NUCLEAR WASTE MANAGEMENT ORGANIZATION

SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

TOWNSHIP OF EAR FALLS, ONTARIO

APM-REP-06144-0019

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

Township of Ear Falls, Ontario

Submitted to:

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REPORT

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Executive Summary

In February, 2012, the Township of Ear Falls, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process, and requested that a preliminary assessment be conducted to assess potential suitability of the Ear Falls area for safely hosting a deep geological repository (Step 3). This request followed successful completion of an initial screening conducted during Step 2 of the site selection process. The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated preliminary assessment report (NWMO, 2013).

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

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

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

The desktop geoscientific preliminary assessment showed that the Ear Falls area contains at least five general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. One of the areas is within the Bluffy Lake batholith, and the four other areas are within the metasedimentary rocks of the English River Subprovince.

The Bluffy Lake batholith and the metasedimentary rocks hosting the five identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They are estimated to have sufficient depth and extend over large areas. The bedrock within the five potentially suitable areas has good exposure. All five potentially suitable areas have low potential for natural resources; are easily accessible using the existing road network; contain limited surface constraints; and are amenable to site characterization.

While the identified general potentially suitable areas appear to have favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The main uncertainties are associated with the proximity of the regional Sydney Lake fault zone, the low resolution of available geophysical data, and the variable degree of metamorphism and migmatization (partial melting of the rock) that the metasedimentary rocks have experienced in the geological past.

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

Table of Contents

TABLES

FIGURES (IN ORDER FOLLOWING TEXT)

APPENDICES

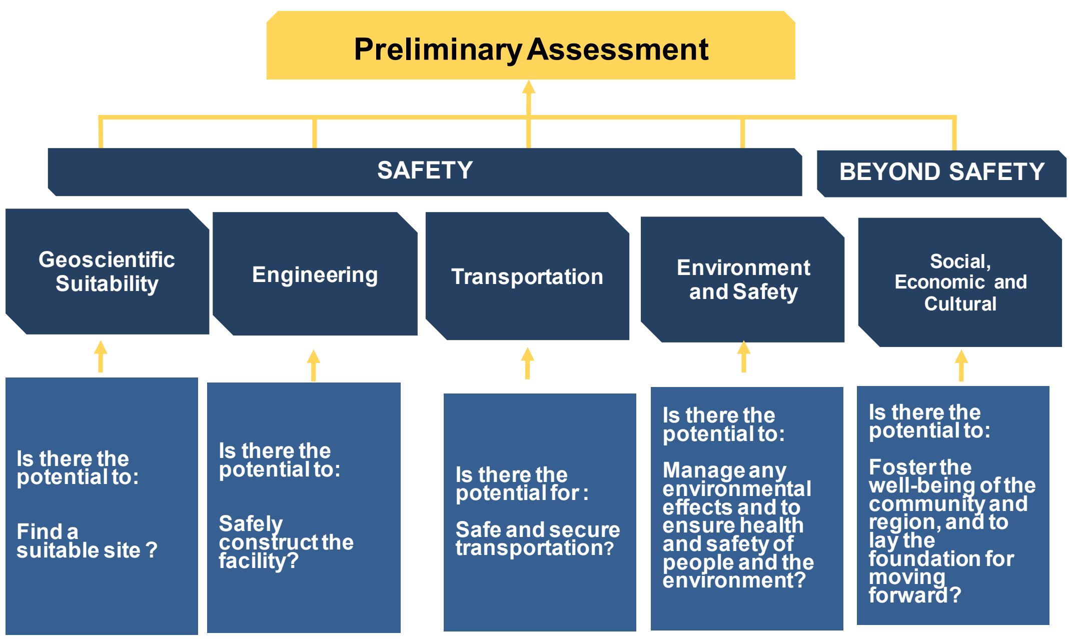
SUPPORTING DOCUMENTS

1.0 INTRODUCTION

1.1 Background

In February, 2012, the Township of Ear Falls, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Ear Falls area for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process (Golder, 2011).

The overall preliminary assessment is a multidisciplinary study integrating both technical and community well-being assessments as illustrated in the diagram below. The five components of the preliminary assessment address geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. A brief description of the project, the approach and the findings of the preliminary assessment are documented in an integrated preliminary assessment report (NWMO, 2013).



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

- ***Phase 1 - Desktop Study***. For all communities electing to be the focus of a preliminary assessment. This phase involves desktop studies using available geoscientific information and a set of key geoscientific characteristics and factors that can be realistically assessed at the desktop phase of the preliminary assessment.
- ***Phase 2 - Preliminary Field Investigations***. For a subset of communities selected by the NWMO, to further assess potential suitability. This phase involves preliminary field investigations that include high resolution geophysical surveys, geological mapping and the drilling of deep boreholes.

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

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

1.2 Desktop Geoscientific Preliminary Assessment Approach

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

The desktop preliminary geoscientific assessment built on the work previously conducted for the initial screening (Golder, 2011) and focused on the Township of Ear Falls and its periphery, which are referred to as the “Ear Falls area” (Figure 1.1). The boundaries of the Ear Falls area have been defined to encompass the main geological features within the Township of Ear Falls and its surroundings. The Phase 1 Desktop Geoscientific Preliminary Assessment included the following review and interpretation activities:

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

The details of these various studies are documented in three supporting documents: terrain analysis (JDMA, 2013); geophysical interpretation (Mira, 2013); and lineament interpretation (SRK, 2013). Key findings from these studies are summarized in this report.

1.3 Geoscientific Site Evaluation Factors

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

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

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

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

1.4 Available Geoscientific Information

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

1.4.1 DEM, Satellite Imagery and Airborne Geophysics

The digital elevation model (DEM) data for the Ear Falls area is the Canadian Digital Elevation Data (CDED), a 1:50,000 scale, 20 m resolution, elevation model constructed by Natural Resources Canada (NRCan) using provincial data created through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (MNR) (GeoBase, 2011a). SPOT multispectral (20 m resolution) and panchromatic (10 m resolution) orthoimagery were used for identifying surficial lineaments and exposed bedrock within the Ear Falls 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). Four SPOT images (scenes) provided complete coverage for the Ear Falls area. The SPOT imagery was combined with LandSAT 7 imagery from 2000 to 2002 to create seamless false natural colour coverage of the Ear Falls area.

For the Ear Falls area, geophysical data were obtained from available public domain sources, particularly the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC), and were evaluated by MIRA Geoscience (Mira, 2013). This evaluation highlighted the presence of the high resolution Uchi-Bruce Lakes area (GDS1026; OGS, 2003), Pakwash Lake area (GDS1218; OGS, 2002a), and the Trout Lake River area (GDS1222; OGS, 2002b). Such datasets locally overlap each other and overall only cover a small portion of the Ear Falls area. Another aeromagnetic dataset from the GSC Regional Magnetic Compilation (GSC, 2012), covers the entire Ear Falls area but is lower resolution with 805-metre line spacing. This dataset comprises two separate surveys (Ontario #6 and Ontario #7) acquired by the GSC. Additional magnetic data were found in the OGS AFRI database in the form of maps (Laurentian Goldfields Ltd., 2010; Fronteer Development Group Inc., 2004; Grandcru Resources Corp., 2005).

Additional geophysical data, including gravity, radiometric and seismic data were also identified and assess for the Ear Falls area (GSC, 2012). Data from the Lithoprobe program, one seismic line (WS2B) and two magnetotelluric stations (WST062 and WST074), are also located within the Ear Falls area providing some insight into deep structures. An additional low-resolution magnetic and radiometric survey (Dryden-Kenora, Dryden block) was flown at 5,000 m line spacing with a 120 m terrain clearance. Gravity data for the Ear Falls area (GSC, 2012) consists of an irregular distribution of 730 station measurements, comprising roughly a station every 2 to 3 km in the northern portion, and a station every 5 to 15 km along the southern and southeastern portion of the Ear Falls area.

The resolution of the available data was assessed to determine which datasets were most suitable for use in this assessment (Mira, 2013). Where more datasets overlapped (Figure 1.2), the highest quality coverage was used. Various geophysical data processing techniques were applied to enhance components of the data most applicable to the current assessment. Table 1.1 provides a summary of DEM, satellite and geophysical source data information for the Ear Falls area.

Table 1.1: Summary of DEM, Satellite and Geophysical Data Sources for the Ear Falls Area

Dataset	Product	Source	Resolution	Coverage	Date	Additional Comments
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	20 m	Entire Ear Falls 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 Ear Falls area	2006	
Geophysics	Dryden-Kenora, Dryden block (magnetic and Radiometric)	GSC	5000m line spacing / 120m sensor height	Entire Ear Falls area	1996	Quality control and initial processing applied by GSC
	Ontario #06	GSC	805m line	Ear Falls area	1960	Data digitized from

Dataset	Product	Source	Resolution	Coverage	Date	Additional Comments
	(Magnetic)		spacing/152m sensor height	north of 5,594,200mN		contour maps along flight lines flown at a higher elevation than other datasets with a low spatial resolution
	Ontario #07 (Magnetic)	GSC	805m line spacing /305m sensor height	Ear Falls area south of 5,594,200mN	1965	Data digitized from contour maps along flight lines flown at a higher elevation than other datasets with a low spatial resolution
	Uchi-Bruce Lakes Area (GDS1026) (Magnetic, FDEM)	OGS	200m line spacing /60m sensor height	Covers the north central part of the Ear Falls area	1991	Quality control and correction of bad data were applied by OGS
	Pakwash Lake Area (Magnetic, TDEM)	OGS (GDS1218-REV)	250m line spacing /120m sensor height	Covers a small area in the north northwest central part of the Ear Falls area	1992	Quality control and initial processing applied by OGS
	Trout Lake River Area (Magnetic, TDEM)	OGS (GDS1222-REV)	200m line spacing /73m sensor height	Covers a small area in the north northeast central part of the Ear Falls area	1997	Quality control and initial processing applied by OGS
	Red Lake, Dixie North Area (Magnetic)	Fronteer Developme nt Group Inc.	75m line spacing/100m sensor height	~62km^2 in the northwest corner of the Ear Falls area	2003	No digital data available, only images files
	Dixie East/South Properties (Magnetic)	Grandcru Resources Corp.	75m line spacing /60m sensor height	~50km^2 in the northwest corner of the Ear Falls area	2005	No digital data available, only images files
	Goldpines South Property (Magnetic, VLF-EM)	Laurentian Goldfields Ltd.	100m line spacing /34m sensor height	~681km^2 in the northwest quarter of the Ear Falls area	2009	No digital data available, only images files
	GSC Gravity Coverage	GSC	2-15 km / surface	Stations sparsely located over entire Ear Falls area	1944-1997	Good data quality but sparse coverage within southern half of Ear Falls area
	Lithoprobe - Western Superior	GSC	Along roads or at stations / surface	Seismic line crossing central part of the Ear	1999	

Dataset	Product	Source	Resolution	Coverage	Date	Additional Comments
				Falls area with a ~315°N azimuth. Two MT stations located within Ear Falls area.		

1.4.2 Geology

Geological mapping of the Ear Falls area began in the 19th century when Bell traversed the English River and Albany River systems by canoe (Bell, 1873). Dowling (1894) prepared a 1:506,880 scale geological map covering most of the Ear Falls area while Burwash (1920) mapped lands along the Wenasaga River. The first detailed mapping of the area dates from the early 1920s when Bruce (1924) mapped rock exposures within the upper English River valley, including much of the Ear Falls area.

Subsequent bedrock mapping includes a compilation of the Lower English River area by Davies and Pryslak (1967), mapping of the Bluffy, Feaver and Whitemud lake areas by Fenwick (1973), and mapping by Shklanka (1970) of the Bruce Lake area. Breaks et al. (1975;,1976) and Breaks and Bond (1977) mapped portions of the Ear Falls area, and Breaks et al. (1978) carried out mapping of a large portion of the English River Subprovince including the Ear Falls area. Thurston and Paktunc (1985) mapped portions of the northern part of the Ear Falls area, while bedrock geology in the western portion of the area was mapped by Sanborn-Barrie et al. (2004). Figure 1.2 shows a summary of the most recent, detailed geological mapping in the Ear Falls area, as well as available geophysical data. Bedrock geological mapping at a 1:250 000 scale is available for the entire Ear Falls area (OGS, 2011; Figure 1.2)

Regional geological studies are provided by Beakhouse (1977), who proposed a subdivision of the English River Subprovince into a northern gneissic belt and a southern batholithic belt, and Breaks and Bond (1993), who published a detailed study of the English River Subprovince. Van de Kamp and Beakhouse (1979) describe the paragneisses in the Pakwash Lake area while Harris and Goodwin (1975) describe paragneiss in the eastern Lac Seul area.

Geophysical syntheses and interpretation are given by Hall and Brisbin (1982), Gupta and Wadge (1986), Gupta and Barlow (1984), and Nitescu et al. (2003; 2006). Corfu and Davis (1992), Corfu and Stott (1993), Corfu et al. (1995), Corfu and Stott (1996), and Larbi et al. (1998) summarize geochronology and tectonic evolution. Structural evolution is discussed by Card and Ciesielski (1986), Sanborn-Barrie (1991), Card (1990), Kamieni et al. (1990), and Hrabi and Cruden (2006). Additional geological and structural descriptions are provided by Stone (1981), and Borowik (1998) for the Sydney Lake fault zone. National seismicity data sources were reviewed to provide an indication of seismicity in the Ear Falls area (Hajnal et al., 1983; Hayek et al., 2009, 2011; NRCan, 2012).

In addition to the above publications, Golder made extensive use of Ontario Ministry of Northern Development and Mines (MNDM) Assessment Files (AFRI) and industry publications. Notable among the latter are the results of a detailed exploration program carried out by Laurentian Goldfields Ltd. (2010) on their Goldpines South Property which comprises 144 semi-contiguous mining claims roughly centreed over the north end of Pakwash Lake (Figure 1.1). Laurentian Goldfield Ltd. (2010) included a high resolution airborne magnetic and VLF-EM survey and comprehensive soil and lake sediment sampling, as well as a property-wide mapping and prospecting program.

1.4.3 Hydrogeology and Hydrogeochemistry

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

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

1.4.4 Natural Resources – Economic Geology

Information regarding the mineral resource potential for the Ear Falls area has been obtained from a variety of sources including general syntheses of mineralization in the Canadian Shield Region (Fyon et al., 1992; Breaks and Bond, 1993), studies within the Ear Falls area (Shklanka, 1968; Breaks et al., 1975 and 2003; Breaks and Bond, 1993), economic geology studies and reports such as Vos et al. (1982); Storey (1986); Gerow and Bellinger (1990); Breaks (1991); Hinz et al. (1994); and Farrow (1996) as well as MNDM Mineral Deposit Inventories (MDI), Assessment Files (AFRI) and publications by industry (in particular NI 43-101 reports). Work by Laurentian Goldfields Ltd. (2010) carried out as part of their detailed exploration program also provided information on the mineral potential of the gneissic metasedimentary rocks for a portion of the Ear Falls area.

The availability of information is good throughout the Ear Falls area with the most detailed information available for areas having some mineral potential, such as the greenstone belt in the northern portion of the Ear Falls area and the former Griffith Iron Mine at the margin of the Bruce Lake pluton. Limited data are available for the interior portions of the intrusive bodies and for the gneissic metasedimentary rocks in the south-central portion of the Ear Falls area.

1.4.5 Rock Geomechanical Properties

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

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

2.0 PHYSICAL GEOGRAPHY

2.1 Location

The Township of Ear Falls is approximately 350 km² in size, and is situated in the District of Kenora in northwestern Ontario (MMAH, 2004). The settlement area of Ear Falls is located at the northwestern end of Lac Seul, approximately 98 km northwest of Vermillion Bay and 65 km southeast of Red Lake (Figure 1.1). The Township of Ear Falls and its periphery, referred to in this report as the "Ear Falls area", is approximately 3,688 km^2 in size. Satellite imagery for the Ear Falls area is presented on Figure 2.1.

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

2.2 Topography and Landforms

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

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

The land surface elevation within the Ear Falls area is shown on Figure 2.2 as a DEM and ranges from a low of about 316 m at the shores of Oak Lake in the southwest to a high of 452 m on a hill about 8 km south of Celt Lake, with this amount of relief being expressed over a lateral distance of about 60 km. The Griffith open pit mine, east of Bruce Lake, extends down to an elevation of 289 m. The map of elevation allows for the delineation of the major topographic features in the area.

The major topographic high in the Ear Falls area is located north of Lac Seul and south of Whitemud Lake (Figure 2.2). This is the largest contiguous topographic high in the area, with a large part of the Bluffy Lake batholith being located within the upland. Local summits within this feature exhibit elevations of about 430 to 450 m. A second topographic high exists west of Pakwash Lake, in the northwest corner of the Ear Falls area. Here, elevations rise toward the west. There is a minor area of high elevation around Anishinabi Lake and extending north to near Camping Lake. In this area, the topography exhibits numerous hills separated by narrow lows or depressions. It is also worthy to note the long, linear topographic ridge associated with the prominent Lac Seul moraine that runs roughly north-south through the centre of the Ear Falls area, west of Lac Seul and Wenasaga Lake. Along its length, the Lac Seul moraine typically rises 30 to 50 m above the surrounding ground surface and reaches a maximum elevation of over 440 m north of Wenasaga Lake.

The major topographic lows in the Ear Falls area are the basins and outlets associated with the main lakes and rivers that drain toward the lowest elevations in the southwest corner of the Ear Falls area around Oak Lake (Figure 2.2). Lac Seul, the largest lake in the area, occupies a relatively large topographic basin in the southeast corner of the area and drains westward through a break in the Lac Seul moraine via the English River and into Camping Lake. Pakwash Lake covers another topographic low that connects via the Chukuni River with Camping Lake.

Areas of steep slope form the margins of many of the rugged landforms in the Ear Falls area, such as ridges and knobs. Such slopes are often associated with bedrock terrain (JDMA, 2013), with some notable exceptions (e.g., end moraines, kames, drumlins and melt water channels). As the available Northern Ontario Engineering Terrain Study (NOEGTS) mapping (Figure 2.3) is of coarse resolution compared to more detailed surficial geology mapping which is locally available in the Ear Falls area (Figure 2.4), the presence of steep slopes may be used as an indicator of possible bedrock terrain where detailed mapping is unavailable.

2.3 Watersheds and Surface Water Features

The Ear Falls area is drained by the English River that forms part of the Nelson drainage system, which flows into Hudson Bay through the Nelson River. The Nelson River drains an area of more than 1,000,000 km^2, including the southern parts of Alberta, Saskatchewan and Manitoba, and smaller parts of North Dakota, Minnesota and northwestern Ontario, making it the single largest contributor of fresh water to Hudson Bay.

Surface water in the Ear Falls area generally flows from the upland areas in the north and east toward lower elevations in the southwest. The eastern area drains into Lac Seul, either directly or through Whitemud Lake into Bluffy Lake, then Wenasaga Lake before flowing into Lac Seul. The northwest outlet of Lac Seul flows westward into the English River. In the northern portion of the Ear Falls area, the Troutlake River drains westward into Bruce Lake before flowing into Pakwash Lake. The outlet at the southern end of Pakwash Lake forms the Chukuni River, which flows to the south and joins with the English River to the west of the settlement area of Ear Falls. The English River then flows toward the southwest through Camping Lake, Barnston Lake and Wegg Lake, before joining with the Wabigoon River south of the Ear Falls area, and eventually the Winnipeg River.

Surface water flow over the Bruce Lake pluton is separated by the Lac Seul moraine and dominated by flow of the Troutlake River into Bruce Lake. To the east of the Lac Seul moraine, the pluton is covered by several small lakes and channels that flow northward out of the Ear Falls area before joining with the Troutlake River, which then flows back into the Ear Falls area on the west side of the Lac Seul moraine.

