NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Interpretation

TOWNSHIP OF IGNACE, ONTARIO

APM-REP-06144-0014

NOVEMBER 2013

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PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT

LINEAMENT INTERPRETATION

TOWNSHIP OF IGNACE, ONTARIO

NWMO REPORT NUMBER:
APM-REP-06144-0014

November 2013

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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 (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Ignace area for safely hosting a deep geological repository (Step 3). This request followed a successful completion of an initial screening conducted during Step 2 of the site selection process.

The preliminary assessment is a multidisciplinary desktop 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 lineament investigation assessment completed as part of the desktop geoscientific preliminary assessment of the Ignace area (Golder, 2013). The lineament assessment focused on identifying surficial and geophysical lineaments and their attributes using publicly-available digital datasets, including surficial (satellite imagery, digital elevation) and geophysical (aeromagnetic) datasets for the Ignace area. The assessment of interpreted lineaments in the context of identifying general areas that have the potential to meet NWMO's geoscientific site evaluation factors is provided in the desktop preliminary geoscientific assessment report (Golder, 2013). The lineament investigation interprets the location and orientation of potential bedrock structural features (e.g., individual fractures or fracture zones) within the context of the local and regional geological setting. The approach undertaken in this desktop lineament investigation is based on the following:

- Lineaments were interpreted from multiple, readily-available datasets (aeromagnetic, CDED, SPOT and LandSAT);
- Lineament interpretations were made by documented specialist observers and using a standardized workflow;
- Lineament interpretations were analyzed based on an evaluation of the quality and limitations of the available datasets;

- Interpreted lineaments were separated into three categories (ductile, brittle, dyke) based on their character expressed in the aeromagnetic data.
- Lineament interpretations were analyzed using reproducibility tests, particularly the coincidence of lineaments extracted by different observers, coincidence of lineaments extracted from different datasets, relative ages and/or documentation in literature; and
- Final classification of the lineament interpretation was done based on length and reproducibility.

The distribution of lineaments in the Ignace area reflects the bedrock structure, resolution of the datasets used, and surficial cover. Surficial lineament density, as demonstrated in this assessment, is closely associated with the distribution and thickness of overburden cover that masks the surficial expression of bedrock structures. Surficial lineament density was observed to be highest in the central and southwestern part of the Ignace area where the thickness and extent of surficial cover is relatively low. Lineament density is also influenced by the resolution of the datasets as demonstrated by the comparison of aeromagnetic lineament density interpreted from high and low resolution surveys. This observation suggests that areas mapped as having a low density of geophysical lineaments (the Indian Lake, Basket Lake and central part of the White Otter Lake batholiths) likely have a similar lineament density as was interpreted in areas with higher resolution data (Revell batholith and surrounding area).

It may be possible, with further detailed investigation, to assign the formation of the identified lineaments to distinct deformation events. However, it is difficult at the desktop stage to provide any constraint on the timing of lineament development beyond denoting all identified brittle and dyke lineaments as composite structures that were formed during a protracted period of deformation post-dating approximately 2.690 billion years ago.

TABLE OF CONTENTS

LIST OF TABLES IV

1 INTRODUCTION 1
1.1 SCOPE OF WORK 1
1.2 QUALIFICATIONS OF THE INTERPRETATION TEAM 3
1.3 REPORT ORGANIZATION 5

2 SUMMARY OF PHYSICAL GEOGRAPHY AND GEOLOGY 7
2.1 PHYSICAL GEOGRAPHY 8
2.2 BEDROCK GEOLOGY 8
2.2.1 INTRUSIVE ROCKS 9
2.2.2 MAFIC DYKES 11
2.2.3 GREENSTONE BELTS 12
2.2.4 FAULTS 13
2.2.5 METAMORPHISM 14
2.3 GEOLOGICAL AND STRUCTURAL HISTORY 15
2.4 QUATERNARY GEOLOGY 18
2.5 LAND USE 19

3 METHODOLOGY 21
3.1 SOURCE DATA DESCRIPTIONS 21
3.1.1 SURFICIAL DATA 21
3.1.2 GEOPHYSICAL DATA 25
3.2 LINEAMENT INTERPRETATION WORKFLOW 26
3.2.1 STEP 1: LINEAMENT IDENTIFICATION AND CERTAINTY LEVEL 27
3.2.2 STEP 2: REPRODUCIBILITY ASSESSMENT 1 (RA_1) 28
3.2.3 STEP 3: REPRODUCIBILITY ASSESSMENT 2 (RA_2) 29

4 FINDINGS 31
4.1 DESCRIPTION OF LINEAMENTS BY DATASET 31
4.1.1 SURFICIAL DATASETS (DEM AND SPOT) 31
4.1.2 GEOPHYSICAL DATA 32
4.2 DESCRIPTION AND CLASSIFICATION OF INTEGRATED LINEAMENT COINCIDENCE (RA_2) 33
4.3 DESCRIPTION OF LINEAMENTS BY MAJOR GEOLOGICAL UNIT 34

5 DISCUSSION 37
5.1 LINEAMENT DENSITY 37
5.2 REPRODUCIBILITY AND COINCIDENCE 39
5.3 LINEAMENT LENGTH 40
5.4 FAULT AND LINEAMENT RELATIONSHIPS 41
5.5 RELATIVE AGE RELATIONSHIPS 41

6 SUMMARY 45

REFERENCES 47

REPORT SIGNATURE PAGE 51

LIST OF FIGURES (IN ORDER FOLLOWING TEXT)

Figure 1: Township of Ignace and surrounding area.

Figure 2: Regional tectonic setting of the Ignace area.

Figure 3: Bedrock geology of the Ignace area.

Figure 4: Surficial geology of the Ignace area.

Figure 5: CDED digital elevation data.

Figure 6: SPOT satellite data.

Figure 7: Pole reduced magnetic field for the Ignace area.

Figure 8: CDED reproducibility assessment (RA_1).

Figure 9: SPOT reproducibility assessment (RA_1).

Figure 10: Aeromagnetic reproducibility assessment (RA_1).

Figure 11: Ductile features of the Ignace area

Figure 12: Lineament classification by reproducibility assessment (RA_2).

Figure 13: Lineament classification by length.

Figure 14: Lineament orientations of batholiths and plutons in the Ignace area.

LIST OF TABLES

Table 1 Summary of the geological and structural history of the Ignace area. 17

Table 2 Summary of source data information for the lineament interpretation, Ignace area. 23

Table 3 Summary of 1:50,000 scale CDED tiles used for lineament interpretation. 24

Table 4 Summary of SPOT imagery used for lineament interpretation. 24

Table 5 Summary of attribute table fields populated for the lineament interpretation. 28

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 overall preliminary assessment of potential suitability 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). The objective of the desktop geoscientific preliminary assessment is to determine whether the Ignace area contains general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

This report presents the findings of a lineament investigation assessment completed as part of the desktop geoscientific preliminary assessment of the Ignace area (Golder, 2013). The lineament assessment focussed on identifying surficial and geophysical lineaments and their attributes using publicly-available digital datasets, including surficial (satellite imagery, digital elevation) and geophysical (aeromagnetic) datasets for the Ignace area. The assessment of interpreted lineaments in the context of identifying general areas that have the potential to meet NWMO's geoscientific site evaluation factors is provided in the desktop preliminary geoscientific assessment report (Golder, 2013). The lineament assessment focused on the Township of Ignace and its periphery, referred to as the "Ignace area" in this report.

1.1 SCOPE OF WORK

The scope of work for this assessment includes the completion of a lineament interpretation of remotely-sensed datasets, including surficial (satellite imagery, digital elevation) and geophysical (aeromagnetic) datasets for the Ignace area (approximately 6,200 km^2), in northwestern Ontario (Figure 1). The lineament investigation interprets the location and orientation of potential bedrock structural features (e.g., individual fractures or fracture zones) and helps to evaluate their relative timing relationships within the context of the local and regional geological setting. For the purpose of this report, a lineament is defined as, 'an extensive linear or arcuate geologic or topographic feature'. The approach undertaken in this desktop lineament investigation is based on the following:

- Lineaments were mapped from multiple, readily-available datasets that include satellite imagery (Système Pour l'Observation de la Terre; SPOT), digital elevation models (Canadian Digital Elevation Data; CDED), and aeromagnetic geophysical survey data;
- Lineament interpretations from each source data type were made by two documented specialist observers for each dataset (*e.g.,* geologist, geophysicist). Ductile geophysical lineament interpretations were made using the aeromagnetic geophysical survey data by an automated picking routine with confirmation by a single documented specialist observer.
- Lineaments were analyzed based on an evaluation of the quality and limitations of the available datasets, age relationships, reproducibility tests, particularly the coincidence of lineaments extracted by different observers, coincidence of lineaments extracted from different datasets, and/or documentation in literature; and
- Classification was done to indicate the significance of lineaments based on orientation, length, reproducibility and coincidence.

These elements address the issues of subjectivity and reproducibility normally associated with lineament investigations and their incorporation into the methodology increases the confidence in the resulting lineament interpretation.

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

- **Ductile lineaments:** Features which were interpreted as being associated with the internal fabric of the rock units (including sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation) were classified as ductile lineaments. This category also includes recognizable penetrative shear zone fabric.
- **Brittle lineaments:** Features interpreted as fractures (joints or joint sets, faults or fault zones, and veins or vein sets), including those that offset the continuity of the ductile fabric described above, were classified as brittle lineaments. This category also includes brittle-ductile shear zones, and brittle partings interpreted to represent discontinuous re-activation parallel to the ductile fabric. At the desktop stage of the

investigation, this category also includes features of unknown affinity. This category does not include interpreted dykes, which are classified separately (described below).

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

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

1.2 QUALIFICATIONS OF THE INTERPRETATION TEAM

The project team employed in the lineament interpretation component of the Phase 1 Desktop Geoscientific Preliminary Assessment of Potential Suitability consists of qualified experts from J.D. Mollard and Associates (2010) Limited, Regina (JDMA), Golder Associates Ltd., Mississauga, and Patterson, Grant and Watson, Toronto (PGW). JDMA coordinated the lineament interpretation with the support of PGW who conducted the lineament interpretation on the geophysical data.

Following is a brief description of the qualifications of project team members.

Lynden Penner, M.Sc., P.Eng., P.Geo. has undertaken the advancement of lineament research through the application of aerial and satellite imagery, DEMs, and GIS technology for a variety of projects including oil and gas exploration, potash mine development, groundwater exploration and contamination, CO_2 sequestration studies, and assessing gas leakage from oil and gas wells beginning in 1986 and continuing to present. Given his expertise in mapping and understanding lineaments, Mr. Penner advised project team members on lineament mapping approaches and assisted with mapping lineaments from remotely sensed imagery and worked with the project team to evaluate the significance of the mapped, coincident and linked lineaments.

Dr. Jason Cosford, Ph.D., P.Geo. has contributed to a wide range of terrain analysis studies conducted by JDMA, including routing studies (road, rail, pipeline, and transmission line), groundwater exploration, granular resource mapping, and environmental sensitivity analyses. Dr. Cosford, Mr. Penner and Dr. Jack Mollard were responsible for shallow groundwater studies for the Weyburn CO_2 sequestration research project. Dr. Cosford provided interpretation of the surficial lineaments and coordinated the evaluation of lineament attributes, and oversaw the preparation of integrated lineament datasets.

Shayne MacDonald, B.Sc., is an experienced GIS technician and remote sensing specialist. He provided GIS and image processing support for these studies and assisted with developing integrated lineament datasets under the direction of Dr. Cosford.

Jessica O`Donnell, M.Sc., is an experienced GIS technician and remote sensing specialist. She provided GIS and image processing support for these studies and assisted with developing integrated lineament datasets under the direction of Dr. Cosford.

Charles Mitz, M.Eng., P.Geo. is a Senior Engineering Geologist with Golder who has a broad background in geoscience including extensive experience in geotechnical engineering, waste management and hydrogeology in both fractured rock and porous media. He has 20 years of experience in the consulting field, including the management of a number of high profile and multidisciplinary projects. Recently he has worked on the development of the generic geoscientific site selection process and has been involved in the initial geoscientific screening studies for a number of potential sites in the Canadian Shield crystalline rock environment in northern Ontario. Mr. Mitz holds a Bachelor's Degree in Geological Science from Queen's University and a Master's Degree in Civil Engineering from the University of Western Ontario. In this study, Mr. Mitz was the second interpreter of the surficial lineaments.

Dr. James Misener, Ph.D., P.Eng. is President of PGW and a senior geophysicist with 37 years of experience in all aspects of geophysics and geophysics software applications. Dr. Misener founded Geosoft Inc. and led its development of world-leading geosciences software applications until he succeeded Dr. Paterson as President of PGW. He has directed implementation of geophysical data processing systems; initiated and managed major continental scale compilations of aeromagnetic/marine magnetic data in North America and worldwide including interpretation of aeromagnetic, radiometric, gravity and electromagnetic surveys in: Algeria, Brazil, Cameroon, Niger, Ivory Coast, Zimbabwe, Malawi, Kenya, China, Suriname, and Ireland. Dr. Misener provided interpretations of geophysical survey data, and provided interpretation of geophysical lineaments.

Stephen Reford, B.A.Sc., P.Eng. is a senior consulting geophysicist and Vice-President of PGW. Mr. Reford has more than 30 years of experience in project management, acquisition and interpretation of airborne magnetic, electromagnetic, radiometric, gravity and digital terrain data throughout and gamma-ray spectrometer surveys for clients throughout Canada and around the world. Projects include management of the geophysical component of Operation Treasure Hunt for the Ontario Ministry of Northern Development and Mines as well as a similar role for the Far North Geoscience Mapping Initiative (2006-2009). Mr. Reford has served as a consultant to the International Atomic Energy Agency (IAEA) in gamma-ray spectrometry and is co-author of two books on radioelement mapping. Mr. Reford coordinated the interpretation of geophysical data, and was the second interpreter of the geophysical lineaments.

1.3 REPORT ORGANIZATION

Section 2.0 describes the geological setting of the Ignace area, which includes subsections on physical geography, bedrock geology, geological and structural history, Quaternary geology, and land use. Section 3.0 provides information on the source data and explains the methodology used to identify and assess lineaments. Section 4.0 presents the findings of the lineament interpretation with a description of lineaments by each dataset and a description and classification of integrated lineaments. Section 5.0 offers a discussion of the findings, specifically the lineament density, reproducibility and coincidence, lineament length, fault and lineament relationships, and relative age relationships. Section 6.0 is a summary of the report.

The primary source for all of the background information presented herein is the main report written by Golder (2013). This report also draws upon information from the supporting reports on terrain analysis (JDMA, 2013) and geophysics (PGW, 2013).

2 SUMMARY OF PHYSICAL GEOGRAPHY AND 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 (Figure 2). The Superior Province has been subdivided in recent years into lithotectonic terranes and domains (Percival and Easton, 2007; Stott et al., 2010). Terranes are defined as tectonically bounded regions with characteristics distinct from adjacent regions prior to their accretion into the Superior Province, while domains refer to lithologically distinct portions within a terrane (Stott et al., 2010).

The Ignace area is situated in the central 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 (Figures 2 and 3). The Wabigoon Subprovince is about 900 km long and 150 km wide and bounded by the Winnipeg River Subprovince to the northwest, the English River Subprovince to the northeast, and the Quetico Subprovince to the south (Blackburn et al., 1991). The Wabigoon Subprovince 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 Physical Geography, Bedrock Geology, Structural History, Quaternary Geology and Land Use, present summaries of the information presented in Golder (2013), JDMA (2013) and PGW (2013) where applicable, in order to provide the necessary context for discussion of the results of this lineament assessment (Section 5.0).

2.1 PHYSICAL GEOGRAPHY

A detailed discussion of the physical geography of the Ignace area is provided in a separate terrain analysis report (JDMA, 2013), and the following is a summary of that information. The Ignace area exhibits topographic and drainage features that are characteristic of the Canadian Shield physiographic region, a low-relief, dome-like, gently undulating land surface. Topography in the Ignace area is generally subdued due to prolonged erosion but is also rugged and hilly with roughly 190 m of relief variation, ranging from a minimum elevation of about 368 m to a maximum elevation of about 554 m across the Ignace area. Topographic highs generally correspond to bedrock outcrops while topographic lows are generally areas of thicker overburden. Exposed bedrock covers roughly 2,340 km^2 (38%) of the Ignace area (Figures 3 and 4; JDMA, 2013).

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 approximately 18% (1,115 km^2) of the entire area occupied by water bodies (JDMA, 2013). The large lakes are sufficiently large to conceal lineaments up to about ten kilometres in length, and nests of lakes have additional potential to conceal lineaments, especially when the lakes are located in areas where lineaments are obscured by overburden deposits (see also Section 2.4). There is considerable relief between the lakes in most areas.

2.2 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 regional-scale distribution of the geological units (1:250,000) mapped by the OGS are shown in Figure 2. Six additional detailed geological map tiles (1:50,000) have been superimposed on the OGS regional bedrock geology map and are presented in Figure 3. 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.

2.2.1 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 3). The Indian Lake batholith is bounded by the Raleigh Lake greenstone belt along its southwestern and southernmost margins and elsewhere by gneissic tonalite (Figure 3).

