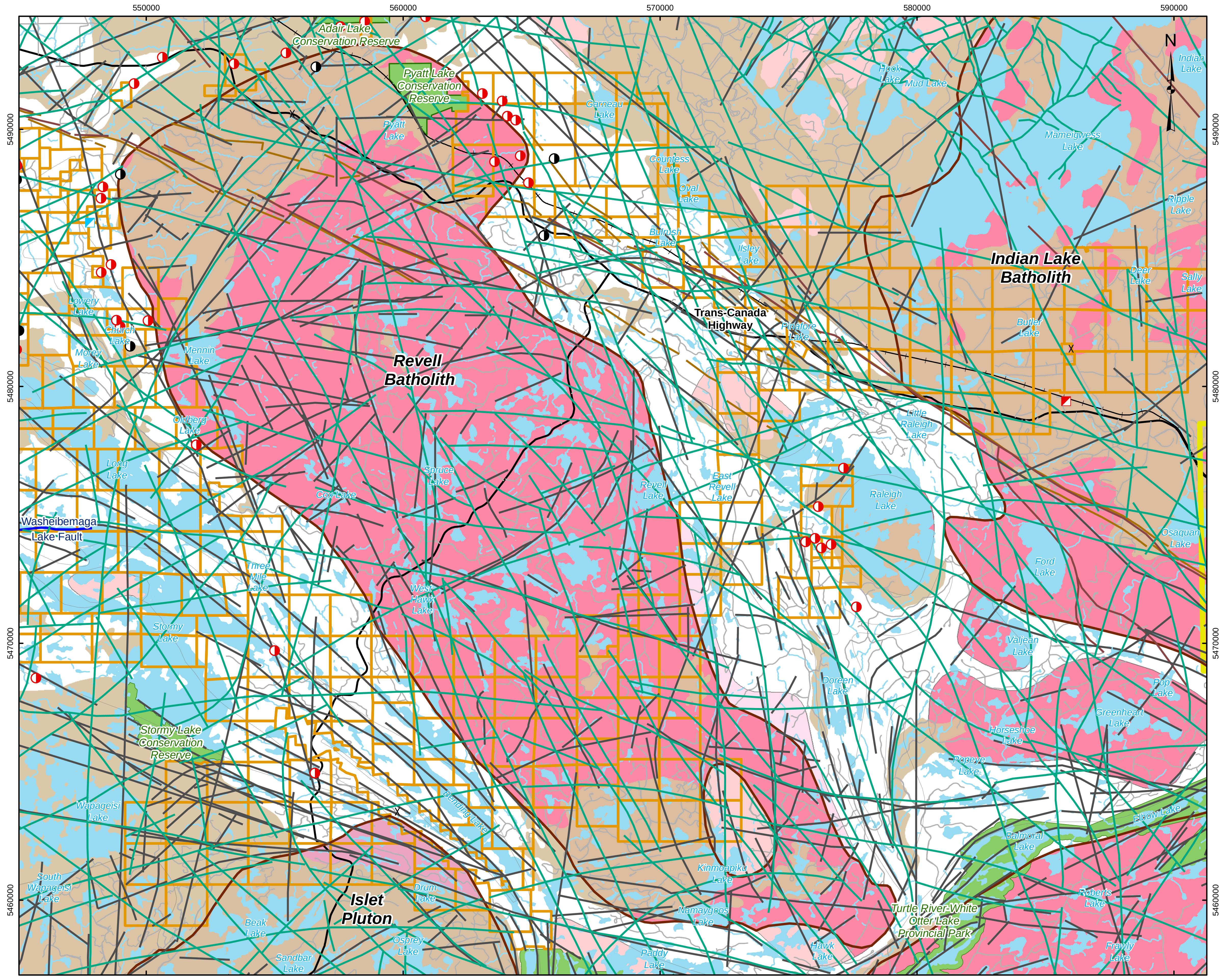
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Key Geoscientific Characteristics
of the Ignace Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 7.1	
GIS	PM/JB	7 Nov. 2013		
CHECK	CM	7 Nov. 2013		
REVIEW	GWS	7 Nov. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\Ignace\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\KeyGeoscientificCharacteristicsIgnaceArea.mxd