The Troutlake River exhibits a distinct dendritic drainage pattern over a major wetland complex to the east of Bruce Lake. The outflow from Bruce Lake, through a northern outlet near the margin of the pluton, heads westward toward a northeast inlet on Pakwash Lake.

Topographic control of drainage over the eastern portion of the Bluffy Lake batholith results in elongated lakes and straight drainage courses that reflect the underlying bedrock structure. Surface flow over the eastern portion of the batholith drains northward to Whitemud Lake, which then flows westward through Bluffy Lake and southward from Wenasaga Lake to Lac Seul. The western portion of the Bluffy Lake batholith is covered by the relatively large expanse of Bluffy Lake. The inflow and outflow channels of Bluffy Lake appear linear and oriented northeast-southwest, suggesting structural control, but the lake itself, though similarly oriented, lacks straight shorelines, elongated islands, or linear bays.

The Wenasaga Lake batholith forms a topographic high that divides surface flow into several small watersheds. The northern portion of the batholith drains northward to Bruce Lake, whereas the southern portion drains southward to the English River or Detector Lake. The easternmost extent of the Wenasaga Lake batholith is separated by the Lac Seul moraine, which directs surface flow eastward into Bluffy Lake or Wenasaga Lake. While there are several wetlands, there are no large lakes covering the Wenasaga Lake batholith.

The Ear Falls area contains a large number of lakes of various sizes, with about 18% (646 km^2) of the area occupied by water bodies. Fourteen lakes within the area are larger than 10 km^2, six of which are larger than 20 km^2. The largest is Lac Seul, which covers 284 km^2 of the Ear Falls area and extends beyond the Ear Falls area to a total area of more than 1,200 km^2.

The largest lakes, such as Lac Seul, Pakwash Lake, Wenasaga Lake, Whitemud Lake, Camping Lake, Barnston Lake, and Wegg Lake generally occur within terrain underlain by gneissic metasedimentary rocks of the English River Subprovince that extend through the centre of the Ear Falls area, which could add considerable uncertainty to the identification of surface lineaments in these areas. Large lakes also cover portions of the main plutons. The western part of the Bruce Lake pluton is covered by Bruce Lake (18.1 km^2) while the largest lake on the Bluffy Lake batholith is Bluffy Lake (25 km^2). In the southwest corner of the Ear Falls area, rocks of the Winnipeg River Subprovince are covered by Anishinabi Lake (33 km^2) and Oak Lake (42.6 km^2). Table 2.1 summarizes depth and surface area information for the larger lakes in the Ear Falls area.

Table 2.1: Dimensional Characteristics of Selected Lakes in the Ear Falls Area

Lake	Perimeter (km)	Area (km^2)	Max depth (m)	Mean depth (m)
Lac Seul	3766.8	1209.7	47	...
Pakwash Lake	177.3	87.2	17	7
Bluffy Lake	90.4	25.0	...	...
Anishinabi Lake	75.8	33.0	88	31
Bruce Lake	44.8	18.1	...	...
Oak Lake	163.4	42.6	...	...
Wenasaga Lake	33.8	18.8	...	...
Wegg Lake	45.2	15.6	...	...
Wabaskang Lake	176.6	57.9	29	8
Wine Lake	67.1	15.1	...	...
Whitemud Lake	50.8	12.5	...	...
RL-075[1]	34.5	11.7	...	...
Camping Lake	42.0	11.2	...	...
Wilcox Lake	41.7	10.6	...	...

[1] South of Bruce Lake – Part of the Experimental Lakes

... Information not available

Wetlands depicted on Figure 2.5 are from the Wetland Unit map file produced by the MNR. Cross checking with the SPOT imagery indicates that the wetland mapping is unreliable and incomplete throughout the Ear Falls area. For example, the SPOT imagery indicates more extensive wetland to the east of the Lac Seul moraine than is captured in the wetland mapping. An extensive wetland complex, identified in both the wetland mapping and SPOT imagery, is located on the Bruce Lake pluton between Bruce Lake and the Lac Seul moraine. This wetland extends over 42 km^2 and covers much of the western half of the Bruce Lake pluton. Another large wetland complex is located northwest of Pakwash Lake in an area underlain by the Birch-Uchi greenstone belt.

Bathymetric maps can form a useful source of information for understanding the vertical extent of lake basins. For example, the MNR completed bathymetry surveys of selected lakes in the late 1960s and early 1970s. The resulting maps consist of contour plots based on soundings, with summary information in the map margin, such as maximum and mean depth. The greatest known lake depth in the Ear Falls area is 88 m in Anishinabi Lake (JDMA, 2013). Lac Seul has a reported maximum depth of 47 m (MNR, 2013).

2.4 Land Use and Protected Areas

Figure 2.6 shows a summary of land disposition and ownership within the Ear Falls area, including protected areas, parks and reserves, and Crown Reserve land.

2.4.1 Land Use

Forestry is a major industry in the area and the region includes a number of private timber companies currently managing forestry operations. There are four Forestry Management Units (FMUs) within the Ear Falls area. The Township of Ear Falls lies in the southwestern limit of the Trout Lake FMU, which extends north of the Township, and is managed by Domtar. South of the Township of Ear Falls, the Whiskey Jack FMU has been managed by MNR since it was surrendered by Abitibi-Consolidated in 2009. The Red Lake FMU extends west from the northwestern corner of the Township and is operated by the Red Lake Forest Management Company. The Lac Seul FMU, operated by McKenzie Forest Product Inc., includes the Lac Seul islands within the Township of Ear Falls.

2.4.2 Parks and Reserves

There are two provincial parks and two conservation reserves in the Ear Falls area (Figure 2.6). The Pakwash Provincial Park is 40 km^2 in size (LIO, 2012). The eastern portion of the park lies within the Township of Ear Falls on the eastern shores of Pakwash Lake, with the remainder of the park extending west of the Township. This Provincial Park includes a campground and day use areas along the lake operated by the Friends of Pakwash, in partnership with the MNR and Ontario Parks (Ontario Parks, 2010). The West English River Provincial Park is a waterway park that extends approximately 60 km along the English River. The portion of the park that falls within the Ear Falls area extends mostly along the shores of Oak, Wilcox, Goose and Wegg lakes, southwest of the Township.

There are also two conservation reserves in the Ear Falls area (Figure 2.6; LIO, 2012), the Bruce Lake and Lac Seul Islands conservation reserves. The Lac Seul Islands Conservation Reserve covers a total regulated area of 147.23 km^2 encompassing the islands on Lac Seul, some of which fall within the Township of Ear Falls. The Bruce Lake Conservation Reserve is approximately 60 km^2 and is located northeast of the Township of Ear Falls.

2.4.3 Heritage Sites

The cultural heritage screening examined known archaeological and historic sites in the Ear Falls area, using the Ontario Archaeological Sites Database, the Ontario Heritage Trust Database and the National Historic Sites Database. There are 77 registered archaeological sites in the Ear Falls area, with the majority concentrated around Lac Seul. There are no National or Provincial Historic Sites in the Ear Falls area (Ontario Heritage Trust, 2012; Parks Canada, 2012a; 2012b).

The 77 registered archaeological sites include 63 sites recorded within the archaeological sites database that provide no information (such as time period or cultural affiliation) aside from their location. Of the remaining 14 sites, 12 are identified as pre-contact (prior to European arrival) Aboriginal sites, with three also having a later Euro-Canadian or historical Aboriginal occupation. Two sites have been identified as pre-contact Aboriginal activity sites: one being a Shield Archaic period fishing station and the other a Woodland period chipping station. The remaining two sites are Euro-Canadian railway/marine sites. These sites demonstrate a long duration of occupation by both Aboriginal and Euro-Canadian people in the area.

The potential for archaeological and historical sites along the English River and its associated tributaries is considered to be high as it was used as major transportation route for both Aboriginal and Euro-Canadian people. There is also a high concentration of archaeological sites around Lac Seul, but no information other than their location is known.

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

3.0 GEOLOGY

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

The Ear Falls area is underlain by ca. 3 to 2.6 billion year old bedrock of the Superior Province of the Canadian Shield – a stable craton created from a collage of ancient plates and accreted juvenile arc terranes that were progressively amalgamated over a period of more than 2 billion years (Figure 3.1). The Canadian Shield forms the stable core of the North American continent.

The Superior Province covers an area of approximately 1,500,000 km^2 stretching from the Ungava region of northern Québec through the northern part of Ontario and the eastern portion of Manitoba, and extending south through to Minnesota and the northeastern part of South Dakota. The Superior Province has been historically subdivided into various regionally extensive east-northeast-trending subprovinces based on lithology, age and metamorphism (e.g., Card and Ciesielski, 1986; Card, 1990) as shown on Figure 3.1. However, the subdivision of the Superior Province has been recently revised in terms of 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 Ear Falls area lies largely within the English River Subprovince, which generally corresponds to the English River Basin, which lies north of the Winnipeg River terrane (Figure 3.2). The English River Subprovince is an east-west trending, 30 to 100 km wide by 650 km long belt of metasedimentary and plutonic rocks extending from Manitoba to the Moose River Basin in the James Bay Lowlands. In the Ear Falls area it is bordered to the north and south by the Uchi and Winnipeg River subprovinces, respectively. The northern part of the Ear Falls area is within the Uchi Subprovince while the southwestern corner falls within the Winnipeg River Subprovince.

Figure 3.3 shows a north-south geological section through the Ear Falls area based on the tectonic setting and interpretation of Lithoprobe Line 2B (Calvert et al. 2004; Zeng and Calvert, 2004), and Figure 3.4 shows the general bedrock geology and main structural features of the English River Subprovince and of portions of its bounding subprovinces (Uchi and Winnipeg River subprovinces). The English River Subprovince, which underlies the majority of the Ear Falls area, consists primarily of clastic metasedimentary rocks that have undergone regional migmatization and are intruded by ca. 2.7 to 2.65 billion year old plutonic rocks (Breaks, 1991). The sedimentary protoliths have been interpreted as being mainly greywacke and mudstone/shale derived from reworked volcanic source rocks within the Uchi Subprovince (Breaks and Bond, 1993). These rocks were deposited in an inter-arc basin between ca. 2.708 and 2.698 billion years ago (Sanborn-Barrie et al., 2004; Percival and Easton, 2007). Metavolcanic rocks are rare in the area, accounting for only about 2% of the rocks of the English River Subprovince.

The Uchi Subprovince is a relatively narrow, east-trending region dominated by belts of ca. 2.292 to 2.723 billion year old metavolcanic and subordinate metasedimentary rocks that interweave intrusive complexes up to 3 billion years old (Stott and Corfu, 1991; Corfu and Stott, 1996; Sanborn-Barrie et al., 2004). The boundary between the Uchi and English River subprovinces has been recognized in parts to be faulted (e.g., Stone, 1981) while in others to be conformable or gradational (e.g., Breaks and Bond, 1993). The Sydney Lake fault zone is an east-striking strike-slip fault that separates the metavolcanic and felsic plutonic rocks of the Uchi Subprovince to the north from the gneissic metasedimentary rocks of the English River Subprovince to the south (Figure 3.4).

The Winnipeg River Subprovince is dominated by a belt of felsic intrusive rocks bordering the English River Subprovince along most of its length. The Winnipeg River batholithic terrane is underlain by variously deformed and recrystallized plutonic rocks including gneissic plutons ranging in age from approximately 3.168 to 2.830 billion years as well as younger potassic plutons ranging from 2.700 to 2.660 to billion years in age (Beakhouse et al. 1995). The contact between the English River Subprovince and the Winnipeg River Subprovince is not sharply defined by any specific tectonic boundary, but rather by the predominance of gneissic metasedimentary rocks to the north and plutonic rocks to the south. Provincial-scale mapping by Percival and Easton (2007) and Stott et al. (2010) place the boundary between the two subprovinces to the south of the Township of Ear Falls (Figure 3.4)

3.1.2 Geological History

Direct information on the geological and structural history of the Ear Falls area is limited. The geological and structural history summarized below integrates the results from studies undertaken elsewhere throughout and proximal to the regional area shown on Figure 3.4.

As shown on Figure 3.2 most of the Ear Falls area is underlain by gneissic metasedimentary rocks of the English River Subprovince, which comprises the northernmost part of the Winnipeg River terrane and is bound to the north by the Uchi Subprovince of the North Caribou terrane. The Winnipeg River and North Caribou terranes were initially individual protocontinents assembled between approximately 3.4 and 2.8 billion years ago through the addition of magmatic and crustal material in continental arcs, and through accretion of allochthonous crustal fragments (Corfu et al., 1995; Sanborn-Barrie et al., 2004; Percival, 2004, Percival and Easton, 2007; Stott et al. 2010). Approximately 2.72 to 2.70 billion years ago, juxtaposition of the two terranes occurred contemporaneously with the accumulation of the sediments of the English River Subprovince. These sediments were mostly deposited between approximately 2.704 and 2.696 billion years ago (Corfu et al. 1995; Corfu and Stott, 1996; Sanborn-Barrie et al. 2004) in an interarc basin sedimentary setting, with much of the sediment believed to have been derived from a volcanic-dominated source in the Uchi Subprovince (van de Kamp and Beakhouse, 1979; Breaks, 1991; Breaks and Bond, 1993). It is noteworthy that Hrabi and Cruden (2006) re-assess $^{207}Pb/^{206}Pb$ ages for detrital zircons and suggest that the deposition of the English River sediments may have substantially occurred before approximately 2.704 billion years ago date and may have been contemporaneous with the cessation of arc volcanism in the Uchi Subprovince approximately 2.713 billion years ago. Regional low-pressure, high-temperature metamorphism that occurred in the area approximately 2.691 billion years ago (Corfu et al., 1995; Sanborn-Barrie et al., 2004) resulted in widespread migmatization of the precursor sedimentary rocks, leaving in the Ear Falls area a dominance of migmatites composed of two or more petrographically distinct components.

Intrusion of early tonalitic to dioritic plutons such as the Bluffy Lake batholith occurred approximately approximately 2.699 to 2.698 billion years ago, while the localized intrusion of peraluminous granites was coincident with the approximately 2.691 billion year old regional metamorphic event (Sanborn-Barrie et al., 2004). Stratigraphic evidence in the form of inclusion of gneissic xenoliths suggests that the Bruce and Pakwash Lake plutons may be late syn-deformational or post- deformational intrusions. Two more episodes of metamorphism affected parts of the English River Subprovince between approximately 2.68 and 2.67 billion years ago (Sanborn-Barrie et al., 2004).

The youngest Precambrian rocks in the Ear Falls area are a series of rare mafic dykes, typically Paleo to Neoproterozoic in age (approximately 2.170 to 1.0 billion years old), that crosscut all older rock types. Although such dykes are relatively common in the northwest part of the Superior Province, few have been identified in the Ear Falls area. Only a series of Proterozoic mafic dykes, the Ear Falls dykes, are recognized at the former Griffith Iron Mine in the western margin of the Bruce Lake pluton.

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

Table 3.1: Summary of the Geological and Structural History of the Ear Falls Area

Time Period (billion years ago)	Geological Event
ca. 3.4 to 2.8	Progressive growth of the North Caribou and Winnipeg River terranes through the additions of magmatic and crustal material in continental arcs and through accretion of allochthonous crustal fragments (Tomlinson et al., 2004).
ca. 2.740 to 2.735	Emplacement of early plutons in the Uchi Subprovince.
ca. > 2.704 to 2.69	Timing of collision between the North Caribou terrane and the Winnipeg terrane (Corfu et al., 1995; Hrabi and Cruden, 2006; Sanborn-Barrie and Skulski, 2006). [D_1] ▪ Emplacement of late granitic to granodioritic plutons within the Winnipeg River Subprovince between approximately 2.71 and 2.69 billion years ago (Breaks and Bond, 1993). ▪ Accumulation and syn-depositional deformation of sediments in the English River Subprovince between approximately 2.704 and 2.699 billion years ago (e.g., Sanborn-Barrie et al., 2004).
ca. 2.698	Timing of intrusion of calc-alkaline plutons into sedimentary rocks of the English River Subprovince (Hrabi and Cruden, 2006). Their emplacement provides constraint on the maximum age of D_2 deformation. [2.698 > D_2 > 2.691 Ga]
ca. 2.691 to 2.68	Major regional deformation, amphibolite to granulite facies metamorphism, anatexis and emplacement of peraluminous granitic intrusions (Sanborn-Barrie et al., 2004). [D_3]
ca. 2.68 to > 2.67	Dextral semi-brittle movement in the Sydney Lake fault zone (Sanborn-Barrie et al., 2004; Hrabi and Cruden, 2006). [D_4] ▪ Granulite facies metamorphic event approximately 2.680 billion years ago within the Winnipeg River Subprovince (Corfu et al., 1995). ▪ Continued metamorphism and pegmatite emplacement within the English River Subprovince (Sanborn-Barrie et al., 2004).
ca. 2.67 to 2.4	Late fault (re)activation (Hrabi and Cruden, 2006; Hanes and Archibald, 1998). [D_5]
ca. < 2.4 to > 1.9	Regional faulting and brittle fracturing (Kamineni et al., 1990). [D_6]
ca. 1.9 to 1.7	Emplacement of the Ear Falls dykes (Symons et al., 1983). [D_6 con't]
Post-1.7	A complex interval of erosion, brittle fracture, repeated cycles of burial and exhumation, and glaciations, particularly from the latest Miocene to the present. [D_6 con't]

Little information is available on the geological history of the Ear Falls area for the period following the approximately 1.9 to 1.7 billion year old emplacement of the Ear Falls dykes. However, other areas of the Superior Province provide evidence of younger events, including multiple generations of Proterozoic dyke emplacement between approximately 2.5 and 1.0 billion years ago and a major period of volcanism between approximately 1.1 and 1.0 billion years ago (Osmani, 1991). This period of volcanism is associated with the emplacement of the Logan sills in the Thunder Bay – Nipigon area, about 240 km east-southeast of the Ear Falls area, and the alkali complexes extending from the north shore of Lake Superior to the northeast as far as the James Bay Lowlands, interpreted to be related to the Midcontinent Rift event in the Lake Superior Basin (Sutcliffe, 1991; Heaman and Easton, 2006; Heaman et al., 2007). Proterozoic sedimentation in the northwest Superior Province includes the Animikie and Sibley Groups of the Thunder Bay – Nipigon area, which formerly extended further to the west than their present distribution. The reviewed literature, however, provides no evidence that such Paleoproterozoic sedimentation extended to the Ear Falls area.

During the Paleozoic, much of the Superior Province was inundated by shallow seas. Paleozoic strata dating from the Ordovician to Devonian (approximately 485 to 359 million years ago) are preserved within the Hudson Bay Basin and Michigan Basins in northern Ontario/Nunavut and southwestern Ontario, respectively. The presence of a small outlier of Paleozoic strata known as the Temiskaming outlier in the New Liskeard area in northeastern Ontario indicates that Paleozoic cover was formerly much more extensive and that much of the present surface of the Canadian Shield lies close to an exhumed paleoplain interpreted to be of Ordovician age (Brown et al., 1995). However, no evidence exists that Paleozoic strata were present in the Ear Falls area (Johnson et al., 1992).

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

3.1.3 Regional Structural History

The structural history summarized below integrates the results from studies undertaken elsewhere throughout and proximal to the regional area shown on Figure 3.4. It is understood that there are potential difficulties in regional correlation of specific structural events within a D_x numbering system and in the application of such a system to the local geological history. Nonetheless, this summary represents a preliminary interpretation for the Ear Falls area, which may be modified after site-specific information has been collected. Rocks within the metasedimentary migmatite-dominated English River Subprovince have undergone multiple phases of folding, shearing, fracturing and faulting (Westerman, 1977; Breaks et al., 1978; Breaks, 1991) and generally follow an easterly trend paralleling the subprovince boundaries. Structures in the English River Subprovince have been traditionally interpreted to have developed in four Archean deformation stages (Breaks, 1991). More recently, Hrabi and Cruden (2006) interpreted the recognized deformation events as components of a single, protracted and complex orogeny. The work of Hrabi and Cruden (2006), which considers D_1 to D_5 events to be components of a single protracted and complex orogeny, offers a descriptive summary of the deformation events in the English Subprovince and is regarded as the most applicable interpretation of the structural geology of the Ear Falls area. Along with a protracted younger history of brittle deformation, herein termed D_6, the six deformation events form the basis of the following description of the structural history.

