NUCLEAR WASTE MANAGEMENT ORGANIZATION
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Phase 1 Geoscientific Desktop Preliminary Assessment, Terrain and Remote Sensing Study

TOWNSHIP OF IGNACE, ONTARIO

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

PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT

TERRAIN AND REMOTE SENSING STUDY

TOWNSHIP OF IGNACE, ONTARIO

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Prepared for:

G.W. Schneider, M.Sc., P.Geo.
Golder Associates Ltd.
6925 Century Avenue, Suite 100
Mississauga, Ontario
Canada L5N 7K2

Nuclear Waste Management Organization
22 St. Clair Avenue East 6th Floor
Toronto, Ontario
Canada M4T 2S3
NWMO Report Number: APM-REP-06144-0012

Prepared by:

D.P. van Zeyl, M.Sc.
L.A. Penner, M.Sc. P.Eng., P.Geo.
J.D. Mollard and Associates (2010) Limited
810 Avord Tower, 2002 Victoria Avenue
Regina, Saskatchewan
Canada S4P 0R7

EXECUTIVE SUMMARY

In November, 2011, the Township of Ignace, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process, and requested that a preliminary assessment be conducted to assess the 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.

The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated report (NWMO, 2013). The objective of the desktop geoscientific preliminary assessment is to determine whether the Township of Ignace and its periphery, referred to as the "Ignace area, contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

This report presents the findings of a terrain and remote sensing assessment completed as part of the desktop geoscientific preliminary assessment of the Ignace area (Golder, 2013). The assessment provides information on the nature and distribution of overburden deposits in the area, and discusses the role of drift deposits in concealing and censoring the lengths of lineaments. The main information sources used include the Canadian Digital Elevation Data (CDED) elevation model, the SPOT satellite imagery, and the maps and reports from the Northern Ontario Engineering Geology Terrain Study (NOEGTS). The assessment addresses the following seven objectives:

- Evaluate the nature, areal extent and depth of overburden materials;
- Delineate areas of exposed bedrock or relatively thin overburden cover;
- Identify features that may preserve evidence of neotectonics;
- Establish the main site accessibility constraints;
- Determine and/or confirm watershed and sub-catchment boundaries;
- Infer groundwater recharge and discharge zones and divides; and
- Infer regional and local groundwater and surface flow directions.

The report provides an overview of the bedrock and Quaternary geology within the Ignace area, including estimates of overburden thickness. Drainage divides delineated in the provincial

quaternary watershed file were confirmed using the CDED surface model. Groundwater flow within drift deposits and in shallow bedrock aquifers in the Ignace area is expected to mimic the pattern of surface flow, with groundwater divides coinciding with drainage divides and discharge occurring into creeks, rivers, lakes and wetlands.

Conclusive identification of features indicative of paleo-seismic events and reactivation of ancient bedrock structures due to cycles of glacial loading and unloading cannot be identified using currently available sources of information. Field investigations would be required to identify such features. The main accessibility constraints in the Ignace area are large lakes, rivers, and steep slopes. The Ignace area contains an abundance of primary roads and dense networks of secondary roads are present in some areas of active forest harvesting. The main roads and forestry roads provide good access for site reconnaissance aimed at preliminary site characterization.

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1 INTRODUCTION

In November, 2011, the Township of Ignace, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Ignace area for safely hosting a deep geological repository (Step 3). 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 (NWMO, 2013).

This report presents the findings of a terrain and remote sensing assessment completed as part of the desktop geoscientific preliminary assessment of the Ignace area (Golder, 2013). The objective of the desktop geoscientific preliminary assessment is to determine whether the Township of Ignace and its periphery, referred to as the "Ignace area", contain general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

1.1 OBJECTIVES

This report presents an analysis of the terrain in the Ignace area using existing remote sensing and geoscientific information sources. The report provides information on the nature and distribution of overburden deposits in the area, and discusses the role of drift deposits in concealing and censoring the lengths of lineaments. The main information sources relied on in this terrain assessment are the Canadian Digital Elevation Data (CDED), the SPOT satellite imagery, and the maps and reports from the Northern Ontario Engineering Geology Terrain Study (NOEGTS). Additional data sources included the Water Well Information System, the Ontario Drill Hole Database, and the Assessment File Research Imaging (AFRI) database. This assessment makes use of remote sensing and geoscientific information sources to address the following seven objectives:

- Evaluate the nature, areal extent and depth of overburden materials;
- Delineate areas of exposed bedrock or relatively thin overburden cover;
- Identify features that may preserve evidence of neotectonics;
- Establish the main site accessibility constraints;
- Determine and/or confirm watershed and sub-catchment boundaries;

- Infer groundwater recharge and discharge zones and divides; and
- Infer regional and local groundwater and surface flow directions.

The objectives above were carried out for the Ignace area (Section 1.2) using the data and methodology described in Section 1.3.

1.2 IGNACE AREA

The Ignace area is approximately 88.5 km by 70.1 km in size, encompassing an area of about 6,200 km^2 (Figure 1). The approximate western, northern, eastern and southern limits of the Ignace area are (UTM Zone 15, NAD83): 545048, 5509876, 633551, and 5439828 m. The settlement area of Ignace is located on the northeast shore of Agimak Lake.

1.3 DATA AND METHODS

This section summarizes the remote sensing and geoscientific data sources that were used in the terrain study for the Ignace area, including an evaluation of the quality of the data. The data sets are all publically available.

1.3.1 NOEGTS

Overburden deposits within the Ignace area were mapped as part of a program undertaken between 1977 and 1980 entitled the Northern Ontario Engineering Geology Terrain Study (NOEGTS). These studies divided the landscape into a set of distinct terrain units within which the engineering characteristics are broadly predictable. The terrain units were delineated by identifying landforms from black and white air photos taken in the late 1960s and early 1970s at a scale of approximately 1:50,000. Interpreted terrain units were checked against published and unpublished maps and reports that documented previous field visits and observations. A limited amount of fieldwork was undertaken in 1978, which involved observing terrain conditions from roads in order to corroborate the aerial photo interpretation. The results of the terrain studies were intended to provide a framework for regional planning and a database on which to conduct site studies. 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.

Recently, the Ontario Geological Survey (OGS) digitized the NOEGTS maps and published the digital data in the form of a miscellaneous release of data (OGS, 2005a). For the current assessment, JDMA clipped part of the NOEGTS digital map layer and then transformed it from geographic coordinates into Universal Transverse Mercator (UTM) projection (Zone 15).

Four Northern Ontario Engineering Geology Terrain Studies (Mollard and Mollard, 1980a, b; Roed, 1980b, d) along with six maps at a scale of 1:100,000 (Mollard, 1980a, b, c, d; Roed, 1980a, c) describe the terrain conditions in the Ignace area. These reports provide background information on the physiography, and bedrock and Quaternary geology, followed by descriptions of the occurrence and nature of the engineering geology terrain units outlined on the accompanying maps. The terrain reports include estimates of the distribution and thickness of overburden deposits. They also discuss the influence of the terrain conditions on general construction (e.g., location and construction of highways, town sites, waste disposal sites, cottage subdivisions, airfields), aggregate resource potential (e.g., asphalt aggregate, traffic gravel, base course and sub-base for pavement structures) and groundwater resource potential.

1.3.2 CDED

This subsection describes the digital elevation model used to evaluate the terrain in this assessment. Section 4.2 describes the drainage basin analysis conducted in this assessment using the CDED elevation model as the representation of the landscape.

Canadian Digital Elevation Data, 1:50,000 scale, 0.75 arc second (20 m) elevation models (GeoBase, 2011a) served as important data sources for analyzing and interpreting the terrain in the Ignace area. The digital elevation model (DEM) used for this assessment was constructed by Natural Resources Canada (NRCan) using data assembled through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (OMNR). The source data were 1:20,000 scale topographic map data generated through the Ontario Base Mapping (OBM) program, which was a major photogrammetric program conducted across Ontario between about 1978 and 1995. Four main OBM data sets were used: OBM contours, OBM spot heights, WRIP stream network, and lake elevations derived using the OBM spot heights and OBM water features. CDED data sets are provided in geographic coordinates, referenced horizontally using North American Datum 1983 (NAD83) and vertically based on the Canadian Geodetic Vertical Datum 1928 (CGVD28). Ground elevations are recorded in metres relative to mean sea level.

CDED generally provides a good quality representation of the land surface in high relief areas. However, relatively poor quality representation can be found in flat areas, where the elevation model is, in some instances, based on elevation values obtained from a single elevation contour, with large areas around the contour where elevation values must be interpolated. These areas display a distinct stair-step or terraced pattern in the DEM. Slope values are relatively steep along the margins of these steps, as the step represents an artificially abrupt shift in elevation.

JDMA converted the elevation matrices provided by GeoBase from geographic coordinates to UTM projection using bilinear resampling, which assigns a value to each output cell based on a weighted average of the four nearest cells in the input raster. Compared with cubic convolution, bilinear resampling can sometimes produce a noticeably smoother surface, whereas cubic convolution can produce a sharper image. However, the differences between the two methods are generally trivial and the selection of bilinear resampling made here was arbitrary. After projection, each file was assembled into a single-band mosaic with a 20 m cell size and 32-bit pixel type.

Surface analyses were performed on the digital elevation model in order to characterize slope and relief. Slope was calculated using the standard grid-based method employed in ArcGIS, which involves fitting a plane to the elevation values of a three by three neighbourhood centred on the processing cell. Slope is defined as the maximum slope of that plane, which can also be thought of as the dip of the plane, and aspect is equivalent to the dip direction. Relief was calculated in two ways. The first was by subtracting the average elevation within a radius from the elevation value in the processing cell. The second was defined as the range in elevation within a circular window. The second relief calculation represents a high pass filter. The density of steep slopes was calculated as the number of points with a slope of at least 6° within a 2 km radius. The threshold of 6° was found to be effective in distinguishing between the rugged bedrock-controlled areas and the areas of gentle slope associated with thicker overburden cover.

1.3.3 SPOT

SPOT multispectral orthoimagery at a resolution of 20 m and panchromatic imagery at 10 m resolution formed an important information source for identifying exposed bedrock within the Ignace area (GeoBase, 2011b). SPOT multispectral data consist of several 8-bit bands, each recording reflected radiation within a particular spectral range. SPOT 5 images were acquired using the HRG sensor (Table 1). Each image covers a ground area of 60 km by 60 km.

For quality control, NRCan provides images that have a maximum of 5% snow and ice cover, 5% cloud cover and a maximum viewing angle of 15°. NRCan orthorectified the SPOT images using three data sources: 1:50,000 scale Canadian Digital Elevation Data (CDED), National Road Network (NRN), and Landsat 7 orthoimagery. The orthoimages are provided in GeoTIFF format, projected using Universal Transverse Mercator (UTM) projection referenced to the North American Datum 1983 (NAD83). A comparison of lake shorelines in the SPOT imagery with those delineated in the Ministry of Natural Resources (MNR) waterbody file suggests that the georeference is generally accurate to within 20 to 40 m or better.

Six SPOT images (or 'scenes') provided complete coverage for the Ignace area (Table 2). The scenes are from the SPOT 5 satellite with three images acquired in May 2006 and three in October 2007. The images captured during May cover the western part of the Ignace area, whereas the images captured in October cover the eastern part.

In order to assist with the interpretation of the location and extent of bedrock outcrops in the Ignace area, JDMA performed two types of multivariate analyses on the SPOT multispectral data: principal component analysis and unsupervised classification. Prior to performing these analyses, water bodies were removed from the SPOT images in order to maximize contrast in the dry areas. This was accomplished by removing values from the shortwave-infrared band (band 4) that were below a threshold. The shortwave band displays a bimodal histogram with one high-valued mode representing dry land surfaces that reflect shortwave radiation and a lower-valued mode for areas that largely absorb shortwave radiation. The latter generally represents water bodies, but can also represent dark forest areas or shadows in front of north-facing cliffs where sunlight is absorbed.

Principal component analysis based on all four SPOT bands was found to generate composite images that provided the best definition of the various land cover types thereby enabling optimal interpretation of the presence of bedrock exposures. For that purpose, principal component analysis generally produced composite images that were at least slightly superior to those produced by combining any of the raw SPOT bands. For each image, four components were generated and then the first three components were used to generate the composite image, referred to as the PCA composite image. Campbell (1987) provides more information on the use of principal component analysis in remote sensing.

Table 1 Characteristics of SPOT 5 multispectral bands.

Satellite, sensor, band no.	Wavelength (µm)	Pixel size (m)
SPOT 5, HRG, B1	0.50-0.59 (green)	20
SPOT 5, HRG, B2	0.61-0.68 (red)	20
SPOT 5, HRG, B3	0.78-0.89 (near-infrared)	20
SPOT 5, HRG, B4	1.58-1.75 (shortwave-infrared)	20

Table 2 List of SPOT 5 multispectral images acquired.

Scene ID	Satellite	Date of image
S5_09153_4954_20060529	SPOT 5	May 29, 2006
S5_09204_4925_20060529	SPOT 5	May 29, 2006
S5_09216_4857_20060529	SPOT 5	May 29, 2006
S5_09105_4954_20071025	SPOT 5	October 25, 2007
S5_09120_4925_20071025	SPOT 5	October 25, 2007
s5_09134_4857_20071025	SPOT 5	October 25, 2007

An unsupervised classification aimed at mapping bedrock exposures was attempted, but was eventually abandoned and is only described below for reference. Unsupervised classification generates distinct unimodal groups from the four SPOT bands using an iterative self-organizing (ISO) cluster procedure employed within ArcGIS. The ISO cluster algorithm is an iterative process that computes the minimum Euclidean distance when assigning each candidate cell to a cluster. The first step that JDMA took in the unsupervised classification was to classify the four SPOT bands into fifteen classes and to interpret the fifteen classes in light of the features (e.g., bedrock outcrops, clearcuts) interpreted in the PCA composite image. If a set of the fifteen classes delineated the interpreted bedrock exposures exclusively, then this completed the classification and these classes were used to generate a map depicting bedrock exposures. However, in many cases the classes mapping bedrock exposures also mapped wetlands and clearcuts. The next step was to mask the four SPOT bands in order to exclude areas that were both distinctly unrelated to bedrock exposures and effectively delineated by a set of classes, such as areas with a high vegetation index. The cluster analysis was then performed a second time on the masked data.

After several attempts at the unsupervised classification, the only areas where this type of technique could be used in a straightforward way were in the areas undisturbed by the forest industry in recent decades. It is difficult to make an accurate appraisal of the extent of bedrock exposure within fresh clearcuts. Some of the exposed land within fresh clearcuts represents exposed mineral soil rather than bedrock. Even in the areas not disturbed by the forest industry, there remain challenges in using unsupervised classification to map the exposed bedrock accurately and reliably. For instance, certain parts of wetlands can exhibit similar spectral characteristics as exposed bedrock. Alluvial sediments exposed in creek valleys also display similar spectral properties. Additional issues contribute to the unreliability of this technique. As a result, the identification of bedrock exposure from SPOT imagery in this assessment (Section 5.2.5) has relied on the PCA composite images.

1.3.4 DRILL HOLES AND WATER WELLS

A preliminary review was made of data on overburden thickness obtained from databases compiled by the OGS and the Ontario Ministry of the Environment (MOE). Section 5.1 summarizes the results of the subsurface information reviewed, and in Section 5.2, these data are used to supplement the more comprehensive data compiled from the NOEGTS reports. At this stage in the preliminary assessment, the descriptions of the extent, nature and thickness of overburden deposits provided in the NOEGTS reports are superior to the information generated from water well and drill hole data as part of the current assessment.

Water well records from the Ministry of the Environment Water Well Information System for the Ignace area were acquired (MOE, 2012). The geographic coordinates of the water wells appear to be generally accurate to within about 50 m, but one of the wells appears to be displaced by about 380 m into a swamp from the only nearby property shown in the SPOT imagery, indicating that the positional accuracy of the wells can be questionable. Thirty-three well records within the Ignace area were found to contain data on depth to bedrock, most of which are located within the Township of Ignace, surrounding Agimak Lake. The wells were drilled between 1963 and 2006.

The Ontario Drill Hole Database was compiled by the Ontario Geological Survey from assessment files, with the most recent official release of the database in December 2005 (OGS, 2005b). A preliminary analysis of the drill hole database was completed during this assessment. Several assessment files were reviewed to check the drill hole locations and depth to bedrock data and to better understand the terrain conditions in the areas where drilling had taken place. Assessment files are stored in the Assessment File Research Imaging (AFRI) database held by the

OGS. Some of the assessment files contain descriptions of overburden cover, site accessibility and other useful information, including photographs of work sites.

The OGS establishes the geographic coordinates of the drill holes using one of a variety of methods, including some approximate georeferencing methods, such as positioning the drill hole in the centre of a claim for lack of additional supporting information. Some of the drill hole plans submitted in assessment files are very difficult to interpret. As a result, the location of the drill holes can be off by hundreds of metres in some cases. This makes interpreting the depth to bedrock information in light of terrain conditions interpreted from SPOT imagery difficult, as a distance of 100 to 200 m can mean the difference between a hilltop location and a location between rock ridges where drift would be expected to be thicker.

Within the Ignace area, the drill holes are generally located southwest of the Trans-Canada Highway, within the Raleigh Lake and Bending Lake greenstone belts, which provides complimentary coverage in areas lacking MOE water well records.

Some manipulation of the OGS diamond drill hole data was necessary to obtain estimates of drift thickness. Firstly, some of the holes were drilled during winter from drill rigs stationed on lake ice. As a few of the holes with the greatest depth to bedrock recorded are shown in the SPOT imagery and confirmed through review of the original assessment files to be positioned on lakes, it is assumed that the recorded length of drill hole down to bedrock includes the water column. As a result, as a first attempt to eliminate this issue, the drill holes located within 50 m of lakes were excluded from the analysis. However, it is not known if this procedure effectively excluded all drill holes drilled from lake ice, because the positional error in the drill hole coordinates is known to be much larger than 50 m in some cases. Unfortunately, the database does not include information on what month the drilling took place, since if it did then this would more effectively allow for the exclusion of holes drilled on lake ice by excluding holes drilled within a distance of lakes during the winter months. Secondly, the dip angles of the drill holes below horizontal ranges from 30 to 90° and an average dip of about 50°. As a result, the vertical depth to bedrock had to be calculated from the recorded dip angle and length of drill hole to bedrock.