LEGEND

- Municipal Boundary (Township of Ignace)
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- X Developed Prospect with Reserves
- Discretionary Occurrence
- Occurrence
- Past Producing Mine with Reserves
- Past Producing Mine without Reserves
- Mapped Fault
- Mapped Dyke (MRD 126)
- Interpreted Dyke (PGW, 2012)
- Geophysical Lineament
- Surficial Lineament
- Outline of Major Batholith/Pluton
- Protected Area
- Active Mining Claims
- Overburden Cover

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- Unfavourable Geology

Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development, May 8, 2013
Mineral Inventory - Mineral Deposit Inventory of Ontario v2, 2004
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR 2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

2.5 1.25 0 2.5 5 7.5

SCALE 1:150,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

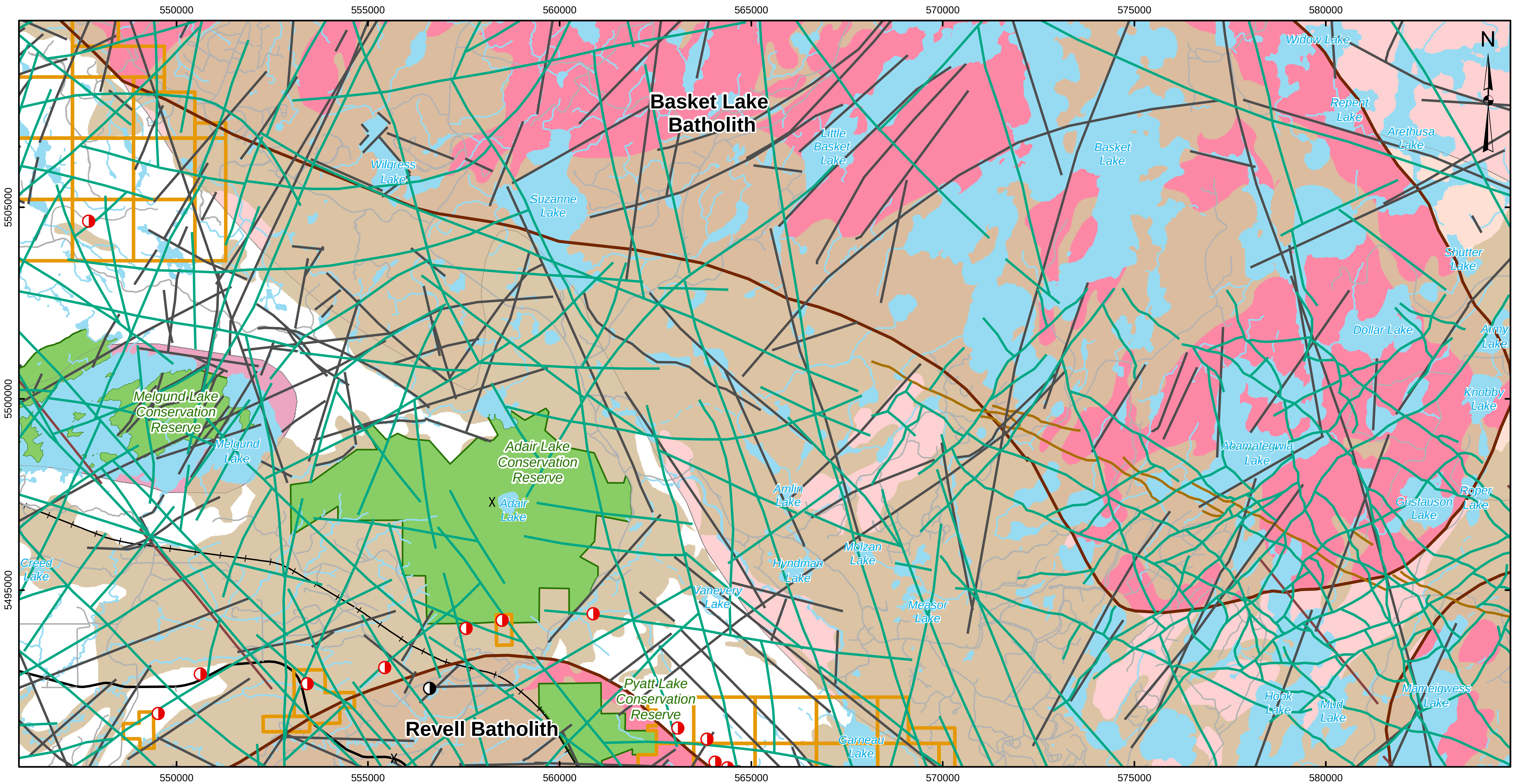
TITLE

Key Geoscientific Characteristics
of the Revell Batholith

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012		
GIS	PM/JB	7 Nov. 2013		
CHECK	CM	7 Nov. 2013		
REVIEW	GWS	7 Nov. 2013		

Golder Associates
Mississauga, Ontario

FIGURE: 7.2



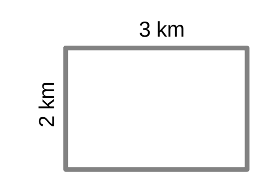
LEGEND

- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- X Developed Prospect with Reserves
- Discretionary Occurrence
- Occurrence
- Mapped Dyke (MRD 126)
- Interpreted Dyke (PGW, 2012)
- Geophysical Lineament
- Surficial Lineament
- Outline of Major Batholith/Pluton
- Protected Area
- Active Mining Claims
- Overburden Cover

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- Unfavourable Geology

Approximate Size of Repository Footprint



REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development, May 8, 2013
Mineral Inventory - Mineral Deposit Inventory of Ontario v2, 2004
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR
2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

2.5 1.25 0 2.5 5 7.5
SCALE 1:125,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Key Geoscientific Characteristics of the Basket Lake Batholith

Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 7.3	