The first deformation event (D_1) is interpreted to have generated a weak foliation (S_1) oriented parallel to bedding in low-grade metamorphic rocks located in the north and south margins of the English River Subprovince (Hrabi and Cruden, 2006). At higher metamorphic grades, S_1 is enhanced by migmatitic leucosomes (Hrabi and Cruden, 2006). D_1 is interpreted to have overlapped with the initial migmatization stages of sedimentary rocks and is bracketed between the time of deposition of sedimentary rocks, before approximately 2.704 billion years ago, and the age of a suite of tonalite intrusions dated at approximately 2.698 billion years old and deformed by D_2 (Hrabi and Cruden, 2006). Folds related to this fabric are not commonly found and have only been documented by Breaks (1991) and Hynes (1997, 1998).

The second deformation event (D_2) was the most pronounced, and generated an east-trending moderate to intense foliation (S_2) and a stretching lineation (L_2) of varying orientation (Hrabi and Cruden, 2006). F_2 folds are isoclinal and fold the S_1 foliation and migmatitic leucosomes (Hrabi and Cruden, 2006). Migmatization of sedimentary rocks continued during D_2 and the resulting migmatitic layering is interpreted to represent a composite S_0-S_1-S_2 foliation (Hrabi and Cruden, 2006). The maximum age of the D_2 deformation is constrained by the approximately 2.698 billion year old suite of tonalite intrusions which are overprinted by the S_2 foliation (Hrabi and Cruden, 2006).

Hrabi and Cruden (2006) attribute D_3 deformation to a period of extension. Extensional faults are indirectly evident from Lithoprobe seismic reflection profiles and are attributed to D_3. This extensional phase is consistent with the presence of approximately < 2.701 billion year old conglomeratic basins distributed along the south margin of the English River Subprovince and the three-dimensional (3D) geometry of the Uchi and English River subprovinces inferred from Lithoprobe profiles (Calvert et al., 2004) with upwarp of the Moho beneath the English River Subprovince. Based on the timing of the D_2 event, D_3 is therefore constrained to have occurred betwen approximately 2.691 and 2.68 billion years ago.

The fourth deformation event (D_4) is attributed to have curved east- to northeast-trending sinistral shear zones (Hrabi and Cruden, 2006). Upright moderately east- to southeast-plunging F_4 folds associated with a steeply-dipping penetrative S_4 foliation are also attributed to D_4 (Hrabi and Cruden, 2006). In terms of geometry and kinematics, D_4 shear zones are similar to the well-documented Miniss River fault located about 80 km east of the Ear Falls area (Hrabi and Cruden, 2006). The Miniss River fault is 1 to 2 km wide (Breaks, 1991), with a long history of ductile and brittle deformation (Bethune et al., 1999). The age of a portion of the mylonitic ductile strain along the Miniss River fault is constrained by the age of a granitic dyke dated at approximately 2.681 billion years old, which is deformed and offset by a sinistral shear band within the fault (Bethune et al., 2006). Dextral reactivation of the southwestern portion of the Miniss River fault is interpreted to have occurred approximately 2.670 billion years ago (Bethune et al., 2006), the age of titanite porphyroblasts generated during retrograde metamorphism linked to the reactivation of the fault (Corfu et al., 1995), and may be attributed to D_5 (see below). Therefore an age range of between approximately 2.68 and 2.669 billion years old is considered a suitable approximation for the timing of D_4.

The regional fault systems are known to have a protracted displacement history and early thrust faulting along the Sydney Lake fault zone is likely to have pre-dated the most significant component of displacement on the Miniss fault (Stone, 1981). Hrabi and Cruden (2006) hence assign faults associated with the Sydney Lake fault to a fifth deformation event (D_5). Bethune et al. (2006) propose that dextral reactivation of the Miniss River fault about 2.670 billion years ago was effectively driven by the stress regime of the younger Sydney Lake fault.

Geometric and kinematic relationships strongly suggest a protracted history of late fault movement that is collectively ascribed to a D_6 phase of deformation. For example the latest displacement of the Sydney Lake fault crosscuts the Miniss River fault (Bethune et al., 2006). This interpretation is consistent with Ar-Ar geochronology indicating that motion along the Sydney Lake fault continued until approximately 2.640 billion years ago (Hanes and Archibald, 1998). 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 until approximately 2.400 billion years ago. Further episodes of brittle deformation are inferred to have caused the formation of brittle fractures and faults, and to have reactivated pre-existing faults and fractures in the region. Numerous generations of fracture formation or reactivation have been identified post-dating approximately 2.5 billion years in northwestern Ontario (Kamineni et al., 1990; Brown et al., 1995).

3.1.4 Mapped Regional Structure

Two regionally extensive east-trending shear zones occur within the Ear Falls area: the Sydney Lake fault zone and the Long Legged Lake fault zone (Figure 3.5).

The Sydney Lake fault zone is 0.5 to 2 km wide and approximately 250 km long (Stone, 1981; Bethune et al., 2006), separating the metavolcanic and felsic plutonic rocks of the Uchi Subprovince to the north from the migmatitic metasedimentary rocks of the English River Subprovince to the south. Displacement along the Sydney Lake fault is interpreted to have evolved from reverse (south over north) motion to dextral motion with the magnitude of the dextral component estimated to vary from 6 km (Stott and Corfu, 1991) to 30 km (Stone, 1981) along strike, whereas the displacement magnitude of the reverse component is estimated to be between 2 and 3 km (Stott and Corfu, 1991; Corfu et al., 1995).

The Long Legged Lake fault zone is split in two segments, running along the southern margin of the Pakwash pluton and the northeast margin of the Bruce Lake pluton, respectively (Figure 3.5). This fault zone is interpreted to be related to the Sydney Lake fault zone. Cataclastic textures are superimposed on mylonitic textures indicating that brittle deformation followed ductile deformation (Stone, 1981). No evidence of large-scale post-Archean activity along these two fault zones has been reported in the available literature.

Smaller scale north-northeast-trending faults, displaying little or no offset in stratigraphy, are abundant throughout the Uchi Subprovince and Red Lake region along the north boundary of the Ear Falls area (Gupta and Wadge, 1986). Brittle deformation having no discernible displacement is noted throughout the Ear Falls area in the form of lineaments, identifiable through terrain analysis and geophysical interpretation.

3.1.5 Metamorphism

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in a few publications since the 1970s, including Fraser and Heywood, (1978); Kraus and Menard (1997); Menard and Gordon (1997); Berman et al. (2000); Easton (2000a and 2000b) and Berman et al. (2005). The thermochronologic record for major parts of the Canadian Shield are given in a number of studies such as those by Berman et al. (2005), Bleeker and Hall (2007), Corrigan et al. (2007), and Pease et al. (2008).

The Superior Province largely preserves low pressure – low to high temperature Neoarchean metamorphism from approximately 2.710 to 2.640 billion years ago, but there is a widespread tectonothermal overprint of

Archean crust by Paleoproterozoic deformation and typically amphibolite facies metamorphism across the Churchill Province through northernmost Ontario under the northern Hudson Bay lowland, western Manitoba, northern Saskatchewan and Nunavut (e.g., Skulski et al., 2002; Berman et al., 2005).

In the Archean Superior Province, the relative timing and grade of regional metamorphism corresponds to the lithologic composition of the subprovinces (Easton, 2000a; Percival et al., 2006). Granite-greenstone subprovinces contain the oldest, Neoarchean metamorphism of lower greenschist to amphibolite facies in volcano-sedimentary assemblages and synvolcanic to syntectonic plutons. Both metasedimentary and associated migmatite-dominated subprovinces, such as the English River and Quetico subprovinces, and dominantly plutonic and orthogneissic subprovinces, such as the Winnipeg River Subprovince, display younger, syntectonic middle amphibolite to granulite facies metamorphism (Breaks and Bond, 1993; Corfu et al., 1995).

Sub-greenschist facies metamorphism in the Superior Province is restricted to limited areas, notably within the central Abitibi greenstone belt (e.g., Jolly, 1978; Powell et al., 1993) and locally within the Uchi Subprovince (Thurston and Paktunc, 1985). Most late orogenic shear zones in the Superior Province experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through $^{40}Ar/^{39}Ar$ dating to approximately 2.500 billion years ago (Powell et al., 1995). The distribution of contrasting grades of metamorphism is a consequence of relative uplift, block rotation and erosion from Neoarchean orogenesis and subsequent local Proterozoic orogenic events and broader epeirogeny during Proterozoic and Phanerozoic eons. In northwestern Ontario, the concurrent post-Archean effects are limited to poorly documented reactivation along faulted Archean terrane boundaries (e.g., Kamineni et al., 1990 and references therein).

Overall, most of the Canadian Shield, outside of unmetamorphosed late tectonic plutons, contains a complex episodic history of tectonometamorphism largely of Neoarchean age with broad tectonothermal overprints of Paleoproterozoic age around the Superior Province and culminating at the end of the Grenville Orogeny approximately 950 million years ago.

Major regional deformation and metamorphism within the English River Subprovince culminated approximately 2.691 billion years ago with two later episodes of metamorphism and pegmatite emplacement approximately 2.680 and approximately 2.669 billion years ago (Corfu et al., 1995; Sanborn-Barrie et al. 2004). Corfu et al. (1995) consider the timing (short lived and apparently cyclical) of metamorphism in the English River Subprovince to be consistent with thermal perturbations related to injection of granitic magmas generated through partial crustal melting.

Metamorphic grades are lower within the Uchi Subprovince in the north part of the Ear Falls area where lower amphibolites facies dominate along the contact with the adjacent English River strata grading to greenschist facies over most of the remainder of the Uchi Subprovince (Breaks et al., 1978).

Upper-greenschist facies metamorphic grade in the English River Subprovince is restricted to near its contact with the greenstone belts at the north of the subprovince. Metamorphic grade rapidly increases southward reaching upper-amphibolite facies (Breaks and Bond, 1977; 1993), although variable uplift of the English River Subprovince and the extensive fault systems frequently obscure this trend (Stone, 1981; Breaks and Bond, 1993). Two main occurrences of hornblende-granulite facies metamorphism occur near the Ear Falls area: one proximal to left side of the Miniss River fault, approximately 80 km east of the Ear Falls area, and the other about 30 km west of the settlement area of Ear Falls. Thermobarometry indicates pressure-temperature conditions of

4-6 Kbar and approximately 700-725°C for the granulite facies indicating granulite metamorphism of low to medium pressure and high temperature (Chipera and Perkins, 1988; Breaks and Bond, 1993). Potential exists for the granulite isograds to extend into the Ear Falls area, given the relative proximity of granulite facies metamorphism to the area. This could result in a possible lateral gradation of granulite-amphibolite facies within the Ear Falls area. Confirmation of the existence of lateral gradation in metamorphic grade across the Ear Falls area would need to be investigated in future stages of the site evalution process.

3.1.6 Erosion

There is no site-specific information on erosion rates for the Ear Falls area. Past studies reported by Hallet (2011) provide general information on erosion rates for the Canadian Shield. The average erosion rate from wind and water on the Canadian Shield is reported to be about 2 m per 100,000 years (Merrett and Gillespie, 1983). Higher erosion rates are associated with glaciation. The depth of glacial erosion depends on several regionally specific factors, such as the ice-sheet geometry, topography, and history (occupation time and basal conditions: temperature, stress, and amount of motion), as well as local geological conditions, such as overburden thickness, rock type and pre-existing weathering.

Flint (1947) made one of the first efforts to map and determine the volume of terrestrial glacial sediment in North America, on the basis of which he inferred that the Plio-Pleistocene advances of the Laurentide ice-sheet had accomplished only a few tens of feet of erosion of the Canadian Shield. White (1972) pointed out that Flint's (1947) study ignored the much larger quantity of sediment deposited in the oceans, and revised the estimate upward by an order of magnitude. Subsequently, Laine (1980; 1982) and Bell and Laine (1985) used North Atlantic deposits and all marine sediment repositories of the Laurentide ice-sheet (excluding the Cordilleran Ice Sheet), respectively, to calculate a minimum value for erosion of 120 m averaged over the ice-sheet over 3 million years. Hay et al. (1989) contended that the depth of sediment of Laurentide provenance in the Gulf of Mexico is greatly overestimated by Bell and Laine (1985) and reduced the estimate of regional erosion to 80 m over the same period.

3.2 Local Bedrock and Quaternary Geology

Information on local bedrock geology for the Ear Falls area was obtained from the various published reports for the area, geological maps (Section 1.5.1), and the geophysical interpretation of the area conducted as part of this preliminary assessment (Mira, 2013). Findings from the geophysical, lineament and terrain analyses carried out as part of the preliminary assessment of the Ear Falls area (Mira, 2013; SRK, 2013; JDMA, 2013) are integrated in this report to provide insight on the lithological variability, structures and extent of the overburden cover for each of the major lithological units in the Ear Falls area.

High quality geophysical data are available for the north-central portion of the Ear Falls area from a survey flown for Laurentian Goldfields Ltd. and for small sections of the northern boundary of the Ear Falls area (Mira, 2013). For the balance of the Ear Falls area, the geophysical data are regional, on 800 m line spacings.

3.2.1 Bedrock Geology

The regional and local bedrock geology of the Ear Falls area is shown on Figures 3.4 and 3.5, respectively while a conceptual cross section across the Sydney Lake fault zone is shown on Figure 3.6. The total magnetic field and the first vertical derivative of the residual magnetic field over the Ear Falls area are shown on Figures 3.7 and 3.8, respectively. The regional Bouguer gravity data are shown on Figure 3.9.

The geology of the Ear Falls area is dominated by a roughly east-west trending belt of gneissic metasedimentary rocks that underlies most of the Township and extends significantly beyond its boundaries to the east, west and south. In the Ear Falls area, these gneissic metasedimentary rocks are intruded by a number of large plutonic bodies: the Bluffy Lake and Wenasaga Lake batholiths, and the Bruce Lake pluton in the northeast part of the Ear Falls area; and the Wapesi Lake batholith in the southeast portion of the area. Smaller granitic/tonalitic intrusions are also mapped within the gneissic belt. The bedrock geology in the southwestern and northernmost portions of the Ear Falls area includes granitic intrusions of the Winnipeg River Subprovince and greenstone and granitic rocks of the Uchi Subprovince (i.e., Long Legged Lake dome and Birch-Uchi greenstone belt), respectively (Figures 3.4 and 3.5).

The gneissic metasedimentary rocks of the English River Subprovince and the main intrusive bodies occurring in the Ear Falls area are further described in the following subsections.

3.2.1.1 Gneissic Metasedimentary Rocks of the English River Subprovince

Archean gneissic metasedimentary rocks of the English River Subprovince (Figure 3.4) underlie the largest portion of the Ear Falls area. These gneissic metasedimentary rocks formed as a result of high-grade metamorphism of precursor sedimentary rocks which were deposited after approximately 2.705 to 2.708 billion years ago (Corfu et al. 1995), with an estimated depositional age range from approximately 2.696 to 2.704 billion years ago given by Sanborn-Barrie et al. (2004). The tectonic setting in which deposition of original sediments took place has remained controversial with various settings proposed, including forearc, foreland, inter-arc, and back-arc basins. Hrabi and Cruden (2006) note that either a forearc basin or a peripheral foreland basin or some combination of the two would be consistent with the sedimentology and general chronological and tectonic context. The original sediments are inferred to have consisted of immature turbiditic greywacke and mudstones (pelite), and thought to have been supplied by erosion of the adjacent volcanic edifices of the Uchi Subprovince (van de Kamp and Beakhouse, 1979) with a probable minor contribution of debris from the Winnipeg River Subprovince (Breaks and Bond, 1993). This is supported by sedimentary features locally preserved as well as geochemical signatures, metamorphic mineralogical assemblages, and remnant rafts and inclusions of the relict sedimentary rock in the gneissic metasedimentary rocks (Harris and Goodwin, 1976; van de Kamp and Beakhouse, 1979; Breaks and Bond, 1993; Laurentian Goldfields Ltd., 2010).

Syn-deformational, low-to-medium pressure, high-temperature metamorphism in the area approximately 2.690 billion years ago produced migmatization (i.e., partial melting) of the precursor sedimentary rocks. The resulting migmatitic gneisses are composed of two or more petrographically distinct components and classified according to their content of leucosome, which is the component of the rock that formed from segregated partial melting of the precursor sedimentary rock (Breaks, 1991). Metatexites have 0 to 60% leucosome, whereas diatexites have >60% leucosome (Breaks, 1991). The resulting migmatitic rocks in the English River Subprovince are generally composed of two or more petrographically distinct components, but metatexite is the most predominant lithology in the Ear Falls area. The leucosome composition varies but is typically quartz-bearing and generally granitic in composition (Breaks and Bond, 1993).

The gneissic metasedimentary rocks in the Ear Falls area are characterized by a simple fabric of migmatitic layering parallel to banding, which corresponds to a stromatic metatexite. The layers have well defined lower and upper boundaries; grain size varies from 0.25 mm to 1.0 mm (van de Kamp and Beakhouse, 1979). Van de Kamp and Beakhouse (1979) considered the layering to probably represent original bedding, although the extensive migmatization makes such interpretation uncertain. Lighter colored layers typically correspond to coarse grained, between 40 to 1.5 m thick, mica-rich feldspathic greywacke, locally internally laminated and cross-laminated. Darker colored layers typically correspond to fine-grained, 4 to 40 cm thick, mica-poor pelite. Rare occurrences of polymictic metaconglomerate, up to 40 m wide, have also been reported in some parts of the Ear Falls area (Harris and Goodwin, 1976; van de Kamp and Beakhouse, 1979).

A detailed description of the English River gneiss is given by Laurentian Goldfields Ltd. (2010) for the gneissic metasedimentary rocks south of Pakwash Lake (Figure 3.5). The metasedimentary rocks of the English River Subprovince in this area are described as psammitic to pelitic, variably recrystallized and strongly foliated and banded. The mineral assemblage consists dominantly of quartz and biotite, with minor feldspar and occasional porphyroblasts of garnet. Differences in proportions of quartz and biotite are attributed to compositional differences in the original sedimentary protolith consisting of interbedded mudstone and muddy sandstone. Sedimentary layering is not preserved in this area. The metasedimentary rocks are frequently intruded by pegmatite dykes of dominantly tonalitic composition and ranging from centimetre-wide stringers to several metres in diameter. They are consistently parallel to the main foliation in the rock but the degree to which the dykes are transposed is variable.

In a small portion of the Township of Ear Falls between the Bruce Lake and Pakwash Lake plutons, bedrock has been mapped as metamorphosed fine grained clastic rocks and siliciclastics with less than 10% granitic leucosome. In this area, the metasedimentary rocks also comprise chert-magnetite ironstone (Sanborn-Barrie et al., 2004) and are considered to be part of the Uchi Subprovince. Along the western shore of Bruce Lake these metasedimentary rocks contain an 80 m thick, interbedded banded iron formation (Griffith deposit) that was previously mined (see Section 5.2).