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 3). 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 3). 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 3). 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 3). 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. 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 (Figure 3), the Paddy Lake and Adele Lake plutons described above are a subset of this complexly deformed and poorly defined suite of crystalline rocks.

2.2.2 MAFIC DYKES

Mafic dykes are widespread throughout the Superior Province (Figure 2) 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, 1991). 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, 1991). 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 (Figure 2). 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.

2.2.3 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 3). Together these greenstone belts cover approximately 458 km^2 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.

2.2.4 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 (Figures 2 and 3). 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 3). 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; Figure 2).

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 (Figure 3). 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 (Figure 2) 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 3). 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 (Kameneni et al., 1990; Stone, 2009a).

2.2.5 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., 1991; 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

2.3 GEOLOGICAL AND STRUCTURAL HISTORY

Direct information on the geological and structural history of the Ignace area is limited. The geological and structural history summarized below and in Table 1 integrates the results from studies undertaken elsewhere throughout and proximal to the regional area shown in Figure 2. 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 ago 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.

Table 1 Summary of the geological and structural history of the Ignace area.

Time period (billion years ago)	Geological event
ca. 3.0	Assemblage of the oldest rocks in the Ignace area comprising the Marmion terrane – essentially a micro-continent comprising tonalite basement rocks dominated by the Marmion batholith which occurs immediately south of the Ignace area.
ca. 3.0 to 2.74	Progressive growth of the Marmion terrane through the additions of magmatic and crustal material in continental arcs and through accretion of allocthonous crustal fragments. This growth included the emplacement of the Phyllis Lake gneisses and tonalites 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., 1991). The result of this volcanic period is the Raleigh Lake and Bending Lake greenstone belts (Stone, 2010a). Sedimentation within the greenstone belts was largely synvolcanic, although sediment deposition in the Bending Lake area may have continued past the volcanic period (Stone, 2009b; Stone, 2010b). Synvolcanic to post-volcanic plutonism in the Ignace area included minor mafic intrusions (possibly flow centres) of gabbroic composition and the intrusion of tonalitic phases of the Revell batholith, approximately 2.737 to 2.732 billion years ago (Larbi et al., 1998; Buse et al., 2010). D_1-D_2 (Percival, 2004)
ca. 2.71	Collision of the Winnipeg River-Marmion terrane and a northern superterrane (Uchian Orogeny) (Corfu et al., 1995).
ca. 2.70 to 2.67	Collision of the volcanic island arc (Western Wabigoon terrane) against the superterrane (Central Superior Orogeny) (Percival et al., 2006; Stone, 2010a). The central Superior Orogeny was accompanied by widespread regional plutonism. In the Ignace area, this resulted in emplacement of intrusive rocks including the major batholiths of interest in this assessment. Specific dates include: ▪ Ca. 2.694 billion years ago: Crystallization age of the youngest phase of the Revell batholith; ▪ Ca. 2.685 billion years ago: Crystallization age of the White Otter Lake batholith; ▪ Ca. 2.671 billion years ago: Crystallization age of the Indian Lake batholith; and ▪ Ca. 2.697 to 2.684 billion years ago: an interval of sanukitoid magmatism (Stone, 2010a), which is expressed in the Ignace area by the emplacement of small plutons, such as the Islet pluton (Stone, 2009a) D_3 and D_4 (Percival, 2004).
ca. 2.6 to 2.4	Regional faulting and brittle fracturing (Kamineni et al., 1990).
ca. 2.12	Emplacement of the northwest trending Kenora-Fort Frances dyke swarm (Southwick and Halls, 1987).
ca. 1.947	Brittle reactivation of regional-scale faults (Peterman and Day, 1989).
ca. 1.900	Emplacement of the west-northwest trending Wabigoon dyke swarm (Fahrig and West, 1986; Osmani, 1991).
ca. 1.13 to 1.14	Emplacement of the northwest trending dykes of Eye–Dashwa swarm (Kamineni and Stone, 1983).
Post-1.14	A complex interval of erosion, brittle fracture, repeated cycles of burial and exhumation, and glaciations, particularly from the latest Miocene to the present.

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 (Figures 2 and 3), 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.

2.4 QUATERNARY GEOLOGY

Information on Quaternary geology in the Ignace area is described in detail in the terrain report (JDMA, 2013) and is summarized here. 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 (Figure 4). 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 4, 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 end moraines (Lac Seul, Hartman, Eagle-Finlayson moraines) extending through the Ignace area recording the progressive retreat of the ice sheet (Figure 4).

The Hartman moraine is a significant Quaternary landform in the Ignace area that divides the area into distinct zones based on the thickness of Quaternary deposits. Thicker till, glaciofluvial outwash, and deep-water glaciolacustrine deposits occur north of this moraine, whereas surficial deposits are generally thinner to the south (Figure 4). Areas mapped as bedrock terrain to the north of the Harman moraine represent a spattering of islands within a proglacial lake known as Glacial Lake Agassiz that subsequently contracted into a set of large modern lakes.

Information on the thickness of Quaternary deposits within the Ignace area has been largely derived from terrain evaluation, and is described in detail in JDMA, 2013a. Measured thicknesses are limited to a small number of water well records for rural residential properties, typically along the TransCanada highway, and to diamond drill holes concentrated in the greenstone belts. Recorded depths to bedrock in the Ignace area range from 0 to 80 m, with an average of about 7 to 10 m. The thickness of the Quaternary deposits southwest of the highway in the periphery of the Township of Ignace is typically less than 5 m. The thickest overburden is inferred to occur along the axes of the Eagle-Finlayson, Hartman, and Lac Seul moraines. The impact that the variable distribution of Quaternary sediments has on the results of the lineament interpretation will be discussed in Section 5.

2.5 LAND USE

Land use within the Ignace area is limited mostly to forestry and to linear infrastructure corridors like roads, railways, pipelines and electrical transmission lines. These features do not negatively impact the interpretation of bedrock lineaments.

3 METHODOLOGY

3.1 SOURCE DATA DESCRIPTIONS

The lineament interpretation was conducted using available surficial (CDED digital elevation models, SPOT satellite imagery), and geophysical (aeromagnetic) datasets for the Ignace area. Available data were assessed for quality, processed and reviewed before use in the lineament interpretation. CDED (Figure 5) and SPOT (Figure 6) datasets were used to identify surficial lineaments expressed in the topography, drainage, and vegetation. The resolution of the CDED and SPOT datasets was consistent across the Ignace area and provided sufficient detail to allow for the identification of surficial lineaments as short as a few hundred metres in length. The higher resolution of the SPOT imagery allowed for finer structures to be identified that were not resolved by the CDED data; but, the CDED data often revealed subtle trends masked by the surficial cover captured in the SPOT imagery. The geophysical dataset for the Ignace area included low resolution coverage across the entire Ignace area as well as smaller regions of increased resolution within the area (Figure 7). In all cases, the best resolution data available was used for the lineament interpretation. The aeromagnetic data proved useful to interpret bedrock structure beneath areas of extensive surficial cover. Table 2 provides a summary of all of the source datasets used for the lineament interpretation.

3.1.1 SURFICIAL DATA

CDED (Canadian Digital Elevation Data)

Canadian Digital Elevation Data, 1:50,000 scale, 0.75 arc second (20 m resolution) elevation models (GeoBase, 2011a) served as important data sources for analyzing and interpreting lineaments in the Ignace area. The digital elevation model (DEM) used for this assessment, shown as a slope raster in Figure 5, was constructed by Natural Resources Canada (NRCan) using provincial data created through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (MNR). The data represented 1:20,000 scale source data acquired through the Ontario Base Mapping (OBM) program, which was a major photogrammetric program conducted across Ontario between 1978 and 1995. Four main OBM datasets were used: OBM contours, OBM spot heights, WRIP stream network, and lake elevations derived using the OBM spot heights and OBM water features. CDED datasets 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. It was determined that the resolution of the DEM dataset was sufficient to undertake the lineament interpretation.

The files were transferred 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 was arbitrary. The projected files were then assembled into a mosaic (Figure 5; JDMA, 2013). Table 3 lists the tiles used in the final mosaic.

Hillshaded representations of the CDED elevation data were built using illuminated azimuths of 045º and 315º and solar incidence angles of 45º from the horizon. 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. Figure 5 shows the calculated slope from the CDED elevation data for the Ignace area. The hillshade and slope rasters were most useful for mapping lineaments.

Table 2 Summary of source data information for the lineament interpretation, Ignace area.

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	20 m	Entire area	1978 - 1995	Hillshaded and slope rasters used for mapping
Satellite Imagery	SPOT 5; Orthoimage, multispectral/ panchromatic	Geobase	10 m (panchromatic) 20 m (multispectral)	Entire area	2006 (west) 2007 (east)	Panchromatic mosaic used for mapping
Geophysics	Geological Survey of Canada Regional Magnetic Compilation	Geological Survey of Canada	805 m line spacing Sensor height 305 m	Entire Ignace area	1965	Lowest resolution dataset
	Sturgeon Lake-Savant Lake Survey (GDS1033)	Ontario Geological Survey	200 m line spacing Sensor height 45 m	Covers 48.1 km^2 in northeast corner of Ignace area	1990	Limited usefulness due to minimal coverage in Ignace area
	Lumby-Finlayson Lakes Survey (GDS1060)	Ontario Geological Survey	200 m line spacing Sensor Height 81 m	Covers 48.0 km^2 in southeast corner of Ignace area	2009	Limited usefulness due to minimal coverage in Ignace area
	Stormy Lake Survey (GDS1107)	Ontario Geological Survey	200 m line spacing Sensor Height 73 m	Covers 2050.7 km^2 in western part of Ignace area	2001	Covers the entire Revell batholith
	Takara Resources Survey (AFRI 20000003895)	Evans 2008 Pelletier 2008	100 m line spacing Sensor Height 60 m	Covers 300 km^2 in northwestern corner of Ignace area	2008	Useful for detailed understanding

GSC = Geological Survey of Canada

Table 3 Summary of 1:50,000 scale CDED tiles used for lineament interpretation.

NTS Tiles:	Ground Resolution (arcsec.)
52F/01	0.75
52F/08-09	0.75
52F/16	0.75
52G/03-06	0.75
52G/11-14	0.75

SPOT (Système Pour l'Observation de la Terre) Imagery

SPOT multispectral (20 m resolution) and panchromatic (10 m resolution) orthoimagery (the latter is shown on Figure 6), were used for identifying surficial lineaments and exposed bedrock within the Ignace area (GeoBase, 2011b). SPOT multispectral data consist of several bands, each recording reflected radiation within a particular spectral range, and each having a radiometry of 8-bits (or a value ranging from 0 to 255). Six SPOT images (scenes) provided complete coverage for the Ignace area (Table 4). 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 and the images captured in October cover the eastern part. SPOT 5 images were acquired using the High Resolution Geometric (HRG) sensor. Each image covers a ground area of 60 km by 60 km.

Table 4 Summary of SPOT imagery used for lineament interpretation.

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

For For quality control, Natural Resources Canada (NRCan) provides images that have a maximum of 5% snow and ice cover, 5% cloud cover and a maximum viewing angle of 15º. 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). It was determined that the resolution of the SPOT dataset was sufficient to undertake the lineament interpretation. The scenes were processed to create a single panchromatic mosaic (Figure 6; JDMA, 2013). An automated contrast matching technique was applied to the images which minimizes sharp variances in pixel intensity, giving the single image a cohesive appearance. The images were extended beyond the defined boundaries of the Ignace area to allow for the mapping of continuous lineaments extending beyond the Ignace area.

3.1.2 GEOPHYSICAL DATA

The geophysical dataset incorporates aeromagnetic, gravity and radiometric data available across the entire Ignace area, however only aeromagnetic data was used for this lineament interpretation. The coarse resolution of the gravity and radiometric data were insufficient to interpret lineaments. Table 2 provides a summary of the acquisition parameters for each aeromagnetic dataset used. The magnetic data located within the Ignace area were processed using several common geophysical techniques in order to enhance the magnetic response to assist with the interpretation of geophysical lineaments. The enhanced magnetic grids used in the lineament interpretation include the first and second vertical derivatives, and the tilt angle filter grids. These enhanced grids were processed and imaged using the Geosoft Oasis Montaj software package. Acquisition parameters, processing methods and enhanced grids associated with the geophysical datasets used in the lineament interpretation are discussed in detail in PGW (2013). Three additional magnetic grids using a combination of gradient and amplitude equalization filters were prepared using the Encom (Pitney Bowes) Profile Analyst software package in order to highlight the edges of magnetic sources. The combination of all of the enhanced magnetic grids provide much improved resolution of subtle magnetic fabrics and boundaries in areas that appear featureless in the total magnetic field. Figure 7 shows a compilation of the total field (reduced to pole) of the merged magnetic datasets in the Ignace area. The quality of geophysical data varied significantly across the Ignace area, as a function of the flight line spacing, the flying height and the age of the survey. The integrity of the higher quality data was maintained throughout and the poorest resolution data was only used where higher resolution data was unavailable. It was determined that overall the quality of the data was sufficient to perform the lineament interpretation at the scale of the Ignace area.

The majority of the Ignace area is covered by low-resolution aeromagnetic data published by the Geological Survey of Canada (GSC) and downloaded from their Geoscience Data Repository for

Geophysical and Geochemical Data (GSC, 2012). This data was acquired at a flight line spacing of 805 m and a sensor height at 305 m.

Three higher resolution magnetic/electromagnetic surveys, published by the Ontario Geological Survey (OGS), were available for use in the lineament interpretation. These include the Sturgeon Lake-Savant Lake survey (OGS, 2003) that covers the extreme northeastern corner of the Ignace area with a flight line spacing of 200 m and a sensor height of 45 m, the Lumby-Finlayson Lakes survey (OGS, 2009) that covers the extreme southeastern corner of the Ignace area with a flight line spacing of 200 m and a sensor height of 81 m, and the Stormy Lake dataset (OGS, 2011) that covers much of the western half of the Ignace area with a flight line spacing of 200 m and sensor height of 73 m (Figure 7). These surveys were focused on the greenstone belts, but also covered plutonic rocks in the western half of the Ignace area.

An additional dataset, acquired in 2008 for Takara Resources, covers a small portion of the Ignace area straddling the Basket Lake and Indian Lake batholiths, and also overlaps a small portion of the Stormy Lake survey area (Figure 7). The Takara Resources survey data was retrieved from a review of assessment files (Evans, 2008) and is presented in the geophysical assessment by PGW (2013). This data was acquired with a flight line spacing of 100 m and a sensor height of 60 m.

3.2 LINEAMENT INTERPRETATION WORKFLOW

Lineaments were interpreted using a workflow designed to address issues of subjectivity and reproducibility that are inherent to any lineament interpretation. The workflow follows a set of detailed guidelines using publicly available surficial (DEM, SPOT) and geophysical (aeromagnetic) datasets as described above. The interpretation guidelines involved three steps:

1. Identification of lineaments by two interpreters for each dataset (DEM, SPOT, MAG) and assignment of certainty level (1, 2 or 3);
2. Integration of lineament interpretations by dataset (Figures 8, 9, 10) and first determination of reproducibility (RA_1); and
3. Integration of lineament interpretations for all three datasets (Figures 12 and 13) and second determination of coincidence (RA_2).

Each identified lineament feature was classified in an attribute table in ArcGIS. The description of the attribute fields used is included in Table 5. Fields 1 to 9 are populated during the first step.

Fields 10 and 11 are populated during the second step. Fields 12 to 19 are populated in the third and final step.

A detailed description of the three workflow steps, as well as the way each associated attribute field is populated for interpreted lineament is provided below. Ductile geophysical lineaments, were picked using the aeromagnetic geophysical survey data by an automated picking routine with confirmation by a single documented specialist observer (Figure 11).

3.2.1 STEP 1: LINEAMENT IDENTIFICATION AND CERTAINTY LEVEL

The first step of the lineament interpretation was to have each individual interpreter independently produce GIS lineament maps, and detailed attribute tables, for each of the three datasets. This action resulted in the production of two interpretations for each of the DEM, SPOT, and aeromagnetic datasets and a total of six individual GIS layer-based interpretations. Each interpreter assigned a certainty/uncertainty descriptor (attribute field 'Certain' = 1-low, 2-medium or 3-high) to each feature in their interpretation based on their judgment concerning the clarity of the lineament within the dataset. Where a surface lineament could be clearly seen on exposed bedrock, it was assigned a certainty value of 3. Where a lineament represented a bedrock feature that was inferred from linear features, such as orientation of lakes or streams or linear trends in texture, it was assigned a certainty value of either 1 or 2. For geophysical lineaments, a certainty value of 3 was assigned when a clear magnetic susceptibility contrast could be discerned and a certainty value of either 1 or 2 was assigned when the signal was discontinuous or more diffuse in nature. The certainty classification for all three datasets ultimately came down to expert judgment and experience of the interpreter.

The geophysical dataset also allowed the interpreter to assess the feature type of the lineament. Dyke lineaments were characterized as linear traces in which the magnetic signal of the feature were higher than the surrounding bedrock, whereas the brittle geophysical lineaments were interpreted as linear features with magnetic signals lower than the surrounding bedrock. The ductile lineaments were traced as curvi-linear features using the geophysical data representing the internal fabric of the rock units. These lineaments were initially identified using an automated picking routine, and the accuracy was confirmed by a single documented specialist observer.