Data on depth to bedrock obtained from the Ontario Drill Hole Database must be interpreted carefully. Drilling often is carried out in areas where extensive stripping of the overburden has taken place, and some drill sites might be preferentially located in areas of thin overburden, biasing the drift thickness data to low values. Without knowing the terrain conditions where the drilling took place, it is generally unclear over what areas the data on depth to bedrock are representative.

2 SUMMARY OF GEOLOGY

A detailed discussion of the geological setting of the Ignace area, including bedrock geology and structural history, is provided in a separate report (Golder, 2013), and a summary is presented below.

The Ignace area is underlain by Archean bedrock of the Superior Province of the Canadian Shield – a tectonically stable craton created from a collage of ancient plates and accreted juvenile arc terranes (Card and Ciesielski, 1986; Percival and Easton, 2007). 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. The Superior Province has also 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 portion of the Wabigoon Subprovince, which is characterized by thin, bifurcated and anastomosing greenstone belts separated by large, commonly oval-shaped masses of felsic plutonic rocks. 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., 1992). The Wabigoon Subprovince is further subdivided into three lithotectonic terranes: the granitoid Marmion terrane, the predominantly volcanic Western Wabigoon terrane, and the plutonic Winnipeg River terrane. The Ignace area includes portions of all three terranes. 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).

The following sections on bedrock geology and structural history, present summaries of the information presented in Golder (2013), in order to provide the necessary context for discussion of the results of this terrain analysis.

2.1 BEDROCK GEOLOGY

The bedrock geology of the Ignace area is described in detail in Golder (2013), and the following is a summary of that information. The bedrock geology of the Ignace area is dominated by a number of granitic to granodioritic batholiths (Stone, 2010a). These large rock masses intruded into the metavolcanic and metasedimentary supracrustal rocks of the Raleigh Lake and Bending Lake greenstone belts, and to a lesser extent the Phyllis Lake greenstone belt, as well as an older assemblage of foliated and/or gneissic tonalites. The initial screening report for the Ignace area (Golder, 2011) identified a number of geological units with geoscientific characteristics that are potentially suitable for hosting a deep geological repository within the Ignace area. These units include the Indian Lake batholith, as well as the White Otter Lake and Revell batholiths. The bedrock of the Ignace area exhibits evidence of both ductile and brittle deformation and is transected by at least two suites of undeformed diabase dykes.

2.1.1 INTRUSIVE ROCKS

The Indian Lake batholith (approximately 2.671 billion years old; Tomlinson et al. 2004) is composed of medium- to coarse-grained, massive to weakly foliated, light grey-white to pale pink biotite granite. Available detailed geological mapping of the Indian Lake batholith suggests that the majority of this body is compositionally uniform (Stone et al., 2007b). The batholith measures approximately 55 km in length from west to east and 25 km from north to south within the Ignace area. It underlies the Township of Ignace and extends beyond the township boundaries for a considerable distance to the east, covering a total surface area of approximately 1,600 km^2 (Figure 2). The Indian Lake batholith is bounded by the Raleigh Lake greenstone belt along its southwestern and southernmost margins and elsewhere by gneissic tonalite.

The White Otter Lake batholith (approximately 2.685 billion years old; Buse et al., 2010) is composed of medium- to coarse-grained, light grey-white to pink biotite granite. Available detailed geological mapping of the White Otter Lake batholith suggests that the majority of this body is compositionally uniform (Stone et al., 2007a). The batholith measures approximately 65 km in length from west to east and 20 km from north to south within the Ignace area. The batholith continues for a considerable distance to the south beyond the Ignace area boundary. The White Otter Lake batholith is bounded by the Raleigh Lake and Bending Lake greenstone belts as well as gneissic tonalite along its northwestern and northern margins and elsewhere primarily by gneissic tonalite.

The Revell batholith is an elongate northwest trending pluton extending 40 km in length and 10 to 15 km in width. The Revell batholith is a compositionally heterogeneous igneous body with distinct and internally mappable early, intermediate and late phases (Stone et al., 2007a; Stone et al., 2011a; 2011b). The earliest phase of the Revell batholith is an oval-shaped body of biotite tonalite (approximately 2.734 billion years old; Stone et al., 2011b) exposed primarily in the southeastern corner and along the western margin of the batholith (Figure 2). An intermediate phase identified as hornblende tonalite (approximately 2.732 billion years old; Stone et al., 2011a; 2011b) is mapped along its southwestern and northeastern margins. The late phase of the Revell batholith is characterized generally as a biotite granodiorite to granite and also includes potassium-feldspar megacrystic biotite granite. A sample of the megacrystic facies, from the centre of the Revell batholith, yielded an age of approximately 2.694 billion years old (Buse et al., 2010; Stone et al., 2011a). The Revell batholith is surrounded by the Raleigh Lake and Bending Lake greenstone belts.

An additional large igneous body, the Basket Lake batholith, is exposed in the northwestern corner of the Ignace area (Figure 2). The Basket Lake batholith measures approximately 10 to 15 km in width from southwest to northeast and 35 km in length from northwest to southeast. Almost half of this batholith extends beyond the Ignace area to the northwest. The Basket Lake batholith has a granodioritic to quartz-monzonitic composition (Stott, 1973; Sage et al., 1974). 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.

The Ignace area hosts a number of additional, smaller felsic to intermediate plutons such as the Islet and Paddy Lake plutons in the southwestern corner of the Ignace area, the Adele Lake and Norway plutons in the southeastern corner of the Ignace area, the Melgund Lake stock in the northwest corner of the Ignace area, and the Raleigh Lake intrusions in the centre of the Ignace area (Figure 2). The Islet pluton is compositionally heterogeneous, predominated by coarse-grained, grey to pink, and massive diorite to monzonite with local mafic phases as well as granitic units around its margins. It is considered to be a member of the sanukitoid suite of late intrusive rocks, and has a potential association with gold and platinum group metal mineralization (Stone, 2009a). No direct age determinations have been documented for the Islet pluton, however sanukitoid plutons cross-cut most other lithologies and show a narrow range of ages from approximately 2.697 to 2.684 billion years old (Stone, 2010a). The Paddy Lake pluton is composed of coarse-grained and strongly banded biotite tonalite. A high degree of strain within the pluton fabric precludes a precise interpretation of its origin as either a product of magmatic processes or a strongly deformed arkosic sedimentary rock (Stone, 2009b). No direct age determinations have been documented for the Paddy Lake pluton. The Adele Lake pluton is a compositionally heterogeneous rock mass with distinct, and internally mappable, phases (Stone et al., 2007a and 2007b). The predominant phase is biotite tonalite to granodiorite, which is locally gneissic (approximately 2.989 billion years old; Tomlinson et al., 2001). Additional phases include tonalite to granodiorite gneiss and hornblende tonalite (approximately 2.721 billion years old; Tomlinson et al., 2001). The Norway pluton (approximately 2.690 billion years old; Stone, 2010a) and the Melgund Lake stock are additional examples of the compositionally heterogeneous sanukitoid suite described above. The Raleigh Lake intrusions comprise three epizonal granitic stocks enclosed within the metavolcanic rocks of the Raleigh Lake greenstone belt (Figure 2). These small bodies are compositionally similar to the large granodioritic to granitic batholiths that dominate the Ignace area.

The majority of the region in the northeastern portion of the Ignace area surrounding the Basket Lake and Indian Lake batholiths has been mapped as compositionally heterogeneous tonalitic gneiss and foliated tonalite (Figure 2). Throughout the Wabigoon Subprovince these gneisses yield a broad range of ages (approximately 3.009 to 2.673 billion years old) and appear to exhibit an episodic history of development. The tonalitic gneisses show a wide variety of textures, folding and strongly foliated to mylonitized zones. Locally, tonalite gneiss is gradational in composition to amphibolite gneiss of volcanic or migmatized sedimentary rock origin. More felsic phases are gradational to biotite tonalite and are cut by felsic dykes of the younger plutonic suites (Stone, 2010a). Although mapped as distinct plutonic units, the Paddy Lake and Adele Lake plutons described above are a subset of this complexly deformed and poorly defined suite of crystalline rocks.

2.1.2 Mafic dykes

Mafic dykes are widespread throughout the Superior Province including multiple generations (the Kenora-Fort Frances, Wabigoon, and Eye-Dashwa swarms) of dyke emplacement between approximately 2.5 and 1.0 billion years ago (Osmani, 1992). Within the Ignace area, early dyke emplacement, typically in a northwesterly orientation, occurred between approximately 2.20 and 1.96 billion years ago, represented by the Kenora-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 100 to 200 m in width. Fahrig and West (1986) give a K/Ar age of approximately 1.900 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 approximately 90,000 km^2 (Osmani, 1992). Within the Ignace area, Kenora-Fort Frances dykes occurs in clusters in the Melgund 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 approximately 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 approximately 1.150 to 1.130 billion years ago (Easton et al., 2007). Kamineni and Stone (1983) give K/Ar ages of approximately 1.132 and approximately 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 (Heaman and Easton, 2006; Easton et al., 2007). Though Eye-Dashwa swarm dykes are mapped by the OGS in the surrounding region, none are identified in the Ignace area.

2.1.3 GREENSTONE BELTS

Metavolcanic/metasedimentary rocks occur in the western portion of the Ignace area within the Bending Lake and Raleigh Lake greenstone belts, and to a lesser extent in the eastern portion of the area within the Phyllis Lake greenstone belt (Figure 2). Together these greenstone belts cover approximately 458 km2 within the Ignace area. The metavolcanic and metasedimentary supracrustal rocks in the greenstone belts show intense planar fabrics of tectonic origin with complex curved trajectories that parallel geologic contacts (Stone et al., 1998; Stone, 2010a).

The Bending Lake greenstone belt occurs south of the Revell batholith and trends northwesterly. It is mostly composed of mafic metavolcanic rocks, gabbro, intermediate metavolcanic rocks, and clastic metasedimentary rocks (wacke and argillite; Stone, 2010a). The Raleigh Lake greenstone belt occurs north of the Revell batholith and also trends northwesterly. Although dominated by mafic metavolcanic rocks, the Raleigh Lake greenstone belt contains about thirty percent intermediate to felsic fragmental metavolcanic rocks (Stone, 2010a). These two greenstone belts coalesce and extend for a considerable distance beyond the northern and western boundaries of the Ignace area as part of the approximately 2.745 to 2.712 billion years old Kakagi Lake-Savant Lake volcanic belt (Stone, 2010a). 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. A felsic tuff (approximately 2.955 billion years old; Tomlinson et al., 2003) and a conglomeratic unit with detrital zircon ages of between 2.718 and 2.700 billion years old (Tomlinson et al., 2001) provide bounding constraints on the age of the Phyllis Lake greenstone belt.

2.1.4 FAULTS

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. 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).

The only regional-scale faults that have been mapped within the Ignace area are the northeast-trending Finlayson-Marmion fault zone located approximately 35 km southeast of the Township of Ignace and the east- trending Washeibemaga Lake fault (referred to as the "Bending Lake fault" by Stone, 2009b), located approximately 28 km west of the Township of Ignace (Figure 2). These two fault orientations, trending northeast and east, are considered to be consistent with the orientation of known fault structures at the regional scale. For example, larger subprovince-bounding faults such as the east-trending Quetico fault to the south of the Ignace area, which is characterized as a dextral-sense strike-slip fault structure (e.g., Kameneni et al., 1990).

The northeast-trending Finlayson-Marmion fault zone occurs as a broad zone of strike-slip ductile to brittle-ductile deformation (Stone and Halle, 1999). It is one of several splayed, northeast-trending, structural features evident at the regional scale (Figure 2). The fault is a complex braided structure with strong aeromagnetic contrast showing bifurcations and splays occurring in both the horizontal and vertical planes. 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 offset at Lumby Lake, in the southeastern part of the Ignace area. Stone (2010a) reports that the Finlayson-Marmion fault zone does not cut the Steep Rock Lake greenstone belt to the south of the Ignace area, and therefore may have ceased to move by approximately 2.780 billion years ago, although the cross-cutting relationship between the fault and the approximately 2.671 billion year old Indian Lake batholith indicates that the temporal constraints of the Finlayson-Marmion fault zone 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 2). 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 Era (Kamineni et al., 1990; Stone, 2009a).

2.1.5 METAMORPHISM

Metamorphism in the Central Wabigoon region, 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 approximately 2.701 billion years ago (Easton, 2000). 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 in the Central Wabigoon region is generally restricted to greenschist facies, and increases locally to middle-amphibolite facies in some rocks of the greenstone belts (Sage et al., 1974; Blackburn et al., 1992; Easton, 2000; Sanborn-Barrie and Skulski, 2006). Very high-grade (i.e. granulite facies) or very low-grade (eg. zeolite facies) metamorphism is largely absent from the central Wabigoon (Stone, 2010a).

A low to medium grade metamorphic overprint is recognized within the rocks of the Ignace area, mainly within the rocks of the Raleigh Lake and Bending Lake greenstone belts and within marginal zones of the Revell batholith. High metamorphic grade in the Ignace area is found in tonalite rocks surrounding plutons and greenstone belts, where there is widespread migmatization of rocks. In the Raleigh Lake greenstone belt, greenschist facies metamorphic grade varies to amphibolite facies. Presence of the mineral assemblage of garnet+amphibole+feldspar+biotite is widespread in the rocks of the greenstone belt (Stone et al., 1998) and numerous amphibolite and garnetiferous layers and clasts are found in rocks of the belt (Blackburn and Hinz, 1996). 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 variable metamorphic grade, up to amphibolite facies. Rocks at the margins and in thin extensions of the 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 greenschist facies metamorphism within the metavolcanic rocks bordering the northwest part of the Revell batholith in Melgund and Revell townships, which grade to amphibolite facies near the contact with the Revell batholith. These observations imply a contact metamorphic aureole associated with the emplacement of the batholith. Stone (2010a) used aluminum in hornblende geobarometry to determine that the approximately 3.0 to 2.72 billion year old phases yielded average crystallization pressures of approximately 6 kilobars, while the approximately 2.690 billion year old and younger plutonic intrusions (such as the Indian lake, Revell, and Indian Lake batholiths) crystallized at approximately 4 kilobars.

2.2 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. It is understood that there are potential problems in regional correlation of specific structural events within a Dx numbering system and in the application of such a system to the local geological history. Nonetheless, this summary represents an initial preliminary interpretation for the Ignace area, which may be modified after site-specific information has been collected.

The description provided here is based primarily on available structural syntheses of portions of the Western Superior Province (Kamineni et al. 1990; Percival, 2004; Bethune et al., 2006; Sanborn-Barrie and Skulski, 2006; Stone, 2010a) and is a summary of the detailed history documented in Golder (2013). Five episodes of penetrative strain (D_1 to D_5) have affected the central Wabigoon Subprovince (Kamineni et al, 1990; Percival, 2004). The D_5 event may have spanned the transition between ductile and brittle deformation. D_5 was followed by a poorly constrained D_6 episode of localized brittle deformation (e.g. Peterman and Day, 1989).

The first two episodes of deformation, D_1-D_2, produced and subsequently modified an S1 gneissic layering through the progressive development and overprinting of this foliation by tight to isoclinals 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 Wabigoon Subprovince. The D_1-D_2 episode is estimated to have occurred between approximately 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. 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 approximately 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 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 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 approximately 2.671 billion years old Indian Lake batholith suggests that D_5 continued longer than has been documented. This is also consistent with the interpretation by Kamineni et al. (1990) that suggests regional east-oriented dextral transpression occurred along major terrane bounding shear zones between approximately 2.685 and 2.500 billion years ago, including the regional-scale Quetico fault. In addition, Hanes and Archibald (1998) suggest that approximately 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 approximately 2.690 and 2.400 billion years ago.

A D_6 episode of deformation is inferred to have potentially re-activated pre-existing faults in the Ignace area. 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 approximately. 1.900 billion years old Wabigoon dykes are straight and continuous across the Ignace area (Figure 2), and one dyke cuts across the Finlayson-Marmion fault zone without apparent offset. This relationship suggests that only limited fault movement, if any, has occurred along this fault since the emplacement of the Wabigoon dykes approximately 1.900 billion years ago.

A simplified geological history for the Ignace area and surrounding region is provided in Table 3.

Table 3 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 approximately 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).
ca. 2.745 to 2.711	A major period of volcanism, derived from subduction, occurred in the Winnipeg River-Marmion terrane (Blackburn et al., 1992). 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. 1.900	Emplacement of the west-northwest trending Wabigoon dyke swarm (Fahrig and West, 1986; Osmani, 1992).
ca. 1.13 to 1.14	Emplacement of the northwest trending dykes of Eye–Dashwa swarm (Kamineni and Stone, 1983).
Post-1.14	A complex interval of erosion, brittle fracture, repeated cycles of burial and exhumation, and glaciations, particularly from the latest Miocene to the present.

2.3 QUATERNARY GEOLOGY

This section provides an overview of the Quaternary geology to provide a framework for the details presented in Section 5 on the nature and extent of drift deposits in the area. Section 5 describes the role that these deposits play in concealing lineaments and censoring their lengths.

The Quaternary deposits in the Ignace area accumulated during and after the last glacial maximum, known as the Late Wisconsinan Glaciation, with a significant amount of the material deposited during the progressive retreat of the Laurentide Ice Sheet. Advancement of the Laurentide Ice Sheet from the northeast across the area deposited a veneer of till throughout the areas mapped as bedrock terrain on Figure 3 (Mollard and Mollard, 1980a), with thicker accumulations of till mapped as morainal terrain. During the retreat of the Laurentide Ice Sheet, significant deposition of glaciofluvial outwash and glaciolacustrine plains occurred, with the three major, north-west trending, end moraines extending through the Ignace area recording the progressive retreat of the ice sheet. From southwest to northeast across the Ignace area, these end moraines are the Eagle-Finlayson moraine, the Hartman moraine and the Lac Seul moraine.