GIS	PM/JB	7 Nov. 2013		
CHECK	CM	7 Nov. 2013		
REVIEW	GWS	7 Nov. 2013		

G:\Projects\2012\12-1152-0026_NWMO_Phase1_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\KeyGeoscientificCharacteristicsBasketLakeBatholith.mxd

LEGEND

- Municipal Boundary (Township of Ignace)
- Ignace
- Main Road
- Local Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- X Developed Prospect with Reserves
- Discretionary Occurrence
- Occurrence
- Past Producing Mine without Reserves
- Prospect
- Mapped Fault
- Mapped Dyke (MRD 126)
- Interpreted Dyke (PGW, 2012)
- Geophysical Lineament
- Surficial Lineament
- Outline of Major Batholith/Pluton
- Protected Area
- Active Mining Claims
- Overburden Cover

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- Unfavourable Geology

Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Lineaments - Lineament Interpretation Township of Ignace, Ontario (JDMA, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development, May 8, 2013
Mineral Inventory - Mineral Deposit Inventory of Ontario v2, 2004
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR
2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10

SCALE 1:200,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Key Geoscientific Characteristics of the Indian Lake Batholith

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 7.4	
GIS	PM/JB	7 Nov. 2013		
CHECK	CM	7 Nov. 2013		
REVIEW	GWS	7 Nov. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Ignace\Draft_Integrated_Report\KeyGeoscientificCharacteristics\IndianLakeBatholith.mxd

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.
Transportation	**6.** The site should have a route that exists or is amenable to being created that enables the safe and secure transportation of used fuel from existing storage sites to the repository site.	**6.1** The repository should be located in an area that is amenable to the safe transportation of used nuclear fuel. **6.2** The repository should be located in an area that allows appropriate security and emergency response measures during operation and transportation of the used nuclear fuel.