It is understood that some of the lineament attributes (e.g. width and relative age) will be further refined as more detailed information becomes available in subsequent stages of characterization should the community be selected by the NWMO and remain interested in advancing in the site selection process.

Table 5 Summary of attribute table fields populated for the lineament interpretation.

	Attribute	Brief Description
1	Rev_ID	Reviewer initials
2	Feat_ID	Feature identifier
3	Data_typ	Dataset used (DEM, SPOT, Geophys)
4	Feat_typ	Type of feature used to identify each lineament (i.e., dyke, fault, etc if known)
5	Name	Name of feature (if known)
6	Certain	Certainty value (1-low, 2-medium or 3-high)
7	Length*	Length of feature is the sum of individual lengths of mapped polylines (not end to end) and is expressed in kilometres
8	Width**	Width of feature; This assessment is categorized into 5 bin classes: A. < 100 m B. 100 – 250 m C. 250 – 500 m D. 500 – 1,000 m E. > 1,000 m
9	Azimuth	Vector average direction of all line segments forming the lineament (1 – 180°)
10	Buffer_RA_1	Buffer zone width for first reproducibility assessment
11	RA_1	Feature value (1 or 2) based on first reproducibility assessment
12	Buffer_RA_2	Buffer zone width for second reproducibility assessment
13	RA_2	Feature value (1, 2 or 3) based on second reproducibility assessment (i.e., coincidence)
14	Geophys	Feature identified in geophysical dataset (Yes or No)
15	DEM	Feature identified in DEM dataset (Yes or No)
16	SPOT	Feature identified in SPOT dataset (Yes or No)
17	F_Width	Final interpretation of the width of feature
18	Rel_age	Relative age of feature, in accord with regional structural history
19	Notes	Comment field for additional relevant information on a feature

* The length of each interpreted feature is calculated based on the sum of all segment lengths that make up that lineament.

**The width of each interpreted feature is determined by expert judgment and utilization of a GIS-based measurement tool. Width determination takes into account the nature of the feature as assigned in the Feature type (Feat_typ) attribute.

3.2.2 STEP 2: REPRODUCIBILITY ASSESSMENT 1 (RA_1)

The two individual GIS lineament maps from each dataset were then integrated to provide a single interpretation for the DEM (Figure 8), SPOT (Figure 9) and aeromagnetic (Figure 10) data that included the results of the first stage reproducibility assessment (RA_1). Reproducibility is judged based on the coincidence, or lack thereof, of interpreted lineaments within an assigned buffer zone. For example, if a lineament was identified by both interpreters within an overlapping buffer zone, then it was deemed coincident and assigned a reproducibility value of two (RA_1 = 2). An initial buffer zone width (Buffer_RA_1) of 200 m was selected to evaluate coincidence. For many of the lineaments, coincidence could be demonstrated with a smaller buffer width, and in these cases a buffer width of either 100 m or 50 m, depending on the maximum offset, was entered in the attribute field. Where a lineament was identified by only one of the interpreters, it received a buffer zone width of zero (Buffer_RA1 = 0) and a reproducibility value of one (RA_1 = 1) in the attribute table.

Where coincident interpreted lineaments were identified, the one line that appeared to best represent the surficial or geophysical expression of the feature (based on the judgment of the integrator) was retained and assigned attributes. In some instances, where deemed appropriate, either an existing line was edited or a new line was drawn as part of the merging process to best capture the expression of the lineament. The decision of whether to retain or edit an existing line, or to draw a new line, was based largely on expert judgment that followed these guidelines: 1) where one continuous lineament was drawn by one interpreter, but as individual, spaced or disconnected segments by the other, a single continuous lineament was carried forward with a reproducibility value of two (RA_1 = 2) provided that the continuous lineament was deemed a better representation of the feature; and 2) where two interpreted lineaments were coincident over less than three-quarters of the total length of the longest lineament, the longest lineament was segmented and each portion was attributed with RA_1 values accordingly. Otherwise, if the two lineaments were coincident for more than three-quarters of the length of the longer lineament, they were considered coincident and assigned a reproducibility value of two (RA_1 = 2).

3.2.3 STEP 3: REPRODUCIBILITY ASSESSMENT 2 (RA_2)

In step 3, the three dataset-specific interpretations were integrated into a single map following a similar reproducibility assessment (RA_2) procedure. In this second assessment, reproducibility is based on the coincidence, or lack thereof, of interpreted lineaments between different individual datasets within an assigned buffer zone (Buffer_RA_2). Coincident lineaments were assigned a Buffer_RA_2 value of 200 m, 100 m, or 50 m, depending on the maximum distance between individual lineaments. Where coincident lineaments were identified, one of the existing lines was selected or edited to represent that feature; and, where appropriate, a new line was drawn that best captured the merger of individual lineaments, in a process similar to the integration of RA_1 lineaments. The merged lineaments were then assigned a reproducibility value (RA_2) of two or three, depending on whether the feature was identified in any two or all three of the assessed datasets. Whether two or more lineaments exhibited full or partial RA_2 coincidence was determined by the interpreter using a similar process as described for RA_1 in Section 3.2.2. That is, for full coincidence of two or more lineaments, a single integrated feature, attributed accordingly, is carried forward into the final mapped interpretation. Otherwise, a lineament is segmented and attributed according to the partial coincidence of overlapping lineaments, and the partial segments are carried forward into the final mapped interpretation. If a lineament was identified in only one dataset, and thus not a coincident lineament, it received a reproducibility value of one (RA_2 = 1) in the attribute table. The datasets within which each feature has been identified is indicated in the appropriate attribute table field (Geophys, DEM, SAT).

4 FINDINGS

4.1 DESCRIPTION OF LINEAMENTS BY DATASET

4.1.1 SURFICIAL DATASETS (DEM AND SPOT)

Interpreted lineaments from the CDED and SPOT datasets are shown on Figures 8 and 9, respectively. The following paragraphs provide an overview of results from these surface-based interpretations.

A total of 710 lineaments comprise the dataset of merged lineaments identified by the two interpreters from the CDED digital elevation data (Figure 8). These lineaments range in length from 659 m to 46.5 km, with a geometric mean length of 4.2 km and a median length of 4.0 km. The most notable feature of the CDED lineament orientations when plotted on a rose diagram weighted by length are the dominant northerly trend, and the additional prominent trends of west-northwest (about 285°), north-northwest (about 335º) and north-northeast (about 025º). There is also a notable trend to the east-northeast at about 067º (Figure 8 inset). A weaker cluster of northeast trending (about 045°) lineaments is also evident (Figure 8 insert). A total of 389 of the CDED lineaments (55%) were assigned a certainty value of 3. Certainty values of 2 and 1 were assigned to 281 (39%) and 40 (6%) of the CDED lineaments, respectively. The RA_1 reproducibility assessment shows coincidence between the two pickers for 269 of the CDED lineaments (38%, RA_1 = 2) and a lack of coincidence for 441 of the CDED lineaments (62%, RA_1 = 1).

The SPOT lineament dataset compiled from the merger of lineaments identified by the two interpreters yielded a total of 1,084 lineaments (Figure 9). The length of the SPOT lineaments ranges from 225 m to 38.5 km, with a geometric mean length of 2.3 km and a median length of 2.2 km. When the azimuths of the lineaments are plotted on a rose diagram weighted by length (Figure 9 inset), there appear to be two dominant orientations. The most prominent orientation is toward the northeast at about 040º and the secondary trend is toward the northwest at about 290º. There are also less prominent north-northwest- and east-northeast-trending sets. Thirty two percent (32%) of the SPOT lineaments, a total of 342, were assigned a certainty value of 3. Certainty values of 2 and 1 were assigned to 599 (55%) and 143 (13%) of the SPOT lineaments, respectively. The reproducibility assessment shows coincidence for 417 (38%) of the SPOT lineaments (RA_1 = 2), and a lack of coincidence for 667 (62%) of the SPOT lineaments (RA_1

= 1). The number of lineaments identified by a single interpreter (RA_1 = 1) was comparable for each of the SPOT interpreters. This suggests that the lack of coincidence for 62% of the SPOT lineaments between the two interpreters generally reflects the indistinct nature of the features with the available data.

Orientation data for the CDED lineaments appear to be more scattered than those for the SPOT lineaments, with only broadly comparable dominant orientations of west-northwest, north and northeast. Both interpretations are affected by the increased Quaternary cover in the northeastern half of the Ignace area, showing a markedly lower lineament density in this area. The lineaments identified in the CDED dataset appear to be more uniformly distributed across the remainder of the Ignace area in comparison with those identified from the SPOT data.

4.1.2 Geophysical data

The airborne geophysical data interpretation was able to distinguish between features that could be interpreted as brittle or dyke lineaments (Figure 10), or ductile lineaments (Figure 11). The ductile features are useful in identifying the stratigraphy and internal structure within the greenstone belts. The degree of deformation within the greenstone belts and the "wrapping" of the greenstone stratigraphy around the younger plutons is also clearly visible in the ductile lineaments. In this report, the ductile lineaments are shown to provide context to our understanding of the tectonic history of the Ignace area, but were not included in the statistical analysis undertaken with the dataset. Therefore the following discussion relates only to those lineaments interpreted as brittle or dyke lineaments.

A total of 764 lineaments comprise the dataset of merged lineaments identified by the two interpreters from the geophysical data (Figure 10). Of the 764 lineaments, 677 are interpreted as faults, while 87 are interpreted as dykes (Figure 10). The length of the geophysical lineaments ranged from less than 100 m up to 47.3 km, with a geometric mean length of 4.7 km and a median length of 5.2 km. Azimuth data, weighted by length, for the geophysical lineaments interpreted as faults exhibit a dominant orientation to the north-northwest at 340º. Other prominent orientations include a westerly trend at 285º and a northeasterly trend at 067º (Figure 10 inset). The 87 lineaments identified as dykes, which includes smaller segments of the same dyke, belong to the northwest trending (295º to 310º) suite of Wabigoon dykes. The distribution of these dykes appears clustered within a narrow linear trend toward the northwest that passes roughly through the middle of the Ignace area and cuts the northern portion of the Adele Lake pluton, the southern extent of the Indian Lake batholith, and the northernmost portion of the Revell batholith (Figure 10).

633 (94%) of the geophysical faults were assigned the highest level of certainty (Certainty = 3), while 5% and 1% of the faults were given certainty values of two and one, respectively. 76 (87 %) of the dykes identified from geophysical data were assigned a certainty value of 3, while 11 (13%) of the dykes were given certainty values of two. No dyke was given a certainty value of 1. The reproducibility assessment identified coincidence for 659 faults (97%) (RA_1 = 2) and a lack of coincidence for 18 of the interpreted faults (3%) (RA_1 = 1). The reproducibility assessment identified coincidence for 79 of the interpreted dykes (91%) (RA_1 = 2) and a lack of coincidence for 8 of the interpreted dykes (9%) (RA_1 = 1).

4.2 DESCRIPTION AND CLASSIFICATION OF INTEGRATED LINEAMENT COINCIDENCE (RA_2)

The integrated lineament dataset produced by determining the coincidence of all lineaments interpreted from the CDED data, SPOT imagery, and geophysics data is presented on Figures 12 and 13. Figure 12 displays the lineament classification based on the coincidence values determined by Reproducibility Assessment 2 (RA_2). Figure 13 displays the lineament classification based on length of interpreted lineaments. The merged lineaments were classified by length using four length bins: >10 km, 5-10 km, 1-5 km and <1 km. These length bins were defined based on an analysis of the lineament length frequency distributions for the Ignace area.

The merged lineament dataset contains a total of 1,998 lineaments that range in length from less than 100 m to 49.6 km. The geometric average length of these lineaments is 3.2 km and the median length is 3.1 km. Lineaments in the >10 km and 5-10 km length bins represent 14% and 20% of the merged lineaments, respectively, while lineaments in the 1-5 km and <1 km length bins represent 55% and 11% of the merged lineaments, respectively. Orientation data for the merged lineament dataset (inset of Figures 12 and 13) exhibit a fairly uniform distribution of three prominent trends. There are trends to the west-northwest (285º to 310º), north-northwest to N (340º to 005º) and northeast (045º to 067º). It should be noted that the rose diagrams in Figures 12 and 13 are weighted by lineament length, and thus, these orientations are influenced by longer lineaments.

The reproducibility assessment required some lineaments to be broken into several line segments to which different reproducibility values were assigned. This is because lineaments may be coincident for just one segment and not for the entire length. For this reason, the total number of line segments (2,091) analyzed in the reproducibility assessment is larger than the total number of lineaments in the integrated data set (1,998). Results from the Reproducibility (coincidence) Assessment 2 (RA_2) for this dataset show 29 lineament segments (1%) were identified and coincident on all three datasets (RA_2 = 3), and 410 lineament segments (20%) were coincident with a lineament from one other dataset (RA_2 = 2). A total of 1,652 lineament segments (79%) lacked a coincident lineament from the other datasets (RA_2 = 1). There is greater coincidence between surficial lineaments (interpreted from digital elevation data and satellite imagery) than between the geophysical lineaments and either of the surficial datasets. Only about 6% of the geophysical lineaments (46 out of 764) were coincident with a mapped surficial lineament. Dykes interpreted from geophysical data have coincidence values of one (RA_2 = 1), given that they do not appear to exhibit a distinct surficial expression that was recognized in either the satellite imagery or the digital elevation data.

In areas of good bedrock exposure and where high resolution geophysical data are available, such as in the Revell batholith and in the Raleigh Lake and Bending lake greenstone belts, up to 6% of geophysical lineaments coincided with surface lineaments interpreted from either of the CDED or SPOT datasets. In areas of good bedrock exposure, but where only low resolution geophysical data are available such as the Adele Lake pluton, coincidence decreases. Over the Indian Lake batholith, where there is extensive surficial cover, many potential surficial lineaments are obscured by the surficial cover. Interpreted lineaments in this area therefore mostly have coincidence values (i.e. RA_2 values) of 1, reflecting the fact that only geophysical lineaments are observed where extensive surficial cover exists.

4.3 DESCRIPTION OF LINEAMENTS BY MAJOR GEOLOGICAL UNIT

As described in Section 2.2, the bedrock geology of the Ignace area is dominated by large granitic bodies that intrude older metavolcanic and metasedimentary rocks associated with greenstone belts. These granitic bodies include the Indian Lake, Revell, Basket Lake, and White Otter Lake batholiths, as well as the smaller Islet, Paddy Lake and Adele Lake plutons (Figures 3 and 14). The following discussion describes the dominant interpreted lineament orientations for each of these rock bodies.

There were 306 lineaments identified over an area of approximately 455 km^2 of the Revell batholith. Azimuth data, weighted by length, for the lineaments from the Revell batholith exhibit dominant west (270º to 285º) and northwest (315º to 340º) trends and a strong east-northeast (067º) trend (Figure 14). Wabigoon dykes cross the northern portion of the Revell batholith.

The Indian Lake batholith spans approximately 1,366 km^2 of the Ignace area. A total of 322 lineaments were mapped over the Indian Lake batholith. Given its large area the lineament density over this batholith is relatively low, likely due to the thick surficial cover. The rose diagram, weighted by length, for lineaments from the Indian Lake batholith shows three strong trends; to the west-northwest at 280º to 295º, to the northwest and north at 340º to 005º, and to the northeast at about 045º to 055º (Figure 14). Wabigoon dykes intrude the southwest portion of the Indian Lake batholith. Importantly, the interpretation from this assessment exhibits some consistency with the results from Storey (1986) who documented joint sets in the Indian Lake batholith oriented at, 045°, 070°, and 290°.

There were 200 lineaments identified over an area of approximately 429 km^2 of the Basket Lake batholith. Orientation data for the Basket Lake batholith on a rose diagram weighted by length, indicates strong trends to the north-northwest at 340º to 350º and a wide range of northeasterly trends that are strongest between 055º and 065º (Figure 14). Weak trends to the northwest and east-west are also observed in lineaments from the Basket Lake batholith. A small swarm of Wabigoon dykes cut across the southern margin of the Basket Lake batholith.

The White Otter Lake batholith covers most of the southern portion of the Ignace area (approximately 942 km^2), where 455 lineaments were identified. The easternmost extent of the batholith is defined in part by the mapped Finlayson-Marmion fault. The rose diagram weighted by length for lineament azimuths from this batholith shows two dominant trends, one to the north-northwest between 340º and 355º, and one to the northeast between 035º and 050º. A weaker trend of around 295º is also evident (inset Figure 14).

A total of 82 lineaments were identified on the Islet pluton, which covers an area of 144 km^2. Azimuth data for all the lineaments indicate a range of orientations, with the two strongest trends observed to the northeast at 060º to 065º and to the northwest at approximately 310º (Figure 14). Both of these trends, and in particular the northwest trend, appear to be strongly influenced by the geophysical lineaments.

The Paddy Lake pluton covers an area of 115 km^2, where a total of 101 lineaments were mapped. The rose diagram for these lineaments appears very similar to that for the neighbouring Islet Lake pluton (Figure 14). The strongest trend is observed to the northeast at 060º to 065º. Two strong northwesterly trends are also observed at 290º and 310º.