The three, northwest-trending major end moraines in the area, although partly mapped as ground moraine (Figure 3), are generally formed of cross-stratified gravelly sand or sandy gravel of deltaic ice-contact origin, with only minor till inclusions (Mollard and Mollard, 1980b; Roed, 1980b). Barnett et al. (1998) describe the Hartman, Lac Seul, and Eagle-Finlayson moraines as stratified moraines comprising predominantly glaciofluvial and glaciolacustrine sediments even though diamicton can cover large surface areas of the moraines.

The Hartman moraine is a significant Quaternary landform in the Ignace area. Although it generally does not represent a first-order topographic feature, it divides the area into distinct zones based on the thickness of drift deposits. Thicker till, glaciofluvial outwash, and deep-water glaciolacustrine deposits occur north of this moraine, whereas surficial deposits are generally thinner to the south. Areas mapped as bedrock terrain to the north may represent the locations of scattered islands within a proglacial lake known as glacial Lake Agassiz that subsequently contracted into a set of large modern lakes (Mollard and Mollard, 1980a, b; Roed, 1980b).

Since the disappearance of the ice sheets and the gradual draining or drying up of glacial lakes about 9,000 years ago, modern streams have developed alluvial flood plains and organic deposits have accumulated in wet depressions. Many of the organic deposits in the area are located within the trough formed between the south flank of the Hartman moraine and a sub-parallel highland a short distance to the southwest (Figure 3). Further details are discussed in Section 5.

3 TOPOGRAPHY

Topography is an important aspect of the terrain, as it plays a role in controlling surface water and shallow groundwater flow directions and can reveal much about the bedrock structure and overburden deposits. The following descriptions of the topography in the Ignace area rely heavily on the representation of the landscape by the CDED digital elevation model.

3.1 ELEVATION

The landscape within the Ignace area (Figure 4) ranges in elevation from about 368 to 554 m, with this amount of relief being expressed over a lateral distance of about 80 km. The map of elevation allows for the delineation of the major and minor topographic features in the area. Section 4.3 describes drainage patterns associated with the major topographic highs and lows.

The major topographic high is an elongate feature about 20 km wide and 85 km long extending northwest from the southeast corner of the area (Figure 4). For convenience within this report, this feature has been termed the Revell-Gulliver highland by the authors. 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. This feature is split into separate blocks by distinct topographic lows clearly defined by the 460 m elevation contour shown on the inset map on Figure 4, where examples of these breaks have been labelled the Balmoral, Campus, Doan and Little Turtle lows for convenience in this report. The most prominent break is the Campus low, which represents a 90 m deep trench coinciding with the northwest margin of the Adele Lake Pluton. This low contains significant wetlands and is included within the Campus Lake Conservation Reserve (Figure 1). Structural control on the topographic lows breaking the Revell-Gulliver highland include 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 (Figure 2). Section 3.2 provides additional maps and description to help define the structurally controlled lows that bound blocks of high ground within the Revell-Gulliver highland.

The major topographic lows in the Ignace area are the outlets associated with the main rivers that drain the Revell-Gulliver highland, shown in blue and labelled on the inset map on Figure 4 as the

English, Wabigoon and Turtle lows. The Bending low is the surface expression, characterized by long narrow ridges and lakes, of the Bending Lake greenstone belt (Figure 2).

The major end moraines are the highest relief Quaternary deposits in the area. They are topographically evident in certain areas, but overall they generally do not represent first-order topographic features and large parts of them are barely discernible in the digital elevation model (Figure 4). Paralleling the Hartman moraine (Figure 3) to the southwest is a low-relief trough termed the Ilsley-Gulliver trough by the authors and shown on the inset map on Figure 4. Section 5.2.4 describes the extensive organic deposits found within this trough, which the Trans-Canada Highway avoids by generally traversing the high ground along the margins of this feature.

Knobs and ridges typically extend 90 to 100 m above the large lakes in the Basket Lake, Indian Lake and White Otter Lake batholiths (Figure 4). For example, most of the large lakes north of the Revell-Gulliver highland are at an elevation of about 400 m, with the highest nearby knobs and ridges extending to elevations of about 500 m.

3.2 RELIEF

Relief is a metric that can be defined in different ways, and the calculated value of relief depends on the horizontal dimension considered in the calculation. As indicated in Section 3.1, the total relief in the Ignace area is about 186 m, which places an upper limit on the amount of relief within local zones. Relief was calculated in two ways. The first was by subtracting the average elevation within a certain radius from the elevation value in the processing cell (termed departure), providing an indication of the degree to which a point is expressed negatively or positively within an area. The second was defined as the range in elevation within a circular window, providing an indication of the maximum relief within the window.

A map of departures from the average elevation within a 20 km radius (Figure 5) can be used to provide additional definition of high ground within the Ignace area, including further definition of the Revell-Gulliver highland and the areas of high ground within the batholiths. The inset map provided on Figure 5 shows the areas that are at least 15 m higher than average at this scale of calculation. The Revell batholith contains some large areas of high ground, whereas most of the areas of high ground in the Basket Lake, Indian Lake and White Otter Lake batholiths are isolated ridges or ridge complexes surrounded by large areas of low elevation.

A map of departures from the average elevation within a 2 km radius (Figure 6) can be used to highlight the nature of knobs, ridges and trenches in the more rugged parts of the Ignace area.

Knobs and ridges are shown in shades of red whereas trenches are shown in shades of blue. The inset map shown on Figure 6 displays the areas at least 10 m higher than average, which provides an image of the shapes and distribution of hills in the area. Mollard and Mollard (1980b) 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 view is illustrated by the long narrow ridges displayed in the Bending Lake greenstone belt ('Bending low' on Figure 6) as compared with the characteristic knobby terrain of the adjacent Revell batholith. Many of the knobs in the Basket Lake batholith and some in the Indian Lake and White Otter Lake batholiths (Figure 6) display 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.

A map showing the range in elevation within a 250 m radius (Figure 7) provides an indication of the location and extent of high and low relief areas within and between the batholiths. The upper limit of relief calculated at this scale is about 100 m. From Figure 7, and in particular the inset map, it appears that the main batholiths in the Ignace area can be ranked in order of decreasing occurrence of high relief as the White Otter Lake, Basket Lake, Revell and Indian Lake batholiths.

3.3 SLOPE

The distribution of slope within the Ignace area is highly skewed towards values less than about 10°, with values below this cutoff representing about 97% of the data. Only about 10% of the area is represented by a slope value of 6° or more (Figure 8). Part of the reason for this is the presence of large lakes represented in the digital elevation model as flat areas, but the flatness of the area is not restricted to the lakes. Even the rugged bedrock terrain is made up of areas of gentle slope interrupted only at the margins of knobs, ridges and trenches. The tops of ridges and knobs generally display gentler slopes than what is represented around their flanks. Some areas display a densely packed arrangement of knobs, trenches and ridges. Steep slopes are common in a band sometimes up to 500 m or wider extending around the margins of some lakes.

As indicated above, areas of steep slope form the margins of many of the rugged landforms in the Ignace area, such as ridges and knobs. As steep slopes on the surface of the Precambrian Shield are often associated with irregularities in the bedrock topography, with some notable exceptions (e.g., end moraines, kames, eskers), it is assumed that the presence of steep slopes in the Ignace area can be an approximate indicator of minimal overburden cover. Many of the extensive areas lacking steep slopes are relatively flat due to the presence of drift filling lows in the bedrock topography.

A map showing the density of steep (≥6°) slopes within a 2 km radius was prepared to provide a general indication of the areas where the thickness of overburden might be relatively low and conversely where the surficial deposits could be thicker (Figure 9). Examination of Figure 9 indicates that the areas associated with the White Otter Lake, Revell and Basket Lake batholiths are characterized by higher densities of steep slopes compared with the area around the Indian Lake batholith. This finding appears to correlate well with the extent of overburden cover associated with the main batholiths as shown on Figure 3.

The presence of thick drift will obstruct the identification and characterization of surface structures, such as lineaments. For example, areas of low slope density can be expected to be areas of low surface lineament density due to masking of the surface expression of lineaments by drift. In addition, thick drift can hinder bedrock-mapping activities, which can result in less confidence in the geologic model developed for the area.

The areas of low slope density shown on Figure 9 are areas where SPOT and CDED could be less reliable in identifying the presence or absence of a lineament. These are the areas where the lineament interpreter is blinded to some extent by the presence of thick overburden. The use of low slope density as an indicator of low confidence in identifying the presence or absence of a lineament also accounts for the areas covered by lakes, as the lakes are represented as flat surfaces in the digital elevation model. The use of slope density in this way is not applicable in all parts of the Canadian Shield. For example, some locations contain flat areas with minimal overburden cover and abundant bedrock exposure. In such cases, the bedrock topography itself contains minimal relief, so the flatness is not a product of drift filling the lows. The slope density map in the current assessment is only presented to suggest a broad pattern of areas where it could be relatively difficult to develop a detailed model of the bedrock structure and lithology.

4 DRAINAGE

Surface water and drainage are important factors to consider in the preliminary assessment. The larger lakes, some of which are 10 km or more across, can completely or partially conceal the surface expression of geological structures thus adding uncertainty to the results of a lineament interpretation comparing surficial and geophysical data sets (JDMA, 2013). Surface water flow is also a useful indicator of groundwater flow at shallow depth. Section 4.1 provides information on the size, distribution and depth of lakes in the Ignace area. Section 4.2 describes the existing watershed map file and the drainage analysis conducted by JDMA, and Section 4.3 describes surface drainage within the Ignace area.

4.1 WATERBODIES AND WETLANDS

The Ignace area contains a large number of lakes of various sizes, twenty-seven 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 area occupied by water bodies (Figure 10 and Table 4). The large lakes are sufficiently large to conceal geological structures up to about 10 km in length, and clusters of small lakes can conceal the surface expression of geological structures, especially when the lakes are located in areas covered by overburden.

In general, the lakes on the Revell-Gulliver highland are much smaller (< 20 km^2) than those located to the north and south (Figure 10). The Revell batholith contains no lakes larger than about five square kilometres, rendering this feature an area where a higher level of confidence can be obtained in identifying lineaments from SPOT and CDED. The largest lakes on this batholith are Revell Lake (5.1 km^2) and Mennin Lake (4.9 km^2). The Basket Lake, Indian Lake and White Otter Lake batholiths contain the largest lakes, which could contribute to uncertainty in the identification of surface lineaments in these areas.

Wetlands depicted on Figure 10 are from the Wetland Unit map file produced by the Ministry of Natural Resources, and obtained from Land Information Ontario. This file does not include some significant wetlands identified in the SPOT imagery. JDMA performed some preliminary infill mapping to improve the completeness of the wetlands map.

The main concentrations of extensive wetlands are located in three main settings. The largest concentration is located within the Ilsley-Gulliver trough, confined between the margins of the Hartman moraine and the Revell-Gulliver highland. The next largest concentration is located immediately southwest of the Lac Seul moraine. Finally, there is a large wetland within the Campus low, along which the Campus Creek extends. The wetlands in each of these areas can be expected to be associated with relatively thick, poorly drained overburden deposits.

Table 4 Size of lakes larger than 10 km^2 in the Ignace area.

Lake	Perimeter (km)	Area (km^2)
Dibble Lake	75.3	10.7
Bending Lake	61.1	11.3
Pekagoning Lake	56.4	11.6
Melgund Lake	56.8	12.0
Agimak Lake	46.6	12.5
Scotch Lake	56.6	12.6
Sandbar Lake	24.4	12.9
Abamategwia Lake	49.7	13.1
Wapageisi Lake	62.4	13.1
Irene Lake	39.5	14.4
Elsie Lake	34.9	14.5
Gulliver Lake	83.2	14.6
Cecil Lake	23.9	15.7
Nora Lake	69.4	16.2
Wintering Lake	68.8	16.6
Raleigh Lake	85.5	17.3
Long Lake	54.7	18.4
Paguchi Lake	70.0	24.9
Sandford Lake	82.2	29.3
Barrel Lake	111.0	30.4
Stormy Lake	123.9	34.7
Sowden Lake	68.2	37.6
Indian Lake	85.3	40.2
Kukukus Lake	177.1	41.9
Basket Lake	134.8	42.9
Mameigwess Lake	86.5	52.7
White Otter Lake	233.4	84.6

[1]Metrics obtained from LIO OHN Waterbody file (LIO, 2012)

Bathymetric maps can form a useful source of information for identifying surface structures and for understanding the vertical extent of lake basins. The Ministry of Natural Resources completed surveys of selected lakes in the late 1960s and early 1970s. The resulting bathymetry maps consist of contour plots based on soundings, with summary information in the map margin, such as maximum and mean depth. Although the point density of these surveys was likely limited, the contour maps can reveal sub-aqueous structural features that could support the delineation of new or existing surface features. Figure 10 indicates the lakes within the Ignace area for which bathymetry data exist. The inset map shows the depth contour map of Mameigwess Lake revealing the presence of a northward-trending, deep structure at least 12 km long. Except for Raleigh Lake, surveys exist only for lakes north of the Revell-Gulliver highland, which includes the Indian Lake and Basket Lake batholiths. The greatest known lake depth is 50 m, which was measured in Mameigwess Lake (Table 5), located over the Indian Lake batholith. The maximum depth of the other lakes ranges 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.

Table 5 Maximum and mean depths of lakes northeast of the Hartman Moraine.

Lake	Area (km^2)[1]	Volume (km^3)[2]	Max depth (m)	Mean depth (m)
Heathwalt Lake	8.2	0.04	8	5
Sandbar Lake	12.9	0.06	14	5
Wintering Lake	16.6	0.09	16	5
Agimak Lake	12.5	0.04	16	3
Kukukus Lake	41.9	0.21	20	5
Basket Lake	42.9	0.25	20	6
Cecil Lake	15.7	0.20	24	13
Victoria Lake	9.3	0.09	28	10
Raleigh Lake	17.3	0.18	29	10
Paguchi Lake	24.9	0.22	30	9
Abamategwia Lake	13.1	0.13	33	9
Indian Lake	40.2	0.37	36	9
Mameigwess Lake	52.7	0.86	50	16
Clearwater West Lake[3]	36.1	0.98	73	27

[1]Area obtained from LIO OHN Waterbody file
[2]Volume and depth values obtained from summary data in margin of MNR depth maps (MNR, 2012)
[3]Located south of White Otter Lake (outside of Ignace area)

4.2 WATERSHEDS

A watershed, also known as a catchment, basin or drainage area, includes all of the land that is drained by a watercourse and its tributaries. JDMA conducted a drainage basin analysis in order to confirm and, where possible, partition the most detailed available mapping of watersheds by the Ontario Ministry of Natural Resources. The delineation of drainage divides can be useful for determining surface water flow directions and contributing to an initial understanding of the shallow groundwater flow system. The main drainage systems in the Ignace area are described in Section 4.3.

The best available watershed delineation for the Ignace area is the quaternary watershed file produced by the Ontario Ministry of Natural Resources (MNR). According to the metadata for this file, a quaternary watershed is a polygon feature that identifies a subdivision of a tertiary watershed (MNR tertiary watersheds are generally equivalent to the sub-sub-division of drainage areas produced by the Water Survey of Canada). The boundaries of the quaternary watersheds were created based on the Provincial DEM and Enhanced Flow Direction products released between 2006 and 2008. The watershed boundaries are generally consistent with the regional hydrology available for Ontario. The horizontal positional accuracy of the quaternary watershed boundaries is variable depending on the nature and spatial distribution of the raw DEM information, and thus cannot be quantified without on-site investigation and verification. In general, positional accuracy in northern Ontario is within 400 m, but there is no statistical level of confidence available.

JDMA modelled the movement of water over the landscape using the watershed analysis function in the program TNTmips with the CDED elevation model as the surface model. The CDED digital elevation model used for this assessment was created by NRCan (Section 1.3.2) using the same provincial data on which the Provincial DEM was constructed. As a result, the DEM used here is comparable with that used by the Ministry of Natural Resources to construct the quaternary watersheds.

The procedure that JDMA followed in the drainage analysis was to confirm the boundaries in the quaternary watershed file and then to subdivide the quaternary watersheds where possible. It is important to note that the quaternary watersheds do not represent the smallest catchments that can be delineated in most areas, as local ridges and highland complexes are present within many of the quaternary watersheds that serve to further control surface flow directions within the basin. The drainage analysis in this assessment was conducted with no *a priori* knowledge of the quaternary catchments. Rather, only the tertiary catchments were examined during the drainage analysis.

The result of the drainage analysis is a single set of lines and polygons, which represents a merged watershed file (Figure 11). The inset map on Figure 10 illustrates the tertiary watersheds in the Ignace area. As there is virtually no limit to the number of times that a watershed can be subdivided, JDMA had to limit the minimum size of basin in order to maintain a consistent scale of delineation across the Ignace area. Where drainage divides created by JDMA matched reasonably with the quaternary watershed boundaries, the procedure was to accept the existing quaternary watershed boundary. Newly delineated drainage divides were then used to subdivide the quaternary watersheds. In some instances, the quaternary watershed file contained a drainage divide that was not delineated by JDMA during the drainage analysis. A field entitled 'Type' was created in the merged file denoting whether each portion of the catchment boundary was modelled by JDMA and MNR (0), only JDMA (1), or only MNR (2). JDMA made an effort to ensure that the newly delineated drainage divides honoured the existing watercourse map file where possible.

4.3 Surface Flow

This section describes the drainage systems in the Ignace area and surface water flow over the main batholiths identified (Golder, 2011) as potentially suitable for the siting of a deep geological repository.

The Ignace area is contained entirely within the Nelson River Drainage Area, which drains into Hudson Bay through the Nelson River. Draining an enormous area of about 1,148,350 km^2 mostly to the west of the Ignace area, the Nelson Drainage Basin includes the southern parts of Alberta, Saskatchewan and Manitoba, and smaller parts of North Dakota, Minnesota and northwest Ontario. The Nelson River is the single largest contributor of freshwater to Hudson Bay and James Bay.