The thickness of the gneissic metasedimentary rocks has been indirectly assessed through seismic reflection and magnetotelluric data collected as part of the Lithoprobe project (Calvert et al. 2004; Zeng and Calvert, 2004; Mira, 2013). The belt is generally inferred to be thinner northeast of Manitou Falls, near unnamed tonalite intrusives and thicker north of McKenzie Bay (Lac Seul). More specifically, Nitescu et al. (2006) integrated surface geologic mapping with gravity and magnetic data, and Lithoprobe seismic data from Line 2B running through the Township of Ear Falls (Calvert et al., 2004), inferring that the gneissic metasedimentary rocks are on the order of less than 1 km thick where they are underlain by intrusions, and up to 4 km thick where they are not. Gravity data for the region (Figure 3.9) shows a pronounced gravity high beneath the northern English River Subprovince, which has been the subject of considerable study (e.g., Gupta and Barlow, 1984; Nitescu et al., 2003). Nitescu et al. (2006) hypothesized that the source of this gravity anomaly is likely due to dense intrusions that formed in response to low-pressure, high-temperature metamorphism, and which underlie the gneissic metasedimentary rocks in many places within the English River Subprovince.

Aeromagnetic surveys (Figures 3.7 and 3.8) over the gneissic metasedimentary rocks of the English River Subprovince exhibit a subdued magnetic response. However, there are a number of areas exhibiting an elevated magnetic response. Some of these magnetic anomalies are coincident with mapped geologic features, such as granites or granodiorites, but they are more frequently mapped as undifferentiated gneissic metasedimentary rock (Mira, 2013). A prominent magnetic high is situated within the western half of the gneissic belt, west of Manitou Falls, and is on the order of 20 by 10 km in size. Another magnetic high is found to the northeast of Lac Seul, and is on the order of 5 by 10 km in size. It is probable that these magnetic highs represent geologic units that have not been recognized during field mapping within the gneissic belt. Where these anomalies extend into high resolution datasets, such as along the boundary between the GSC and the Laurentian Goldfields Ltd. dataset, they are much better resolved (Mira, 2013).

3.2.1.2 Wenasaga Lake Batholith

The Wenasaga Lake batholith is a granitic mass approximately 7 km wide by 26 km long. No information on its thickness was found in the available literature. This batholith is an S-type, peraluminous, biotite-muscovite granite, which likely formed by the partial melting of the sedimentary host rock in conjunction with local injections of fresh magma (Breaks, 1991; Breaks and Bond, 1993). Uniformity of response throughout different aeromagnetic surveys (Figures 3.7 and 3.8) generally support the lithological homogeneity of this batholith; nevertheless, a variety of facies have been observed ranging from massive to foliated with cataclastic facies locally present. Facies are well exposed in a blast-cut along the former Griffith Iron Mine rail line near Detector Lake (Breaks et al., 2003); at this location, biotite-muscovite pegmatitic leucogranite grades into a biotite-rich granite containing inclusions of gneissic metasedimentary rocks incorporated from the surrounding country rock.

The batholith is estimated to be of a similar age to the surrounding metasedimentary rocks, between approximately 2.698 and 2.691 billion years old (Breaks, 1991; Corfu et al., 1995). Two schistosities have been identified within this intrusion (Breaks et al., 2003); the first schistosity is coincident with the first period of metamorphism and generally parallels the metasedimentary fabric, and a second schistosity, relating to a second period of metamorphism, is superimposed over the first one and is difficult to recognize except in mafic dykes which postdate folding.

The Sydney Lake fault zone borders the southern boundary of the batholith while a major splay of the Sydney Lake fault zone, the Long Legged Lake fault zone, passes to the north of the batholith. Otherwise the batholith is free of known major structural features.

Aeromagnetic surveys (Figures 3.7 and 3.8) consist of a mixture of high and low resolution coverage from three different datasets. Magnetic response is generally observed to be low in central part of the batholith. A small pluton, referred to as the D-nut pluton (Laurentian Goldfields Ltd., 2010), is evident as a distinct geological unit at the west end of the batholith. There is also a strong magnetic response at the east end of the batholith, which continues east of the mapped geologic contact. There are some additional elevated magnetic responses observed along the northern contact with the metasedimentary rocks, which bear similarity to nearby iron formations (Mira, 2013). The southern margin of the batholith generally does not show a magnetic response at its mapped contact with the metasedimentary rocks. The gravity response (Figure 3.9) is moderate, as it is situated along the transition zone between the English River and Uchi subprovinces. The gravity response of this batholith generally blends in with the regional trend (Mira, 2013).

3.2.1.3 Bruce Lake Pluton

The Bruce Lake pluton has been described by Shklanka (1970) and Breaks and Bond (1993). The approximately 200 km^2 pluton intrudes both the gneissic metasedimentary rocks and the Birch-Uchi greenstone belt near the contact between the Uchi and English River subprovinces, in the northeastern portion of the Township of Ear Falls (Figure 3.5). No information was found in the available literature on the thickness of the Bruce Lake pluton.

The composition of the Bruce Lake pluton varies from medium-grained biotite-hornblende diorite to quartz diorite to locally monzodiorite and gabbro with enclaves of sedimentary and volcanic rocks (Breaks and Bond, 1993;

Sanborn-Barrie et al., 2004). Compositional variation is described by Breaks and Bond (1993) as chaotic and gradational, with few readily mappable contacts between the different rock phases. Fragments or enclaves of mafic metavolcanic rocks and hornblendite are commonly incorporated within the pluton, whereas intermediate metavolcanic and trondhjemite to quartz diorite enclaves are rare. The rock is medium-grained, light- to medium-grey and mainly massive with only localized and weak foliation (Shklanka, 1970).

The Bruce Lake pluton appears to have intruded into the gneissic metasedimentary rocks of the English River Subprovince as evidenced by the presence of enclaves of metasedimentary rocks within the pluton (Shklanka, 1970; Breaks and Bond, 1993). This interpretation is supported by the apparent "wrapping" of the iron formation around the pluton as can be seen on the aeromagnetic survey for the area (Figures 3.7 and 3.8), and by the presence of at least one schistosity, pre-dating the Bruce Lake pluton, in the metasedimentary rocks around the intrusion (Shklanka, 1970). This interpretation suggests a relative intrusion timing of between approximately 2.69 and 2.67 billion years, based on the timing of the regional deformation described (Section 3.1.2) by Breaks (1991) and Stott and Corfu (1991).

A continuation of the Long Legged Lake fault zone runs along the north side of the pluton, while a short southeasterly oriented splay extends into the pluton along the north shore of Bruce Lake. Otherwise the pluton is free of known major structural features.

The general extent of the pluton is visible in aeromagnetic surveys (Figures 3.7 and 3.8) that show a relatively consistent magnetic response over most of the Bruce Lake pluton. Sharp aeromagnetic highs along the southern margin and the western limit of the intrusion mark the presence of oxide facies iron formation bordering the pluton (Mira, 2013). The magnetic high in the western limit of the intrusion coincides with the former Griffith Iron Mine ore body (Section 5.1). The gravity field shows no discernible response to the pluton and cannot be differentiated from the regional trend (Figure 3.9).

3.2.1.4 Bluffy Lake Batholith

The Bluffy Lake batholith is an elongated body with a surface extension of approximately 705 km^2, located approximately 12 km east of the Township of Ear Falls (Figure 3.5). The Bluffy Lake batholith is composed of multiple intrusive phases with composition ranging from tonalite to quartz diorite and textures ranging from massive to foliated and locally gneissic (Breaks, 1991). Contacts with the metasedimentary country rock are typically sharp (Breaks, 1991).

The absolute age of the Bluffy Lake batholith has been estimated as approximately 2.698 billion years old (Corfu et al., 1995). Comparing this age with the waning of the Kenora Orogeny at approximately 2.7 billion years ago, and considering the presence of foliation and localized gneissic textures, the Bluffy Lake batholith is probably partly syntectonic, although older phases (approximately > 3.0 to 2.7 billion years old) may exist in parts of the batholith (Breaks, 1991). The western edge of the Bluffy Lake batholith is bordered by the eastern extension of the Sydney Lake fault zone but otherwise the batholith is free of known major structural features.

Aeromagnetic surveys (Figures 3.7 and 3.8) indicate a relatively strong magnetic response over the Bluffy Lake batholith, that likely reflects the presence of more magnetic minerals. The low resolution of the aeromagnetic data did not allow for the identification of different intrusive phases within the batholith but the continuance of the aeromagnetic signature into the metasedimentary rocks of the English River Subprovince to the southwest suggests that the Bluffy Lake batholith underlies the gneissic metasedimentary rocks in this area. The Bluffy Lake batholith straddles a regional high to low gravity trend from south to north (Figure 3.9), and the batholith blends into regional gravity field trend (Mira, 2013). Based on a regional gravity survey, Gupta and Wadge (1980 and 1986) modelled a sheet thickness of less than 1.5 to 3 km for the Bluffy Lake batholith.

3.2.1.5 Wapesi Lake Batholith

The Wapesi Lake batholith covers an area of approximately 635 km^2, though only a small portion (approximately 50 km^2) occurs within the extreme southeast of the Ear Falls area (Figure 3.5). The age of the Wapesi Lake batholith is estimated by Breaks (1991) as between approximately 2.692 and 2.668 billion years. No information regarding the thickness of the Wapesi Lake batholith has been found in the available literature.

Breaks and Bond (1993) described the batholith as a southwesterly-tapering massive, coarse-grained to pegmatitic, muscovite-biotite and biotite-muscovite quartz monzonite diatexite. These authors suggest that the Wapesi Lake batholith is the result of partial melting of the surrounding gneissic metasedimentary rocks of the English River Subprovince.

The batholith is known to be sparsely fractured at the outcrop scale and the northern margin of the batholith was assessed as a dimension stone prospect by Hinz et al. (1994) who describe a 2 km section containing only 11 joints (orientations: 008; 022 to 036; 080 to 090; and 131). Sheet jointing was also noted at three locations.

Aeromagnetic surveys (Figures 3.7 and 3.8) do not clearly define the limits of the batholith. Aeromagnetic response is generally low with little or no contrast between the batholith and the surrounding country rocks. The Wapesi Lake batholith shows a negative gravity response relative to the surrounding rocks within the Ear Falls area (Figure 3.9).

3.2.1.6 Minor Intrusions

In addition to the intrusive bodies described above, the Ear Falls area contains a number of smaller intrusions, including: the Pakwash Lake pluton in the northwestern section of the Township of Ear Falls (mostly beneath Pakwash Lake), the McKenzie Bay stock, and a number of small unnamed bodies intruded into the gneissic metasedimentary rocks of the English River Subprovince. In the southwestern portion of the Ear Falls area there are also granitic intrusions of the Winnipeg River Subprovince (Figure 3.5). The Pakwash Lake pluton is approximately 10 km^2 and is structurally and mineralogically similar to the Bruce Lake pluton. The composition of the pluton ranges from quartz diorite to diorite, with weak foliation. Relative to the Bruce Lake pluton, the Pakwash Lake pluton has less quartz and more mafic minerals Shklanka (1970). Shklanka (1970) suggests a common parentage and contemporaneous age for the Bruce Lake and Pakwash Lake plutons based on their overall mineralogical similarities.

Two small granitic intrusions are located just to the east of the Ear Falls area and in the extreme southeast of the Ear Falls area respectively. The larger Mckenzie Bay stock (mapped extent approximately 25 km^2) is located along McKenzie Bay in Lac Seul immediately to the north of the Wapesi Lake batholith. Van de Kamp and Beakhouse (1979) describe it as dioritic in composition with a probable igneous parentage. Aeromagnetic surveys (Figures 3.7 and 3.8) suggest that the McKenzie Bay stock may extend beneath the gneissic metasedimentary rocks for a considerable distance to the east and west of its mapped extent (Mira, 2013).

Several small elongated and elliptical granitic bodies are mapped within the gneissic metasedimentary rocks in the Ear Falls area. Some of these intrusions are mapped as muscovite-bearing granitic rocks along the Sydney Lake fault zone, while others are mapped as foliated tonalities within the gnessic belt mostly south and west of the Township of Ear Falls (Figure 3.5). These granitic bodies are generally about 2 to 25 km long and up to

1 km wide, and are concordant to the ductile fabric of the gneissic belt. The latter suggests that these bodies were generated by partial melting of the surrounding metasedimentary rocks during migmatization.

Laurentian Goldfields Ltd. (2010), based on high resolution geophysical surveys and field mapping, identified a number of small intrusions within the gneissic metasedimentary rocks, between the Long Legged Lake and Sydney Lake fault zones, west of the Wenasaga Lake batholith. Amongst these is a round-shaped intrusion named the “D-nut” and located east of Pakwash Lake. This body has a prominent geophysical expression caused by a magnetic rim around the intrusion. The area has almost no outcrop exposure and the intrusion was identified from a single glacially polished outcrop as a K-feldspar-rich granite with significant disseminated magnetite.

The granitic complex in the southwestern portion of the Ear Falls area (Figure 3.5) is part of the Winnipeg River Subprovince. The main portion of the complex is mapped as a massive granodiorite to granite and is centred over the Anishinabi Lake area. This approximately 30 km^2 central phase of the complex is bordered by foliated tonalites and metavolcanics.

No information on the thickness and age of any of the unnamed intrusions described in this section was found in the reviewed literature.

3.2.1.7 Mafic Dykes

As shown on Figure 3.5, no mafic dykes are shown on published regional mapping for the Ear Falls area (MRD 126). However, pre-deformational (i.e., > approximately 2.69 billion years old) amphibolitized mafic dykes are known to occur throughout the English River Subprovince (Breaks and Bond, 1993). They are typically narrow and transposed into the main foliation. These older dykes are commonly preserved as attenuated and dismembered fold hinges (Laurentian Goldfields Ltd., 2010). Younger, undeformed dykes are rare in the Ear Falls area, although a set of Proterozoic mafic dykes (the Ear Falls dykes) was recognized at the former Griffith Iron Mine, adjacent to the western edge of the Bruce Lake pluton. Typically narrow (i.e., <1 m), the dykes have been dated to be between approximately 1.9 and 1.7 billion years old (Symons et al., 1983). These dykes are the youngest Precambrian rocks preserved in the Ear Falls area.

Apart from the Ear Falls dykes, no other mafic dykes, mapped or interpreted, have been identified within the Ear Falls area, which lies outside of the highly concentrated regional dyke swarms that are prevalent along, and northeast of, the northeastern shoreline of Lake Superior.

3.2.2 Quaternary Geology

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

The Quaternary geology of the Ear Falls area is dominated at surface by different types of glacial deposits that accumulated with the progressive retreat of the ice sheet during the end of the Wisconsinan glaciation. This period of glaciation began approximately 115,000 years ago and peaked about 21,000 years before present, at which time the glacial ice front extended south of Ontario into what is now Ohio and Indiana (Barnett, 1992).

The Quaternary geology of the Ear Falls area is dominated by glaciolacustrine silts and clays, and end and ground moraines. At surface there are also minor amounts of glaciofluvial (sand and gravel) deposits (i.e., esker, kame, delta and outwash plain deposits; Figures 2.3 and 2.4) as well as post-glacial organic deposits of peat, muck and organic-rich silts and clays found in bogs and swamps throughout the area. Recently deposited alluvial silts and clayey silts are also present along parts of the English River and some small streams.

Ice from the Wisconsinan glaciation laid down the oldest known Quaternary deposits in the Ear Falls area: a stratum of sandy, stoney till mapped by Ford (1981), who described the unweathered till as massive to fissile with poor to moderate matrix cohesion. Unweathered till is usually olive-grey whereas the weathered till is brown to greyish brown. The extent of till over the Ear Falls area is unknown due to the extensive overlaying mantle of glaciolacustrine clays and silts at the surface. The till is not known to be exposed at the surface within the Ear Falls area except for a small area near the northeast corner of Bruce Lake. While earlier glacial and interstadial deposits are encountered in a few northern Ontario locations (e.g., the interstadial or interglacial Missinaibi beds of the Moose River drainage or the interstadial Owl Creek beds of the Timmins area) none are encountered in the Ear Falls area. It is likely that any earlier deposits in the Ear Falls area have been largely or entirely removed by glacial erosion which stripped away the pre-existing overburden and eroded the crystalline bedrock.

Glaciofluvial deposits are exposed in several areas within the Township of Ear Falls and include a number of small eskers, portions of the Lac Seul moraine and numerous sand bodies scattered about the area (Figure 2.3). The sands are typically fine to medium grained and are moderately well sorted and quartz rich (Ford, 1981).

The northward retreat of the ice sheet in the Ear Falls area started approximately 12,000 years ago and the Ear Falls area first became ice-free approximately 10,500 years ago (Dyke et al., 2003). Ice front fluctuations during the deglaciation resulted in the deposition of the Lac Seul moraine, which forms a prominent northwesterly-trending linear feature that can be traced for more than 200 km across northwestern Ontario and runs along the easternmost portion of the Township of Ear Falls (Figure 2.3).

During the waning of the Wisconsinan glaciation, drainage was blocked from flowing northward by the residual ice mass still remaining over the Hudson Bay basin. This created a large ice-dam lake, known as Lake Agassiz that covered much of northwestern Ontario and the majority of the Ear Falls area. Lake Agassiz was the largest of several glacial lakes that bordered the southern margin of the retreating ice sheet during the late Wisconsinan glaciations, covering a maximum area of approximately 1 million km^2 (Bajc et al., 2000). Clays and silts were laid down as Lake Agassiz gradually inundated the area approximately 9,900 years ago and these fine-textured glaciolacustrine deposits cover much of the Ear Falls area to thicknesses exceeding 4 m, as indicated in water well records (Section 4). Wave action in Lake Agassiz also produced a series of well-developed terraces on the Lac Seul moraine and sandy aprons bordering the moraine (Shklanka, 1970).

Information on the thickness of Quaternary deposits in the Ear Falls area was largely derived from the terrain evaluation (JDMA, 2013). Measured thicknesses are limited to a small number of water well records for rural residential properties, a small number of water well records along the highways and from diamond drillholes in the former Griffith Iron Mine and in the Birch-Uchi greenstone belt in the northern portion of the Ear Falls area (Figure 4.1). A detailed accounting of recorded depths to bedrock in the Ear Falls area is provided by JDMA (2013), and depths generally range from 0 to 45 m, with an average of 15 m. The thickest overburden is inferred along the axis of the Lac Seul moraine (Figure 2.3).

The gneissic metasedimentary rocks of the English River Subprovince are partially covered by overburden in the Ear Falls area (Figure 2.3). Published NOEGTS mapping for the Ear Falls area (JDMA, 2013) indicates that approximately 27% of the surface of the gneissic metasedimentary rocks in the Ear Falls area consists of bedrock terrain. The largest contiguous area mapped as bedrock terrain occurs south of the Bluffy Lake batholith, between Celt Lake, Aerofoil Lake and Lac Seul. Additional areas mapped as bedrock terrain include the area south of Camping Lake and the area west of Pakwash Lake and south of the Long Legged fault zone. Comparison to the detailed Quaternary geological mapping (Figure 2.4) indicates that the NOEGTS coverage is of low resolution and may substantially overstate or understate the actual extent and distribution of bedrock terrain. For example, the large area mapped as bedrock terrain north of Wegg Lake actually contains little exposed bedrock, and the terrain analysis suggests that there is actually better bedrock exposure in the area mapped as morainal terrain immediately to the west and northwest (JDMA, 2013).

The Wenasaga Lake batholith is almost entirely covered by overburden. Terrain analysis carried out as part of the desktop geoscientific preliminary assessment of the Ear Falls area (JDMA, 2013) indicates that approximately 4% of the surface of the Wenasaga Lake batholith consists of exposed bedrock or bedrock with only a thin veneer of Quaternary sediments. However, the Wenasaga Lake batholith does have terrain characteristics indicative of the presence of more extensive unmapped bedrock outcrop (JDMA, 2013; Ford, 1981).

A substantial portion of the Bruce Lake pluton is covered by overburden deposits, and a relatively high percentage of the eastern portion of the pluton is covered by lakes. The most extensive organic deposit in the Ear Falls area is located on the west margin of the pluton. Bruce Lake also covers part of the pluton. It is difficult to judge the amount of exposed bedrock on the western half of the pluton, where extensive forest harvesting has modified the spectral properties of the surface. Total bedrock terrain on the Bruce Lake pluton has been estimated at 5% (JDMA, 2013).