The Adele Lake pluton covers an area of approximately 375 km^2 from which a total of 197 lineaments were mapped. The orientations of these lineaments appear to follow three major trends (Figure 14). The most prominent orientation is to the northwest at 295º to 300º, with secondary trends north-northwest at 345º to 350º and to the northeast at 060º to 065º. A few Wabigoon dykes cross the middle of the Adele Lake pluton.

5 DISCUSSION

The following sections are provided to discuss the results of the lineament interpretation in terms of lineament density, reproducibility, and lineament length, as well as the relationship between mapped faults and interpreted lineaments, and relative age relationships of interpreted lineaments.

5.1 LINEAMENT DENSITY

The distribution of lineament density differs markedly across the Ignace area (Figures 12 and 13) primarily as a result of geophysical data resolution (Figure 10), and the extent of overburden cover (Figure 4). The highest lineament densities are observed in the west and southwest portions of the Ignace area, while the lowest densities are found in the northeastern half of the area.

An understanding of the distribution and thickness of overburden cover within the Ignace area is essential for interpreting the results of the lineament interpretation, particularly for interpreting information on length and density of surficial lineaments. Thick drift deposits are able to mask the surface expression of lineaments. In areas of thick and extensive overburden, major structures could exist completely undetectable in the SPOT and CDED data, particularly if these areas also contain large lakes. The interpretation of geophysical lineaments, on the other hand, is less affected by surficial cover. The variability of the density of geophysical lineaments in the Ignace area is influenced by the resolution of the available magnetic data (Figure 10), more than the presence or absence of overburden cover. High-resolution aeromagnetic data are available in the Ignace area only for the western portion of the area (i.e. the Revell batholith and Islet pluton) and for the southern portion of the Basket Lake batholith (Figure 10).

An assessment of lineament density by geologic unit shows that lineament density appears highest in the Raleigh Lake and Bending Lake greenstone belts on the west side of the Ignace area (Figures 12 and 13). Among the granitic intrusions in the Ignace area, the Revell batholith and the Adele Lake pluton exhibit the highest lineament density. The lowest lineament densities in the Ignace area are observed in the Indian Lake batholith. Lineament density is also low in the Basket Lake batholith, except for its eastern edge, where the intrusion is covered by high resolution magnetic data. The White Otter Lake batholith displays relatively low lineament density, particularly in its central portion; the highest lineament density within this intrusion is observed in the east, near to the Finlayson-Marmion fault.

The Revell batholith exhibits high lineament density owing to the high-resolution aeromagnetic data, and the relatively well-exposed bedrock, that allows for more detailed interpretations of the geophysical and surficial lineaments, respectively.

Overall, the White Otter Lake batholith exhibits a relatively low lineament density. The White Otter Lake batholith is covered only by low resolution magnetic data. In addition, the central portion is covered by extensive surficial cover and several large lakes, such as Elsie Lake, which largely obscure underlying bedrock structures. The highest lineament densities within the White Otter Lake batholith appear in the east, where there is relatively good bedrock exposure.

In the Adele Lake pluton, lineament density appears relatively high in the western extent of the intrusion owing to well-expressed surficial lineaments due to good bedrock exposure and prominent geophysical lineaments. Lineament density is lower in the eastern portion of the pluton where poor bedrock exposure limits the identification of surficial lineaments.

In both the Indian Lake batholith and the Basket Lake batholith, low surficial lineament densities are observed. This is due to the extensive surficial cover over these batholiths that limits the identification of bedrock structural features in satellite imagery. The density of geophysical lineaments in these batholiths is also low, due to the low-resolution aeromagnetic coverage over most of the area of these intrusions. It is noteworthy that where the Indian Lake batholith has exposed bedrock, such as the area southwest of the settlement area of Ignace, the lineament density is higher and appears similar to the other plutons in the area. This observation suggests that Indian Lake batholith may have a similar lineament density to other plutons in the area, but the surficial cover and low resolution geophysics limits the detection of these structures.

In the Basket Lake batholith low-resolution geophysical survey data covers the northwest portion of the intrusion, while high-resolution data covers the southeast portion of the batholith. As a result, there is a higher density of geophysical lineaments where there is high-resolution geophysical data. The lineament density from the low-resolution geophysical data is similar to that observed for the Indian Lake batholith. This suggests that the density of lineaments in the Basket Lake batholith may be similar to the other intrusions in the Ignace area, but like the Indian Lake batholith, surficial cover and low resolution geophysical data hinder the identification of structural features.

5.2 REPRODUCIBILITY AND COINCIDENCE

Reproducibility values assigned to the lineaments provide a measure of the significance of the bedrock structures expressed in the different datasets. The approach used to assign reproducibility values involved checking whether lineament interpretations from different interpreters (RA_1), and from different datasets (RA_2), were coincident within a specified buffer zone radius. Reproducibility and coincidence values are discussed in detail in Sections 4.1 and 4.2.

The findings from the reproducibility assessment RA_1 indicate that approximately 40% of surficial lineaments were identified by both interpreters (see Figures 8 and 9). Importantly, longer lineaments with higher certainty values were identified more often by both interpreters. The reproducibility assessment of the geophysical lineaments shows that over 90% of the lineaments were identified by both interpreters (Figure 10). As with the surficial lineaments, longer geophysical lineaments with higher certainty values were also recognized more often by both interpreters (RA_1=2).

Coincidence between features identified in the various datasets was evaluated for the second Reproducibility Assessment (RA_2). As would be expected, the surficial lineaments interpreted from CDED and SPOT show the highest coincidence at 31% (422 of 1,361), which corresponds to 20% of total merged lineaments (422 out of 2,091). This is in part explained by the fact that lineaments interpreted from the satellite imagery and the digital elevation data represent surficial expressions of the same bedrock feature. For example, a lineament drawn along a stream channel shown on the satellite imagery is expected to be coincident with a lineament that captures the trend of the associated topographic valley expressed in the digital elevation data. In contrast, 6% of the geophysical lineaments (46 out of 764) were coincident with interpreted surficial lineaments, which corresponds to 2.3% (46 out of 2,091) of the total lineament dataset that shows coincidence. This low coincidence between surficial and geophysical lineaments is not unexpected, and may be the result of various factors, such as: deep structures that are identified in geophysics may not have a surface expression; surficial features may not extend to great depth; structural features may not possess a magnetic susceptibility contrast with the host rock; surface expressions of lineaments may be masked by the presence of overburden; and/or the geometry of the feature (e.g. dipping versus vertical). All these may be further constrained by the resolution of the datasets. Regardless of the degree of coincidence, the observed overlap in dominant lineament orientation between all datasets (see insets on Figures 8, 9 and 10) suggests that all datasets are identifying the same regional sets of structures.

Where surficial cover is thicker and more extensive, the coincidence of interpreted lineaments tended to be lower than in areas of well-exposed bedrock. This observation applies not only to coincidence between surficial lineaments, but also between surficial and geophysical lineaments. For example, in the area to the northeast of the TransCanada highway, where there is more extensive surficial cover, fewer lineaments are coincident than in the area to the southwest where there is extensive bedrock exposure (see section 4.2). It is important to note that while there is a low density of surficial lineaments in the area northeast of the TransCanada highway, there are prominent long-strike geophysical lineaments, demonstrating that the geophysical lineaments are less affected by surficial cover.

Variable coincidence between surface and geophysical lineaments also reflects differing source data resolutions. For instance, in the Revell batholith, where there is high resolution aeromagnetic data available and good bedrock exposure, coincidence values are higher than in the Adele pluton, where there is good bedrock exposure but only low resolution geophysical data is available.

For these reasons it is necessary to objectively analyze the results of the RA_2 assessment with the understanding that RA_2 = 1 does not necessarily imply a low degree of confidence that the specified lineament represents a true geological feature (i.e. a fracture). The true nature of the interpreted features will need to be investigated further during subsequent stages of the site evaluation process.

5.3 LINEAMENT LENGTH

There is no information available on the depth extent into the bedrock of the lineaments interpreted for the Ignace area. In the absence of available information, the interpreted length may be used as a proxy for the depth extent of the identified structures. A preliminary assumption may be made that the longer interpreted lineaments in the Ignace area may extend to greater depths than the shorter interpreted lineaments.

As discussed in Section 4.2, longer interpreted lineaments generally have higher certainty and reproducibility values. Although the existence of interpreted lineaments would need to be confirmed through field observations, certainty and reproducibility values provide a preliminary indication that the longer features identified are related to bedrock structures.

Figure 12 shows the interpreted lineaments classified by lineament length. Four lineament length bins (0-1 km, 1-5 km, 5-10 km, > 10 km) were used for this analysis and a length weighted frequency rose diagram indicates the dominant lineament orientations (inset of Figure 12). Three prominent lineament orientation sets (west-northwest, north-northwest, and east-northeast), each with two main peaks, can be recognized in the length-weighted dataset.

5.4 FAULT AND LINEAMENT RELATIONSHIPS

As discussed above in Section 2.2.4, there mapped structural features in the Ignace area with established relative age relationships. The known mapped faults include the northeast-trending Finlayson-Marmion fault zone and the east-trending Washeibemaga Lake fault, as well as an unnamed west-northwest-striking feature and a bedding-parallel east-northeast-trending feature. Based on the compilation of interpreted lineaments shown in the inset of Figures 12 and 13, the northeast-trending lineament set identified herein appears to correspond in orientation to the Finlayson-Marmion fault zone. In addition, the dominant west-northwest-oriented set of interpreted lineaments appears to correspond to the orientation of the unnamed planar fault mapped to the northwest of the Township of Ignace, as well as the suites of Wabigoon and Kenora-Fort Frances dykes that transect the Ignace area (Figure 3).

The principle neotectonic stress orientation in central North America is generally oriented approximately east-northeasterly (063º ± 28º; Zoback, 1992), although anomalous stress orientations have also been reported in the mid-continent that include a 90º change in azimuth of the maximum compressive stress axis (Brown et al., 1995) and a north-south maximum horizontal compressive stress (Haimson, 1990). Regardless of these local variations, and other potential complicating factors involved in characterizing crustal stresses, including, the effect of shear stress by mantle flow at the base of the lithosphere (Bokelmann, 2002; Bokelmann and Silver, 2002), the degree of coupling between the North American plate and the underlying mantle (Forte et al 2010), and the influence of the thick lithospheric mantle root under the Canadian Shield, it is useful to attempt a preliminary comparison of the regional east-northeasterly neotectonic stress orientation with the orientation of each lineament set identified herein. The west-northwest lineament set would re-activate in a reverse or strike-slip sense, the NNW to N set would re-activate in a reverse to strike-slip sense, and the NE to ENE set would re-activate in a strike-slip sense or in tension.

5.5 RELATIVE AGE RELATIONSHIPS

The structural history of the Ignace area, outlined in Section 2.3, provides a framework that may aid in constraining the relative age relationships of the interpreted bedrock lineaments. In brief summary, six main regionally distinguishable deformation episodes (D_1-D_6) are inferred to have overprinted the bedrock geological units of the Ignace area. D_1-D_2 developed a gneissic foliation and isoclinal folds between approximately 2.725 and 2.713 billion years ago, only in the older gneissic tonalites. D_3-D_4 produced the dominant ductile structures observed within the greenstone belts, including orthogonal folds and steeply dipping foliations, prior to approximately 2.698 billion years ago. D_5 was a protracted event that is interpreted to span the transition from ductile to brittle deformation and involved the activation and possible re-activation of major regional faults between approximately 2.690 and 2.400 billion years ago. D_6 represents multiple events beginning with localized brittle re-activation of major regional faults at approximately 1.947 billion years ago, as well as all younger tectonic events. The most recent period of major fault displacement may be constrained by the approximately 1.900 billion year old Wabigoon dykes that transect the Ignace area with no apparent fault offset.

Given the issues of variable resolution and irregularly distributed overburden cover, it is difficult at the desktop stage of the preliminary assessment of potential suitability to assign temporal relationships with any degree of confidence to the identified lineaments. The only distinction that can be made is between older ductile and younger brittle features, albeit with the caveat that many of the ‘ductile’ lineaments may have developed under brittle conditions and have simply re-activated the pre-existing ductile fabric. Therefore, a tentative preliminary interpretation of the lineament dataset is that the identified ductile (i.e. stratigraphic and foliation-related) lineaments originated largely as pre-2.698 billion year old features while the brittle lineaments (including dyke lineaments) may be considered to be composite D_5-D_6 structures that were formed during a protracted period of time (approximately 2.690 billion years ago to recent).

The interpreted geophysical lineaments are less affected by overburden cover, than the surficial lineaments. Therefore, our understanding of the deformation history of the Ignace area may be guided by the geophysical dataset and its interpretation (Figure 10).

The geophysical lineament interpretation (Figure 10) yields three diffusely distributed lineament sets having west-northwest, north-northwest and east-northeast orientations (Figure 10 inset). In all cases, there is a spread in orientation of approximately 25-30° within sets. Examination of the geophysical lineament interpretation indicates that there are no obvious and consistent cross-cutting relationships between the different sets. There are examples where the west-northwest trending lineaments appear to offset the other two lineament sets; both sinistral and dextral offsets are indicated. There are also examples where the west-northwest trending features are shown to be offset by lineaments of both the north-northwest and east-northeast sets. This may be due to the coarse resolution of the geophysical dataset across much of the Ignace area, which does not provide the necessary detail to discern the structural relationships. However, a detailed examination of the interpretation across the small high-resolution area of the Takara Resources survey in Figure 10 shows a high-density mosaic pattern that again indicates no clearly consistent offsetting relationship between the lineament sets. In addition, the surficial lineaments observed in the Ignace area generally exhibit intersecting sets of lineaments without visibly discernible offsets. The principal lineament orientations in the Ignace area are essentially common to all the major late plutonic bodies (i.e. the Indian Lake, White Otter, Revell, and Basket Lake batholiths). This suggests that the tectonic events related to the development of various lineament sets all continued after the emplacement of the plutons between approximately 2.694 and 2.671 billion years ago.

6 SUMMARY

This report documents the source data, workflow and results from a lineament interpretation of publicly-available digital datasets, including surficial (satellite imagery, digital elevation) and geophysical (aeromagnetic) datasets for the Ignace area. The lineament analysis provides an interpretation of the location and orientation of possible individual fractures or fracture zones and helps to evaluate their relative timing relationships within the context of the regional geological setting. The three step process involved a workflow that was designed to address the issues of subjectivity and reproducibility.

The distribution of lineaments in the Ignace area reflects the bedrock structure, resolution of the datasets used, and surficial cover. Surface lineament density, as demonstrated in this assessment, is closely associated with the distribution and thickness of overburden cover that masks the surficial expression of bedrock structures. Surficial lineament density was observed to be highest in the central and southwestern part of the Ignace area where the thickness and extent of surficial cover is relatively low. Lineament density is also influenced by the resolution of the datasets as demonstrated by the comparison of aeromagnetic lineament density interpreted from high and low resolution surveys. This observation suggests that the Indian Lake, Basket Lake and central part of the White Otter Lake batholiths have a similar lineament density as other intrusions in the area, but the surficial cover and low resolution geophysics limits the detection of structures.

In terms of reproducibility, longer interpreted lineaments generally have higher certainty and reproducibility values. Comparison between the various datasets (RA_2), indicates that the highest level of coincidence is between surficial lineaments interpreted from CDED and Spot. This is in part explained by the fact that lineaments interpreted from the satellite imagery and the digital elevation data represent surficial expressions of the same bedrock feature. The low coincidence between surficial and geophysical lineaments may be the result of various factors: deep structures identified in geophysics may not have a surface expression; surficial features may not extend to great depth; structural features may not possess a magnetic susceptibility contrast with the host rock; surface expressions of lineaments may be masked by the presence of overburden; and the geometry of the feature (e.g. dipping versus vertical). These factors are further constrained by the differing resolution of the various datasets.

The orientations observed for the combined set of lineaments from all sources (except stratigraphic and foliation-related features) include strong trends to the west-northwest (285º and

310º), north-northwest to north (340º and 005º) and east-northeast (045º and 067º). It is noteworthy that the west-northwest and east-northeast oriented lineament sets are consistent with previous field-scale measurements (Storey, 1986). It may be possible, with further detailed investigation, to assign the formation of the identified lineaments to distinct deformation events. However, it is difficult at the desktop stage to provide any further constraint on the timing of lineament development beyond denoting all identified lineaments as composite D_5-D_6 structures that were formed during a protracted period of time post-dating approximately 2.690 billion years ago.