The English River drains the part of the Ignace area northeast of the Hartman moraine, an area shown on the inset map on Figure 11 as the Upper English sub-sub basin. This tertiary watershed includes most of the area associated with the Indian Lake and Basket Lake batholiths. The Wabigoon River drains the northern part of the Revell batholith and the areas around Stormy Lake and Raleigh Lake through the Wabigoon sub-sub basin. Flow through the English and Wabigoon rivers eventually reaches Lac Seul approximately 110 km northwest of the settlement area of Ignace. The Turtle River drains most of the area south of the Revell-Gulliver highland through the Central Rainy sub-sub basin, which includes the areas associated with the southern portion of the Revell batholith and most of the White Otter Lake batholith within the Ignace area. Flow along the Turtle River eventually reaches the Rainy River, which forms the international border approximately 120 km southwest of the settlement area of Ignace. Within the Ignace area, the Wabigoon and Turtle rivers have steeper gradients than the English River, with the drop in head on the former systems about 20 m greater. This reflects either a smaller drop in the bedrock surface northeast of the Revell-Gulliver highland or thicker overburden cover in this area damping out the bedrock relief.

Drainage from the northern part of the Revell batholith flows towards the lowland to the northwest and into the Wabigoon River, whereas the southern part of the batholith drains to the south into Bending Lake and the Turtle River (Figure 11). The main drainage divide on the batholith parallels Highway 622. Flow in the Mennin Lake and Spruce Lake watershed is strongly controlled by the knobby bedrock-controlled fabric of the terrain, with some prominent trench-like creek valleys.

Flow on the surface of the Basket Lake batholith travels from Basket Lake, through Abamategwia Lake, and then northeast into Arethusa Lake and then Mit Lake (Figure 11). This drainage pathway forms the Basket River. The Hartman moraine is the main drainage divide to the southwest of this batholith. There is an isolated and discontinuous highland in the southern part of the batholith, between Basket Lake and Abamategwia Lake, which is characterized by several elongate knobs or disjointed ridges displaying a drumlinoid or ice-scoured appearance (Figure 6).

The portion of the Indian Lake batholith within the Ignace area contains several large lakes, including Mameigwess Lake, Indian Lake, Paguchi Lake, Sandbar Lake, Agimak Lake, Cecil Lake, and Sowden Lake (Figure 11). The circular lake outlines reflect shorelines formed in soils rather than in bedrock. Flow across the surface of the batholith is predominantly controlled by the Revell-Gulliver highland, which drives flow to the north. The main rivers draining through the large lakes into the English River are the Osaquan, Agimak, Gulliver and Bonheur rivers. Within much of the batholith, there is no well-defined highland. Rather, the landscape is made up of lake-studded lowlands interrupted occasionally by isolated hills or knobs (Figure 6).

The portion of the White Otter Lake batholith in the Ignace area contains several large lakes (Figure 11), including Pekagoning, Dibble, Dimple, Nora, White Otter, Elsie, Sandford, and Irene lakes. The Revell-Gulliver highland forces flow across the batholith to the south and west, with lake surface elevations dropping about 10 m from one large lake to the next. There is about 150 m of relief across the batholith.

5 TERRAIN CHARACTERISTICS

An understanding of the distribution and thickness of overburden within the Ignace area is essential for interpreting the distribution of lineaments mapped from satellite imagery and topographic surface data (JDMA, 2013), particularly with respect to lineament length and density. Thick drift deposits are able to mask the surface expression of lineaments. In areas of sporadic drift deposits, the drift can conceal minor lineaments, producing low apparent lineament density, and it can censor the lengths of major structures. In areas of thick and extensive overburden, major structures could exist that would be completely undetected from SPOT and CDED, particularly if these areas also contain large lakes.

Areas of exposed bedrock or thin drift are more readily amenable to site characterization, as such locations would enable further investigation of the potentially suitable bedrock formations through outcrop mapping of bedrock structures and preliminary rock mass characterization.

The purpose of this section is to provide information to help enhance the understanding of overburden deposits in the Ignace area generated through the NOEGTS program (Figure 3). Section 5.1 presents preliminary review of water well and drill hole data on overburden thickness in the Ignace area. Details on the expected composition, distribution and thickness of surficial deposits within the terrain units are presented in Section 5.2.

5.1 DRILL HOLE AND WATER WELL DATA

Data on overburden thickness from water well records collected by the Ministry of the Environment (MOE) (MOE, 2012) and from diamond drill holes compiled by the OGS (OGS, 2005b) were reviewed to supplement the information on overburden deposits compiled from the NOEGTS reports (Section 5.2).

5.1.1 WATER WELL INFORMATION SYSTEM

Water well records from the Ministry of the Environment Water Well Information System (MOE, 2012) for the Ignace area were acquired (Section 1.3.4). Thirty of the thirty-three MOE water wells with records of depth to bedrock are located within the Township of Ignace, around Agimak Lake (Figure 3). There is also a well in Dewan Township, one in Ilsley Township and one near the south shore of Sandbar Lake (Figure 3). Depth to bedrock ranges from 1 to 80 m with the majority being less than 15 m (Table 6). It is unclear whether some of the greatest depths recorded are reliable, but no further investigation of these well records has been carried out as part of this preliminary assessment.

The water well records illustrate the great variability in drift thickness that can occur over short distances. Ten wells located in an area mapped as bedrock terrain along the northwest shore of Agimak Lake have depth to bedrock ranging from 1 to 12 m within a ground distance of 500 m. This also illustrates how the areas mapped as bedrock terrain can include overburden deposits that are 10 m or more in thickness.

5.1.2 Ontario Drill Hole Database

The 124 drill holes in the Ignace area reviewed in this assessment (Section 1.3.4) are mostly located within the Raleigh Lake and Bending Lake greenstone belts (Figure 2), in areas mapped as bedrock terrain (Figure 3), with only a small number of the drill holes located in surficial deposits identified in the 1:100,000 scale NOEGTS mapping. A preliminary review of the drill hole data identified that some of the drill holes were drilled from lake ice platforms and the depth to bedrock value includes the height of the water column.

The maximum depth to bedrock recorded was about 32 m, the average was about 4 m, with twenty-six drill holes (or 20%) recording depths greater than 5 m, and only three drill holes recording depths exceeding 20 m. 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. Averages from these data would carry more meaning if the drill data were confidently assigned to specific terrain conditions at better detail than the 1:100,000 scale NOEGTS mapping of bedrock terrain.

Table 6 Ministry of the Environment water well data on drift thickness.

Well ID	Date	Elevation (m)	Depth water found (m)	Depth to bedrock (m)	Township
3101286	17/09/1977	459	44.2	1	Ignace
3102130	27/10/1986	452	18.3	1	Ignace
3101036	02/12/1975	453	25.9	1	Ilsley
3100043	11/05/1963	455	15.2	2	Ignace
3102480	07/05/1988	451	16.8	2	Ignace
3100832	23/05/1973	456	19.5	3	Ignace
3103427	15/06/1994	454	42.7	3	Ignace
3103470	15/11/1994	458	79.2	3	Ignace
6102381	25/09/1979	463	57.9	3	Ignace
3100920	10/10/1974	450	18.3	4	Ignace
3101159	23/06/1977	456	38.7	4	Ignace
3103537	07/09/1995	453	61.9	4	Ignace
3103431	14/06/1994	456	48.8	4	Ignace
3103428	13/06/1994	454	52.7	4	Ignace
3103264	16/12/1992	454		4	Ignace
3101283	30/08/1977	457	20.7	5	Ignace
3103553	17/11/1995	455	12.2	5	Ignace
3103426	15/06/1994	451	12.2	5	Ignace
3104429	18/04/2005	463	85.3	7	Dewan
3103342	18/09/1993	455	50.9	7	Ignace
3103429	08/06/1994	456	53.3	8	Ignace
3101032	10/09/1975	456	64.0	10	Ignace
3104434	05/05/2005	456	71.6	10	Ignace
3101804	09/06/1982	454	51.2	12	Ignace
3102131	21/09/1986	457	80.8	12	Ignace
7042179	30/12/2006	468	62.8	12	Ignace
3101042	26/10/1975	458		12	Ignace
3101782	13/07/1981	459	15.2	14	Ignace
3101564	30/11/1979	453	68.6	14	Ignace
3103015	18/01/1990	454	19.8	17	Ignace
3101891	17/08/1983	458	38.4	25	Ignace
3104436[1]	10/05/2005	428	39.9	73	Ignace
3102132[1]	01/10/1986	455		80	Ignace

Wells within the Township of Ignace are located within a 3 km radius of each other
[1]Well log not checked to confirm anomalous recorded depth to bedrock

Table 7 Ontario Geological Survey diamond drillhole data on depth to bedrock.

AFRI FID[1]	Count	Drift thickness (m) Min	Max	Mean
52F08NW0009	1	12.0	12.0	12.0
52F08NW0035	1	1.4	1.4	1.4
52F08NW0042	1	3.5	3.5	3.5
52F08SE0004	6	1.4	18.0	8.7
52F08SE0005	1	2.4	2.4	2.4
52F08SE0006	1	8.2	8.2	8.2
52F08SE0007	1	5.4	5.4	5.4
52F08SE0008	1	3.7	3.7	3.7
52F08SE0009	1	1.1	1.1	1.1
52F08SE0010	2	3.6	5.7	4.7
52F08SE0016	3	3.8	13.6	7.5
52F08SE0657	1	1.3	1.3	1.3
52F09NW0007	2	13.4	13.7	13.5
52F09NW0013	8	0.4	11.0	2.7
52F09NW0016	1	0.2	0.2	0.2
52F09SE0013	10	0.5	4.4	2.1
52F09SE0020	1	1.9	1.9	1.9
52F09SE0022	2	0.4	1.9	1.2
52F09SE0023	1	10.3	10.3	10.3
52F09SE2004	4	0.8	0.9	0.9
52F09SW0011	8	1.7	4.7	2.7
52F09SW0018	2	1.8	31.7	16.7
52F09SW0020	2	1.4	1.6	1.5
52F09SW0026	3	2.1	12.6	7.2
52F09SW0043	1	6.5	6.5	6.5
52F09SW0046	2	12.5	23.0	17.7
52F09SW0047	1	7.4	7.4	7.4
52G05NW2001	4	0.8	7.7	3.4
52G05NW2003	4	2.8	3.8	3.1
52G05NW2005	3	3.1	5.9	4.1
52G05SE0001	3	0.9	1.7	1.2
52G05SE0002	5	1.6	5.8	2.8
52G05SE0003	2	2.2	3.2	2.7
52G05SE0004	23	0.2	29.8	2.5
52G05SE0005	1	1.5	1.5	1.5
52G05SE0006	1	1.3	1.3	1.3
52G05SE0007	2	1.1	3.5	2.3
52G05SE0008	2	1.9	3.2	2.6
52G05SW0002	1	0.9	0.9	0.9
52G05SW0003	1	0.5	0.5	0.5
52G05SW0004	3	0.6	2.6	1.4
52G05SW0005	1	1.1	1.1	1.1
Summary	124	0.2	31.7	3.8

[1]Assessment File Research Image (AFRI) file number

5.2 NOEGTS TERRAIN UNITS

5.2.1 MORAINAL TERRAIN

Roed (1980a) suggests that the end moraine-like features in the Ignace area (Figure 3) are nearly flat on top, and typically consist of up to 30 m of cross-stratified gravelly sand or sandy gravel of deltaic ice-contact origin. Within the Ignace area, the Eagle-Finlayson Moraine represents a 100 to 1,000 m wide ridge that extends up to 40 m above the surrounding terrain, along which part of Highway 622 has been routed (Figure 3). Based on its topographic relief, its thickness probably exceeds 40 m or more. The other two moraines in the Ignace area are not distinctly expressed in the landscape to the degree that the Eagle-Finlayson moraine is expressed as a distinct ridge protruding from a low relief plain. As a result, it is not as simple to make estimates of their thickness, especially when considering the possibility that parts of the moraines could have bedrock cores.

In areas mapped as ground moraine shown on Figure 3, the terrain is typically well drained, topography is undulating to knobby, and bedrock knobs and narrow ridges occur along the trend of other moraine-like features (Roed, 1980b). The defining criterion for the landform is that the till is thick enough to largely mask topographic effects of the underlying bedrock (Mollard and Mollard, 1980b).

The three MOE water wells near the east shore of Agimak Lake (Figure 3) located in ground moraine near the Hartman moraine record depths to bedrock ranging from 1.2 to 5.4 m. In contrast, a water well near the south shore of Sandbar Lake is located within an area mapped as ground moraine, and it recorded a depth to bedrock of 73 m, suggesting that drift thickness can reach values this large in areas mapped as ground moraine. These observations are consistent with the findings of Mollard and Mollard (1980b), who suggested that till thickness in areas mapped as ground moraine varies from less than one metre to many tens of metres.

Isolated areas of morainal terrain are mapped in several locations northeast of the Hartman moraine, covering mostly the central and eastern portions of the Indian Lake batholith and south-central portion of the Basket Lake batholith. Ground moraine mapped as a mantle overlying bedrock occurs over the entire surface of the Islet pluton and over some of the large areas not covered by lakes on the White Otter Lake batholith (Figure 3). The areas of ground moraine mapped on the latter batholith between Nora, Elsie, and White Otter lakes display a distinct northeast oriented drumlinoid fabric in the SPOT imagery.

5.2.2 GLACIOFLUVIAL TERRAIN

Four different landform types deposited by glacial meltwater have been mapped (Gartner et al., 1981): ice-contact delta, esker, kame, and outwash plain (or valley train). Materials forming these landforms generally consist of gravel, sand and silt. Outwash deposited in stagnant ice conditions tends to be highly variable in terms of texture and the topography can be irregular. Outwash deposited over proglacial plains or in valleys tends to be less variable in composition.

Glaciofluvial deposits in the Ignace area are generally located northeast of the Hartman moraine, variably covering portions of the Basket Lake and Indian Lake batholiths. An extensive deposit is mapped along the northern boundary of the Revell batholith. Isolated deposits are also mapped in the central portion of the White Otter Lake batholith. Very little information on drift thickness within the glaciofluvial terrain was provided in the NOEGTS reports. Of the 16 MOE water well records in the area northeast of Agimak Lake mapped as glaciofluvial outwash (Figure 3), the depth to bedrock ranges from about 1 to 80 m, with an average of about 12 m. Drift thickness is greater than 10 m in seven of these wells, and it varies substantially over short distances. Eight OGS diamond drill holes located in an area mapped as outwash in Revell Township have depths to bedrock ranging from about 1 to 5 m (Figure 3).

Larger glaciofluvial deposits have the potential to represent significant regional aggregate or groundwater supplies. The good foundation conditions and abundance of suitable borrow and granular materials make these landforms ideal for transportation routes, building sites, forest management staging areas, and airport locations.

5.2.3 GLACIOLACUSTRINE TERRAIN

Glaciolacustrine deposits have been divided into three landform types (Gartner et al., 1981): raised beach ridge, glaciolacustrine delta, and glaciolacustrine plain. All glaciolacustrine terrain mapped in the Ignace area represents lake plain, which is generally composed of silts and clays.

Glaciolacustrine deposits in the Ignace area are generally located northeast of the Lac Seul moraine, but there is also an extensive deposit mapped along the northern boundary of the Revell batholith (Figure 3). These locations represent areas of low elevation within the Ignace area (Figure 4) and within the English sub-basin (Figure 11). No information on the thickness of glaciolacustrine deposits was provided in the NOEGTS reports, and no MOE wells or OGS diamond drill holes that record depth to bedrock are located within areas delineated as glaciolacustrine terrain in the 1:100,000 scale NOEGTS mapping.

The geotechnical properties of silts and clays are usually poor, with low shear strengths that decrease with depth, poor bearing capacities, and high frost susceptibility (Gartner et al., 1981). These materials can have high moisture contents and can be difficult to handle and compact. Glaciolacustrine plains are often associated with poor drainage and organic terrain.

5.2.4 ORGANIC TERRAIN

All types of peatlands have been mapped as organic terrain, with no attempt to distinguish between marsh, swamp, bog, or fen (Gartner et al., 1981). The organic material is peat and muck and the landform is often confined topographically. In most organic terrain, stagnant drainage or wet surface conditions are common.

Mollard and Mollard (1980b) suggest that extensive organic deposits typically occur in areas covered by thick drift, where the peat and muck deposits are generally thin due to the gently undulating character of the terrain. Although peat and muck deposits usually occur as relatively thin surficial layers, in places, these organic materials can be several metres thick, and the thickness can change drastically over very short distances (Mollard and Mollard, 1980a). Organic deposits in the bedrock terrain are typically less extensive but can be thicker, as they fill depressions between bedrock ridges and knobs. The locations of deeper pockets of organic material are difficult to predict reliably without test drilling (Mollard and Mollard, 1980a).

No reliable information from the MOE water well database was found on drift thickness within organic terrain. The OGS drill hole database contains three holes drilled in the major wetland in Revell Township, with depths to bedrock all of about one metre. However, the drilling took place within a pit where previous prospecting and trenching had taken place, and the author of the assessment report describes the pit as one of the few small outcrops within the swamp, like islands within a lake (Prouty, 2001).

The largest concentration of organic deposits mapped in the Ignace area is found between the Hartman moraine and the Revell-Gulliver highland, located within the Ilsley-Gulliver trough, which coincides with the southern portion of the Indian Lake batholith (Figure 3). There is also a notable concentration of less extensive organic deposits south of the Eagle-Finlayson moraine. Extensive organic deposits can also be found north of the Hartman moraine, particularly in the geographic townships of Burk and Furniss and further north. The valley of the Campus Creek, located in the northern portion of the White Otter Lake batholith, contains the most extensive organic deposits enclosed entirely within an area mapped as bedrock terrain.

Exceptionally poor engineering characteristics can be found within areas mapped as organic terrain (Gartner et al., 1981). Peat and muck have very low shear strength and high compressibility. Groundwater tables are at or near the surface in organic terrain and flooding is common.