The Bluffy Lake batholith and the migmatized metasedimentary rocks adjoining its southern margin are located within the largest contiguous area within the Ear Falls area that has been mapped as bedrock terrain. Terrain analysis carried out as part of the desktop geoscientific preliminary assessment of the Ear Falls area (JDMA, 2013) indicates that approximately 78% of the surface of the Bluffy Lake batholith within the Ear Falls area is mapped as exposed bedrock or bedrock with only a thin veneer of Quaternary sediments. The best bedrock exposure and least amount of organic deposits are located within and to the north of a large contiguous block of high ground (8 km by 12 km) extending north south between Celt Lake and Aerofoil Lake. The SPOT imagery displays an abundance of exposed bedrock distributed on low-relief (30 to 40 m) rock ridges distributed amongst narrow depressions with organic and other drift deposits in this area of high ground. Overall, the narrow organic deposits are about as abundant as the bedrock exposures.

The Wapesi Lake batholith is largely covered by overburden. Terrain analysis carried out as part of the desktop geoscientific preliminary assessment of the Ear Falls area (JDMA, 2013) indicates that approximately 18% of the surface of the Wapesi Lake batholith consists of exposed bedrock or bedrock with only a thin veneer of Quaternary sediments.

In addition to the intrusive bodies described above, the Ear Falls area contains a number of smaller intrusions, including: the Pakwash Lake pluton, the McKenzie Bay stock, and a number of small unnamed bodies intruded into the gneissic metasedimentary rocks of the English River Subprovince. These intrusions are covered to varying degrees by overburden ranging from near complete overburden cover (Pakwash Lake pluton) to extensive bedrock exposure some of the small stocks intruding the gneissic metasedimentary rocks (JDMA, 2013). In the southwestern portion of the Ear Falls area there are also granitic intrusions of the Winnipeg River Subprovince (Figure 3.5) having approximately 30% mapped bedrock terrain.

3.2.3 Lineament Investigation

A lineament investigation was conducted for the Ear Falls area using multiple datasets that included satellite imagery (SPOT and LandSAT), digital elevation model data (CDED) and geophysical (aeromagnetic) survey data (SRK, 2013). The lineament investigation identified interpreted brittle (including brittle-ductile) structures in the Ear Falls area, and evaluated their relative timing relationships within the context of the local and regional geological setting. No dykes were identified by the lineament investigation in the Ear Falls area. A detailed analysis of interpreted lineaments is provided by SRK (2013) and key aspects of the lineament investigation are summarized in this section.

For each dataset, brittle lineaments were interpreted by two independent experts using a number of attributes, including certainty and reproducibility (SRK, 2013). The certainty attribute describes the clarity of the lineament within each dataset based on the expert judgement and experience of the interpreter (i.e., with what certainty a feature is interpreted as a lineament). Reproducibility was assessed in two stages (RA_1 and RA_2). Reproducibility assessment RA_1 reflects the coincidence between lineaments interpreted by the two experts. Reproducibility assessment RA_2 reflects the coincidence of interpreted lineaments between the various different datasets used.

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

- **Ductile lineaments**: Features which were interpreted as being associated with the internal fabric of the rock units (including sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation) were classified as ductile lineaments. This category also includes recognizable penetrative shear zone fabric. These features are included to provide context to our understanding of the tectonic history of the Ear Falls area, but were not included in the merged lineament sets or statistical analyses.
- **Brittle lineaments**: Features interpreted as fractures (joints or joint sets, faults or fault zones, and veins or vein sets), including those that offset the continuity of the ductile fabric described above, were classified as brittle lineaments. This category also includes brittle-ductile shear zones, and brittle partings interpreted to represent discontinuous re-activation parallel to the ductile fabric. At the desktop stage of the investigation, this category also includes features of unknown affinity. This category does not include interpreted dykes, which are classified separately (described below).
- **Dyke lineaments**: For this preliminary desktop interpretation, any features which were interpreted, on the basis of their distinct character, e.g., scale and composition of fracture in-fill, orientation, geophysical signature and topographic expression to be dykes were classified as dyke lineaments. Dyke interpretation is largely made using the aeromagnetic dataset, and is often combined with pre-existing knowledge of the bedrock geology of the Ear Falls area. No dyke lineaments were interpreted for the Ear Falls area.

The desktop interpretation of remotely-sensed datasets necessarily includes a component of uncertainty as a result of data quality, the scale of Ear Falls area, expert judgement, the quality of the pre-existing knowledge of the bedrock geology of the Ear Falls area, and the absence of site reconnaissance to “ground truth” tentative hypotheses. Therefore the ductile or brittle categorization of each identified feature, as described herein, is preliminary, and would need to be confirmed during future stages of the site evaluation process.

The SPOT and CDED datasets (Figures 2.1 and 2.2, respectively) were used to identify surficial lineaments expressed in the topography, drainage and vegetation. The SPOT dataset has a uniform resolution of 10 m (panchromatic) and 20 m (multispectral) over the entire Ear Falls area (JDMA, 2013; SRK, 2013). Colour LandSAT imagery was used in combination with the panchromatic SPOT imagery to improve textural contrast. The CDED dataset is at a 1:50,000 scale, with a uniform 20 m resolution over the entire Ear Falls area (JDMA, 2013; SRK, 2013). The resolution of the SPOT and CDED datasets allowed for the identification of surficial lineaments as short as a few hundred metres in length and provided sufficient detail to reveal surficial structural patterns (SRK, 2013). Aeromagnetic datasets (Figures 3.7 and 3.8) were used to identify linear geophysical anomalies indicative of bedrock structures. Regional low resolution data (at 800 m line spacing) is available for the entire Ear Falls area (Figure 1.2). High resolution data (200 m line spacing) is limited to three private aeromagnetic surveys: the Goldpines South Property survey (Laurentian Goldfields Ltd., 2010) centred over Pakwash Lake, and two smaller surveys (Fronteer Development Group Inc., 2004; Grandcru Resources Corp., 2005) along the northern fringe of the Ear Falls area (Figure 1.2). The high resolution geophysical coverage allowed for the identification of geophysical lineaments on the order of 500 m or more in length, while the regional geophysical coverage limited the resolution of geophysical lineaments to features generally on the order of 5 km or more in length.

Figure 3.10 shows the RA_1 surficial lineament interpretation for both SPOT/LandSAT and CDED combined, distinguished on the basis of length. The SPOT dataset yielded a total of 702 surficial lineaments, ranging in length from <1 to approximately 70 km, with a geometric mean length of 4.1 km and a median length of 3.9 km. The CDED dataset yielded a total of 556 lineaments, ranging from <1 to approximately 70 km long with a geometric mean length of 6.5 km and a median length of 6.2 km. The density and distribution of surficial lineaments was seen to be influenced by the extensive (about 75%) overburden/water coverage in the area (Figure 2.3), which masked and truncated the surface continuity of some lineaments. This is particularly evident in the north-central part of the Ear Falls area, where thick overburden cover dominates and the density of surficial lineaments is low. Both the SPOT and CDED datasets offered advantages to characterize the surficial lineaments. The higher resolution of the SPOT imagery, with the LandSAT imagery used as a transparent overlay, allowed for finer structures to be identified that were not resolved by the CDED data, but the CDED data often revealed subtle topographic trends masked by surficial cover and textural contrast in the SPOT imagery.

The aeromagnetic dataset yielded a total of 404 lineaments from the RA_1 interpretation (Figure 3.11), all of which were interpreted as brittle (including brittle-ductile) structures (i.e., fractures), and are distinguished on the basis of length. No dykes were interpreted from the aeromagnetic data for the Ear Falls area. The length of the geophysical lineaments ranges from <1 to 68.8 km, with a geometric mean length of 5.3 km and a median length of 5.4 km. The density and distribution of geophysical lineaments is influenced by the resolution of the geophysical coverage. The density of geophysical lineaments is higher in areas of high resolution, such as over Pakwash Lake and along the northern fringe of the Ear Falls area. Shorter lineaments could be present in areas other than those covered by high resolution aeromagnetic data, but remain undetectable due to the low resolution aeromagnetic coverage. Azimuth data, weighted by length, for the geophysical lineaments exhibit dominant east and east-northeast orientations. Other prominent orientations include minor northwest- and northeast-trends (Figure 3.11).

Aeromagnetic features interpreted as ductile lineaments (i.e., magnetic form lines) have been mapped separately and are shown on Figure 3.12. Such features are useful in identifying the stratigraphy within the gneissic belt and the degree of ductile deformation within the gneissic metasedimentary rocks of the English River Subprovince, particularly near contacts with the interpreted late-stage granitic intrusions. These form lines also trace potential structures within some of the intrusions – particularly the Bluffy Lake batholith and Bruce Lake pluton which show east-west tending linear trends. It should be noted, however, that the density of these features is strongly influenced by the resolution of the geophysical data. A comparison of the brittle (Figure 3.11) and ductile (Figure 3.12) features identified from the aeromagnetic dataset shows that both interpretations highlight an overall east-trending structural grain in the bedrock. The coincidence is greatest in close proximity to the east-trending Sydney Lake fault zone; however, the relationship is evident, in general, across the entire Ear Falls area.

The geophysical lineament data has advantages over surficial lineament data in that it is minimally affected by overburden cover, which may partially or completely mask surficial lineaments. Importantly, aeromagnetic data allows interpretation of lineaments from the surface to potentially great depths. Figure 3.13 shows the distribution of merged surficial and geophysical brittle (including brittle-ductile) lineaments interpreted for the Ear Falls area, classified by length. The merged lineament dataset contains a total of 1,175 lineaments that range in length from <1 to about 70 km. The geometric mean length of these lineaments is 4.0 km and the median length is 3.9 km. There were two dominant lineament trends observed in the merged lineament dataset based on length-weighted frequency, they are east-northeast and east-trending lineaments with minor northwest, north, and northeast trends (Figure 3.13). Lineament orientation trends for the individual geological units in the Ear Falls area (i.e., the gneissic metasedimentary rocks, the Bluffy Lake batholith, Bruce Lake pluton, Long Legged Lake dome, Wapesi batholith and the Winnipeg River plutons) are presented on Figure 3.14 and further discussed in the geologic formation-specific subsections below. It should be noted that the rose diagrams are weighted by lineament length, and thus, these orientations are influenced by longer lineaments. Lineaments longer than 10 km, and lineaments from 5 to 10 km in length, represent 18% and 22% of the merged lineaments, respectively, while lineaments from 1 to 5 km long and less than 1 km long represent 52% and 8% of the merged lineaments, respectively.

SRK (2013) noted the following main trends in the final merged lineament dataset:

- Longer lineaments generally have a higher certainty and reproducibility; and
- There is similar coincidence between surficial lineaments identified in both CDED and SPOT datasets (26.8% of the total merged lineaments are interpreted from both CDED and SPOT) and between geophysical lineaments and surficial lineaments (14.6% of the total merged lineaments are observed in geophysical data and at least one of the surficial datasets).

In order to gain insight into the influence of various lineament lengths on lineament density, Figures 3.15 to 3.18 illustrate how lineament density varies across the Ear Falls area when lineaments are progressively “filtered” by length (i.e., plots showing only lineaments >1 km, >5 km and >10 km and the corresponding “filtered” lineament density). The density plots with lineament lengths filtered are presented to allow one to more clearly see the longer lineaments. The figures show that filtering out the shorter lineaments greatly increases the spacing between lineaments, including within those areas having a high percentage of exposed bedrock and high resolution aeromagnetic data. For example, Figure 3.18 shows that the gnessic metasedimentary rocks contains relatively low density of lineaments that are longer than 10 km, leaving large volumes of rock between interpreted long lineaments.

Figure 3.19 shows the combined datasets (i.e., mapped regional faults, brittle lineaments and ductile features) which helps provide a structural understanding of the Ear Falls area. Mapped faults in the Ear Falls area include the regionally extensive Sydney Lake fault zone and the Long Legged Lake fault zone, which both have coincident interpreted geophysical lineaments. Coincidence of these fault zones with surficial lineaments is not obvious, likely because these mapped faults are interpreted to have originated as ductile to ductile-brittle features with later reactivation in the brittle regime (Stone, 1981), and their early phases pre-date the structural fabric defined by the brittle lineament sets observed in the satellite imagery and CDED. It is probable that the regional mapped faults have undergone multiple episodes of brittle reactivation caused by the same stress conditions that gave rise to some of the identified brittle lineaments.

The following subsections describe the characteristics of the interpreted lineaments for each of the main lithological units/areas, as well as an interpretation of the relative age of the lineaments identified in the Ear Falls area.

3.2.3.1 English River Gneissic Metasedimentary Rocks

A total of approximately 800 lineaments were mapped across the English River gneissic belt in the Ear Falls area (Figure 3.13). Many of the longer lineaments extend beyond the metasedimentary rocks into the plutonic rocks. Overall, lineament density is relatively low compared to intrusions such as the Wenasaga Lake batholith, Long Legged Lake dome and Bluffy Lake batholith (Figure 3.13).

Figure 3.10 shows the surficial lineament distribution over the gneissic metasedimentary rocks. These lineaments range in length from approximately 1 to >35 km. The surficial lineament density is variable across the gneissic metasedimentary rocks, likely reflecting differing overburden cover across the gneissic belt. Higher surficial lineament densities generally coincide with areas of good outcrop exposure, where interpreted surficial lineament spacings are typically in the range of 0.5 to >3 km.

Figure 3.11 shows the geophysical lineament distribution of the gneissic metasedimentary rocks. The geophysical lineaments range in length from <1 to 68.8 km, with a geometric mean length of 5.5 km and a median length of 5.7 km. The generally low density of geophysical lineaments across the gneissic belt likely reflects the low resolution aeromagnetic dataset available for most of the gneissic metasedimentary rocks, and the low regional magnetic susceptibility of metasedimentary migmatites (Breaks, 1991). The geophysical lineament density is markedly higher in the area south of Pakwash Lake where higher resolution aeromagnetic coverage is available from Laurentian Goldfields Ltd. (Figure 3.11). This high resolution aeromagnetic coverage shows linear magnetic features that appear to reflect gneissic banding along with cross-cutting features having a strong northwesterly orientation and a subsidiary orientation to the northeast. Geophysical lineament spacing in the high resolution coverage area is generally on the order of 1 to 3 km.

Little information is available regarding brittle fracturing (e.g., jointing) on an outcrop scale within the gneissic metasedimentary rocks of the English River Subprovince. However, Gabriel (Kenora Granite Company Limited, 2000) describes a sparsely fractured 0.8 ha outcrop of pegmatitic rock south of Cramp Lake (14 km northeast of the settlement area of Ear Falls) as quartz-feldspar pegmatite with a mottled yellow-white colour and having horizontal joints spaced 2.5 to 3 m apart. Laurentian Goldfields Ltd. (2010) also excavated a trench in the gneissic metasedimentary rocks of the English River Subprovince in the Ear Falls area, north of the Sydney Lake fault zone and west of Pakwash Lake. The trench revealed sparsely-fractured, folded metasedimentary rocks having a strong foliation and intruded by thin lenses/dykes of amphibolites, pegmatitic tonalite and medium-grained equigranular tonalite.

Orientation data for the gneissic metasedimentary rocks (Figure 3.14) exhibit dominant east-northeast and east-trending lineaments with minor northwest, north and northeast trends.

3.2.3.2 Wenasaga Lake Batholith

A total of 50 lineaments were mapped over the Wenasaga Lake batholith (Figure 3.13). Many of the long interpreted lineaments extend beyond the batholith into the gneissic metasedimentary rocks of the English River Subprovince.

Interpreted surficial lineaments (Figure 3.10) range in length from approximately 1.5 to 23 km, with dominant orientations of northeast and northwest. The surficial lineament density is moderate to high across the batholith even though overburden cover is extensive over most of the batholith. Surficial lineaments are spaced approximately 1 to 3 km apart.

Figure 3.11 shows the geophysical lineament distribution over the Wenasaga Lake batholith. These lineaments range in length from 8 to 32 km. The geophysical lineament density is generally low, with geophysical lineaments identified primarily along only the northern and southern margins of the batholith, where they follow a northeasterly trend paralleling the Sydney Lake fault zone and the general lithotectonic fabric of the area.

3.2.3.3 Bruce Lake Pluton

A total of 45 interpreted lineaments were mapped over the Bruce Lake pluton. Many of the long interpreted lineaments extend beyond the pluton into the metavolcanic rocks of the Birch-Uchi greenstone belt.

Figure 3.10 shows the surficial lineament distribution over the Bruce Lake pluton. These lineaments range in length from approximately 2 to 30 km. The surficial lineament density is very low over the Bruce Lake pluton, likely due to the extensive overburden cover over most of the pluton.

Figure 3.11 shows the geophysical lineament distribution over the Bruce Lake pluton. These lineaments range in length from 4 to >50 km. The geophysical lineament density is very low in the western half of the pluton, and low to moderate in the eastern half. The aeromagnetic data resolution is higher in the western half of the pluton, where fewer geophysical lineaments were interpreted, suggesting that the low lineament density is not a result of poor survey resolution. The dominant orientation of the lineaments in the Bruce Lake pluton is north-east trending, with variably-oriented features also interpreted.

3.2.3.4 Bluffy Lake Batholith

A total of 161 lineaments were mapped over the 324 km^2 of the Bluffy Lake batholith within the Ear Falls area. Many of the long interpreted lineaments extend beyond the batholith into the gneissic metasedimentary rocks of the English River Subprovince.

Figure 3.10 shows the surficial lineament distribution over the Bluffy Lake batholith. These lineaments range in length from <1 to 36.9 km and appear to include at least three orientations northeast, north-northeast, and north-

northwest within the Bluffy Lake batholith. Spacing of the interpreted surficial lineaments is variable, ranging from approximately 0.5 to 2 km. The surficial lineament density is moderate across the batholiths, likely due to the extensive bedrock exposure of the batholith in the Ear Falls area.

Figure 3.11 shows the geophysical lineament distribution over the Bluffy Lake batholith. These lineaments range in length from approximately 6 km to more than 20 km. The geophysical lineament density is moderate over the batholith, and shows a higher density than is observed in the gneissic metasedimentary rocks of the English River Subprovince. The dominant orientation of the geophysical lineaments is east-trending, and geophysical lineament spacings are approximately 1 to 7 km. This relatively wide spacing may reflect the low resolution of the aeromagnetic coverage over the Bluffy Lake batholith in the Ear Falls area (Figure 3.11).

3.2.3.5 Wapesi Lake Batholith

A total of 23 lineaments were mapped within the small portion of the Wapesi Lake batholith included within the Ear Falls area (Figure 3.13). Many of the long interpreted lineaments extend beyond the batholith into the gneissic metasedimentary rocks of the English River Subprovince.

Figure 3.10 shows the surficial lineament distribution over the Wapesi Lake batholith. These lineaments range in length from approximately 0.77 to more than 45 km, and are spaced up to 5 km apart. The surficial lineament density is generally low across the portion of the Wapesi Lake batholith in the Ear Falls area, likely due to the extensive overburden cover over most of the area.

Figure 3.11 shows the geophysical lineament distribution over the Wapesi Lake batholith. These lineaments range in length from 6 to 35 km with most of their length attributed to the extension of the lineaments beyond the batholith boundaries. The geophysical lineament density is very low over the portion of the Wapesi Lake batholith in the Ear Falls area, with only three geophysical lineaments identified. This may reflect the low resolution aeromagnetic coverage over this portion of the batholith.

3.2.3.6 Minor Intrusions

In addition to the intrusive bodies described above, the Ear Falls area contains a number of smaller intrusions, including: the Pakwash Lake pluton, the eastern extension of the Long Legged Lake dome, the McKenzie Bay stock, and a number of small unnamed bodies intruded into the gneissic metasedimentary rocks of the English River Subprovince. In the southwestern portion of the Ear Falls area there are also granitic intrusions of the Winnipeg River Subprovince (Figure 3.5).