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REPORT SIGNATURE PAGE

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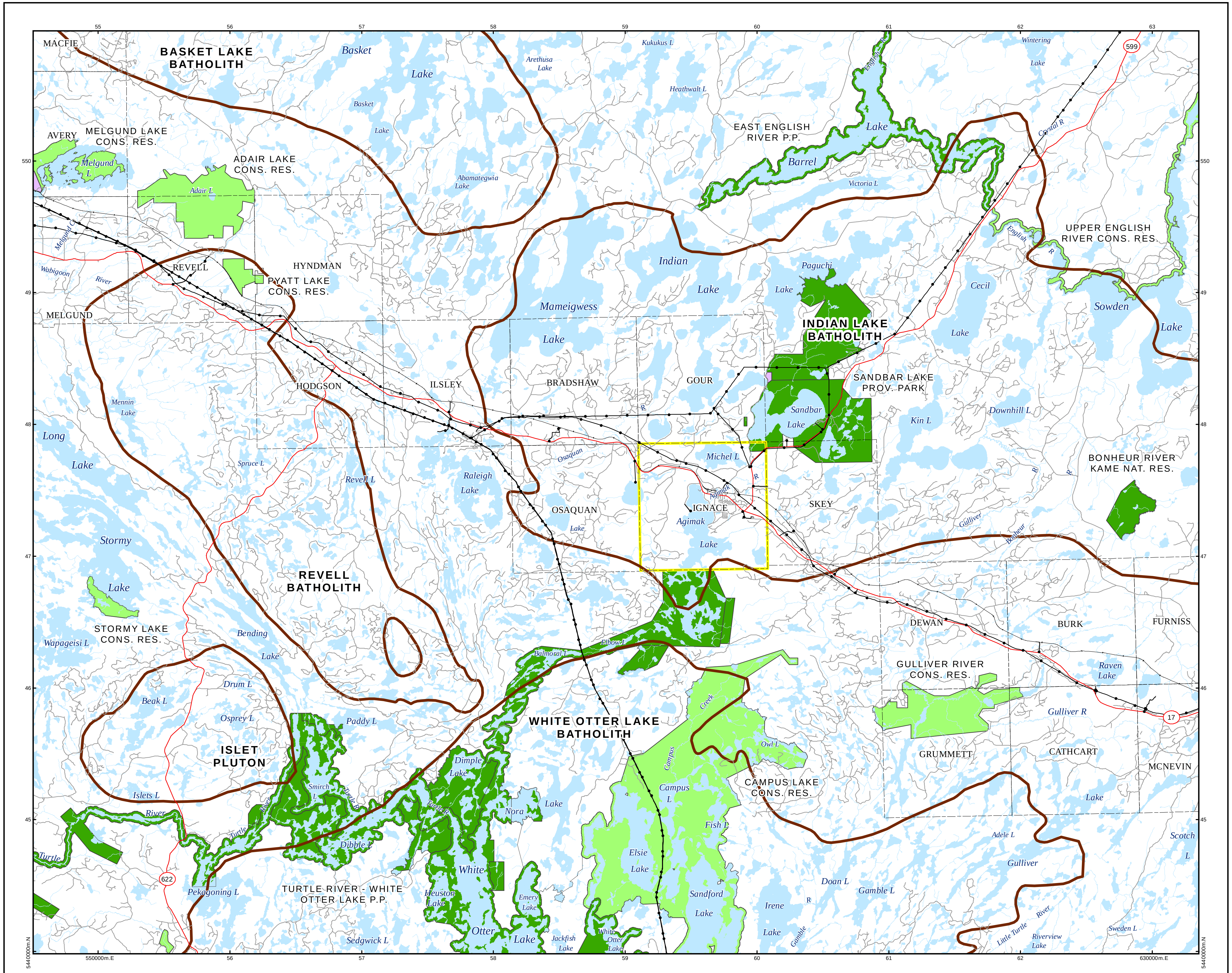
FIGURES



LEGEND

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

Protected areas

- Forest Reserve
- Conservation Reserve
- Provincial Park

Data sources:
Batholiths: Generalized after OGS MRD 126-REV1
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

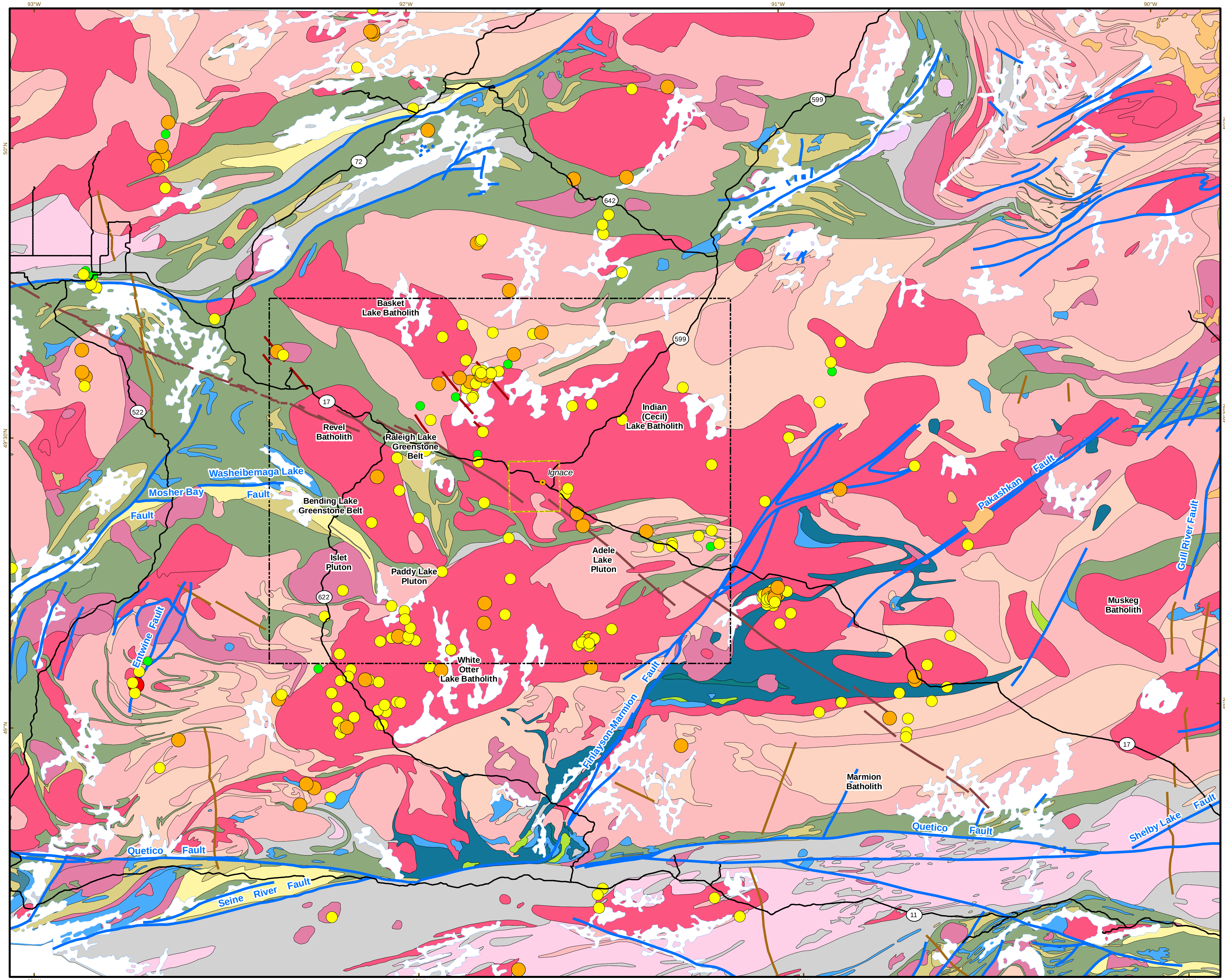
5 km

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
Township of Ignace and surrounding area

DESIGN	DVZ	25 JUN 2012	FIGURE 1	REVISION 5
GIS	DSM	10 OCT 2013		UTM ZONE 15
CHECK	JIC	10 OCT 2013		NAD 1983
REVIEW	GS	10 OCT 2013		1:300,000



LEGEND

- Ignace area
- Township of Ignace
- Main road

Seismic events magnitude

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

Mapped dyke

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

Bedrock geology

- Mafic dykes and related intrsuive rocks
- Hornblendite - nepheline syenite suite
- Massive granodiorite to granite
- Diorite-monzondiorite-granodiorite suite
- Muscovite-bearing granite rocks
- Foliated tonalite suite
- Gneissic tonalite suite
- Mafic and ultramafic rocks
- Coarse clastic metasedimentary rocks
- Metasedimentary rocks
- Felsic to intermediate metavolcanic rocks
- Mafic to intermediate metavolcanic rocks
- Mafic to ultramafic metavolcanic rocks
- Mafic metavolcanic and metasedimentary rocks
- Felsic to intermediate metavolcanic rock
- Metasedimentary and mafic to ultramafic metavolcanics

Data sources:
Geology: OGS MRD 126-REV1 (1:250,000)
Seismic events: Earthquakes Canada (1985-2012)
Road: Selected roads from LIO MNR road segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody

NORTH

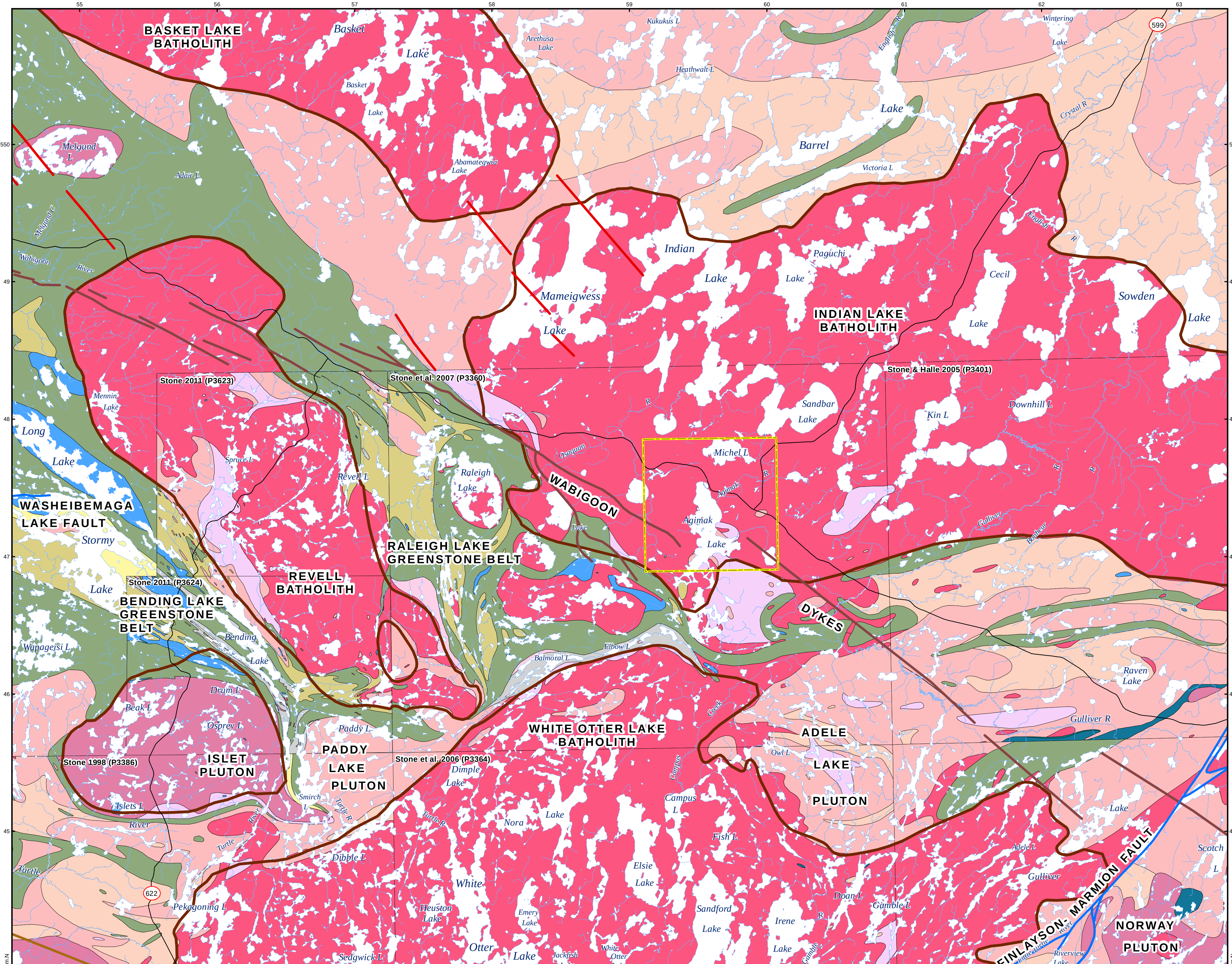
10 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
Regional tectonic setting of the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 2	REVISION 0
GIS	DSM	07 NOV 2012		UTM ZONE 15
CHECK	JIC	07 NOV 2012		NAD 1983
REVIEW	GS	07 NOV 2012		1:750,000



LEGEND

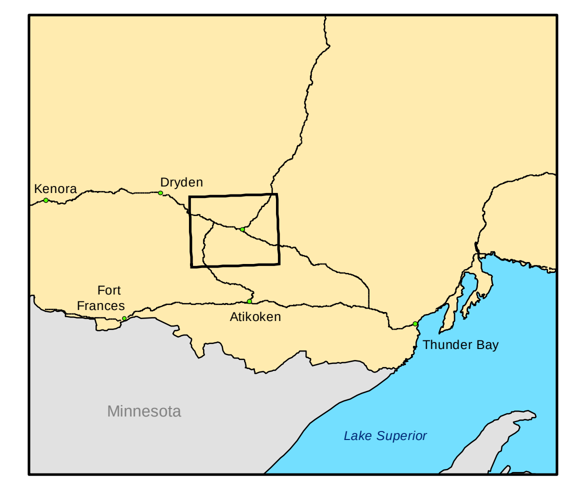
- Township of Ignace
- Main road
- Mapped fault

Mapped dyke

- Kenora-Fort Frances dyke
- Wabigoon dyke
- Dyke (other)
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

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



Data sources:
Bedrock: OGS MRD 126-REV1 (1:250,000)
Bedrock: See references to 1:50k maps
Batholiths: Generalized after OGS MRD 126-REV1
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, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
Bedrock geology of the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 3	REVISION 6
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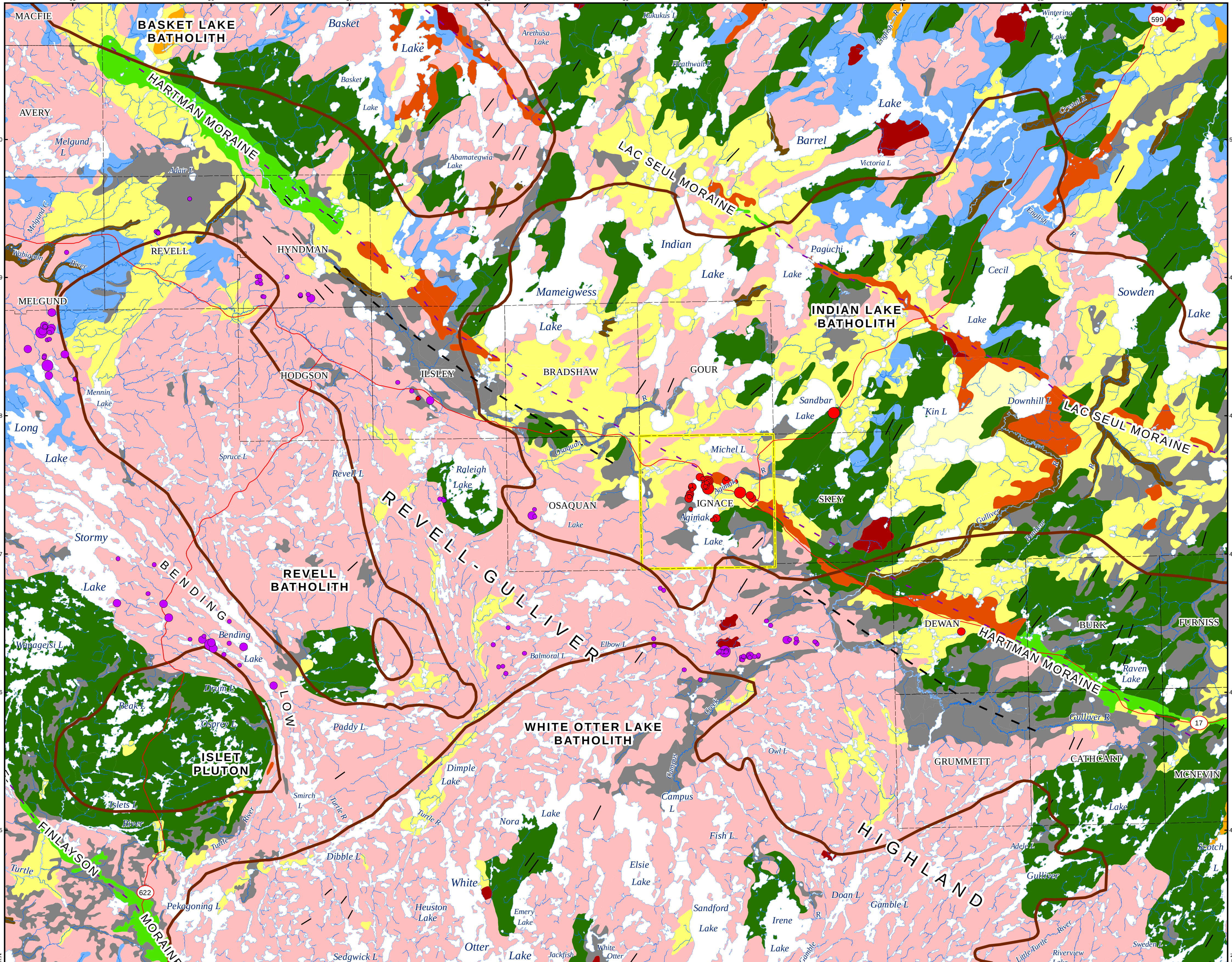
REVIEW	GS	07 NOV 2013		1:300,000