5.2.5 BEDROCK TERRAIN

In general, much of northern Ontario has been mapped as bedrock terrain (Gartner et al., 1981). It is important to note that the areas mapped as bedrock terrain do not necessarily represent exposed bedrock. These areas generally contain a thin mantle of drift, which is less than one metre thick in most places. However, the drift can be much thicker locally, especially on the flanks of outcrops or between bedrock hills. Analysis of the SPOT imagery for the Ignace area indicates that exposed bedrock makes up as approximately up to 10 to 20% of local zones within the broad areas mapped as bedrock terrain. In addition, dense vegetation can limit the number and size of bedrock exposures available for surface-based geological and geotechnical characterization, even in areas of thin to no overburden cover.

In the western part of the Ignace area (Figure 3), Roed (1980a) reports that all bedrock terrain contains patches of discontinuous, sandy, bouldery till less than one metre thick, but in places along the flanks of depressions the till can thicken to more than three metres. Silty clay occupies most depressions in the bedrock terrain, especially where the bedrock terrain borders onto lowlands (Roed, 1980b). Mollard and Mollard (1980b) suggest that the thickness of drift over the masked bedrock surface varies substantially over short distances, and that in general, it is relatively thin (1 to 2 m) on ridge tops and thicker on the lower slopes and in the depressions between bedrock ridges.

The inset map on Figure 3 illustrates that bedrock terrain is associated mostly with the Revell and White Otter Lake batholiths, with only isolated pockets mapped on the Basket Lake and Indian Lake batholiths.

The drift thickness information from the OGS drill hole data selected (Section 1.3.4) for the Ignace area likely provides an overestimate of the conditions generally found within areas mapped as bedrock terrain. As summarized in Section 5.1.2, the maximum depth to bedrock recorded was about 36 m, the average was about 4 m, with twenty-six drill holes (or 20%) recording depths greater than 5 m, and only three drill holes recorded depths exceeding 20 m. These values are generally higher than what is suggested in the NOEGTS reports for bedrock terrain, as described above. However, it should be noted that some areas within the broad zones delineated as bedrock terrain (Figure 3) could perhaps be subdivided into morainal or other surficial deposit types if detailed mapping were done. The true definition of bedrock terrain as described in the NOEGTS reports (drift typically less than 1 m thick) might only be representative of parts of the areas mapped as such. It is important to note that, in addition to overburden, dense vegetation is also effective at concealing bedrock outcrops.

Within bedrock terrain, bearing capacities are usually excellent, blasting is required for excavations, earth borrow is scarce, groundwater resources are unpredictable, and trafficability is poor (Gartner et al., 1981).

5.2.6 TERRAIN SUMMARY

The Indian Lake batholith is primarily overlain by glaciofluvial terrain, with lesser areas covered by morainal and glaciolacustrine terrain. Isolated areas mapped as bedrock terrain are found mostly in the western half of the batholith. The portion of the Basket Lake batholith in the Ignace area appears to be associated with roughly equal areas of bedrock, morainal and glaciofluvial terrain. No clear pattern is discernible. The Revell batholith is primarily associated with bedrock terrain. Glaciofluvial and glaciolacustrine deposits are mapped along the northeastern boundary of the batholith. An isolated area of morainal terrain is mapped in the southern portion of the batholith. The White Otter Lake batholith is also primarily associated with bedrock terrain with isolated areas of organic, morainal and glaciofluvial terrain mapped in the central portion of the batholith. Morainal terrain is also mapped in the far eastern edge of the batholith.

The NOEGTS data shown in Figure 3 also include linear features that represent ice flow direction. These features generally trend in a northeast direction through the Ignace area with the exception of within the northwest portion of the Ilsley-Gulliver trough where they trend to the northwest.

6 GROUNDWATER

A detailed discussion of the hydrogeology of the Ignace area is provided by Golder (2013). Only a brief summary is provided here. In general, shallow groundwater flow is expected to mimic strongly the pattern of surface flow suggested by Figure 11. Steep slopes and the general absence of thick overburden deposits in the areas mapped as bedrock terrain should promote surface runoff. Where permeable deposits cover the bedrock, recharge areas should occur within highlands and along local positively expressed topographic features forming drainage divides such as ridges and local uplands. Thicker drift deposits are likely in the valleys and trench bottoms, and these deposits are expected to represent the most significant surficial recharge zones in bedrock terrain. Discharge in these areas occurs into creeks, rivers, lakes and wetlands. Mollard and Mollard (1980b) suggest that bedrock terrain in the Ignace area is generally well drained, and that bedrock-controlled lineaments in this terrain are expressed as linear depressions that often contain water and deposits of peat.

Bedrock aquifers within the bedrock terrain are likely shallow with recharge occurring through discontinuities such as joints and fractures. Roed (1980b) suggests that groundwater occurs in fractures and along fault zones in the bedrock terrain, but this terrain unit is considered to have only poor to fair potential for groundwater supplies. Mollard and Mollard (1980b) suggest that a large proportion of the groundwater in the bedrock terrain is confined to fractures in the upper 45 to 60 m of bedrock, with permeability varying from impermeable to highly permeable, depending on the spacing, depth and aperture of discontinuities in the bedrock. Many of the drainage courses follow eroded zones of weakness in the underlying bedrock (Mollard and Mollard, 1980b).

North of the Hartman moraine (Figure 4), many of the surficial deposits are permeable and expected to contain high quantities of groundwater. There are local small highland complexes and isolated hills where drift thickness could be minimal, but these local highs are generally surrounded by large lakes and thick likely water-bearing drift deposits.

No information beyond what was presented in the initial screening (Golder, 2011) on groundwater flow at typical repository depths (approximately 500 m) was found during this assessment.

7 NEOTECTONIC FEATURES

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 (Heidbach et al., 2009) is northeast (063° ± 28°). However, a north-south maximum compressive stress axis appears to dominate in the mid-continent including northwestern Ontario. Anomalous stress orientations have been identified in northwest Ontario (Haimson, 1990; Brown et al., 1995; Martino et al., 1997; Maloney et al. 2006).

Repeated cycles of glaciation and deglaciation throughout the Quaternary have induced stresses by sequentially loading and unloading the Earth's crust. The loads associated with glaciation are sufficient to depress the crust by hundreds of metres. Crustal rebound takes place once the weight of the ice is removed and rebound continues to occur today in this area, albeit slowly. The greatest rates of rebound typically occur near the ice-centres, such as around the margins of Hudson Bay.

The stresses associated with cycles of ice loading and unloading, acting along with tectonic stresses, may result in seismic events related to displacements along ancient discontinuities in the bedrock. In addition, the advance of glacial ice may also exert stresses near the bedrock surface during its motion across the landscape. For instance, the glacier can thrust itself against topographic barriers and this can damage the rock and may cause movement along existing discontinuities.

The assessment of neotectonic features in the area may reveal the timing and magnitude of glacially-induced seismic activity and deformations. Conclusive identification of features indicative of reactivation of ancient bedrock structures due to cycles of glacial loading and unloading could not be made using the information sources available in the current assessment. Field investigation would be required to identify such features. Under the appropriate conditions, glaciolacustrine deposits may preserve neotectonic features indicative of paleo-seismic activity.

As stated in Section 5.2.3, glaciolacustrine deposits in the Ignace area are generally located northeast of the Lac Seul moraine and along the northern boundary of the Revell batholith (Figure 3). Some road and water access is available to both of these regions, which may allow for the investigation of the presence of neotectonic features.

8 ACCESSIBILITY CONSTRAINTS

Good access into the central and some marginal parts of the Ignace area is provided by three main paved provincial highways. The Trans-Canada Highway (Highway 17) provides good access to the central part of the Ignace area, including direct access to the marginal parts of the Indian Lake and Revell batholiths (Figure 12). Highways 599 and 622 are secondary highways. Highway 599 extends northeast from the Trans-Canada Highway at the settlement area of Ignace. Highway 622, also referred to as the Bending Lake Road, provides good access onto the central upland part of the Revell batholith.

Roads shown on Figure 12 are based on the Ministry of Natural Resources (MNR) road segment file obtained from Land Information Ontario (LIO). The MNR road segment file contains resource access roads constructed for and used by conventional street legal vehicles. It includes winter roads, and it contains roads not under the jurisdiction of the MNR sourced from the Ontario Road Network. Recreation trails and short-term forest operation roads or forest fire management roads are not included in the file. As this file contains no attribute information, JDMA divided the roads into main roads (Highway 17, 599 and 622), trunk resource roads and resource roads (Figure 12). The classification of trunk roads was subjective, and although the Ontario Road Network could be used for this purpose as it contains a road classification, the MNR road segment file generally contains more resource roads. An evaluation of the MNR road segment file against the SPOT imagery indicates that the coverage is quite good.

The north, west and northeast margins of the portion of the White Otter Lake batholith contained within the Ignace area are only accessible using resource roads (Figure 12). The eastern section of the batholith near Gamble Lake and Gulliver Lake is extremely rugged, with lake-filled, cliff-bounded trenches and many rock ridges. Parts of the interior of the batholith are not accessible by existing roads.

Access onto the Revell batholith is good. Except for the area east of Mennin Lake, a dense network of forestry roads exists throughout the batholith. Forestry roads extend north and south of Highway 622, which traverses through the centre of the batholith (Figure 12). The sinuous trunk road that extends east-west through the northern part of the batholith is referred to in assessment reports as the Twin River Road. The most rugged parts of the batholith are north of Spruce Lake and in the furthest south (Figure 7). The roads generally are located away from the most rugged zones, presumably due to the difficult access. The Trans-Canada Highway provides access to the northern, generally drift-covered part of the batholith.

The Trans-Canada Highway, Highway 599, and several trunk roads provide good access into the areas of the Indian Lake batholith not covered by large lakes and wetlands (Figure 12). The surface of the batholith features some low relief areas associated with thicker overburden cover, punctuated by some high relief areas associated with rock ridges (Figure 7).

Some of the areas not covered by lakes in the Basket Lake batholith have trunk roads leading in from Highway 17, with some smaller forestry roads extending into more remote areas. The topography is highly irregular in the areas between Basket Lake, Abamategwia Lake and Mameigwess Lake, with about 90 m of relief from the lake surfaces to the tops of nearby rock ridges.

9 SUMMARY

This report presents an analysis of the terrain in the Ignace area using available remote sensing and geoscientific information sources. The information enhances and expands upon that presented in the Ignace initial screening report (Golder, 2011). The main information sources relied on in this assessment are the Canadian Digital Elevation Data (CDED) elevation model, the multispectral SPOT satellite imagery and the maps and reports from the Northern Ontario Engineering Geology Terrain Study (NOEGTS). Additional information sources included the Ontario Drill Hole Database, the Water Well Information System, and several geospatial files on drainage features and roads obtained from Land Information Ontario.

The report provides an overview of the bedrock and Quaternary geology within the Ignace area. A map and descriptions of the Quaternary deposits are presented in this report based on the 1:100,000 scale NOEGTS mapping. The Ignace area contains three regionally significant stratified end moraines. Although most of the extensive areas of exposed bedrock or thin drift are located southwest of a subtle linear topographic low termed the Ilsley-Gulliver trough, the Indian Lake and Basket Lake batholiths are dotted with drumlinized upland complexes where drift thickness is likely relatively thin.

Apart from the major end moraines, the thickest overburden deposits in the Ignace area are generally represented as low-relief plains in the digital elevation model. It is inferred that in these areas the relief associated with the bedrock topography is masked by the infilling of drift within the low-lying areas. The broad ridge, termed the Revell-Gulliver highland, extending northwest across the centre of the Ignace area might have formed a topographic barrier to ice flow during the formation of the Hartman moraine, precluding deposition of extensive late-glacial and post-glacial glaciolacustrine and glaciofluvial deposits to the southwest. Many of the areas devoid of thick overburden deposits display rugged shield topography. Steep-sided to cliff-bounded ridges and knobs are common positively expressed landforms in these areas. Steep-walled, narrow to broad and flat-floored trenches are frequently the surface expression of lineaments, and many are lake-filled or contain thick organic deposits.

Estimates of overburden thickness within the Ignace area were extracted from descriptions generated during the NOEGTS mapping program conducted under the auspices of the Ontario Geological Survey (OGS) in the late 1970s as well as analysis of MOE water well records and OGS diamond drill holes. Overburden thickness varies considerably over short distances. The end moraines likely represent the thickest overburden deposits in the Ignace area, with thicknesses commonly reaching 30 to 50 m or more. Areas mapped as ground moraine are expected to display till thicknesses of less than one metre to many tens of metres. Thin organic deposits are common in low-relief areas of thick drift, whereas they can reach much greater thicknesses where they fill high relief basins formed between bedrock ridges and knobs. Within the areas mapped as bedrock terrain, the drift deposits generally occur as patches of discontinuous, sandy, bouldery till less than one metre thick, with deposits up to three metres or more in thickness typically found along the flanks of outcrops or between bedrock hills. Overburden thicknesses of 20 to 35 m have been observed in drill holes located in areas mapped as bedrock terrain. Deposits of rhythmically bedded silty clay occupy most depressions in the bedrock terrain, especially where the bedrock terrain borders onto lowlands.

Drainage divides delineated in the provincial quaternary watershed file produced by the Ministry of Natural Resources (MNR) were confirmed using the CDED surface model. In some instances, the quaternary watersheds were subdivided based on the presence of continuous highlands dividing flow within the watersheds. An updated watershed file was produced including drainage divides not present in the MNR quaternary watershed file.

Groundwater flow within drift deposits and in shallow bedrock aquifers in the Ignace area is expected to mimic the pattern of surface flow, with groundwater divides coinciding with drainage divides and discharge occurring into creeks, rivers, lakes and wetlands. For shallow groundwater flow, which is expected to extend to depths of 45 to 60 m into bedrock, the recharge areas will typically coincide with the drainage divides while discharge zones will be concentrated along the flanks of upland areas and along linear topographic lows. This assessment found no information beyond what was presented in the initial screening (Golder, 2011) on groundwater flow at repository depth.

Conclusive identification of features indicative of reactivation of ancient bedrock structures due to cycles of glacial loading and unloading cannot be identified using the information sources available in the current assessment. Field investigations would be required to identify such features.

The main accessibility constraints in the Ignace area are large lakes, rivers, and steep slopes. The Ignace area contains an abundance of primary roads and dense networks of secondary roads are present in some areas of active forest harvesting. However, large parts of the batholiths are not accessible by existing roads and the presence of lakes reduces the land area available and further renders certain areas inaccessible with the existing road network. The main roads and network of forestry roads provide good access for site reconnaissance aimed at preliminary site characterization.

The terrain analysis illustrates the strong role that overburden deposits and large lakes can play in generating a background of structural and lithological uncertainty in certain areas. The role of overburden deposits in concealing minor structures and censoring the lengths of major structures is apparent when comparing the observed lineament densities (JDMA, 2013) to the areas of thick overburden as determined through the current terrain analysis.

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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. *Precambrian Research*, 132, 245-274.

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

REPORT SIGNATURE PAGE

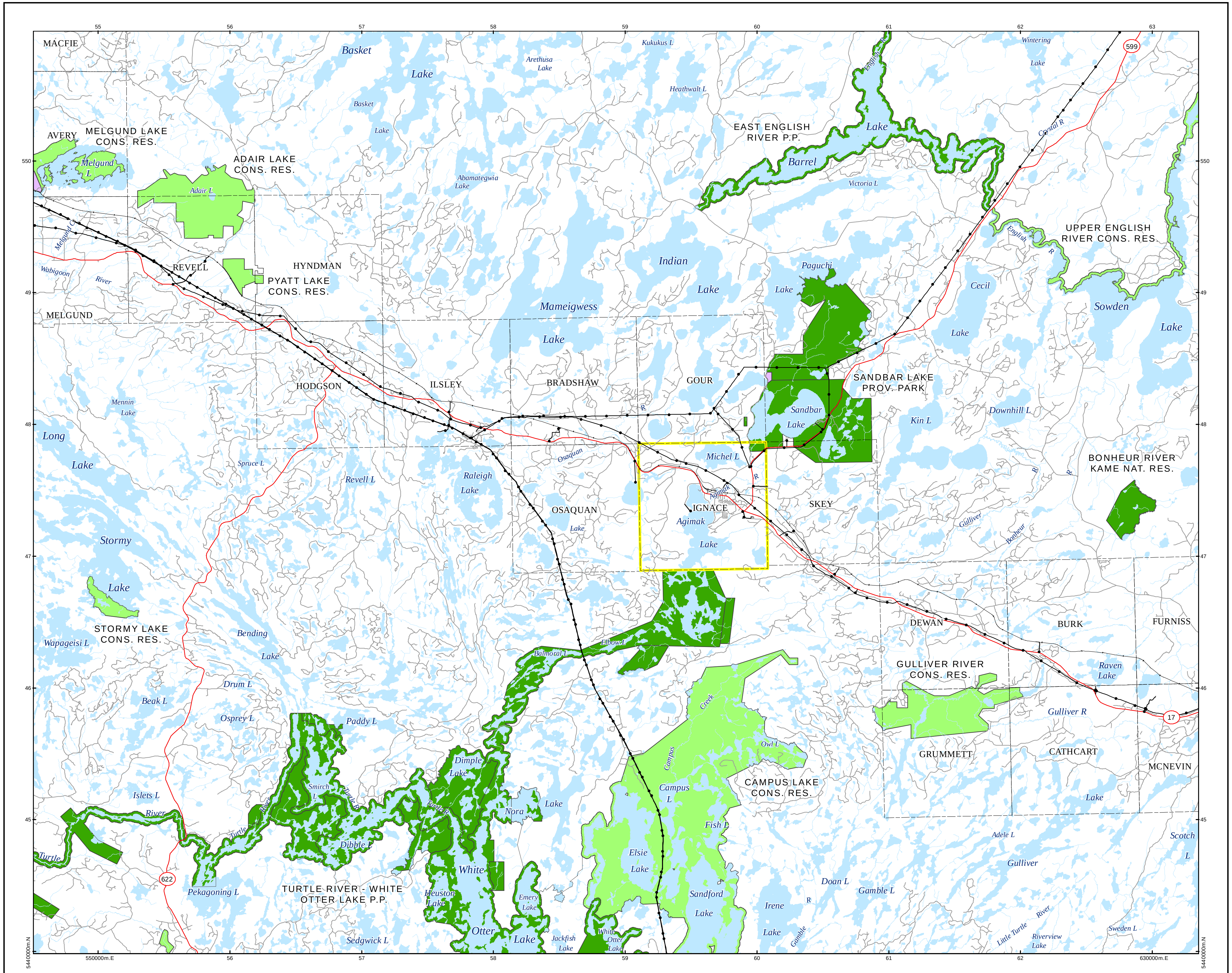
J.D. Mollard and Associates (2010) Limited

David van Zeyl, M.Sc.