A total of 10 lineaments were identified on the Pakwash Lake pluton, which covers an area of 32 km^2 (Figure 3.13). The interpreted lineaments range in length from 1.5 to approximately 20 km, with dominant trends to the northeast and northwest as shown on Figure 3.14. Lineament density over this small pluton is relatively low, likely due to the extensive overburden and lake cover.

The eastern extension of the Long Legged Lake dome and its bordering tonalite units covers approximately 220 km^2 in the northwestern corner of the Ear Falls area, where 100 lineaments were mapped (Figure 3.13). The lineaments range in length from <1 to more than 30 km. Dominant orientations are east-northeast with subsidiary orientations to the northwest and north-northeast (Figure 3.14).

Intrusions of the Winnipeg River Subprovince occur in the southwestern corner of the Ear Falls area and collectively cover approximately 101 km^2 of the Ear Falls area. A total of 109 lineaments were mapped over these intrusions. Many of the long interpreted lineaments extend beyond the intrusions into the gneissic metasedimentary rocks of the English River Subprovince. Figure 3.10 shows the surficial lineament distribution over the intrusions. These lineaments range in length from <1 to nearly 60 km. Dominant trends are to the northeast, east and northwest, with a small number of north-trending structures. Surficial lineament density is moderately high over these intrusions, even though there is significant overburden cover (Figure 3.10). Surface lineament spacing is variable ranging from about 0.5 to approximately 2 km. Figure 3.11 shows the geophysical lineament distribution over the intrusions. These lineaments range in length from 8 to 58 km. The geophysical lineament density is low in this area, likely reflecting the low resolution of the available aeromagnetic data. Geophysical lineaments exhibit the same orientations as the surface lineaments (Figure 3.11).

Numerous east-west trending lineaments were observed within the Birch-Uchi greenstone belt (Figures 3.10 and 3.11). Many of these are concordant or subconcordant to stratigraphy but some may reflect the presence of shearing within the greenstone belt as the stratigraphy generally parallels the regional east-trend followed by the regional Sydney Lake and Long Legged Lake shear zones. Cross-cutting lineaments are prevalent in the surface lineaments and occur in two general trends, north-northeast (paralleling some of the minor mapped faults in this area) and northwest (Figure 3.10).

3.2.3.7 Relative Age Relationships of Lineaments

The identified surficial lineaments in the Ear Falls area are interpreted to represent cross-cutting brittle (including brittle-ductile) deformation features (Figure 3.10; SRK, 2013). Their formation is attributed to deformation processes associated with three episodes (D_4 to D_6) of regional deformation as described in Section 3.1.3. At the desktop stage of preliminary assessment, it is still uncertain whether or not each interpreted lineament is in fact an actual brittle geological feature, or whether or not it has significant expression at depth. Nor are the three dimensional orientations of such features discernible at the desktop stage, and shallow dipping features cannot reliably be differentiated from steeply dipping features. The interpreted geophysical lineaments are less affected by overburden cover and more likely represent bedrock features across the whole of the Ear Falls area (Figure 3.11) although their utility is substantially reduced by the coarse resolution of the regional aeromagnetic coverage over most of the Ear Falls area. At this stage of assessment, it is generally not possible to conclusively assign a particular geophysical lineament to the ductile or brittle regime and many observed geophysical lineaments will likely prove to be transitional with both brittle and ductile components.

The geophysical lineament interpretation (Figure 3.11) yields four lineament sets oriented east-northeast and east-southeast with subsidiary orientations to the northwest and northeast. Examination of the surficial and geophysical lineament interpretation indicates that there are no obvious and consistent cross-cutting relationships between the different sets (Figure 3.13).

The principal lineament orientation in the Ear Falls area is east-west generally following the gneissic fabric of the English River Subprovince. Secondary orientations are predominantly oriented to the northwest and northeast. These orientations reflect a lengthy and complex tectonic history spanning a period of more than one billion years. Transient (on the scale of geological time) stress conditions at different points in the geological history of the Ear Falls area gave rise to particular sets of lineament orientations along with their conjugate sets, with subsequent reactivation and the formation of new brittle fracture sets occurring in response to various orogenic events through the Proterozoic Eon. The assignment of relative age to particular lineament sets is generally not supportable at this desktop stage of assessment.

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

The Ear Falls area lies within the Superior Province of the Canadian Shield, where large parts have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). Figure 3.20 presents the location of earthquakes with a magnitude of 3 or greater that are known to have occurred in Canada from 1627 until 2010; no seismic events exceeding a magnitude m_N of 6 are recorded within 1,000 km of the Ear Falls area. Although Hayek et al. (2011) indicate that the general Western Superior Province has experienced a number of low magnitude, shallow seismic events (generally 5 km focal depth), all recorded earthquakes in the region since 1985 have had a Nutti magnitude m_N of less than 4. Figure 3.21 shows the locations and magnitudes of seismic events recorded in the National Earthquake Database (NEDB) for the period between 1985 and 2011 in the Ear Falls area (NRCan, 2012). Over this time period, all recorded seismic events in the area had magnitudes m_N ranging from less than 1 to 3.

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

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

3.3.2 Neotectonic Activity

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

The movement and interaction of tectonic plates creates horizontal stresses that result in the compression of crustal rocks. The mean of the current major horizontal stress orientation in central North America, based on the World Stress Map (Heidbach et al., 2009), is northeast (63° ± 28°). This orientation coincides roughly with both the absolute and relative plate motions of North America (Zoback, 1992; Baird and McKinnon, 2007), and is controlled by the present tectonic configuration of the North Atlantic spreading ridge (Sbar and Sykes, 1973), which has likely persisted since the most recent Paleocene-Eocene plate reorganization (Rona and Richardson, 1978; Gordon and Jurdy, 1986).

The geology of the Ear Falls area is typical of many areas of the Canadian Shield that have been subjected to numerous glacial cycles during the last million years. Continental scale tectonic movements are therefore overprinted by post-glacial isostasy in the northern portion of the North America plate. During the maximum extent of the Wisconsinan glaciation, approximately 21,000 years ago (Barnett, 1992), the Earth's crust was depressed by more than 300 m in the area bordering Hudson Bay based on an analysis of beach strands by Hillaire-Marcel (1976) – an estimate in general agreement with Brevic and Reid (1999), who estimated a total crustal depression of 340 m in the Minnesota/North Dakota area. The amount of crustal depression in the Ear

Falls area would be of a somewhat greater magnitude than that of the Minnesota/North Dakota area due to its closer proximity to the main centre of glaciation located over Hudson Bay.

Post-glacial isostatic rebound began with the waning of the continental ice sheets and is still occurring across most of Ontario. Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella et al., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1-2 mm/yr) south of the Great Lakes. The ‘‘hinge line’’ separating uplift from subsidence is consistent with data from water level gauges along the Great Lakes, showing uplift along the northern shores and subsidence along the southern ones (Mainville and Craymer, 2005). The vertical velocity contours developed from the lake water level datasets compared well with the postglacial rebound models, which in turn indicated that present day rebound rates in the Ear Falls area should be well below 10 mm/yr, likely between 2 and 4 mm/yr. As a result of the glacial unloading, principal stress magnitudes and orientations are changed. Seismic events could be associated with these post-glacial stress changes as a result of reactivation of existing fracture zones. In addition, natural stress release features can include elongated compressional ridges or pop-ups such as those described by McFall (1993) and Karrow and White (2002).

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

Under the appropriate conditions, glaciolacustrine deposits may preserve neotectonic features indicative of paleo-seismic activity (JDMA, 2013). Existence of such features can be used to extend the seismic record for a region well into the past. As shown on Figure 2.3, glaciolacustrine terrain in the Ear Falls area is generally located between Lac Seul and Pakwash Lake, along the English River and toward the southwest. Some road and water access is available to these regions, which may allow for the investigation of the presence of neotectonic features.

4.0 HYDROGEOLOGY AND HYDRGEOCHEMISRTY

4.1 Groundwater Use

Information concerning groundwater in the Ear Falls area was obtained from the Ontario Ministry of the Environment (MOE) Water Well Record (WWR) database (MOE, 2012). The locations of known water wells are shown on Figure 4.1. There are relatively few wells recorded in the Township of Ear Falls, since the Township obtains water from the municipal service that obtains its water from the English River. A number of scattered wells serving individual private residences exist mostly along Highway 105 and Separation Lake Road.

Water wells in the Ear Falls area obtain water from overburden or shallow bedrock aquifers. The shallow bedrock aquifer is the primary source of exploitable groundwater, while overburden basal sand and gravel deposits, where present, are also used as a groundwater source. The MOE WWR database contains a total of 56 water well records containing useable information[1] for the Ear Falls area. A summary of these wells is provided in Table 4.1.

Table 4.1: Water Well Record Summary for the Ear Falls Area

Water Well Type	Number of Wells	Total Well Depth (m)	Median Well Depth (m)	Static Water Level (mbgs)	Tested Well Yield (L/min)	Depth to Top of Bedrock (m)
Overburden	27	2.5 to 41	17.3	0 to 15	4.5 to 450	N/A
Bedrock	33	11 to 134	39.6	0 to 24	4.5 to 136	0 to 41

N/A = not applicable

4.2 Overburden Aquifers

There are 27 water well records in the Ear Falls area that can be confidently assigned to the overburden aquifer. These wells generally are 2.5 to 41 m deep and have pumping rates of 4.5 to 450 L/min. These values reflect the purpose of the wells (private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from the aquifers.

Water well records indicate that sand or sand/gravel overburden aquifers are present along the Lac Seul Moraine and along Highway 105 and Separation Lake Road (Figure 4.1). The Lac Seul Moraine is the most readily mapped overburden aquifer in the Ear Falls area.

The limited number of well records and their concentration along the main roadways limits the available information regarding the extent and characteristics of the overburden aquifers in the Ear Falls area. However, as several of these water wells are located within glaciofluvial terrain, it is likely that similar terrain mapped in the Ear Falls area (Figure 2.3) will also host shallow overburden aquifers.

4.3 Bedrock Aquifers

No information was found on deep bedrock groundwater conditions in the Ear Falls area at a typical repository depth of approximately 500 m. In the Ear Falls area there are 33 well records that can be confidently assigned to the shallow bedrock aquifer. These wells range from 11 to 134 m in depth, with most wells between 30 to

[1] Wells having no depth or stratigraphic information are excluded.

40 m deep. Measured pumping rates in these wells are variable and range from 4.5 to 136 L/min with yields typically between 30 to 40 L/min. These values reflect the purpose of the wells (private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from the aquifers. Long-term groundwater yield in fractured bedrock will depend on the number and size of fractures, their connectivity, transmissivity, storage and on the recharge properties of the fracture network in the wider aquifer.

The MOE WWRs indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Ear Falls area or anywhere else in northern Ontario.

4.4 Regional Groundwater Flow

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

On a regional scale, shallow (i.e., within approximately the upper 100 m of overburden and fractured bedrock) groundwater flow across the Ear Falls area can be expected to mimic surface water flow systems, with groundwater divides coinciding with drainage divides and discharge occurring into topographic lows. Within each of the tertiary-scale watersheds (Figure 2.5), local topography and terrain conditions will influence the distribution and nature of smaller-scale, localized, groundwater low systems. Recharge patterns are influenced by topography and geological conditions, with the highest rates generally occurring in elevated areas underlain by permeable sand or gravel deposits (e.g., the Lac Seul moraine) or by fractured bedrock in areas where it is exposed or covered by thin overburden. Lowland areas, especially wetlands, store substantial amounts of water and may act alternately as discharge and recharge areas according to seasonal variations.

No information was found in the available literature regarding groundwater recharge rates and temporal patterns in the Ear Falls area. However it is expected to be typical for the Canadian Shield region with elevated recharge in spring and fall, reduced recharge in late summer, and essentially no recharge during frozen winter conditions. Rivard et al. (2009) analyzed trends in groundwater levels and surface water baseflow over the past 50 years throughout Canada. This analysis found no significant temporal trend with respect to long-term changes in surface water drainage and a stable to slight downward trend with respect to regional groundwater trends in northwestern Ontario. Deeper into the bedrock, fracture frequency in a mass of rock will tend to decline, and eventually, the movement of ions will be diffusion-dominated. However, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion-controlled conditions. As such, in the Ear Falls area, it can be expected that features such as deeply penetrating fracture systems will be important in the deep groundwater flow system. The potential effect of such systems would need to be investigated in further stages of the site evaluation process.

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

The orientation of fracture networks relative to the orientation of the maximum horizontal compressive stress may also influence permeability. In this case, a lower effective hydraulic conductivity would be predicted for fractures oriented at a high angle to the maximum compressive stress axis compared to otherwise identical low angle fractures. Horizontal stress measurements from various locations in the Canadian Shield (Kaiser and Maloney, 2005; Maloney et al., 2006) indicate that the axis of maximum horizontal stress is oriented predominantly in the west-southwest direction. This is generally consistent with the World Stress Map; however, anomalous stress orientations are known to exist in a small portion of the northwest Superior Province that includes the Ear Falls area (Brown et al., 1995). A 90° change in azimuth of the maximum compressive stress axis was identified in the near surface in the Whiteshell area of Manitoba (Brown et al., 1995) while a roughly north-south orientation of maximum horizontal compressive stress was found for the Sioux Falls quartzite in South Dakota (Haimson, 1990). In view of the general paucity of data and the anomalous stress orientations in mid-continent, caution is warranted in extrapolating a west-southwest stress orientation to the Ear Falls area without site-specific data. The exact nature of deep groundwater flow systems in the Ear Falls area will need to be evaluated at later stages of the assessment, through the collection of site-specific information, provided the community is selected by the NWMO, and remains interested in continuing with the site selection process.

4.5 Hydrogeochemistry

No information on groundwater hydrogeochemistry was found for the Ear Falls area. Existing literature, however, has shown that groundwater within the Canadian Shield can be subdivided into two main hydrogeochemical regimes: a shallow, generally fresh water flow system, and a deep, typically saline water flow system (Gascoyne, 2004).

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

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

Site-specific conditions will influence the depth of transition from advective to diffusion-dominated flow, which may occur at a depth other than the typical 300 m reported by Gascoyne et al. (1987). Such conditions would need to be evaluated at later stages of the assessment, via site-specific studies.

5.0 NATURAL RESOURCES — ECONOMIC GEOLOGY

Information regarding the mineral resource potential for the Ear Falls area was obtained from a variety of sources including general syntheses of mineralization in the Canadian Shield Region (Fyon et al., 1992; Breaks and Bond, 1993), studies within the Ear Falls area (Shklanka, 1968; Breaks et al., 1975 and 1976; Breaks and Bond, 1993), economic geology studies and reports such as Vos et al. (1982), Storey (1986), Gerow and Bellinger (1990), Breaks (1993), Hinz et al. (1994), Farrow (1996) and Vaillancourt et al. (2003), as well as MNDM Mineral Deposit Inventories (MDI) and Assessment Files (AFRI), and publications by the mining industry.

Metallic mineral potential in the Ear Falls area is mainly associated to rocks of the Birch-Uchi greenstone belt, where base metal and gold occurrences are currently being explored. The potential of these rocks to host economical metallic mineralization has been proven in the past north of the Ear Falls area. Exploration for gold is also ongoing in the gneissic metasedimentary rocks along the Sydney Lake fault zone, and potential for iron deposits exists locally within these rocks; however, the economic mineral potential is considered low within the majority of the gneissic belt. The mineral potential of the major felsic intrusions in the Ear Falls area is low. Figure 5.1 shows the areas of current exploration interest based on active mining claims, as well as known mineral occurrences identified in the OGS's Mineral Deposit Inventory Version 2 (OGS, 2004).

5.1 Metallic Mineral Resources

There are currently no producing mines in the Ear Falls area. However approximately 75 million tonnes of iron ore were extracted from the past-producing Griffith Iron Mine, as described below. No other mineral production is known to have occurred in the Ear Falls area to date. Several mineral occurrences have been identified in the Ear Falls area and exploration activities have taken place in the past and continue today. Potential metallic mineralization in the Ear Falls area includes: iron, base metals, gold, rare metals and rare earth elements.

Base Metals

No base metal deposits, prospects or occurrences are known in the Ear Falls area, although potential for such metallic resources has been proven in the Birch-Uchi greenstone belt immediately north of the Ear Falls area.

Volcanogenic massive sulphide deposits (VMS) were mined at the South Bay Mine, about 55 km northeast of the Township of Ear Falls, and numerous base metal occurrences have been recognized in these metavolcanic rocks. The closest recorded base metal mineral occurrences to the Township of Ear Falls are approximately 10 km north and northwest of its northernmost boundary (Figure 5.1). Exploration is currently ongoing at these locations (see active mining claims on Figure 5.1).

Gold

In the Ear Falls area, potential for gold mineralization is mostly associated with the metavolcanic rocks of the Birch-Uchi greenstone belt. A number of gold occurrences have been identified and are currently being explored by Grandview Gold Inc. in metavolcanic rocks in the extreme northwest corner of the Ear Falls area, about 10 km northwest of the Township, in the Dixie Lake area (Figure 5.1). The type of deposit being explored in this area is similar to those found in the mines of the Red Lake camp (Grandview Gold Inc., 2012). The Red Lake camp, more than 30 km northwest of the Township, hosts one of the country's best known gold mining districts with more than 18 mines having produced nearly 25 million troy ounces of gold since the initial discovery of gold in the area in the 1920s.

Potential for gold mineralization in the gneissic metasedimentary rocks of the English River Subprovince is currently being explored by Laurentian Goldfields Ltd., which holds a large claim along the boundary between the Uchi and English River subprovinces totalling 567 km^2 (Figure 5.1). The company is exploring the source of a large gold-arsenic-antimony geochemical anomaly traced along the Sydney Lake fault zone and a small late tectonic granitic intrusion. The anomaly extends along an east-west trend over a distance of approximately 8 km. In 2012, Laurentian Goldfields Ltd. carried out exploratory drilling on three of seven widely spaced gold-in-soil geochemical targets within the "Goldpines South" prospect. The 972 metre drill program failed to intersect significant gold mineralization but did encounter iron sulphides and weak chloritic and potassic alteration. Further drill testing of geochemical anomalies is planned (Laurentian Goldfields Ltd., 2012).

A gold occurrence is recorded in the Laurentian Goldfield Ltd.'s claims, within the metasedimentary rocks to the west of the Township of Ear Falls near the Chukuni River (MDI Number: MDI52N04SE00020). This occurrence was discovered in 1946 along the south side of the Sydney Lake fault zone within what were described as basaltic flows, which have been locally sheared with stringers of quartz. The shears strike N50W to N60W and dip 55S to 60S and contain up to 2 g/tonne of gold over widths of approximately 1.5 m.

Iron

Iron deposits hosted within the gneissic metasedimentary rocks at the edge of the Bruce Lake pluton were in the past mined at the Griffith Iron Mine, in the northern portion of Township of Ear Falls (Figure 5.1). The Griffith Iron Mine was first explored in the early 1920s. In 1965, a 75-year lease was taken on the property by the Steel Company of Canada Inc. (Stelco), now U.S. Steel Canada. Plant construction and development of the open pit mine began in January of 1966 and operation commenced by February of 1968. When in full production, the Griffith Iron Mine produced about 1.5 million tonnes of pellets annually, with an iron content of 66.4% (Kiex Consulting Limited, 2011).

Between 1968 and 1986, approximately 75 million tonnes of iron ore were produced over the 18 year mine life. The mine closed because of deteriorating economics rather than exhaustion of ore. Remaining reserves are reported to be in the order of 100 million tonnes. Northern Iron Corporation currently holds an option on the former mine and has planned diamond drilling to better define the remaining reserves (Kiex Consulting Limited, 2011).