LEGEND

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

Surficial geology (NOEGTS)

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

Water well (MOE)

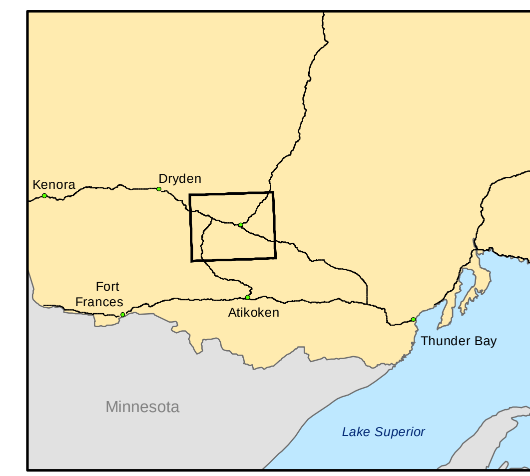
Depth to bedrock (m)

- 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



Data sources:
NOEGTS: OGS MRD 160 (scale 1:100,000)
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
Water well: MOE Water Well Information System
Drill hole: OGS Drill Hole Database (selected)

NORTH

5 km

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
Surficial geology of the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 4	REVISION 6
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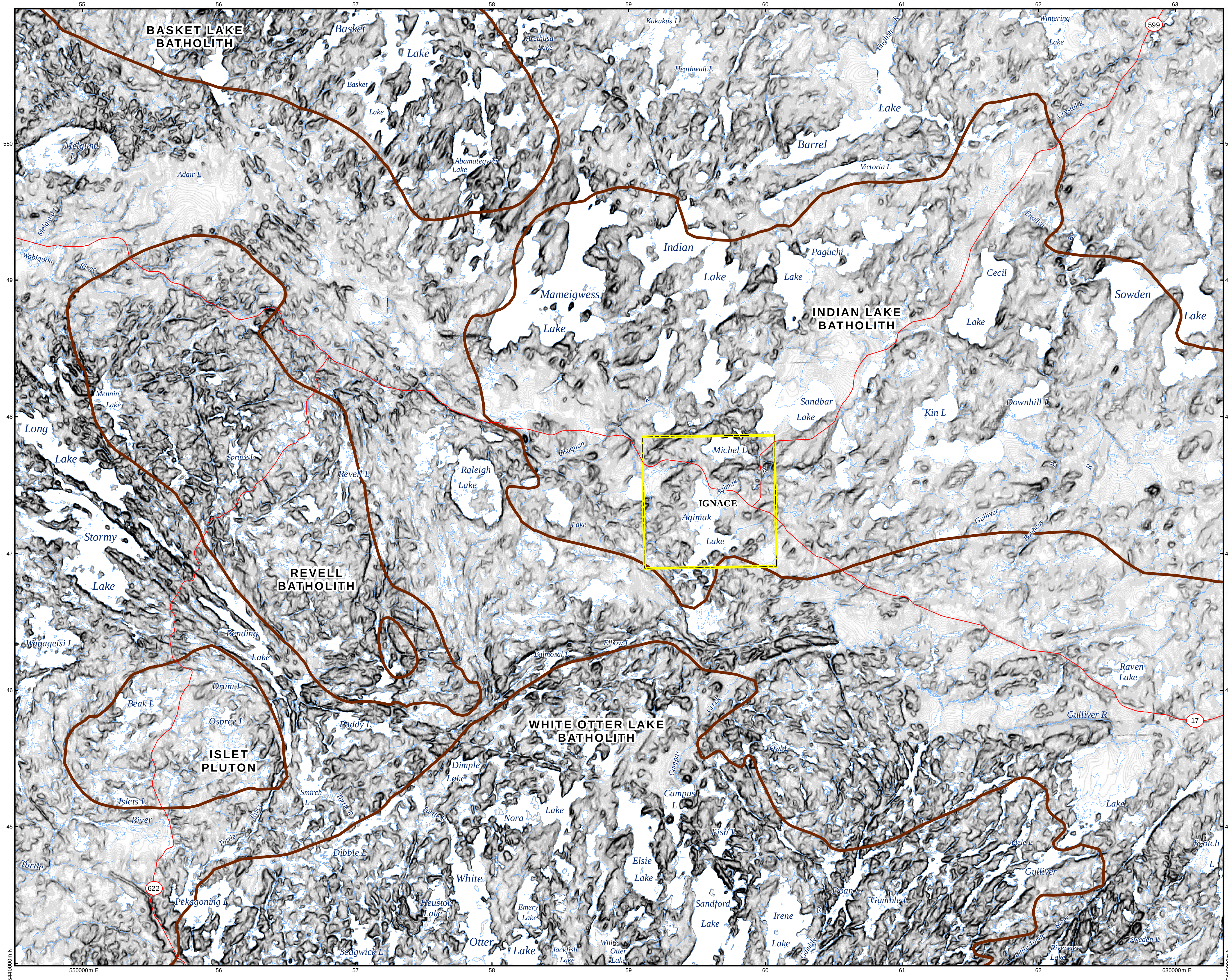
REVIEW	GS	10 OCT 2013		1:300,000



LEGEND

- Main road
- Township of Ignace
- Batholith/Pluton
- Waterbody
- Watercourse

Slope (°)

- 0 - 0.4
- 0.5 - 1.8
- 1.9 - 3.2
- 3.3 - 4.6
- 4.7 - 6.1
- 6.2 - 7.5
- 7.6 - 8.9
- 9 - 10.4
- 10.5 - 36.5

Data sources:
DEM: CDED slope 1:50,000
Batholith/Pluton: Generalized after OGS MRD 126-REV1
Road: LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

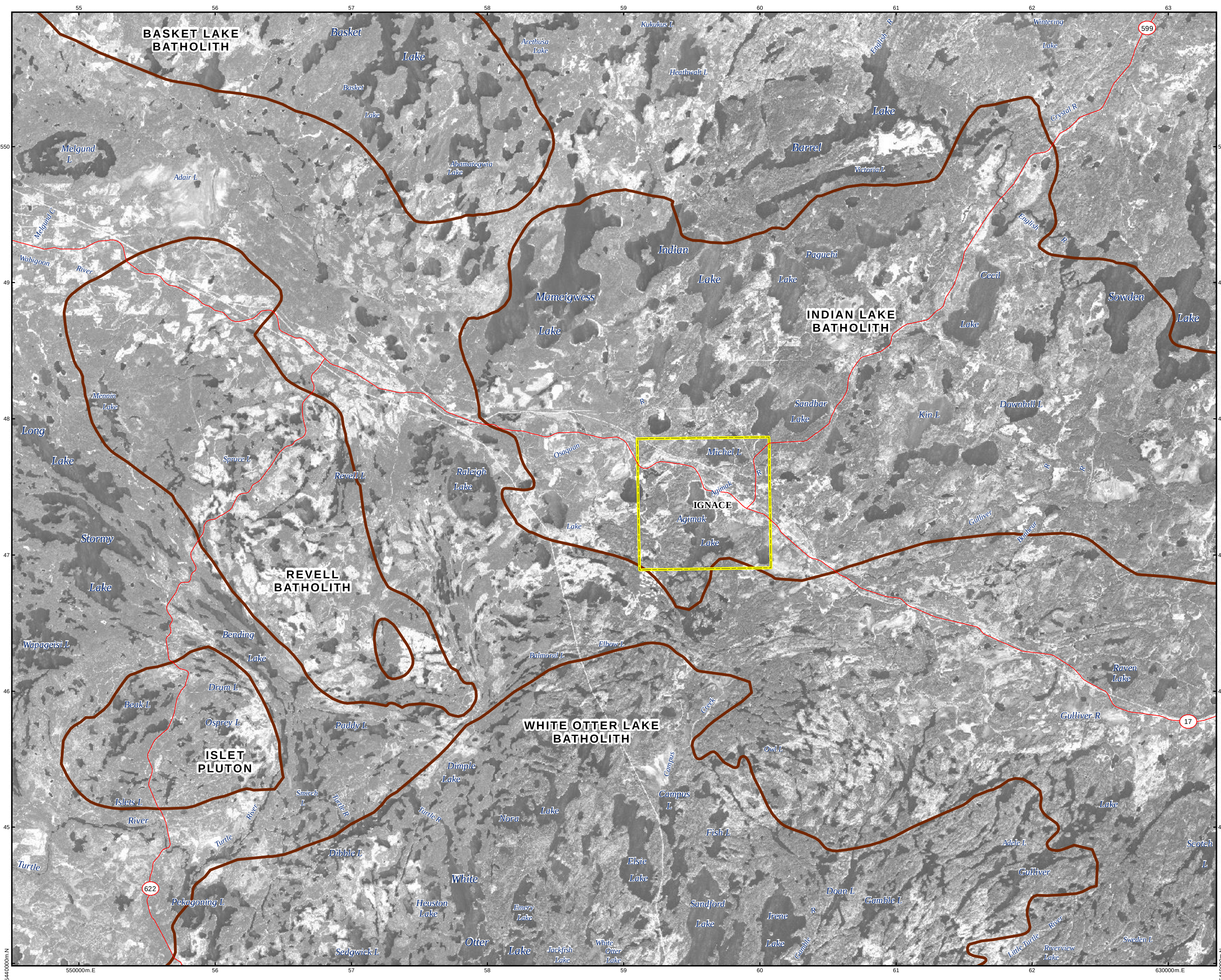
NORTH
5 km

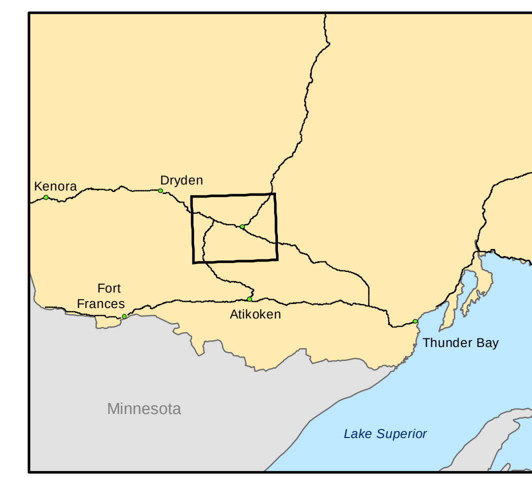
J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
CDED digital elevation data

DESIGN	DVZ	25 JUN 2012	FIGURE 5	REVISION 4
GIS	DSM	08 AUG 2013		UTM ZONE 15
CHECK	JIC	08 AUG 2013		NAD 1983
REVIEW	GS	08 AUG 2013		1:300,000





LEGEND

- Main road
- Township of Ignace
- Batholith/Pluton

Data sources:
SPOT panchromatic: geobase.ca (10m ground resolution)
Batholith/Pluton: Generalized after OGS MRD 126-REV1
Road: LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data

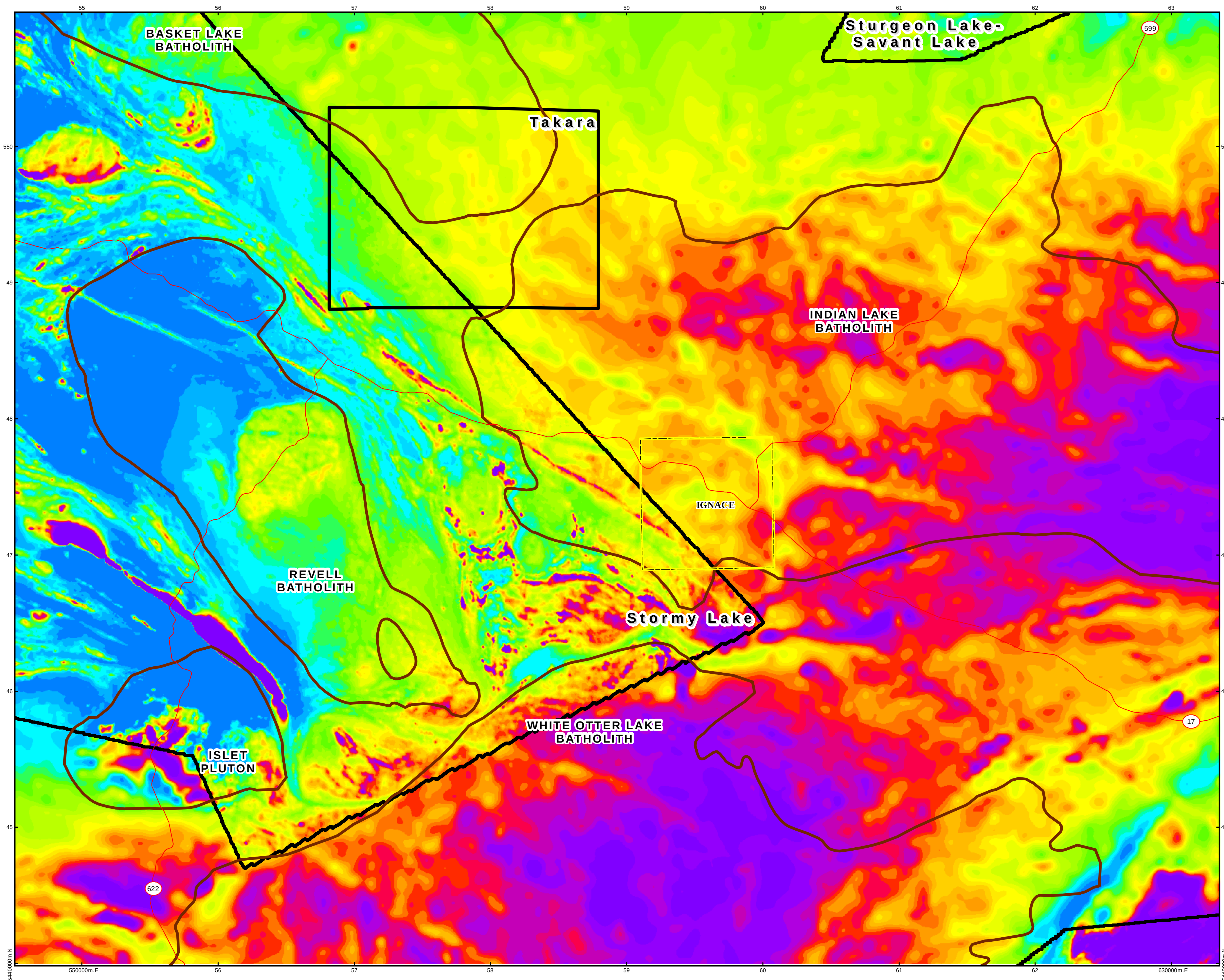
NORTH
5 km

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
SPOT satellite data

DESIGN	DVZ	25 JUN 2012	FIGURE 6	REVISION 4
GIS	DSM	08 AUG 2013		UTM ZONE 15
CHECK	JIC	08 AUG 2013		NAD 1983
REVIEW	GS	08 AUG 2013		1:300,000



LEGEND

- Main road
- Township of Ignace
- Batholith/Pluton
- Higher resolution geophysical surveys

RTP (nT)

- 301 to 29,682
- 241 to 300
- 201 to 240
- 161 to 200
- 141 to 160
- 121 to 140
- 101 to 120
- 81 to 100
- 61 to 80
- 41 to 60
- 21 to 40
- 1 to 20
- -19 to 0
- -39 to -20
- -59 to -40
- -79 to -60
- -99 to -80
- -119 to -100
- -139 to -120
- -159 to -140
- -179 to -160
- -219 to -180
- -239 to -220
- -279 to -240
- -2,598 to -280

Data sources:
Hi-resolution Magnetics: OGS GDS1033, GDS1060, GDS1107
Regional Magnetics: GSC nationwide compilation
Batholith/Pluton: Generalized after OGS MRD 126-REV1
Road: LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data