Lynden Penner, M.Sc., P.Eng., P.Geo.

FIGURES

FIGURES

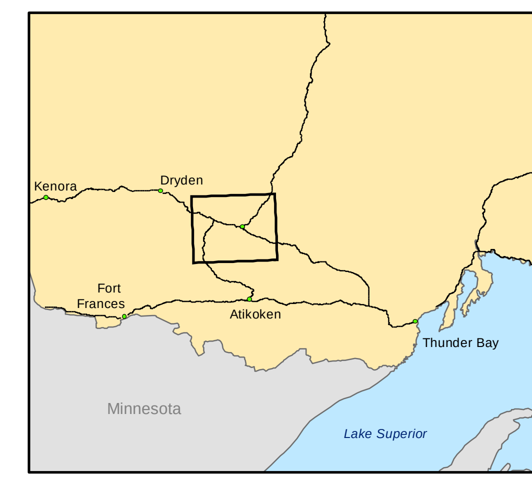


LEGEND

- Rail
- Utility
- Main road
- Local road
- Township of Ignace
- Geographic township
- Waterbody
- Watercourse

Protected areas

- Forest Reserve
- Conservation Reserve
- Provincial Park



Data sources:
Parks: LIO CLUPA designation
Rail: LIO Railway
Road: LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Utility: LIO Utility Line
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

NORTH

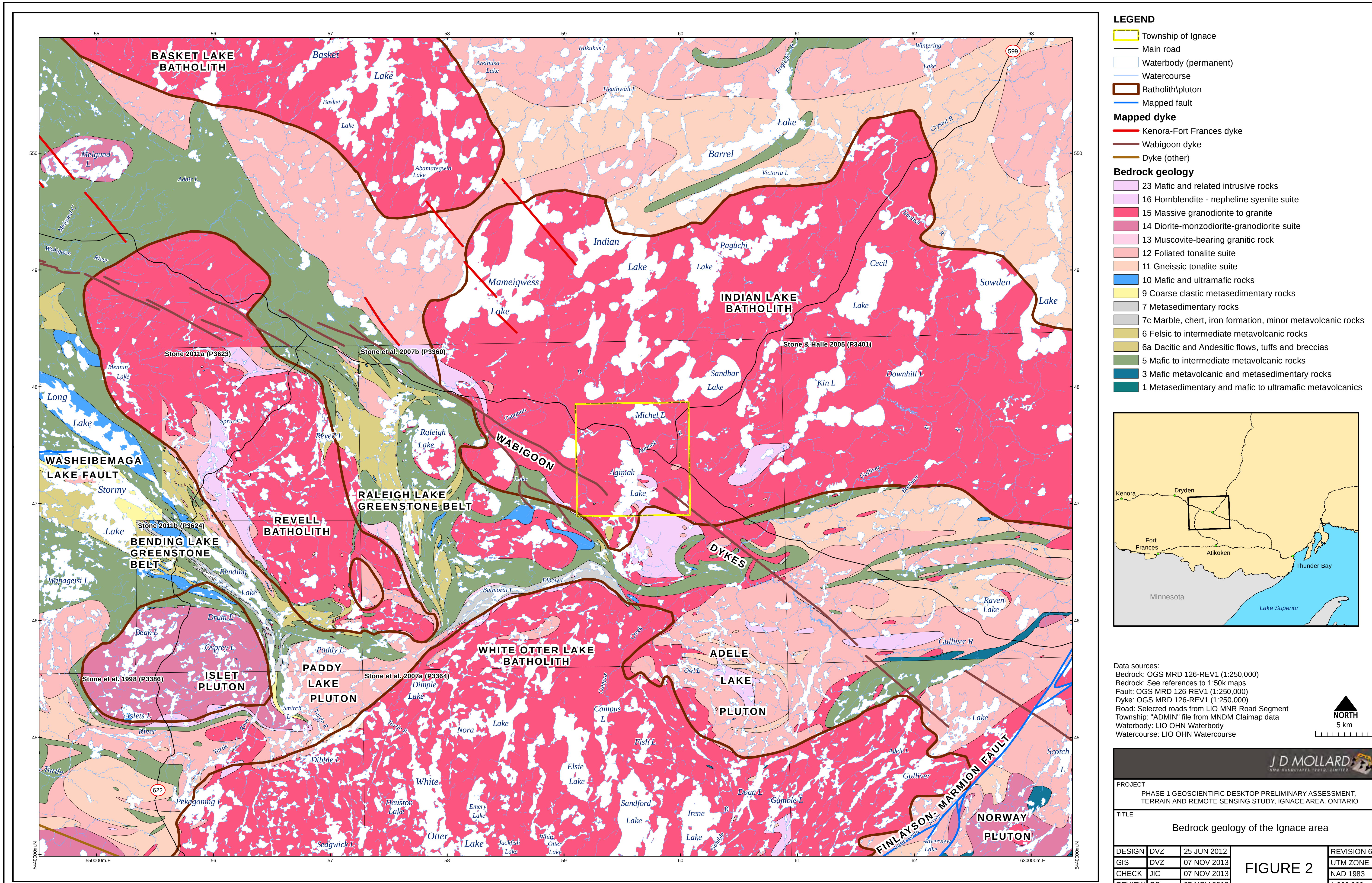
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

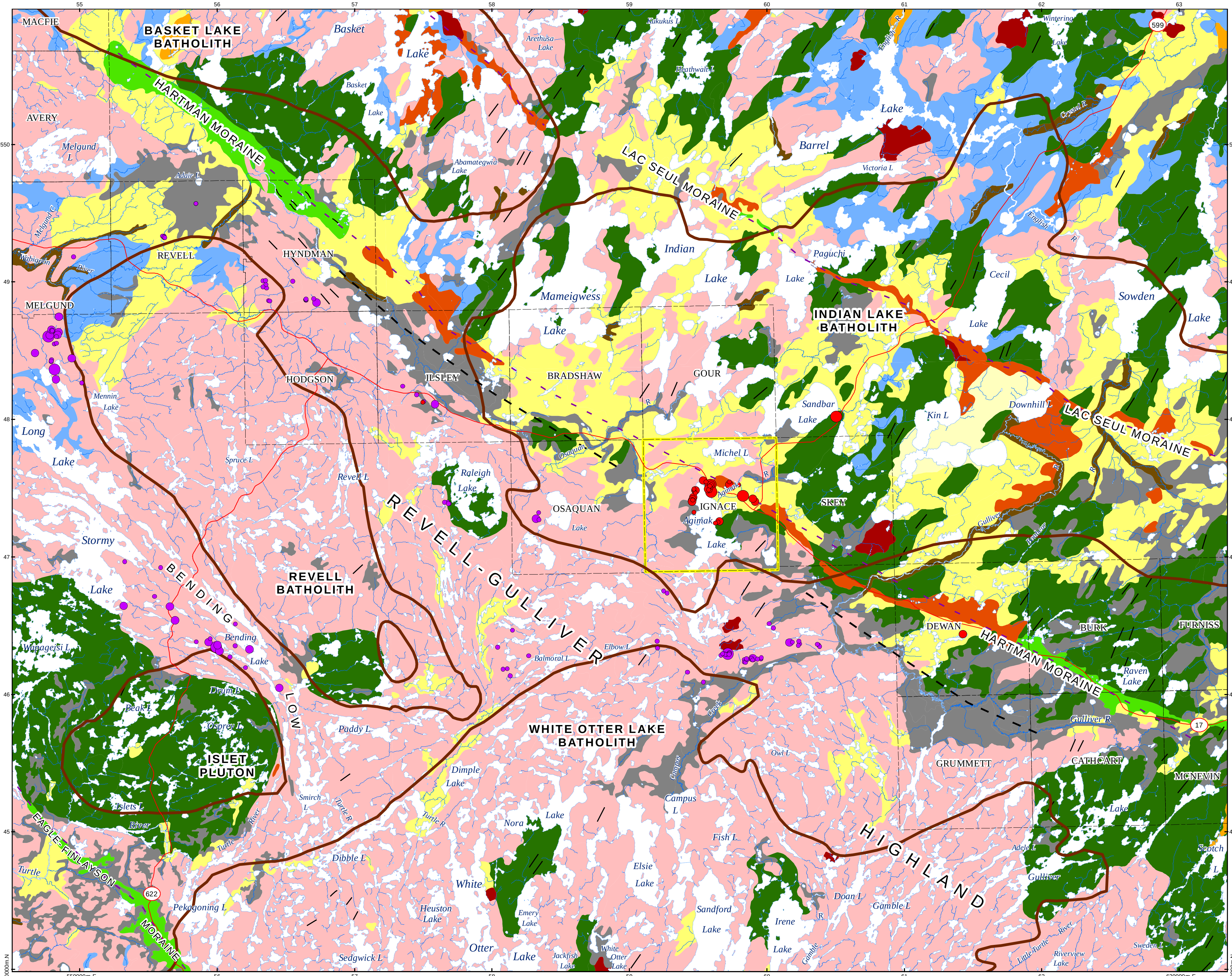
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Township of Ignace and surrounding area

DESIGN	DVZ	25 JUN 2012	FIGURE 1	REVISION 4
GIS	DVZ	31 JUL 2013		UTM ZONE 15
CHECK	JIC\CM	31 JUL 2013		NAD 1983
REVIEW	GS	31 JUL 2013		1:300,000



LEGEND
Township of Ignace
Main road
Waterbody (permanent)
Watercourse
Batholith\pluton
Mapped fault
Mapped dyke
Kenora-Fort Frances dyke
Wabigoon dyke
Dyke (other)
Bedrock geology
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
6a Dacitic and Andesitic flows, tuffs and breccias
5 Mafic to intermediate metavolcanic rocks
3 Mafic metavolcanic and metasedimentary rocks
1 Metasedimentary and mafic to ultramafic metavolcanics
BASKET LAKE BATHOLITH
INDIAN LAKE BATHOLITH
WABIGOON
DYKES
WASHEIBEMAGA LAKE FAULT
RALEIGH LAKE GREENSTONE BELT
REVELL BATHOLITH
BENDING LAKE GREENSTONE BELT
ISLET PLUTON
PADDY LAKE PLUTON
WHITE OTTER LAKE BATHOLITH
ADELE LAKE PLUTON
NORWAY PLUTON
FINLAYSON- MARMION FAULT
Stone 2011a (P3623)
Stone et al. 2007b (P3360)
Stone & Halle 2005 (P3401)
Stone 2011b (P3624)
Stone et al. 1998 (P3386)
Stone et al. 2007a (P3364)
Kenora
Dryden
Fort Frances
Atikoken
Thunder Bay
Minnesota
Lake Superior
550000m.E
630000m.E
5440000m.N
Data sources:
Bedrock: OGS MRD 126-REV1 (1:250,000)
Bedrock: See references to 1:50k maps
Fault: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
NORTH
5 km
J D MOLLARD
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO
TITLE
Bedrock geology of the Ignace area
DESIGN DVZ 25 JUN 2012
GIS DVZ 07 NOV 2013
CHECK JIC 07 NOV 2013
REVIEW GS 07 NOV 2013
FIGURE 2
REVISION 6
UTM ZONE 15
NAD 1983
1:300,000



LEGEND

- Ilsley-Gulliver trough (JDMA)
- End moraine (JDMA)
- Main road
- Batholith\pluton
- Township of Ignace
- Geographic township
- Ice-flow (NOEGTS)
- Waterbody
- Watercourse

Water well (MOE)

Depth to bedrock (m)

- 0.9 - 5.0
- 5.1 - 15.0
- 15.1 - 80.5

Drill hole (OGS)

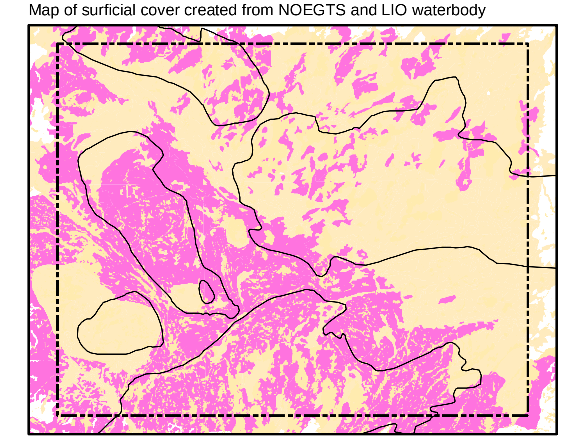
Depth to bedrock (m)

- 0.2 - 5.0
- 5.1 - 15.0
- 15.1 - 31.7

Surficial geology (NOEGTS)

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

Map of surficial cover created from NOEGTS and LIO waterbody



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

Data sources:
Batholiths: Generalized after OGS MRD 126-REV1
NOEGTS: OGS MRD 160 (scale 1:100,000)
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Water well: MOE Water Well Information System
Drill hole: OGS Drill Hole Database (selected)

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Surficial geology of the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 3	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000

LEGEND

- Township of Ignace
- Main road
- Spot height (m)
- Ilsley-Gulliver Trough
- End moraine
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

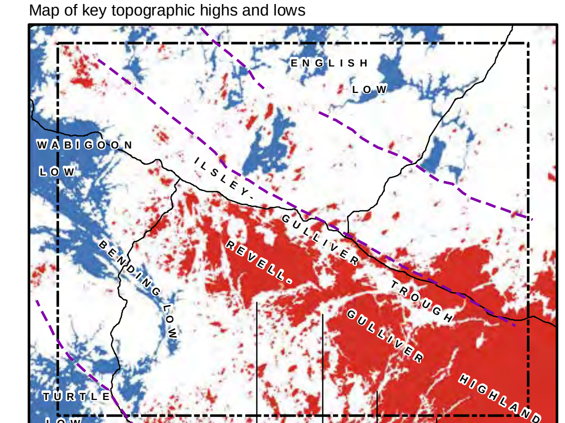
Elevation (m)

- 368 - 376
- 376.1 - 389.7
- 389.8 - 403.4
- 403.5 - 417.1
- 417.2 - 430.8
- 430.9 - 444.5
- 444.6 - 458.1
- 458.2 - 471.8
- 471.9 - 485.5
- 485.6 - 499.2
- 499.3 - 554.6

Slope (°)

- 0 - 0.3
- 0.4 - 1.8
- 1.9 - 3.2
- 3.3 - 4.6
- 4.7 - 6
- 6.1 - 7.4
- 7.5 - 8.8
- 8.9 - 36.1

Map of key topographic highs and lows



LEGEND

- End moraine

Elevation (m)

- 365 - 405
- 405.1 - 460
- 460.1 - 553.8

Data sources:
DEM: CDED elevation and slope (1:50,000)
Batholiths: Generalized after OGS MRD 126-REV1
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Elevation and major topographic features

DESIGN	DVZ	25 JUN 2012	FIGURE 4	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	LAP\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000

LEGEND

- Township of Ignace
- Main road
- Spot height (m)
- End moraine
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

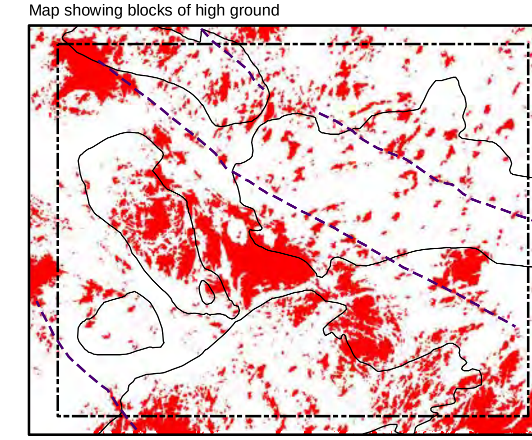
Relief (m)

- -48.4 - -40.7
- -40.6 - -31.7
- -31.6 - -22.6
- -22.5 - -13.6
- -13.5 - -4.5
- -4.4 - 4.5
- 4.6 - 13.6
- 13.7 - 22.6
- 22.7 - 31.7
- 31.8 - 40.7
- 40.8 - 93.2

Slope (°)

- 0 - 0.3
- 0.4 - 1.8
- 1.9 - 3.2
- 3.3 - 4.6
- 4.7 - 6
- 6.1 - 7.4
- 7.5 - 8.8
- 8.9 - 36.1

Map showing blocks of high ground



LEGEND

- End moraine

Relief (m)

- -48 - 15
- 16 - 93

Data sources:
DEM: CDED elevation and slope (1:50,000)
Batholiths: Generalized after OGS MRD 126-REV1
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