Iron formations have also been mapped in the gneissic metasedimentary rocks bordering the south side of the Bruce Lake pluton to the east of the Township of Ear Falls, in the Karas Lake area between the Wenasaga Lake and Bluffy Lake batholiths, and along the north side of the Bluffy Lake batholith in the Whitemud Lake area (Figure 5.1). These iron formations are identifiable on the aeromagnetic survey for the Ear Falls area (Figures 3.7 and 3.8).

Exploratory diamond drilling was carried out in 1957 by Dome Exploration (Canada) Limited in the Karas Lake area, approximately 12 km east of the Township of Ear Falls, where an iron occurrence is recorded (Figure 5.1). The diamond drilling confirmed the presence of an iron formation (Dome Exploration (Canada) Limited, 1957), but the ore was not sufficient in grade and/or tonnage to warrant development at that time. Northern Iron Corporation currently holds claims in this area and is re-evaluating the deposit. Exploratory drilling was completed on the Karas Lake occurrence in 2010, with additional diamond drilling planned for 2012-2013 (Kiex Consulting Limited, 2011). Northern Iron Corporation is also exploring the iron mineralization in the Whitemud Lake area, north of the Bluffy Lake batholith.

Rare Metals and Rare Earths

Rare metals include Li, Rb, Cs, Be, Nb, Ta and Ga and the lanthanide elements (rare earth elements or REE) which are often associated with minerals such as spodumene, lepidolite, beryl and columbite-tantalite in highly fractionated phases of the peraluminous granite suite. The pegmatites of the English River Subprovince are genetically related to small masses of less than 10 km^2 area of chemically fractionated, peraluminous granites (Breaks and Bond, 1993).

Despite some exploration activity over the years, no economic deposits of rare metals have been identified within the Ear Falls area. Rare metals are discussed here under “metallic” mineral resources although they also include non-metals such as the Sandy Creek beryl occurrence located adjacent to the southwestern flank of the Wenasaga Lake batholith (Breaks et al., 2003). Rare metal pegmatites have a diverse mineralogy and chemistry and correspond to beryl, albite spodumene, and complex spodumene types (Breaks, 1991).

Uranium

No deposits, prospects or occurrences of uranium have been identified in the Ear Falls area. The closest uranium occurrence is approximately 35 km south of the Township of Ear Falls, in the Aerobus Lake area (Figure 5.1). Initial uranium exploration in this area dates back to 1955, when nine diamond drillholes intersected mineralized rock. Uranium in this area is associated with a quartz diorite hosted by migmatitic metasedimentary rocks (Breaks et al., 1975). Currently, Delta Uranium Inc. holds exploration land claims over the prospective area and is performing exploration activities.

Radioactive element-enriched pegmatites have been identified within the low- to medium-grade metamorphic rocks along the northern and southern boundaries of the English River Subprovince (Breaks et al., 1976; Breaks and Bond, 1993). While pegmatite-hosted uranium deposits have been historically mined in the Bancroft area (Thurston, 1991), grades in such types of deposits are usually non-economic compared to the high-grade unconformity-hosted uranium deposits that currently account for all Canadian production.

5.2 Non-Metallic Mineral Resources

Known non-metallic mineral resources in the Ear Falls area include sand and gravel, stone, peat, and the Sandy Creek beryl occurrence located in a metasedimentary hosted pegmatite south of the Wenasaga Lake batholith (Figure 5.1).

Sand, Stone and Gravel

A number of sand and gravel pits exist within the Township of Ear Falls, mostly located along the Lac Seul moraine (Figure 2.3), which contains at least 15 sand and gravel pit operations (Ford, 1983).

No rock quarrying operations are known to exist within the Ear Falls area. Storey (1986) evaluated the Ear Falls area for building and ornamental stone potential in the districts of Kenora and Rainy River, Ontario, but no suitable deposits were identified. However, Hinz et al. (1994) describe two potential dimension stone occurrences immediately adjacent to the Ear Falls area. These are the Wenasaga 8 occurrence (MDI Number: MDI52K15NE00014) approximately 10 km to the northeast of the Ear Falls area, and the McKenzie 1 occurrence (MDI Number: MDI52K10SE00001) located about 2 km to the east of the Ear Falls area along the northern flank of the Wapesi Lake batholith. The Wenasaga occurrence is described as a pinkish-brown, equigranular, medium-grained 'granite'. The mineral constituents are: orthoclase (70%), plagioclase (15%), quartz (5%) and hornblende (10%). The northern and central portions of the area mapped are described as massive, with widely spaced (>5 m) joints having two main orientations: 170 to 190 degrees and 234 degrees. Sheet joints range in thickness from 0.5 to 2.0 m. In the southern portion of the occurrence, jointing range from 048 to 050 degrees and 330 to 340 degrees with similar spacing and no observable sheeting. The McKenzie occurrence is described as a medium-grained grey stone with mineralogy dominated by orthoclase (35%), plagioclase (35%), quartz (30%), biotite (3%) and minor muscovite (1%). The exposure is sparsely fractured with orientations: 008 degrees; 022 to 036 degrees; 080 to 090 degrees; and 131 degrees. Over a 2 km section, only 11 joints were recorded.

Peat

Peat exists in low-lying portions of the Ear Falls area. In 1986, Monenco Ontario Limited, on behalf of the Ontario Geological Survey (OGS), carried out an evaluation of a number of peatlands in the Ear Falls area. Some of the examined peatlands showed potential for supporting conventional peat operations, as indicated by high quality peat and thicknesses of 2 m and greater in some areas. One of these deposits is located within the Township of Ear Falls in the area south of the former Griffith Iron Mine between Pakwash Lake and Bruce Lake (Figure 5.1). Despite the commercial potential of some of these deposits in the area, no peat extraction has occurred in the Ear Falls area (Monenco Ontario Limited, 1986).

Diamonds

The potential for the Canadian Shield to host economic diamond deposits has been demonstrated by a number of mines in the Northwest Territories, Nunavut and Ontario. However, no kimberlites or lamproites that could be diamond-bearing have been identified in the Ear Falls area.

Industrial Minerals

No industrial mineral deposits have been identified within the Ear Falls area apart from the Sandy Creek beryl occurrence located in a metasedimentary hosted pegmatite south of the Wenasaga Lake batholith (Figure 5.1). This deposit includes small pegmatite dykes over an area of approximately 20 by 60 m in an area of generally poor exposure. The main pegmatite dyke, which strikes 090° and dips from 65 to 85° to the north, is 1 to 2.5 m thick and bifurcates near its west end (Breaks et al., 2003). No information as to the depth extent of this occurrence is available, and its economic viability has not been proven to date.

5.3 Petroleum Resources

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

6.0 GEOMECHANICAL AND THERMAL PROPERTIES

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

6.1 Intact Rock Properties

Intact rock properties tabulated in Table 6.1 are based on laboratory testing of rock core specimens from boreholes from Pinawa and Atikokan. The table also includes basic rock properties such as density, porosity, uniaxial compressive strength and tensile strength for use in engineering design and structural analyses. These parameters feed into the rock mass classification schemes. No information on intact rock properties is available for the Ear Falls area. In the absence of site-specific information on the intrusions and gneissic metasedimentary rocks of the Ear Falls area, at this early stage of the site assessment process it is useful to look at the geomechanical properties of other intact crystalline rocks such as the Lac du Bonnet batholith, Eye-Dashwa pluton, Chalk River gneissic metasedimentary rocks and similar rock types elsewhere in the northwestern Superior Province. The rock property values presented in Table 6.1 are consistent with the values selected for numerical modelling studies conducted to evaluate the performance of hypothetical repository designs in a similar crystalline rock environment (SNC-Lavalin Nuclear Inc., 2011; Golder, 2012a, b).

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

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

Property	Lac du Bonnet Granite	Eye-Dashwa Granite	Chalk River Gneiss
Thermal Conductivity (W/(mK))	3.4[b]	3.3[b]	
Coef. Thermal Expansion ($x10^{-6}/^{0}C$)	6.6[b]	15[b]	NA

NA = Not Available

[a]Brisbin et al., 2005
[b]Stone et al., 1989
[c]Annor et al., 1979
[d]Eberhardt et al. 1999
[e]Thomas & Hayles 1988
[f]Gorski et al., 2009
[g]Gorski and Conlon, 2010

Site specific geotechnical assessments would need to be conducted during later stages of site evaluation process.

6.2 Rock Mass Properties

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

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

Rock mass properties for the Ear Falls area will need to be investigated at later stages of the assessment through the collection of site-specific information.

6.3 *In Situ* Stresses

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

No site-specific information is available regarding the *in situ* stress conditions within the Ear Falls area. The nearest *in situ* stress measurements were taken in metavolcanic strata at the Campbell Mine (Superior Province/Uchi Subprovince) located approximately 20 km to the north of Ear Falls. The minimum principal stress data available from the Campbell Mine yields an average value of 8 MPa, dipping at an average angle of 46° at depths ranging from 580 m to 670 m. As a check, vertical *in situ* stresses may also be estimated using the unit weight of the rock measured on intact core specimens. Assuming a rock density of 2.8 Mg/m^3, and a corresponding unit weight of 27.5 kN/m^3, the approximate magnitude of the *in situ* vertical stress at a depth of 500 m at the Campbell Mine is 14 MPa.

Horizontal stress conditions are more difficult to estimate; however, over-coring or hydraulic fracturing methods can be used to determine the stresses on a plane at depth and resolve the horizontal *in situ* stress conditions (or resolve inclined principal stresses). A large set of such horizontal stress measurements is available from various locations in the Canadian Shield (Kaiser and Maloney, 2005; Maloney et al., 2006). These data are presented on Figure 6.1. A review of the data available for the Campbell Mine area indicates that the maximum principal stress in that area is 34 MPa (on average) and oriented predominantly in the west-southwest direction. This is generally consistent with the World Stress Map (Heidbach et al., 2009). However, a significant number of measurements (4/11) indicated a maximum principal stress direction approximately 90° to the dominant trend (Maloney and Kaiser, 2005) suggesting that site-specific data are necessary to use the direction of the maximum principal horizontal stress to make predictions regarding the relative permeability of different orientations of fractures.

The observation that the stress state is neither constant nor linear (Maloney et al., 2006) suggests that variability should be expected in the Canadian Shield. Based on the available stress measurement data, Maloney et al. (2006) developed a conceptual model that describes the variable stress state in the upper 1,500 m of the Canadian Shield. The conceptual model identifies a shallow stress released zone from surface to a depth of 250 m, a transition zone from 250 to 600 m and an undisturbed stress zone below 600 m. The undisturbed stress zone can be expected to be representative of far-field boundary stress conditions whereas stresses within the shallow zone tend to be lower as they have been disturbed through exhumation and influenced by local structural weaknesses such as faults (Maloney et al., 2006). Typical repository depths of approximately 500 m fall within the transition zone, where the maximum principal stress may range from approximately 20 to 50 MPa. The data presented by Maloney et al. (2006) indicate an average southwest orientation for the maximum horizontal stress, which is consistent with the World Stress Map (Heidbach et al., 2009), although anomalous stress orientations have been identified in northwest Ontario including a 90° change in azimuth of the maximum compressive stress axis which was identified in the near surface of the Whiteshell area of Manitoba (Brown et al., 1995). In addition, a roughly north-south orientation of maximum horizontal compressive stress was found for the Sioux Falls Quartzite in South Dakota (Haimson, 1990).

If the present orientation of maximum horizontal stress were oriented north-south then north-trending lineaments would be preferentially oriented to open as tension fractures, while the east-trending lineaments would be preferentially oriented to remain closed. However, 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 and Silver, 2000; Bokelmann, 2002), the degree of coupling between the North American plate and the underlying mantle (Forte et al., 2010), the effects of crustal depression and Holocene rebound, and the influence of the thick lithospheric mantle root under the Canadian Shield, make it premature to correlate the regional neotectonic stress orientation with the orientation of mapped lineaments at the desktop stage.

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

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

6.4 Thermal Conductivity

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

There are no site-specific thermal conductivity values or detailed quantitative mineral compositions for the Ear Falls area. The quartz mineral content of the gneissic metasedimentary rocks and intrusive rock types (i.e., the Bruce Lake pluton and the Bluffy Lake, Wenasaga, and Wapesi Lake batholiths) are likely to range from approximately 10% to 60% by volume (Streckeisen, 1976). Thermal conductivity in the gneissic metasedimentary rocks is likely to be both more variable and anisotropic than in undeformed plutonic rocks reflecting the gneissic banding and pervasive recrystallization under regional metamorphism. The range of measured thermal conductivity values for plutonic rock types found in the literature are presented in Table 6.2.

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

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

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

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

The above literature values for thermal conductivity are considered useful for comparison purposes as part of this preliminary assessment. However, actual values would need to be determined at later stages of the assessment.

7.0 POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE EAR FALLS AREA

7.1 Approach

The objective of the Phase 1 desktop geoscientific preliminary assessment is to assess whether the Ear Falls area contains general areas that have the potential to satisfy the geoscientific evaluation factors and safety functions outlined in the site selection process document (NWMO, 2010). The location and extent of general potentially suitable areas would be refined during the second phase of the preliminary assessment through more detailed assessments and field evaluations.

The repository is expected to be constructed at a depth of about 500 mbgs. The surface facilities will require a dedicated surface area of about 600 x 550 m for the main buildings and about 100 x 100 m for the ventilation exhaust shaft (NWMO, 2013). The actual underground footprint at any particular site would depend on a number of factors, including the characteristics of the rock, the final design of the repository and the inventory of used fuel to be managed. For the purpose of this preliminary assessment, it is assumed that the repository would require a footprint in the order of 2 km x 3 km.

The geoscientific assessment of suitability was carried out in two steps. The first step (Section 7.2) was to identify general potentially suitable areas using the key geoscientific characteristics described below. The second step (Section 7.3) was to verify that identified general areas have the potential to meet all NWMO's geoscientific site evaluation factors (NWMO, 2010). The potential for finding general areas was assessed using the following key geoscientific characteristics:

- ***Geological Setting:*** Areas of unfavourable geology identified during the initial screening (Golder, 2011) were not considered. Such areas include rocks of the Birch-Uchi greenstone belt due to their lithological heterogeneity, structural complexity and potential for mineral resources. Intrusive rocks (i.e. batholiths and plutons) and metasedimentary rocks in the Ear Falls area were considered as potentially suitable host rocks (Figure 3.5).

- ***Structural Geology:*** Areas within or immediately adjacent to regional faults and shear zones were not considered. The main structural features in the Ear Falls area are the Sydney Lake and Long Legged Lake fault zones, which crosscut the Ear Falls area and run along the margins of the Bruce Lake pluton, and the Wenasaga Lake and Bluffy Lake batholiths (Figure 3.5). The thickness of potentially suitable units was also considered when identifying potentially suitable areas. The large granitic intrusions and the metasedimentary rocks in the Ear Falls area are likely to range from 1 km to approximately 4 km in thickness in most areas, which is sufficient for the purpose of siting a deep geological repository.

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

- ***Overburden**:* The distribution and thickness of overburden cover is an important site characteristic to consider when assessing amenability to site characterization of an area. For practical reasons, it is considered that areas covered by more than approximately 2 m of overburden deposits would not be amenable to trenching for the purpose of structural mapping. This consideration is consistent with international practices related to site characterization in areas covered by overburden deposits (e.g. Finland; Posiva, 2007). At this stage of the assessment preference was given to areas with greater mapped bedrock exposures. The extent of bedrock exposure in the Ear Falls area is shown on Figure 2.3. Areas mapped as bedrock terrain are assumed to be covered, at most, with a thin veneer of overburden and are therefore considered amenable to detailed geological mapping.

- ***Protected Areas:*** All provincial parks and conservation reserves in the Ear Falls area were excluded from further consideration. The largest protected areas in the Ear Falls area include the Pakwash Provincial Park (40 km^2) and the Bruce Lake Conservation Reserve (60 km^2), which cover part of the Pakwash and Bruce Lake plutons, respectively. The West English River Provincial Park overlies a small portion of the metasedimentary rocks and the granitic rocks of the Winnipeg River Subprovince, and the Lac Seul Islands Conservation Reserve encompasses the islands on Lac Seul (Figure 1.1).
- ***Natural Resources:*** The potential for natural resources in the Ear Falls area is shown on Figure 5.1. Areas with known potential for exploitable natural resources such as the rocks of the Birch-Uchi greenstone belt were excluded from further consideration. In the metasedimentary rocks, areas with known iron mineralization potential and areas along the Sydney Lake fault zone, where potential for gold is being explored, were also not considered. At this stage of the assessment, areas of active mining claims located in geologic environments judged to have low mineral resource potential were not systematically excluded.
- ***Surface Constraints:*** Areas of obvious topographic constraints (density of steep slopes), large water bodies (wetlands, lakes), and accessibility were considered for the identification of potentially suitable areas. While areas with such constraints were not explicitly excluded at this stage of the assessment, they are considered less preferable, all other factors being equal. About 18% of the Ear Falls area is occupied by water bodies of various sizes. The majority of the Ear Falls area is accessible by existing logging roads, with the exception of the south portions of the Bluffy Lake batholith and the adjacent portion of metasedimentary rocks.

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the above key geoscientific characteristics revealed that the Ear Falls area contains general areas where there is a potential to find suitable sites for hosting a deep geological repository. These general areas are located within the Bluffy Lake batholith and the metasedimentary rocks of the English River Subprovince. Figure 7.1 shows features illustrating some of the key characteristics and constraints used to identify general potentially suitable areas, including: bedrock geology; protected areas; areas of thick overburden cover; surficial and geophysical lineaments; existing road network; the potential for natural resources; and mining claims. The legend of Figure 7.1 includes a 2 km by 3 km box to illustrate the approximate extent of suitable rock that would be needed to host a repository.

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

7.2.1 Bluffy Lake Batholith

As discussed in Section 3.2.1, the Bluffy Lake batholith is a multi-phase intrusion that was emplaced approximately 2.698 billion years ago, and extends over approximately 324 km^2 in the Ear Falls aera. It is mostly composed of tonalite and diorite and its thickness is estimated to be approximately 1.5 to 3 km. The Sydney Lake fault zone runs along the western margin of the intrusion, and crosscuts the batholith through its northern portion (Figure 3.5).

Within the Ear Falls area, most of the Bluffy Lake batholith has extensive bedrock exposure, low potential for natural resources, and is free of protected areas and significant surface constraints (i.e., topography and large water bodies). Therefore, the differentiating factors for finding potentially suitable areas within the Bluffy Lake batholith were considered to be mainly structural geology (i.e., away from regional fault zones) and lineament analysis.

The central portion of the Bluffy Lake batholith near the eastern boundary of the Ear Falls area appears to have a number of favourable geoscientific characteristics for hosting a repository. This general area has very good bedrock exposure, which makes it amenable to site characterization. The general area lies approximately 6 km from the Sydney Lake fault zone, which is described as having a 0.5 to 2 km wide zone of deformation. The interpretation of geophysical data (Mira, 2013) did not identify any structures associated with this regional structure in the central portion of the batholith. However, the potential impact of the regional Sydney Lake fault zone on the potential suitability of the identified general area would need to be further assessed in future stages of the site evaluation process.

Bedrock in the central portion of the batholith is mapped as tonalite. The low resolution of available geophysical data did not allow for the identification of distinct intrusive phases within the Bluffy Lake batholith. The lithological homogeneity in the identified general area would need to be further assessed during subsequent site evaluation stages.

Additional insight into the potential suitability of the general area in the central portion of the Bluffy Lake batholith is provided by the analysis of interpreted lineaments, which is described in detail by SRK (2013). Figures 3.11 and 7.1 show that geophysical lineament density in this general area is relatively low, which is likely due to the low resolution of available geophysical data. Higher density of lineaments is observed in the western portion of the Bluffy Lake batholith where higher geophysical resolution is available. The spacing between geophysical lineaments in the central portion of the Bluffy Lake batholith ranges from about 1 to 5 km, and interpreted lineaments show relatively well defined orientations, which is a favourable characteristic from a site characterization perspective.