NORTH

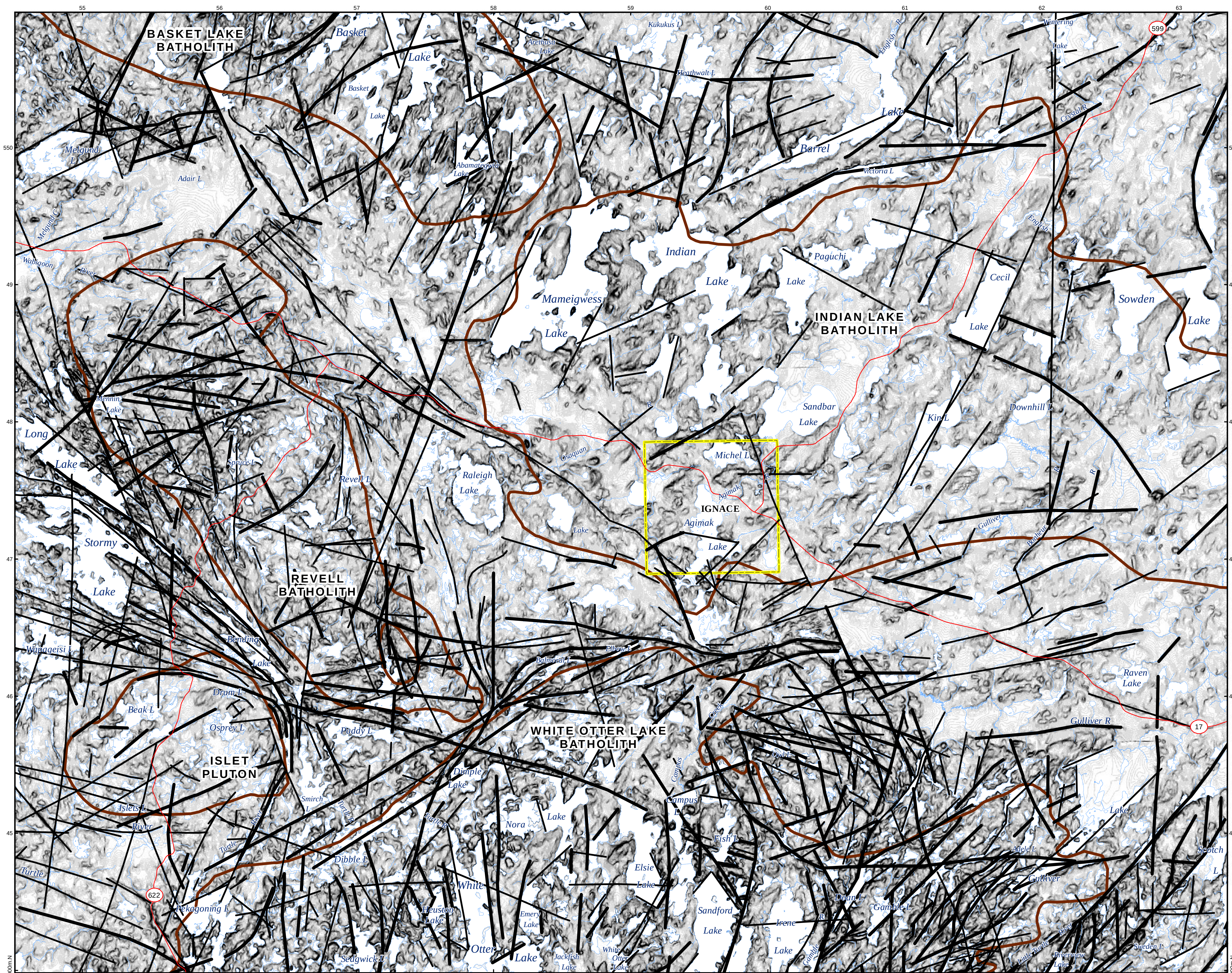
5 km

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
Pole reduced magnetic field for the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 7	REVISION 4
GIS	DSM	07 NOV 2013		UTM ZONE 15
CHECK	JIC	07 NOV 2013		NAD 1983
REVIEW	GS	07 NOV 2013		1:300,000



LEGEND

Main road

CDED lineament RA_1

- 1
- 2

Township of Ignace

Batholith/Pluton

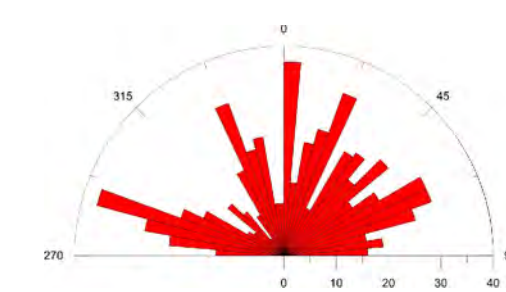
Waterbody

Watercourse

Slope (°)

- 0 - 0.4
- 0.5 - 1.8
- 1.9 - 3.2
- 3.3 - 4.6
- 4.7 - 6.1
- 6.2 - 7.5
- 7.6 - 8.9
- 9 - 10.4
- 10.5 - 36.5

Ignace CDED Data - Length Weighted Frequency Rose Plot



N = 710

Data sources:
DEM: CDED slope 1:50,000
Batholith/Pluton: Generalized after OGS MRD 126-REV1
Road: LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

NORTH

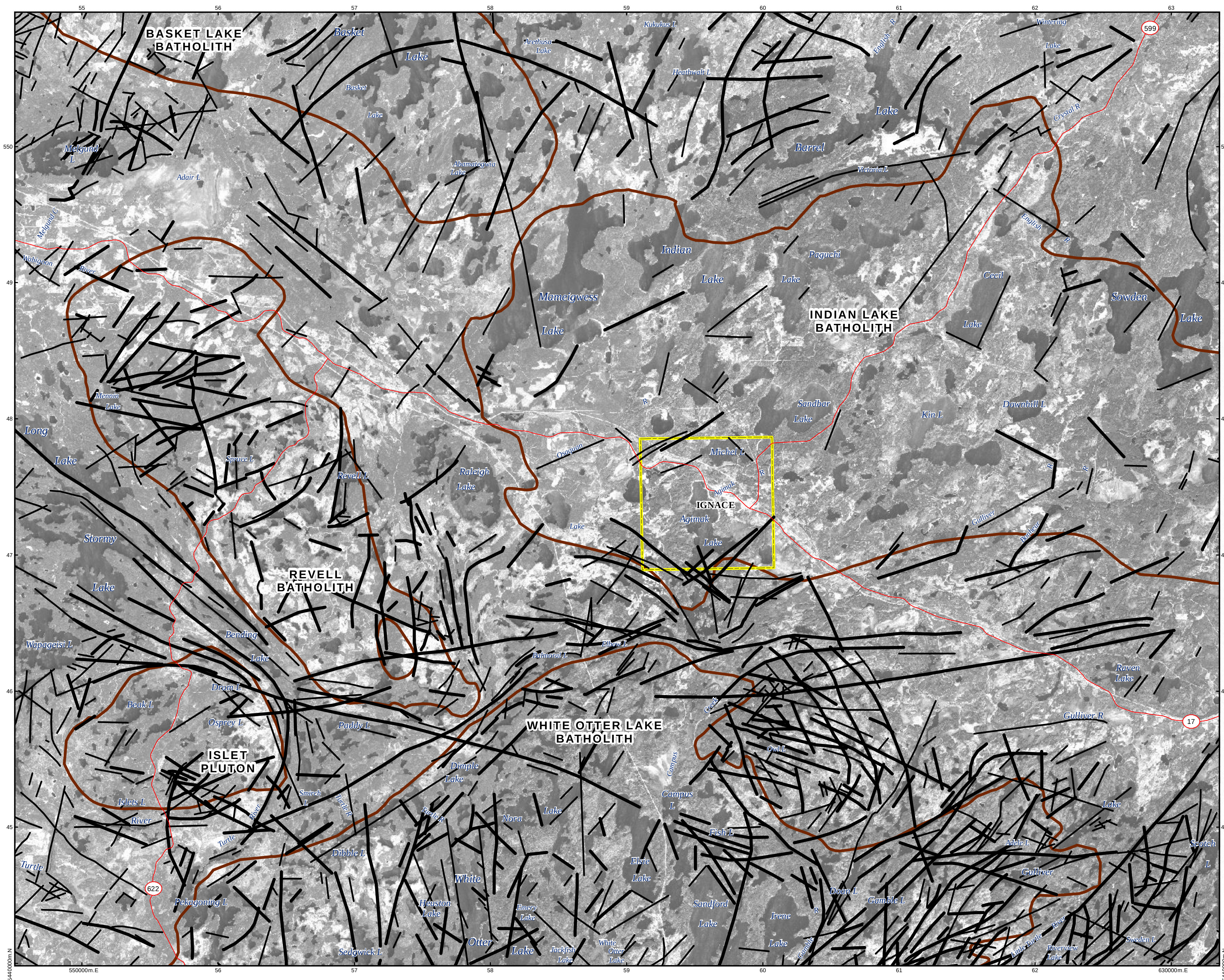
5 km

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
CDED reproducibility assessment (RA_1)

DESIGN	DVZ	25 JUN 2012	FIGURE 8	REVISION 4
GIS	DSM	07 NOV 2013		UTM ZONE 15
CHECK	JIC	07 NOV 2013		NAD 1983
REVIEW	GS	07 NOV 2013		1:300,000



LEGEND

Main road

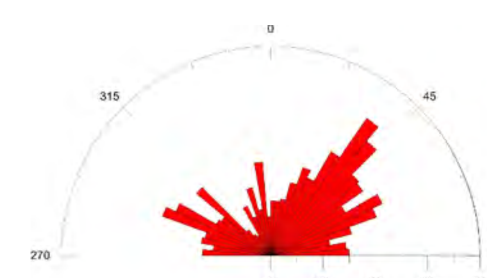
SPOT lineament RA_1

- 1
- 2

Township of Ignace

Batholith/Pluton

Ignace SPOT Data - Length Weighted Frequency Rose Plot



N = 1,084

Data sources:
SPOT panchromatic: geobase.ca (10m ground resolution)
Batholith/Pluton: Generalized after OGS MRD 126-REV1
Road: LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data

NORTH

5 km

J D MOLLARD

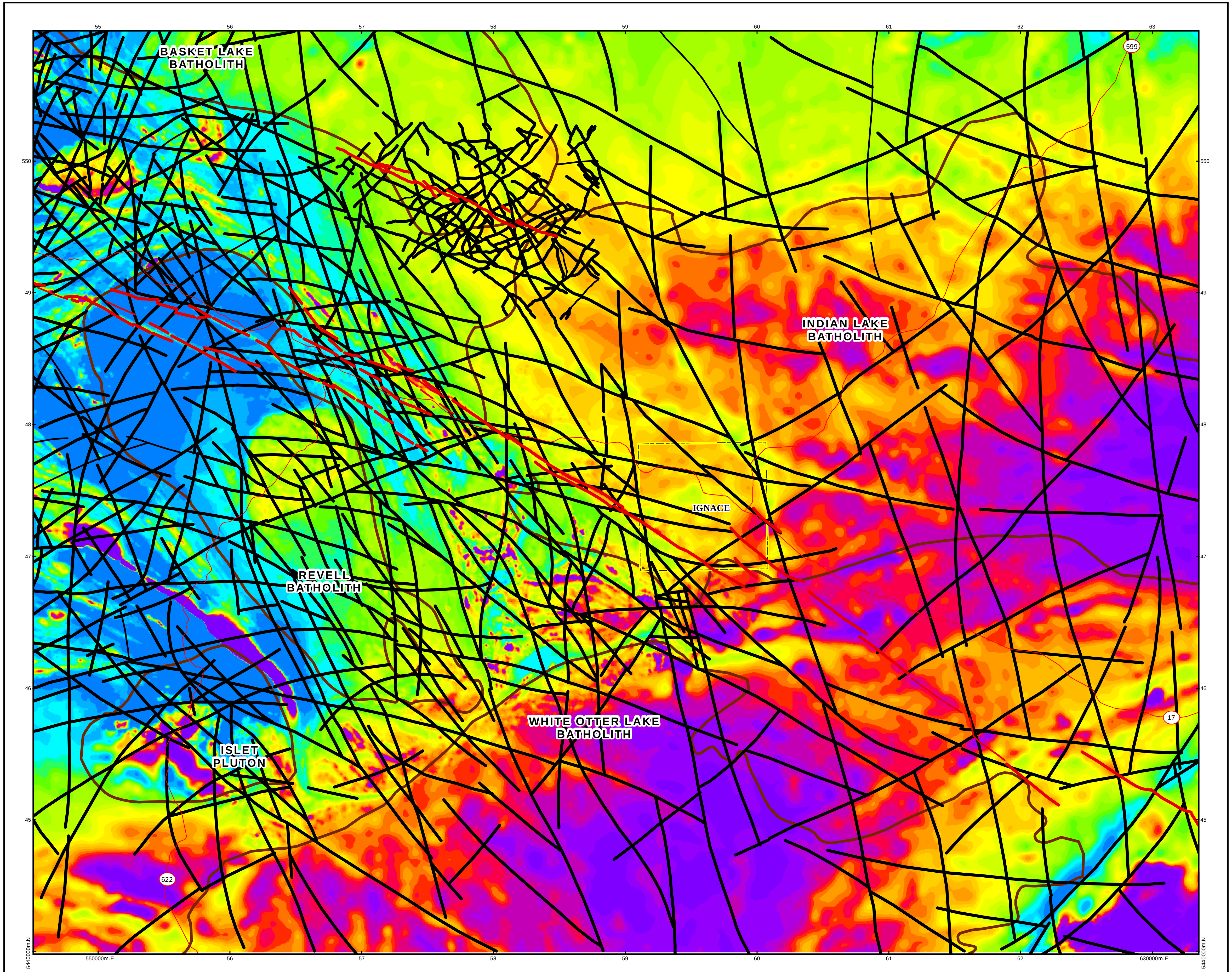
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE

SPOT reproducibility assessment (RA_1)

DESIGN	DVZ	25 JUN 2012	FIGURE 9	REVISION 4
GIS	DSM	07 NOV 2013		UTM ZONE 15
CHECK	JIC	07 NOV 2013		NAD 1983
REVIEW	GS	07 NOV 2013		1:300,000



LEGEND

Main road

Dyke RA_1

- 1
- 2

Fault RA_1

- 1
- 2

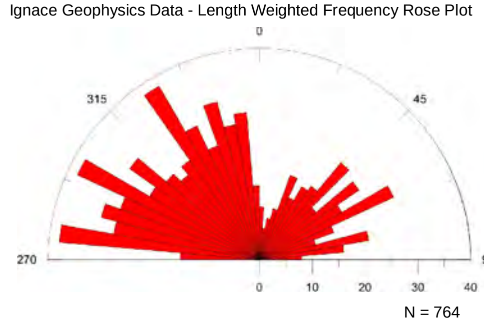
Township of Ignace

Batholith/Pluton

RTP (nT)

- 301 to 29,682
- 241 to 300
- 201 to 240
- 161 to 200
- 141 to 160
- 121 to 140
- 101 to 120
- 81 to 100
- 61 to 80
- 41 to 60
- 21 to 40
- 1 to 20
- -19 to 0
- -39 to -20
- -59 to -40
- -79 to -60
- -99 to -80
- -119 to -100
- -139 to -120
- -159 to -140
- -179 to -160
- -219 to -180
- -239 to -220
- -279 to -240
- -2,598 to -280

Ignace Geophysics Data - Length Weighted Frequency Rose Plot



Data sources:
Hi-resolution Magnetics: OGS GDS1033, GDS1060, GDS1107
Regional Magnetics: GSC nationwide compilation
Batholith/Pluton: Generalized after OGS MRD 126-REV1
Road: LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data

NORTH

5 km

J D MOLLARD

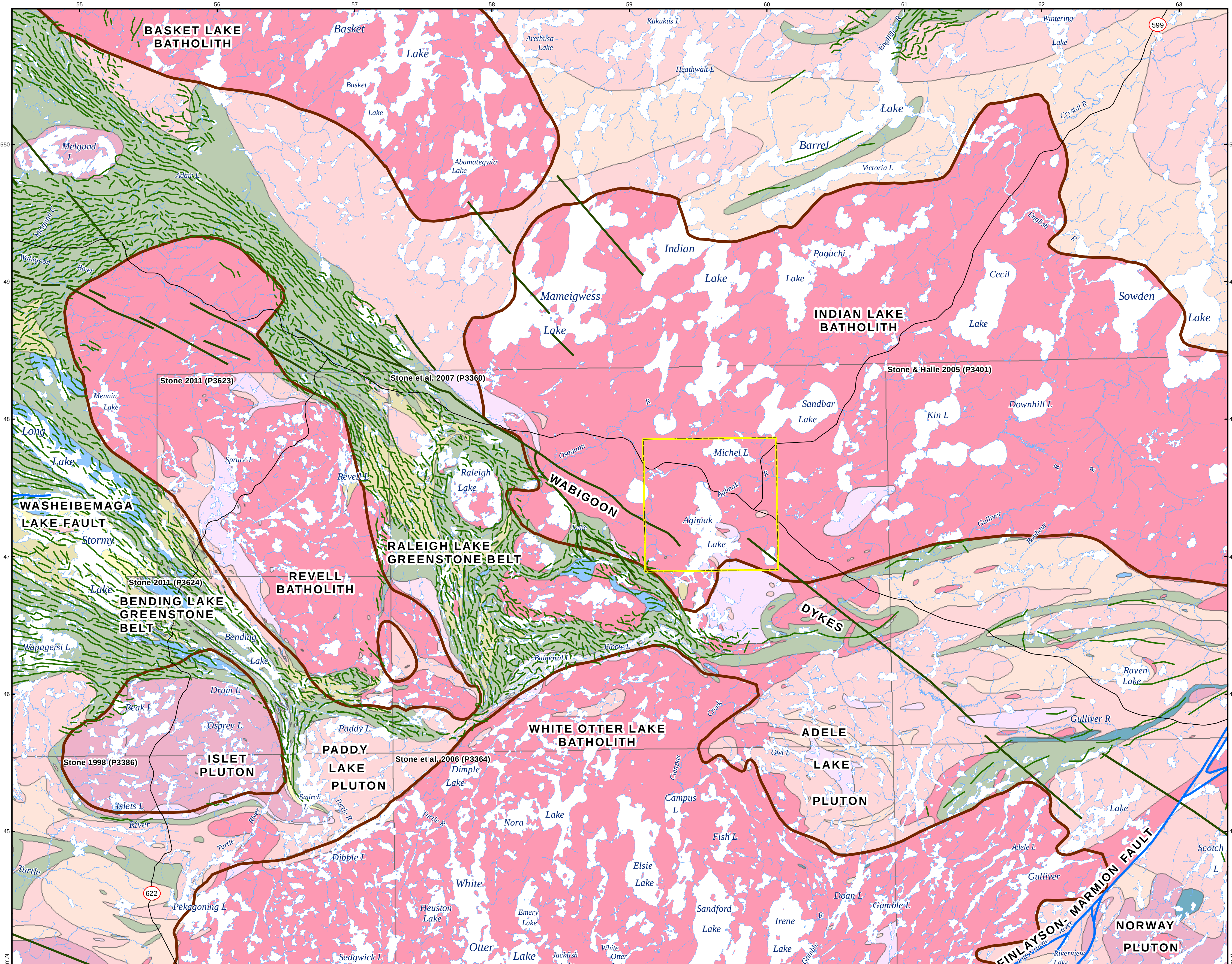
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE

Aeromagnetic reproducibility assessment (RA_1)

DESIGN	DVZ	25 JUN 2012	FIGURE 10	REVISION 4
GIS	DSM	07 NOV 2013		UTM ZONE 15
CHECK	JIC	07 NOV 2013		NAD 1983
REVIEW	GS	07 NOV 2013		1:300,000



LEGEND

- Township of Ignace
- Main road
- Mapped fault
- Ductile feature
- Dyke (OGS)
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

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

Data sources:
Bedrock: OGS MRD 126-REV1 (1:250,000)
Bedrock: See references to 1:50k maps
Batholiths: Generalized after OGS MRD 126-REV1
Fault: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Ductile feature: mapped by PGW from magnetostratigraphy
Road: Selected roads from LIO MNR Road Segment
Township: "ADMIN" file from MNDM Claimap data
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

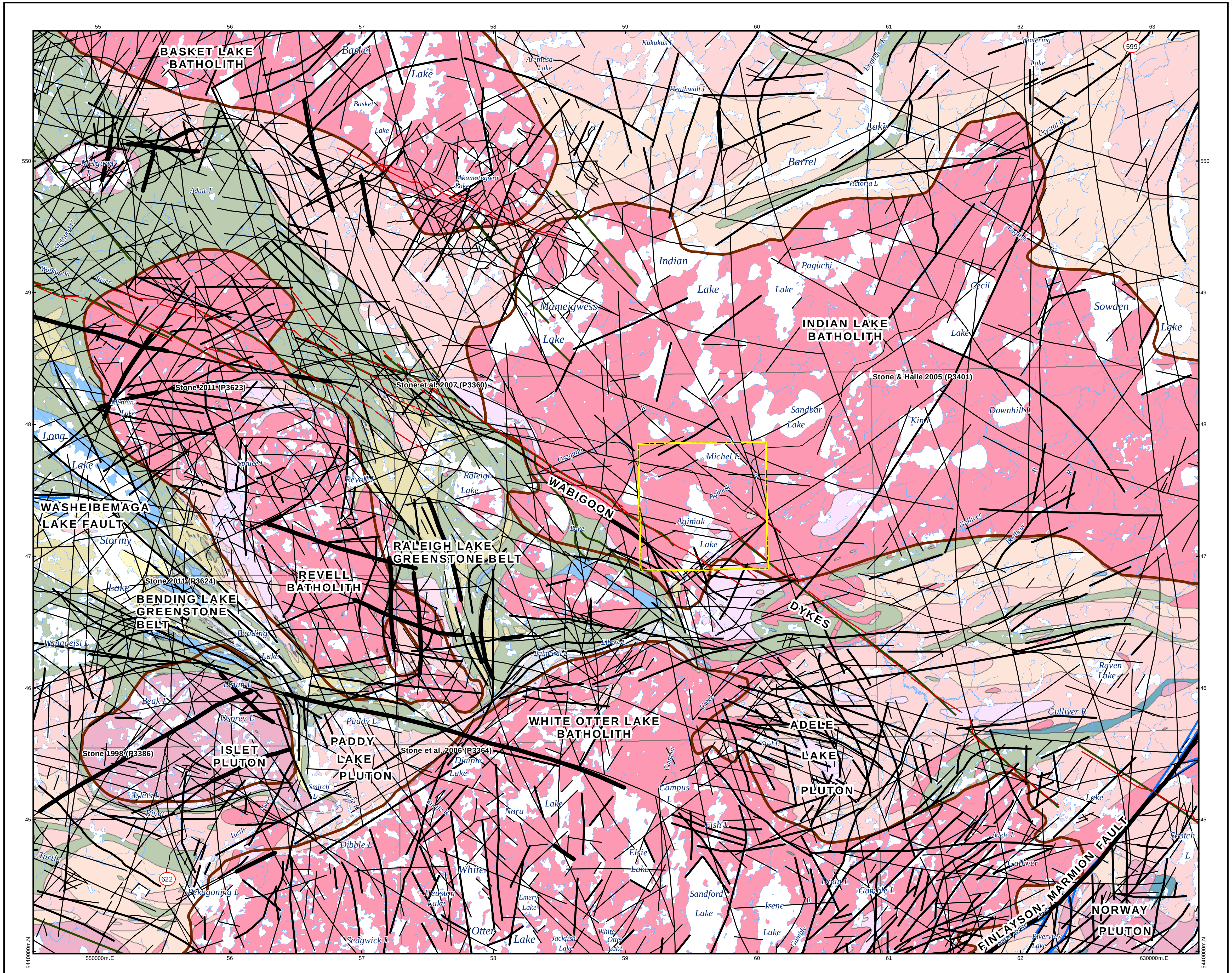
NORTH
5 km

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
Ductile features of the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 11	REVISION 6
GIS	DSM	10 OCT 2013		UTM ZONE 15
CHECK	JIC	10 OCT 2013		NAD 1983
REVIEW	GS	10 OCT 2013		1:300,000



LEGEND

- Township of Ignace
- Main road
- Lineament (dyke)

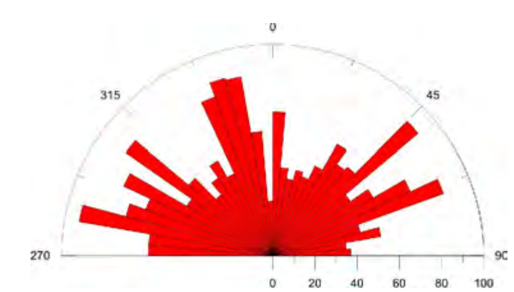
Lineament RA_2

- 1
- 2
- 3
- Mapped fault
- Mapped dyke
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

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

Ignace All Data - Length Weighted Frequency Rose Plot



N = 2,108

Data sources:
Bedrock: OGS MRD 126-REV1 (1:250,000)
Bedrock: See references to 1:50k maps
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

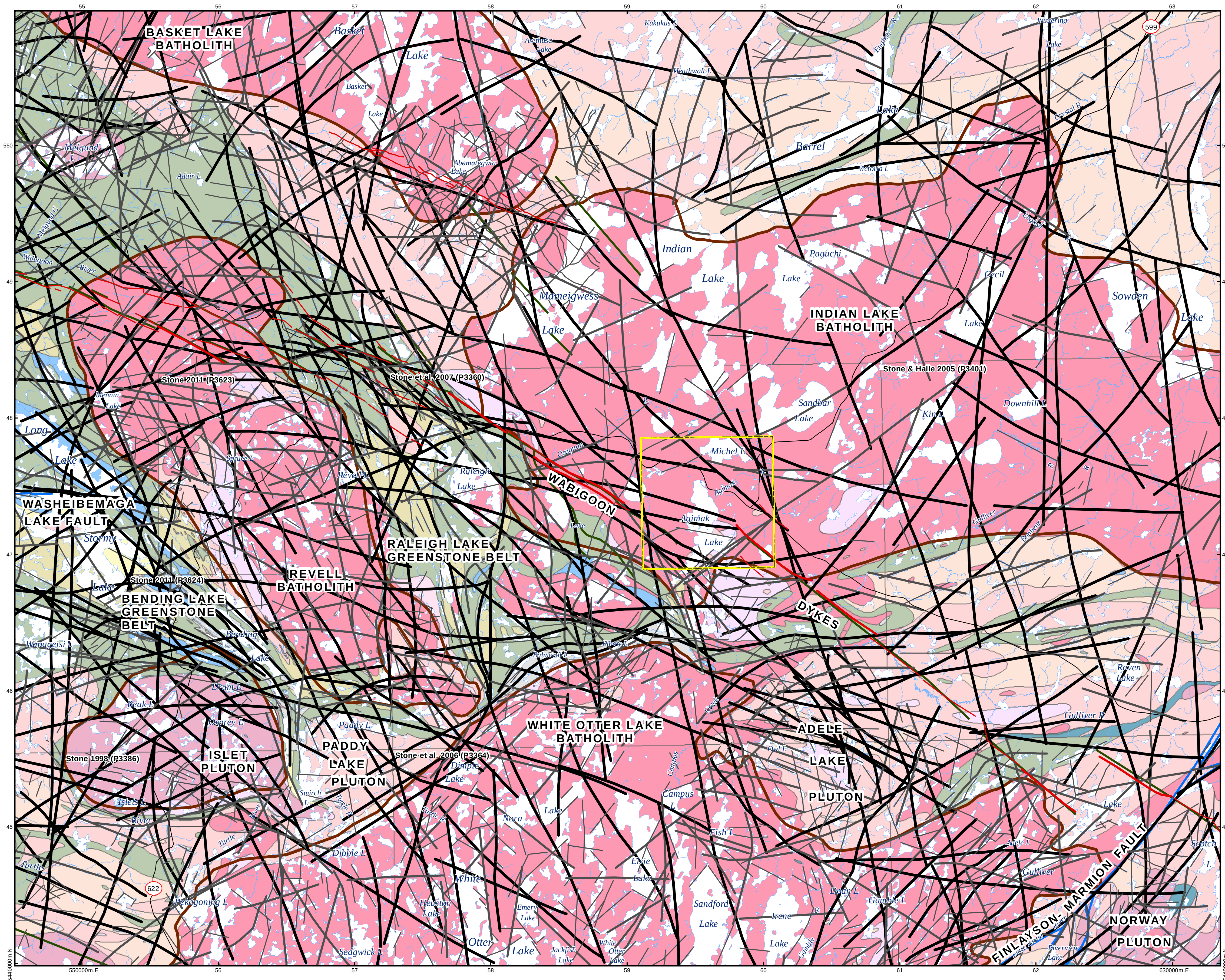
5 km

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
Lineament classification by reproducibility assessment (RA_2)

DESIGN	DVZ	25 JUN 2012	FIGURE 12	REVISION 6
GIS	DSM	07 NOV 2013		UTM ZONE 15
CHECK	JIC	07 NOV 2013		NAD 1983
REVIEW	GS	07 NOV 2013		1:300,000



LEGEND

- Township of Ignace
- Main road

Lineament (dyke)

- 0 - 1 km
- 1 - 5 km
- 5 - 10 km
- 10+ km

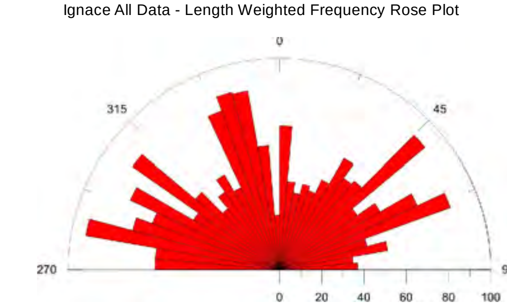
Merged lineaments

- 0 - 1 km
- 1 - 5 km
- 5 - 10 km
- 10+ km
- Mapped fault
- Mapped dyke
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

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

Ignace All Data - Length Weighted Frequency Rose Plot



N = 2,108

Data sources:
Bedrock: OGS MRD 126-REV1 (1:250,000)
Bedrock: See references to 1:50k maps
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

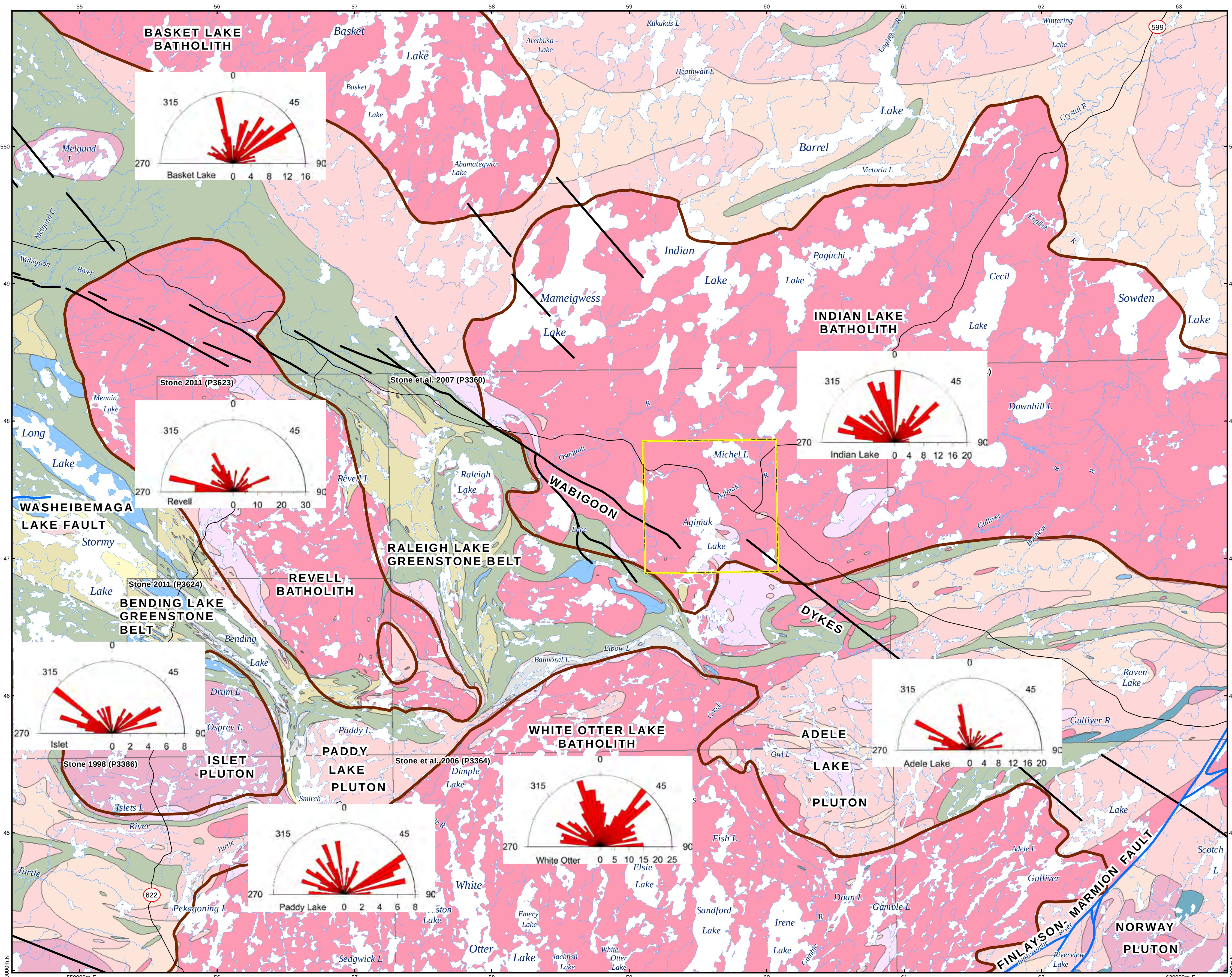
NORTH
5 km

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
Lineament classification by length

DESIGN	DVZ	25 JUN 2012	FIGURE 13	REVISION 6
GIS	DSM	10 OCT 2013		UTM ZONE 15
CHECK	JIC	10 OCT 2013		NAD 1983
REVIEW	GS	10 OCT 2013		1:300,000



LEGEND

- Township of Ignace
- Main road
- Mapped fault
- Dyke (OGS)
- Batholith\pluton
- Waterbody (permanent)
- Watercourse

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
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- 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

Data sources:
Bedrock: OGS MRD 126-REV1 (1:250,000)
Bedrock: See references to 1:50k maps
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

J D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, LINEAMENT ANALYSIS, IGNACE AREA, ONTARIO

TITLE
Lineament orientations of batholiths and plutons in the Ignace area

DESIGN	DVZ	25 JUN 2012	FIGURE 14	REVISION 6
GIS	DSM	07 NOV 2013		UTM ZONE 15
CHECK	JIC	07 NOV 2013		NAD 1983
REVIEW	GS	07 NOV 2013		1:300,000