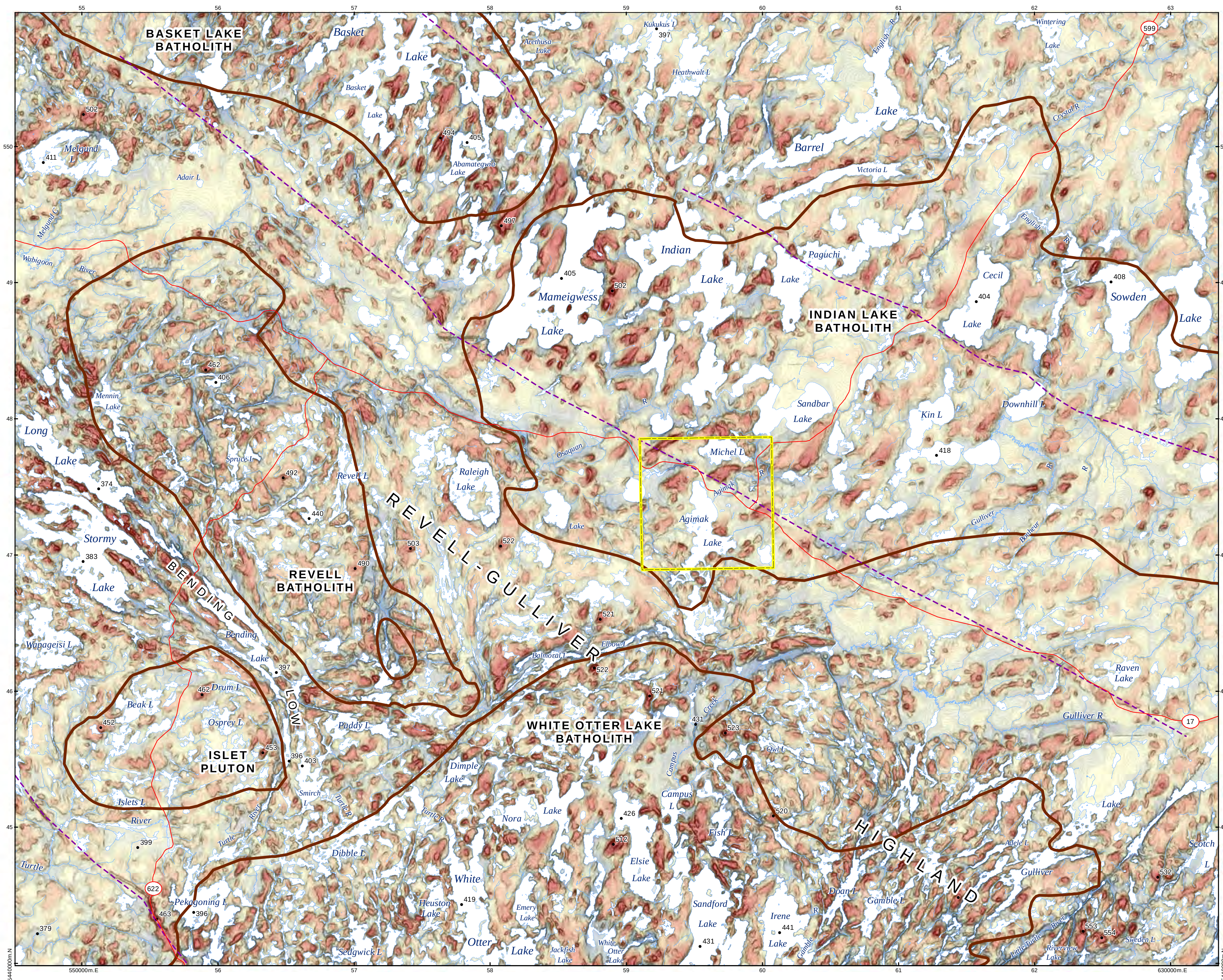
NORTH
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Departure from average elevation within a 20 km radius

DESIGN	DVZ	25 JUN 2012	FIGURE 5	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	LAP\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000



LEGEND

- Township of Ignace
- Main road
- Spot height (m)
- End moraine
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

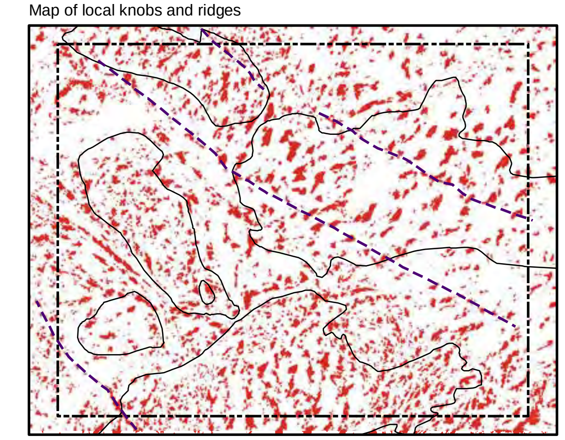
Relief (m)

- -38.7 - -30.4
- -30.3 - -24.9
- -24.8 - -19.4
- -19.3 - -13.9
- -13.8 - -8.5
- -8.4 - -3
- -2.9 - 2.5
- 2.6 - 8
- 8.1 - 13.5
- 13.6 - 18.9
- 19 - 24.4
- 24.5 - 29.9
- 30 - 74.5

Slope (°)

- 0 - 0.3
- 0.4 - 1.8
- 1.9 - 3.2
- 3.3 - 4.6
- 4.7 - 6
- 6.1 - 7.4
- 7.5 - 8.8
- 8.9 - 36.1

Map of local knobs and ridges



LEGEND

- End moraine

Relief (m)

- -39 - 10
- 11 - 75

Data sources:
DEM: CDED elevation and slope (1:50,000)
Batholiths: Generalized after OGS MRD 126-REV1
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

NORTH

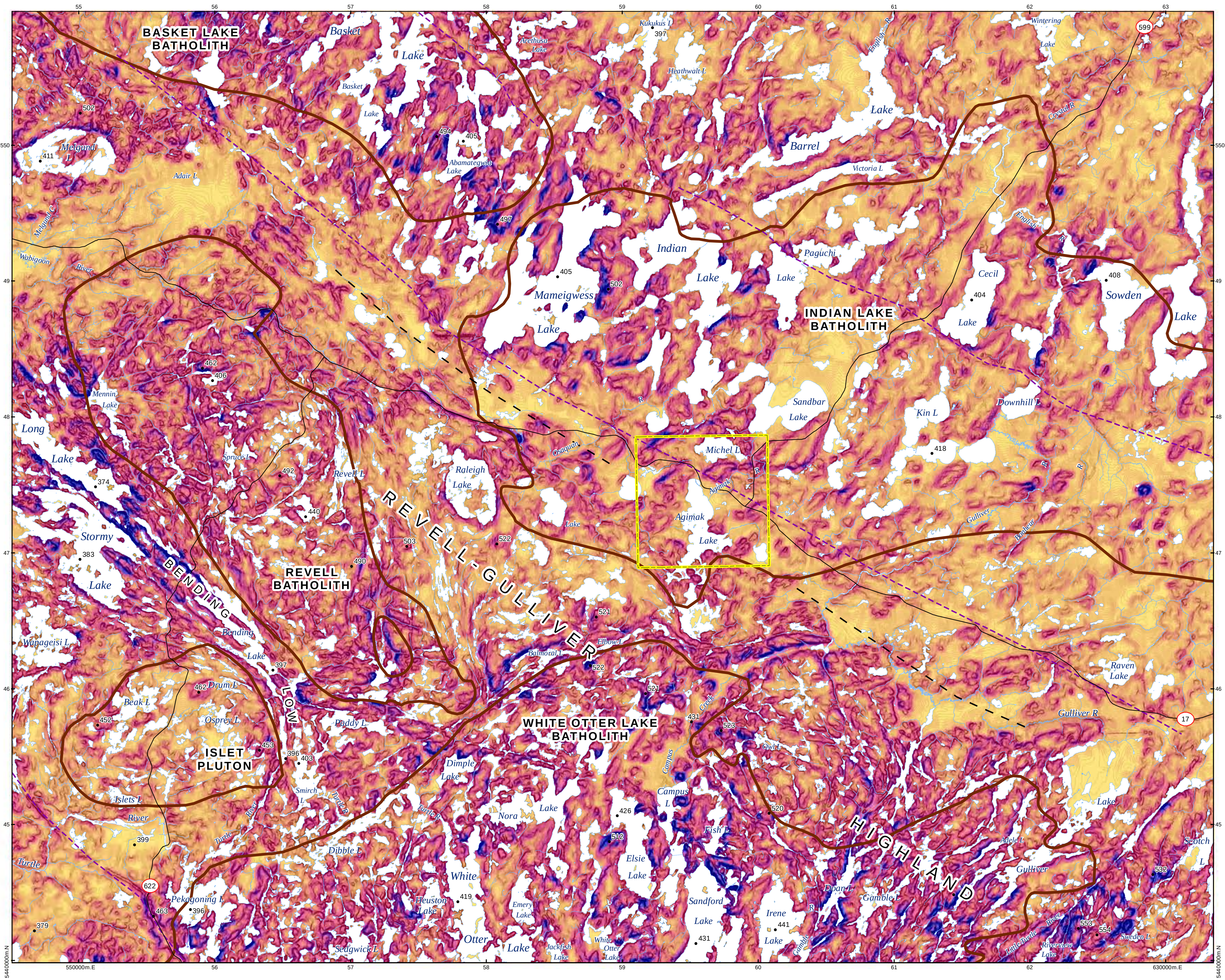
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Departure from average elevation within a 2 km radius

DESIGN	DVZ	25 JUN 2012	FIGURE 6	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	LAP\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000



LEGEND

- Township of Ignace
- Main road
- Spot height (m)
- Ilsley-Gulliver Trough
- End moraine
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

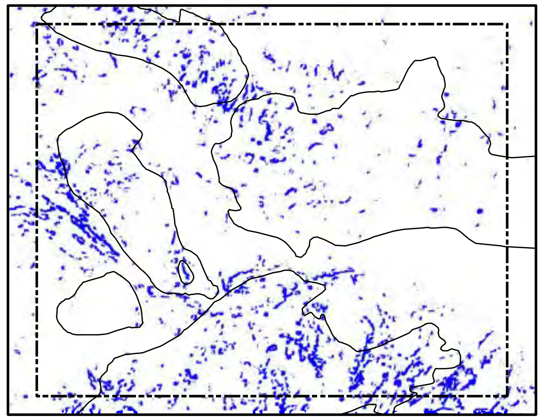
Relief (m)

- 0 - 3.1
- 3.2 - 9.3
- 9.4 - 15.4
- 15.5 - 21.6
- 21.7 - 27.8
- 27.9 - 34
- 34.1 - 40.1
- 40.2 - 46.3
- 46.4 - 52.5
- 52.6 - 96.8

Slope (°)

- 0 - 0.3
- 0.4 - 1.8
- 1.9 - 3.2
- 3.3 - 4.6
- 4.7 - 6
- 6.1 - 7.4
- 7.5 - 8.8
- 8.9 - 36.1

Map of high relief areas



LEGEND

- Batholith

Relief (m)

- 0 - 40
- 41 - 97

Data sources:
DEM: CDED elevation and slope (1:50,000)
Batholiths: Generalized after OGS MRD 126-REV1
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

NORTH

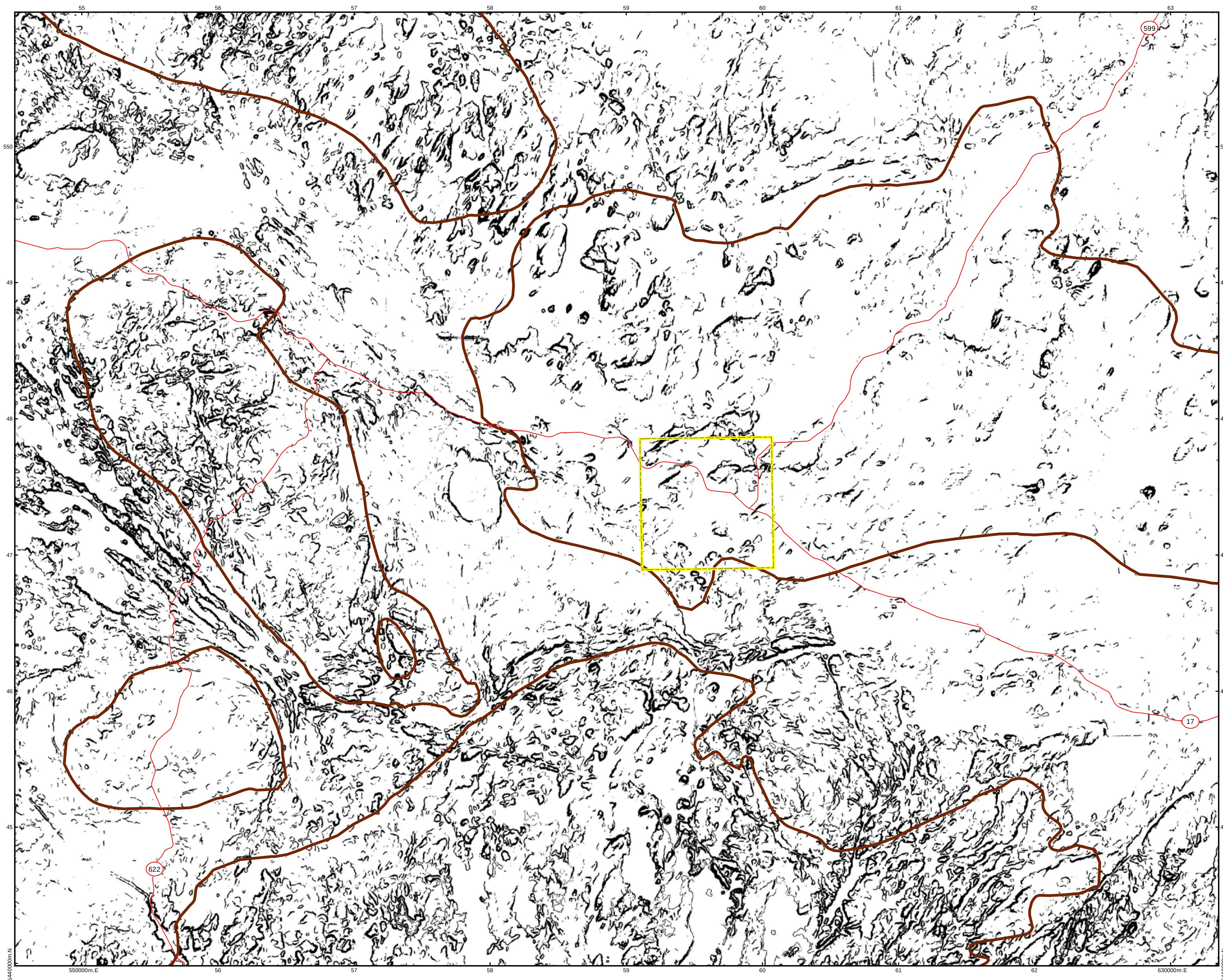
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Range in elevation within 250 m radius

DESIGN	DVZ	25 JUN 2012	FIGURE 7	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	LAP\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000



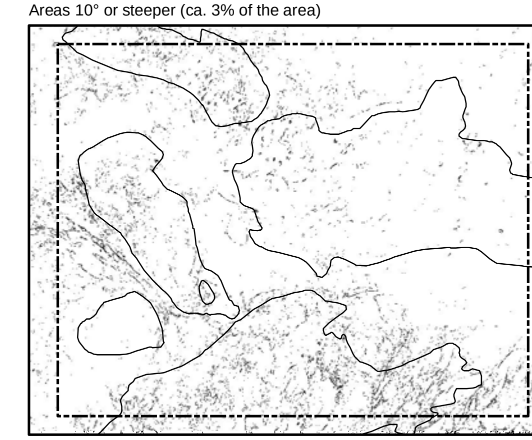
LEGEND

Township of Ignace
Main road
Batholith\pluton

Slope (°)

0 - 6
6.1 - 36.1

Areas 10° or steeper (ca. 3% of the area)



LEGEND

0.14 - 9.9
10 - 36

Data sources:
DEM: CDED elevation and slope (1:50,000)
Batholiths: Generalized after OGS MRD 126-REV1
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data

NORTH

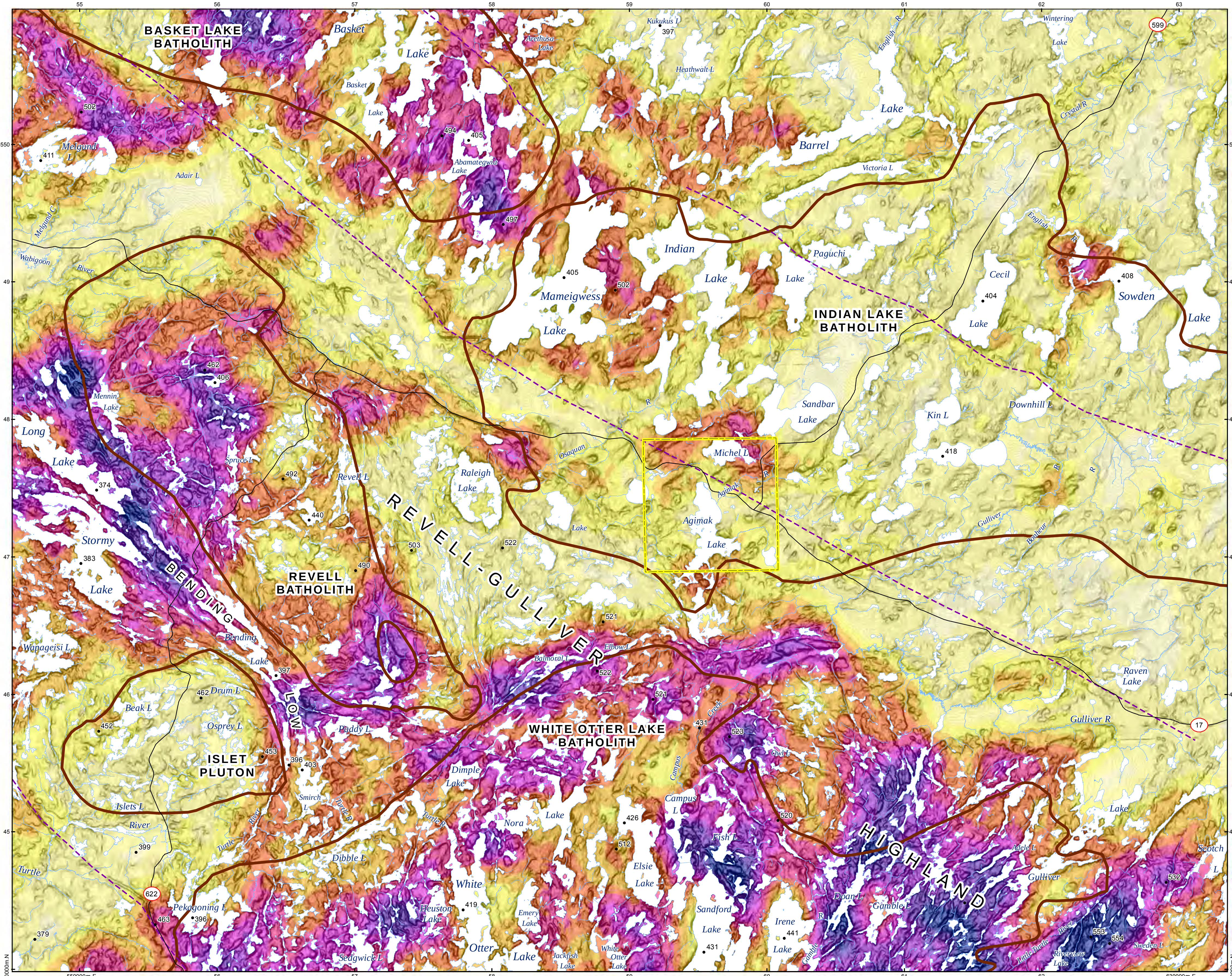
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Areas 6° or steeper in the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 8	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	LAP\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000