APPENDIX B

Geoscientific Data Sources

Table B-1: Summary of Geoscientific Databases for the Ignace 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 are 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 (MRD 126)	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, dyke swarms, iron formations, kimberlites and interpretation of the Precambrian bedrock geology underlying the Hudson Bay and James Bay lowlands Phanerozoic cover.	Regional	Yes
CLAIMaps	CLAIMaps contains active claims, alienations and dispositions. Data includes: links to further land tenure information.	Regional	Yes
Diabase Dykes (MRD 241)	Stott, G.M. and Josey, S.D. 2009. Post-Archean mafic (diabase) dykes and other intrusions of northwestern Ontario, north of latitude 49°30′; Ontario Geological Survey	Regional	Yes
Drill Holes	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
Earthquakes Canada	Geological Survey of Canada Earthquake Search (On-line Bulletin): http://www.earthquakescanada.nrcan.gc.ca/index-eng.php	Regional	Yes
Geochemistry (MRD 242)	Stone, D. 2010. Geochemical analyses of rocks, minerals and soil in the central Wabigoon Subprovince area, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 242.	Regional	Yes
Geochronology (MRD 75)	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)
Geochronology (MRD 275)	Buse, S., Stone, D., Lewis, D., Davis, D. and Hamilton, M.A. 2010. U/Pb Geochronology Results for the Atikokan Mineral Development Initiative	Local	Yes
Geotechnical Boreholes	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

Database	Description	Scale (Regional/Local)	Used? (Yes/No)
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

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

Product	Source	Type	Line Spacing/ Sensor Height	Coverage	Date	Additional Comments
Ontario #7	GSC	Fixed wing magnetic	805m/305m	Entire Ignace area	1965	Recorded on analog charts, navigation and flight path based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum.
GSC Gravity Coverage	GSC	Ground Gravity Measurements	5 to 15km spaced surface stations	Entire Ignace area	1946-74	Bouguer gravity field, first vertical derivative, horizontal gradient and the isostatic residual gravity field were extracted from the GSC gravity compilation. Station locations were extracted from the point data.
Detailed Gravity Coverage	Szewczyk	Ground Gravity Measurements	1 km intervals along roads and lakeshores	Basket Lake batholith, and northern part of Indian Lake batholith	1974	410 gravity stations were collected and listed in an M.Sc. thesis, and results described in Szewczyk and West (1976)
GSC Radiometric Coverage	GSC	Fixed wing radiometric data	5000m/120m	Entire Ignace area	1975 1979 1996	Grids of potassium, equivalent uranium, equivalent thorium, natural air absorbed dose rate, and ratios of eU/K, eTh/K and eU/eTh were extracted from the GSC's nationwide radiometric compilation.

Sturgeon-Savant Lake Survey (GDS1033)	OGS	Helicopter magnetic, FDEM (Aerodat 4 frequency)	200m/45m	Covers 48.1 km^2 in northeast corner of Ignace area	1990	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic coverage, and provides electromagnetic coverage.
Lumby-Finlayson Lakes Survey (GDS1060)	OGS	Helicopter magnetic, TDEM (Aerotem III)	200m/81m	Covers 40.3 km^2 in southeast corner of Ignace area	2009	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic coverage, and provides electromagnetic coverage.
Stormy Lake Survey (GDS1107)	OGS	Fixed wing magnetic, TDEM (Geotem III)	200m/73m	Covers 2,050.7 km^2 in western part of Ignace area	2001	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic coverage, and provides electromagnetic coverage. Covers the entire Revell batholith
Takara Resources Survey (AFRI 20000003895)	OGS	Fixed wing magnetic, radiometric	100m/60m	Covers 300 km^2 in northwestern corner of Ignace area	2008	Magnetic and radiometric surveys flown in 2008 for Takara Resources over a block measuring roughly 20 km by 15 km, focused on the southeastern part of the Basket Lake batholith.