LEGEND

- Township of Ignace
- Main road
- Spot height (m)
- End moraine
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

Slope density

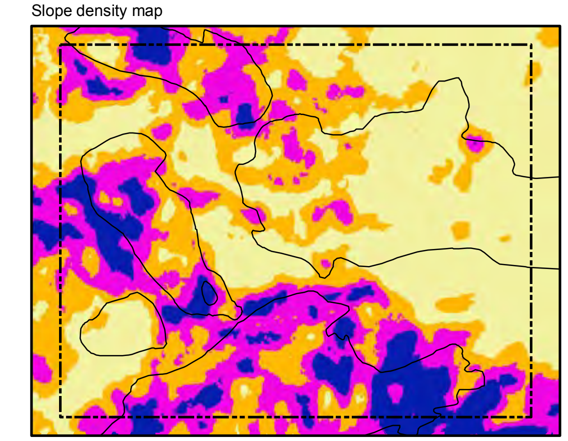
Points/km^2

- 0 - 17.7
- 17.8 - 124.5
- 124.6 - 231.4
- 231.5 - 338.2
- 338.3 - 445
- 445.1 - 551.9
- 552 - 658.7
- 658.8 - 765.5
- 765.6 - 872.3
- 872.4 - 1,131.9

Slope (°)

- 0 - 0.3
- 0.4 - 1.8
- 1.9 - 3.2
- 3.3 - 4.6
- 4.7 - 6
- 6.1 - 7.4
- 7.5 - 8.8
- 8.9 - 36.1

Slope density map



LEGEND

Density

Points/km^2

- 0 - 178
- 179 - 373
- 374 - 599
- 600 - 1,130

Data sources:
DEM: CDED elevation and slope (1:50,000)
Batholiths: Generalized after OGS MRD 126-REV1
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

NORTH

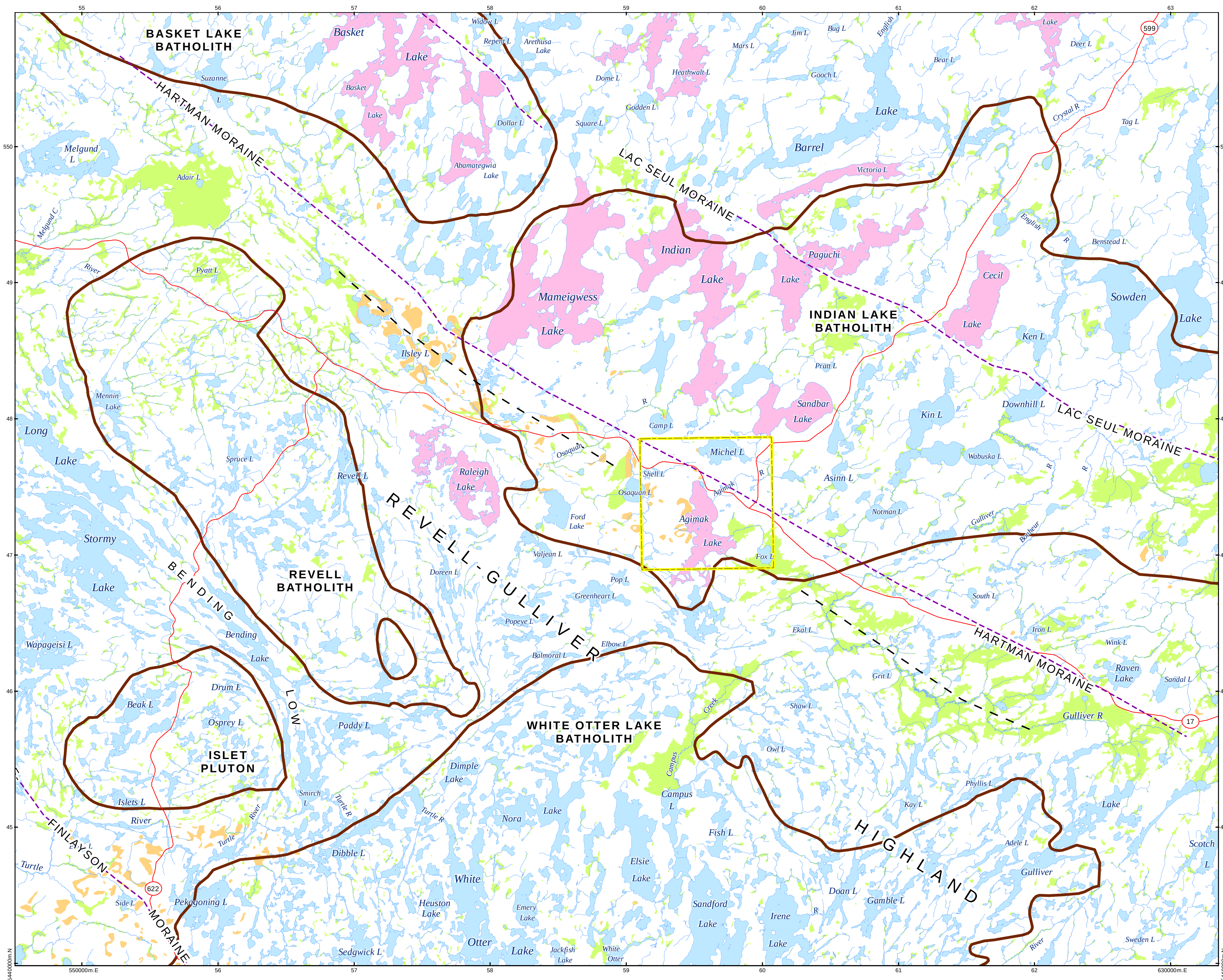
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Density of steep (≥6°) slopes within 2 km radius

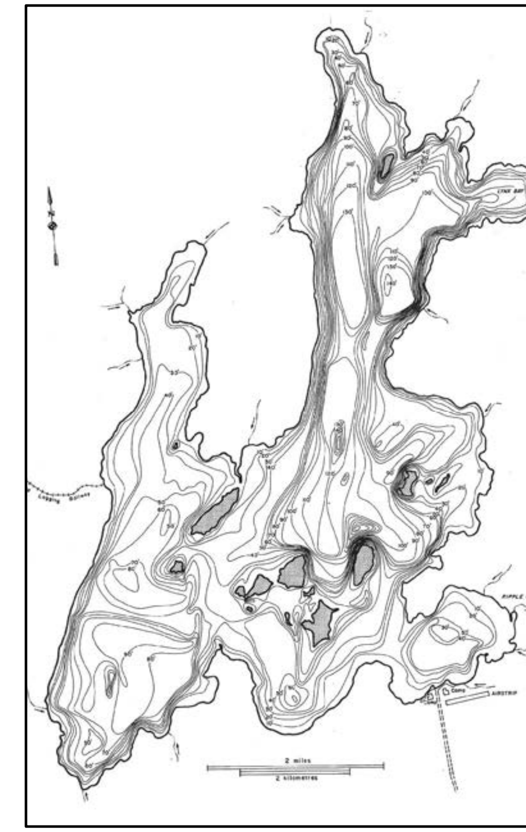
DESIGN	DVZ	25 JUN 2012	FIGURE 9	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	LAP\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000



LEGEND

- Township of Ignace
- Ilsley-Gulliver trough
- End moraine
- Main road
- Batholith\pluton
- Waterbody (depth survey)
- Waterbody (permanent)
- Watercourse
- Wetland (JDMA infill)
- Wetland

MNR depth survey of Mameigwess Lake



Data sources:
DEM: CDED elevation and slope (1:50,000)
Batholiths: Generalized after OGS MRD 126-REV1
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Wetland: LIO Wetland Unit (infilling by JDMA)

NORTH

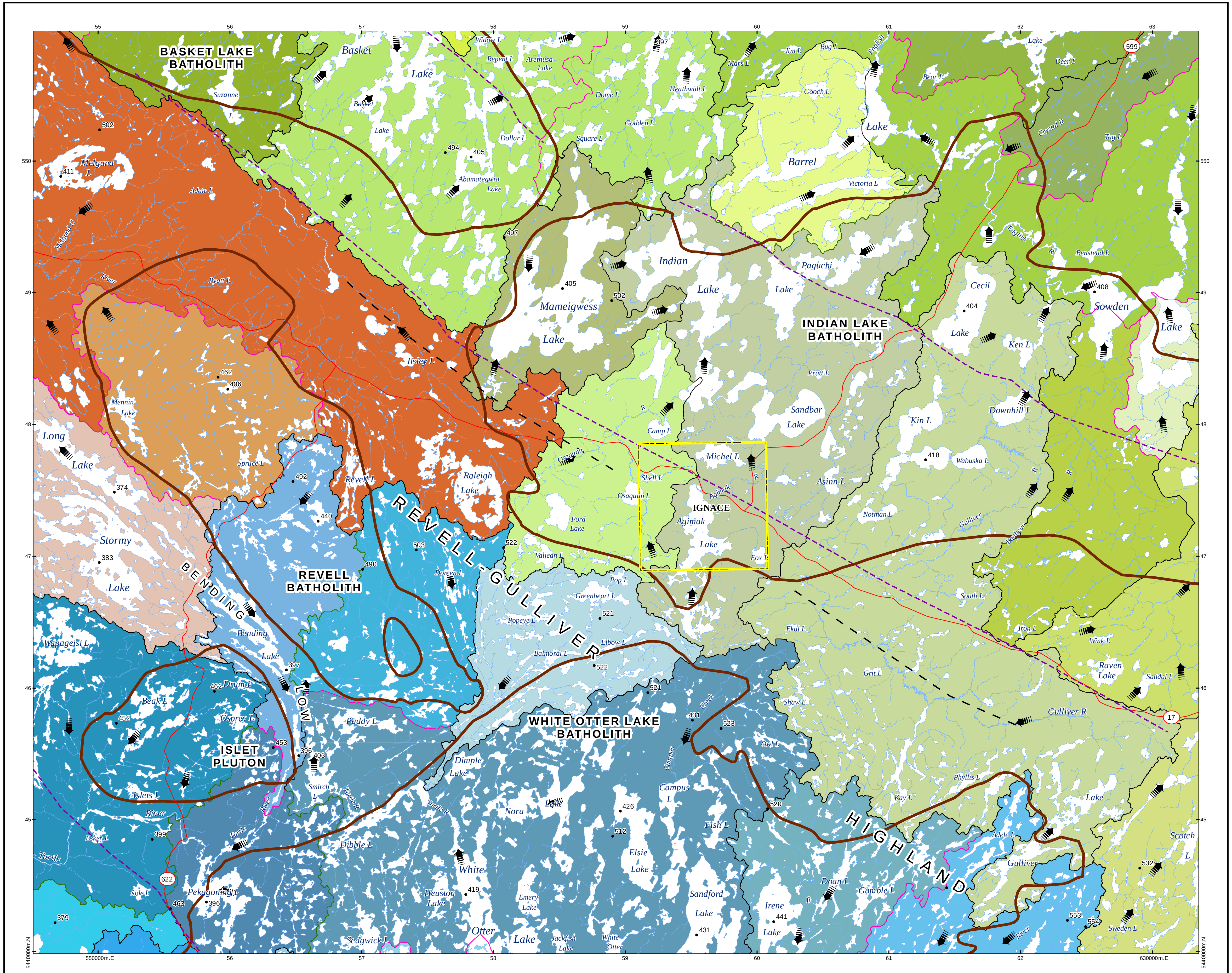
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Surface drainage features of the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 10	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	LAP\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000



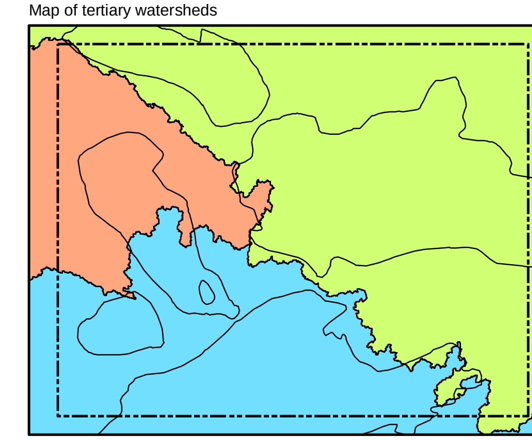
LEGEND

- Township of Ignace
- Flow
- Spot height (m)
- Ilsley-Gulliver trough
- End moraine
- Main road
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

Drainage divide

- MNR/JDMA
- JDMA
- MNR

Map of tertiary watersheds



LEGEND

- Batholith

Tertiary watershed

- Central Rainy sub-sub basin
- Upper English sub-sub basin
- Wabigoon sub-sub basin

Data sources:
DEM: CDED elevation and slope (1:50,000)
Batholiths: Generalized after OGS MRD 126-REV1
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Watershed: LIO quat. watershed (updated JDMA)

NORTH

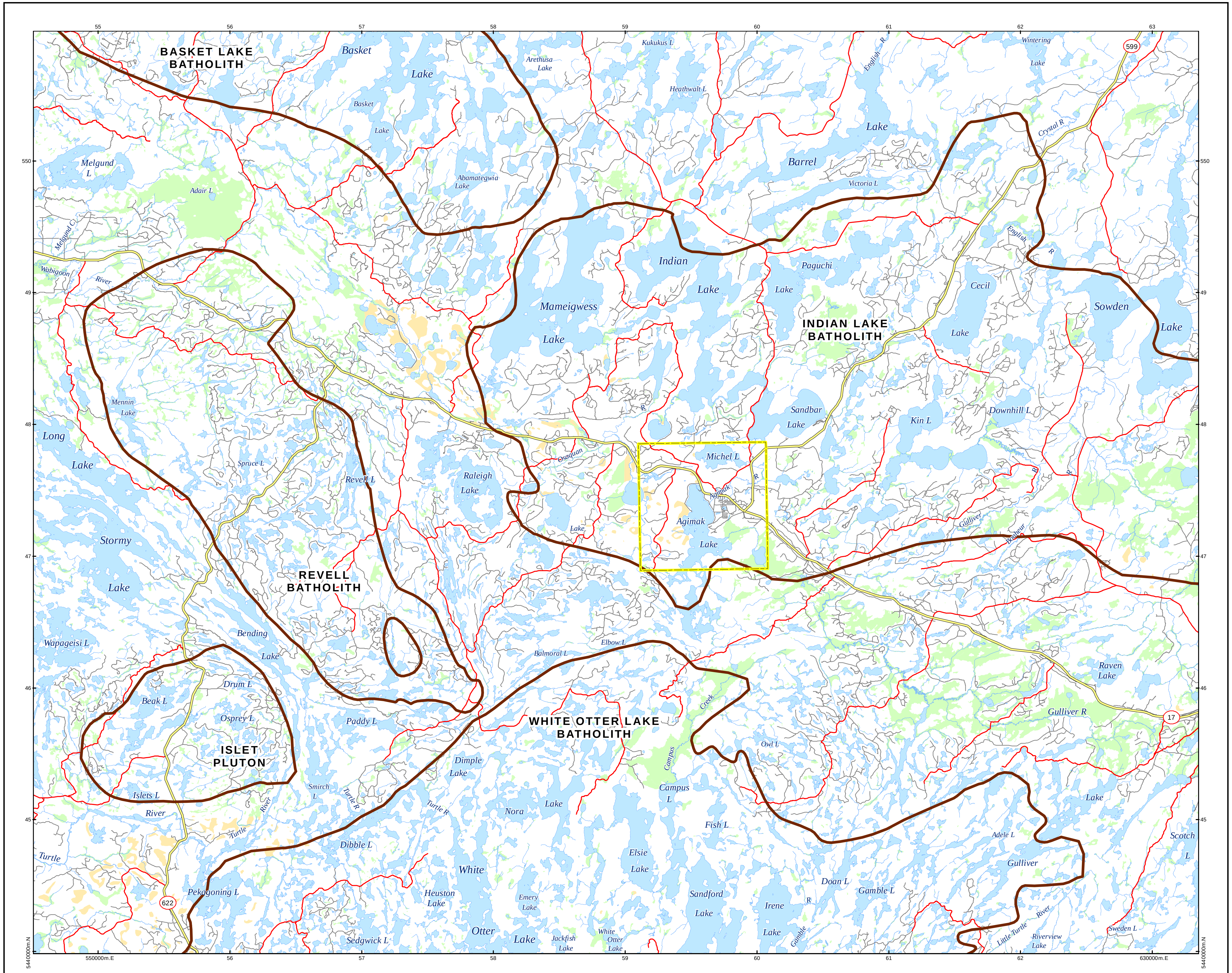
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Watersheds within the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 11	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	LAP\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000



LEGEND

- Township of Ignace
- Batholith\pluton
- Main road
- Trunk resource road
- Resource road
- Waterbody (permanent)
- Watercourse
- Wetland (MNR)
- Wetland (JDMA)

Data sources:
Batholiths: Generalized after OGS MRD 126-REV1
Road: LIO MNR Road Segment (classed by JDMA)
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Wetland: LIO Wetland Unit (infilling by JDMA)

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, IGNACE AREA, ONTARIO

TITLE
Road network in the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 12	REVISION 5
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	LAP\CM	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:300,000