Table B-3: Summary of Geological Mapping Sources for the Ignace Area

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
M1960H	Dyment area, District of Kenora, Ontario	Satterly, J.	ODM	1:31180	1960	partial	Detailed mapping covering portions of the Revell batholith
P.964	Operation Ignace-Armstrong, Ignace-Graham Sheet, Districts of Thunder Bay, Kenora and Rainy River	Sage, R.P. Breaks, F.W. Stott, G.M. McWilliams, G.M.	ODM	1:126720	1974	partial	Detailed mapping over much of the eastern part of the Ignace area. Some structural measurements.
P.1579	Ontario Mineral Potential, Ignace Sheet, Districts of Thunder Bay, Kenora, and Rainy River; Ontario	Springer, J.	OGS	1:250k	1978	full	Background regarding mineral potential.
P.3068 to P.3070	Precambrian Geology of the Melgund Lake Area, McAree Township. Kenora District	Berger. B.R. MacMillan. D. Butler, G.	OGS	1:15840	1987	partial	Detailed mapping of a portion of the Basket Lake batholith.
P. 3318	Precambrian Geology of Pegmatite #1, Raleigh Lake Area	Breaks, F.W. Numnikivi, M.	OGS	1:125	1995	partial	Outcrop scale detailed map of a pegmatite occurrence.
P. 3364	Precambrian Geology, White Otter	Stone, D. Carter, J.	OGS	1:50k	1996 (Revised	partial	Mapping for the White Otter Lake

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
	Lake Area	Halle, J. Pufahl, P.			2007)		area. Includes outcrop-scale measurements (strike-dip-foliation).
P. 3386	Precambrian Geology of the Pekagoning Lake area	Stone, D Halle, J. Chaloux E.	OGS	1:50k	1998	partial	Detailed mapping of the southern part of the Islet pluton. Includes outcrop-scale measurements (strike-dip-foliation).
P. 3360	Precambrian Geology of the Ignace Area	Stone, D Halle, J. Chaloux E.	OGS	1:50k	1999 (Revised 2007)	partial	Detailed mapping of the Township of Ignace and surrounding lands. Includes outcrop-scale measurements (strike-dip-foliation).
P.3401	Precambrian Geology of the Bonheur Area	Stone, D. Halle, J.	OGS	1:50k	2000 (Revised 2005)	partial	Detailed mapping of the eastern portion of the Indian Lake batholith. Includes outcrop-scale measurements (strike-dip-foliation).
GSC 4270 P.3447	Geology and Tectonostratigraphic Assemblages, North Central Wabigoon Subprovince, Ontario	Percival, J.A. Whalen, J.B. Tomlinson, K.Y. McNicoll, V. Stott, G.M.	GSC/ OGS	1:250k	2002	partial	Covers area bordering the eastern fringe of the Ignace area. Useful background with respect to the geological history of the area.
GSC 4284 P.3448	Geology and Tectonostratigraphic Assemblages, South-Central Wabigoon Subprovince, Ontario	Stone, D. Tomlinson, K.Y. Davis, D.W. Frallick, P. Halle, J. Percival, J.A. Pufahl, P.	GSC/ OGS	1:250k	2002	partial	Covers most of the Ignace area. Useful background with respect to the geological history of the area.
P. 2229	Precambrian geology, central Wabigoon Subprovince area, northwestern Ontario	Stone, D.	OGS	1:250k	2010	partial	Detailed compilation map covering most of the Ignace area.
P. 3623	Precambrian geology of the Bending Lake area (north sheet)	Stone, D. Hellebrandt, B. Lange, M.	OGS	1:20k	2011	partial	Detailed mapping of the Bending Lake area. Includes outcrop-scale measurements

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
							(strike-dip-foliation) of large portions of the Revell batholith.
P. 3624	Precambrian geology of the Bending Lake area (south sheet)	Stone, D. Hellebrandt, B. Lange, M.	OGS	1:20k	2011	partial	Detailed mapping of the Bending Lake area. Includes outcrop-scale measurements (strike-dip-foliation) of portions of the Revell batholith and Islet pluton.
P. 2515	Precambrian geology of the Stormy Lake area	Stone, D. Paju, G. Smyk, E.	OGS	1:20k	2011	partial	Detailed mapping of the Bending Lake greenstone belt south of the Revell batholith. Includes outcrop-scale measurements (strike-dip-foliation).

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
6925 Century Avenue, Suite #100
Mississauga, Ontario, L5N 7K2
Canada
T: +1 (905) 567 4444

Golder Associates