The density of surficial lineaments is generally moderate to high throughout the Bluffy Lake batholith, including in the central portion of the intrusion (Figures 3.10 and 7.1). This is likely due to extensive bedrock exposure, which makes surficial lineaments readily mappable. At the desktop stage of assessment, it is uncertain if surficial lineaments represent real bedrock structure and how far they extend to depth, particularly the shorter lineaments.

The central portion of the Bluffy Lake batholith is predominantly Crown land (Figure 2.6), and does not contain any protected areas. This general area is free of active mining claims (Figures 5.1 and 7.1) and mineral resource potential of the Bluffy Lake batholith is considered low. Access to the central portion of the intrusion is good via the Wenasaga Lake Road, which transects the northern portion of the area from southwest to northeast (Figures 1.1 and 7.1). The area is well drained and of moderate relief. The main surface constraints include the presence of some larger water bodies, such as Taber Lake.

7.2.2 Metasedimentary Rocks of the English River Subprovince

As discussed in Section 3.2.1, the metasedimentary rocks of the English River Subprovince dominate the bedrock geology of the Ear Falls area (Figure 3.5). These rocks formed as a result of high-grade metamorphism of precursor sedimentary rocks. The age of deposition of the original sedimentary rocks is estimated to be about 2.704 to 2.696 billion years ago. The thickness of the metasedimentary rocks is estimated to be from less than 1 km locally to up to 4 km (Nitescu et al., 2006).

The metasedimentary rocks in the Ear Falls area generally have low potential for natural resources, and are largely free of protected areas and significant surface constraints (i.e., topography and large water bodies). The differentiating factors for finding potentially suitable areas within the metasedimentary rocks were considered to be mainly bedrock exposure, structural geology (i.e. away from regional fault zones) and, to a limited extent, lineament interpretation.

The assessment of key geoscientific characteristics allowed for the identification of four general potentially suitable areas within the belt of metasedimentary rocks. Two of these general areas are in the eastern portion of the Ear Falls area, northeast of Lac Seul and southeast of Wenasaga Lake. Another general area was identified in the south-central portion of the Ear Falls area, just west of Lac Seul. The fourth general area lies in the western end of the Ear Falls area, south of the Sydney Lake fault zone and north of Wegg and Goose Lakes (Figure 7.1).

All four identified general potentially suitable areas have good bedrock exposure, and are at distances ranging from 6 km to over 20 km from the regional Sydney Lake and Long Legged Lake fault zones. While there are no smaller-scale related faults mapped in any of the four general areas, the potential impact of these major regional structures remains uncertain and would need to be further assessed in future site evaluation stages.

Bedrock in the four general areas identified is uniformly mapped as metasedimentary rocks. Interpretation of geophysical data recognized elevated magnetic responses in some of the identified general areas, which may reflect local variations in lithological characteristics. Given the varying degree of metamorphism in the metasedimentary rocks in the Ear Falls area, lithological homogeneity is uncertain at this stage and would need to be further investigated in subsequent stages of the site evaluation process.

Geophysical lineament density in the four general potentially suitable areas identified within the metasedimentary rocks is generally low, with lineament spacing ranging between 1 to 8 km (Figures 3.11 and 7.1). The low geophysical lineament density is likely due to both the low resolution of the aeromagnetic dataset, and the low regional magnetic susceptibility of the metasedimentary rocks, which could be masking the presence of a higher density of lineaments. The actual density of lineaments would need to be further investigated during subsequent stages of the site evaluation process.

Figures 3.10 and 7.1 show that the surficial lineament density in the three eastern general areas is generally moderate to high, with a lower surficial lineament density observed in the western area. This relatively high surficial lineament densities are explained by the good bedrock exposure in the four general areas identified.

The four identified potentially suitable areas are predominantly Crown land (Figure 2.6) and lie outside of protected areas (Figure 7.1). They are mostly free of active mining claims (Figures 5.1 and 7.1) and mineral occurrences, and do not contain any mapped iron formation. However, the general area identified in the western portion of the Ear Falls area lies just south of an area where ongoing gold exploration activities are taking place. The effect that such activities could have on the potential suitability of the general area would need to be further assessed in future stages of the site selection process. Access to the four general areas is good via the existing highways and a network of logging roads (Figure 7.1). The areas are well drained and have generally minimal lake/wetland cover.

7.2.3 Other Areas

No general areas were identified in the Pakwash and Bruce Lake plutons, the Wapesi and Wenasaga Lake batholiths, the Long Legged Lake dome and the intrusive bodies of the Winnipeg River Subprovince.

Overburden cover in the Wenasaga Lake batholith, the Bruce Lake pluton and Pakwash Lake pluton is extensive and the latter two are also partially covered by protected areas and large water bodies. In addition, all three intrusions are bounded by the regionally extensive Sydney Lake and Long Legged Lake fault zones (Figures 3.5 and 7.1), suggesting the potential for added structural complexity in these geologic units.

The Wapesi Lake batholith appears to have suitable geological characteristics and low density of geophysical lineaments. However, its extent within the Ear Falls area is very limited, and it is largely covered by overburden deposits (Figure 7.1).

The plutonic rocks of the Winnipeg River Subprovince in the southwestern portion of the Ear Falls area have some potentially suitable geological characteristics, but are considered less favourable due to the lithological heterogeneity introduced by the presence of greenstone slivers within them. These rocks also exhibit moderate to high lineament density, have areas of overburden cover, and are partially covered by protected areas. The Long Legged Lake dome in the Ear Falls area is mostly covered by overburden deposits and thus was not considered as a preferred area.

Given the large geographic extent of the Ear Falls area, it may be possible to identify other general potentially suitable areas. However, the five identified general areas are those judged to best meet the preferred key geoscientific characteristics outlined in Section 7.1, based on the currently available information. The location and extent of potentially suitable areas will be refined during Phase 2 of the preliminary assessment through more detailed site evaluations

7.2.4 Summary of Geoscientific Characteristics of the Potentially Suitable Areas

Table 7.1 provides a summary of the key geoscientific descriptive characteristics of the identified general potentially suitable areas in the Ear Falls area.

Table 7.1: Summary of Characteristics of the Bluffy Lake Batholith and Metasedimentary Rocks of the English River Subprovince – Ear Falls

Geoscientific Descriptive Characteristic	General Area				
	Bluffy Lake Batholith	**Metasedimentary Rocks (Eastern)**	**Metasedimentary Rocks (Eastern)**	**Metasedimentary Rocks (South Central)**	**Metasedimentary Rocks (Western)**
Rock Type	Tonalite to granodiorite	Metasedimentary rocks	Metasedimentary rocks	Metasedimentary rocks	Metasedimentary rocks
Age	ca. 2.698 billion years old	ca. 2.692 - 2.691 billion years old	ca. 2.692 - 2.691 billion years old	ca. 2.692 - 2.691 billion years old	ca. 2.692 - 2.691 billion years old
Inferred host rock thickness	1.5 to 3 km	< 1 km to ca. 4 km	< 1 km to ca. 4 km	< 1 km to ca. 4 km	< 1 km to ca. 4 km
Extent of rock unit within the Ear Falls area	Bluffy Lake Batholith: 324 km^2	Metasedimentary Rocks: 2,800 km^2	Metasedimentary Rocks: 2,800 km^2	Metasedimentary Rocks: 2,800 km^2	Metasedimentary Rocks: 2,800 km^2
Relative proximity to mapped major geological features (regional faults/ shear zones, geological sub-province boundaries, etc.)	Sydney Lake FZ – 10 km Long Legged FZ – ca. 20 km	Sydney Lake FZ – ca. 10 to 20 km Long Legged FZ – ca. 20 to 50 km	Sydney Lake FZ – 23 km Long Legged FZ – 50 km	Sydney Lake FZ – 24 km Long Legged FZ – 38 km	Sydney Lake FZ – 6 km Long-Legged FZ – 25 km
Structure: faults, foliation, dykes, joints	Moderate surface lineament density Low resolution geophysics	Moderate apparent surface lineament density Low resolution geophysics	Moderate apparent surface lineament density Low resolution geophysics	Low apparent surface lineament density Low resolution geophysics	Low apparent surface lineament density Low geophysical lineament density
Aeromagnetic characteristics and resolution	Magnetically quiet Low resolution	Generally magnetically quiet, Low Resolution	Magnetically quiet Low Resolution	Magnetically quiet Low Resolution	Magnetically noisy Mixture of High and Low resolution
Terrain: topography, vegetation	Moderate relief	Moderate relief	Moderate relief	Moderate relief, numerous cutovers	Moderate relief, some cutovers
Access	Generally good access along main road	Generally good access throughout via logging roads	Good access along west and south. Poor access in central portion	Good access throughout via logging roads	Good access throughout via logging roads
Resource Potential	Low	Low	Low	Low	Low
Bedrock exposure	Generally high	Generally moderate	ca. 65%	ca. 35%	ca. 30%

Geoscientific Descriptive Characteristic	General Area				
	Bluffy Lake Batholith	Metasedimentary Rocks (Eastern)	Metasedimentary Rocks (Eastern)	Metasedimentary Rocks (South Central)	Metasedimentary Rocks (Western)
Drainage	Generally good	Generally good	Generally good Some wetland	Generally good	Generally good

7.3 Evaluation of the General Potentially Suitable Areas

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

- ***Safe containment and isolation of used nuclear fuel*** Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances?
- ***Long-term resilience to future geological processes and climate change*** Are the rock formations beneath the siting area adequate, such that they will not be substantially altered by natural geological disturbances and events such as earthquakes and climate change?
- ***Safe construction, operation and closure of the repository*** Are rock conditions at the site suitable for the safe construction, operation and closure of the repository?
- ***Isolation of used fuel from future human activities*** Is human intrusion at the site unlikely, for instance, through future natural resource exploration or extraction?
- ***Amenable to site characterization and data interpretation activities*** Can the geologic conditions that are important for demonstrating long-term safety at the site be practically studied and described?

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

An evaluation of the five general potentially suitable areas in the Bluffy Lake batholith and metasedimentary rocks within the Ear Falls area is provided in the following subsections.

7.3.1 Safe Containment and Isolation of Used Nuclear Fuel

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

This requires that:

- The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events;
- The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities;
- The hydrogeological regime within the host rock should exhibit low groundwater velocities;
- The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multiple-barrier system;
- The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement; and
- The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.

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

As discussed in Section 3 and summarized in Table 7.1, available information indicates that the estimated thickness of the Bluffy Lake batholith is expected to be 1.5 to 3 km, while the thickness of the metasedimentary rocks has been estimated to be up to 4 km. Therefore, the rock in the five general areas identified in these geologic units is likely to extend well below typical repository depths (approximately 500 m), which would contribute to the effective isolation of the repository from human activities and natural surface events.

Analysis of lineaments interpreted during this preliminary assessment (Sections 3.2.3) indicates that the five general areas in the Ear Falls area warrant further consideration, as they have the potential to contain structurally bounded rock volumes of sufficient size to host a deep geological repository. The distribution of lineament density as a function of lineament length over the potentially suitable host rock units shows that the variable density and spacing of shorter brittle lineaments is strongly influenced by the amount of exposed bedrock and by the resolution of available geophysical data (Figures 3.13 to 3.16). By classifying the lineaments by length, this local bias is greatly reduced and the spacing between lineaments increases as shorter lineaments are filtered out. Longer lineaments are more likely to extend to greater depth than shorter lineaments. All five general potentially suitable areas exhibit lineament spacing between longer lineaments (i.e., those longer than 5 and 10 km) on the order of 2 to 5 km. The five potentially suitable areas lie at distances ranging from 6 to over 20 km from the regional Sydney Lake and Long Legged fault zones. The potential impact of these major regional structures on the suitability of indentified potentially suitable areas remains uncertain and would need to be further assessed in future site evaluation stages.

As discussed in Section 4.4, there is limited information on the hydrogeologic properties of the deep bedrock in the Ear Falls area. It is therefore not possible at this stage of the evaluation to predict the nature of the groundwater regime at repository depth in the five identified general areas. The potential for groundwater movement at repository depth is, in part, controlled by the fracture frequency, the degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of mineral infilling. Available information within the Canadian Shield indicates that active groundwater flow within structurally bounded blocks tends to be generally limited to shallow fracture systems, typically less than approximately 300 m. At greater depths, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures, thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). Hydraulic conductivity values measured in crystalline rocks at typical repository depths (500 m or greater) at the Whiteshell and Atikokan research areas range from approximately 10^{-15} to 10^{-10} m/s (Ophori and Chan, 1996; Stevenson et al., 1996). Data reported by Raven et al. (1985) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400 to 500 m. Also, experience from other areas in the Canadian Shield indicates that ancient faults, similar to those in the Ear Falls area, have been subjected to extensive periods of rock-water interaction resulting in the long-term deposition of infilling materials that contribute to sealing and a much reduced potential for groundwater flow at depth. Site-specific conditions that can influence the nature of deep groundwater flow systems in the Ear Falls area would need to be investigated at later stages of the site evaluation process.

Information on other geoscientific characteristics relevant to the containment and isolation functions of a deep geological repository, such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, the thermal and geomechanical properties of the rock is limited for the Ear Falls area. The review of available information from other locations with similar geological settings did not reveal any obvious conditions that would suggest unfavourable mineralogical or hydrogeochemical characteristics for the granitic and metasedimentary rocks underlying the five potentially suitable areas identified within the Ear Falls area (Sections 4.0 and 7.2). Site specific mineralogical and hydrogeochemical characteristics, including pH, eH and salinity, would need to be assessed during subsequent site evaluation stages. Similarly, it is expected that the geomechanical and thermal characteristics of the Bluffy Lake batholith within the Ear Falls area may resemble those of the Lac du Bonnet batholith and similar rock types elsewhere in the northwestern Superior Province (Section 6.0) with no obvious unfavourable conditions known at present. These characteristics would need to be assessed during subsequent site evaluation stages.

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

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

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

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

- Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long term;

- The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository;
- The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository; and
- The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.

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

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

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

The Ear Falls area is still experiencing isostatic rebound following the end of the Wisconsinan glaciation (Section 3.3.2). Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella et al., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1-2 mm/yr) south of the Great Lakes. Lake level records (Mainville and Craymer, 2005) indicate that present day rebound rates in the Ear Falls area should be well below 10 mm/yr, likely between 3 and 5 mm/yr. There is no site-specific information on erosion rates for the Ear Falls area. However, as discussed in Section 3.1.6, the erosion rates from wind, water and past glaciations on the Canadian Shield are reported to be low.

In summary, available information indicates that the identified general potentially suitable areas in the Ear Falls area have the potential to satisfy the long-term stability function. The review did not identify any obvious conditions that would cause the performance of a repository to be substantially altered by future geological and climate change processes. The long-term stability of the Ear Falls area would need to be further assessed through detailed multidisciplinary site specific geoscientific and climate change site investigations.

7.3.3 Safe Construction, Operation and Closure of the Repository

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

This requires that:

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

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

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

The areas identified within the Bluffy Lake batholith and the metasedimentary rocks in the Ear Falls area are mapped as having good bedrock exposure. Information on the thickness of overburden deposits is largely limited to a small number of water well records and to diamond drillholes concentrated in the former Griffith Mine and in the greenstone belts in the northern sector of the Ear Falls area. Measured overburden thickness generally range from 0 to 41 m, with an average of 14 m. The thickest overburden is inferred along the axis of the Lac Seul moraine (Figure 2.3). At this stage of the site evaluation process it is not possible to accurately determine the thickness of the overburden deposits in these areas due to the low resolution of available data. However, it is anticipated that overburden cover is not a limiting factor in any of the identified general areas.

In summary, the five identified general potentially suitable areas in the Ear Falls area have good potential to satisfy the safe construction, operation and closure funciton.

7.3.4 Isolation of Used Fuel from Future Human Activities

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

This requires that:

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

The mineral potential in the Ear Falls area is mostly associated with the rocks of the Birch-Uchi greenstone belt (Section 5). The mineral potential of the Bluffy Lake batholith and the metasedimentary rocks in the Ear Falls area is low. Although locally the metasedimentary rocks may have potential for iron deposits and exploration for gold along the Sydney Lake fault zone is ongoing, the potential for mineral resources in the general potentially suitable areas identified area remains low (Sections 5 and 7.2).

The review of available information did not identify any groundwater resources at repository depth for the Ear Falls area. As discussed in Section 4.0, the MOE Water Well Records database shows that all water wells known in the Ear Falls area obtain water from overburden or shallow bedrock sources ranging from 2.5 to 134 m. Experience from other areas in the Canadian Shield has shown that active groundwater flow in crystalline rocks is generally confined to shallow fractured localized systems (Singer and Cheng, 2002). MOE WWRs indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Ear Falls area or anywhere else in northern Ontario. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits potential yield, even if suitable water quality were to be found.

In summary, the potential for the containment and isolation functions of a repository in the Ear Falls area to be disrupted by future human activities is low

7.3.5 Amenability to Site Characterization and Data Interpretation Activities

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

Factors affecting the amenability to site characterization include: geological heterogeneity; structural and hydrogeological complexity; accessibility, and the presence of lakes or overburden with thickness or composition that could mask important geological or structural features

As described in Section 3, bedrock in the Bluffy Lake batholith is mapped as fairly homogeneous, and the resolution of available geophysical data does not allow for the identification of distinct phases within the intrusion. The metasedimentary rocks in the Ear Falls area are also mapped as fairly homogeneous; however, it is uncertain to what degree their lithology has been affected by the the varying degree of metamorphism and migmatization (i.e. partial melting) that these rocks have undergone in the past. The lithological homogeneity of the Bluffy Lake batholith and the metasedimentary rocks would need to be further assessed in future evaluation stages, through the acquisition of higher resolution geophysical data and detailed field mapping.

Interpreted lineaments represent the observable two-dimensional expression of three-dimensional features. The ability to detect and map such lineaments is influenced by topography, the character of the lineaments (e.g., their width, orientation, age, etc.), and the underlying resolution of data used for the mapping. Interpreted geophysical and surficial lineaments in the Ear Falls area, including the identified general areas, exhibit distinct and well defined orientations (i.e. east and northeast; Figures 3.10 and 3.11), which facilitates the mapping and interpretation of these features. The orientation of lineament features in three dimensions (i.e. considering depth) represents another degree of structural complexity that will require assessment through detailed site investigations in future phases of the site selection process.

The characterization and field mapping of structures is strongly influenced by the extent of overburden cover and the presence of large water bodies. Bedrock in the general area identified in the Bluffy Lake batholith is mostly exposed, while bedrock exposure in the general areas within the metasedimentary rocks is variable Although bedrock outcrop is somewhat discontinuous in the general areas in the metasedimentary rocks, the five identified general potentially suitable areas are amenable to site characterization as they have sufficient bedrock exposure and land outside large water bodies.

The five identified general potentially suitable areas in the Ear Falls area are all accessible using existing road networks.

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

8.0 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

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

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

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

The desktop geoscientific preliminary assessment showed that the Ear Falls area contains at least five general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. One of the areas is within the Bluffy Lake batholith, and the four other areas are within the metasedimentary rocks of the English River Subprovince.

The Bluffy Lake batholith and the metasedimentary rocks hosting the five identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They are estimated to have sufficient depth and extend over large areas. The bedrock within the five potentially suitable areas has good exposure. All five potentially suitable areas have low potential for natural resources; are easily accessible using the existing road network; contain limited surface constraints; and are amenable to site characterization.

While the identified general potentially suitable areas appear to have favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The main uncertainties are associated with the proximity of the regional Sydney Lake fault zone, the low resolution of available geophysical data, and the variable degree of metamorphism and migmatization (partial melting of the rock) that the metasedimentary rocks have experienced in the geological past.

Interpreted lineaments suggest that the five identified general areas have the potential to contain structurally bounded rock volumes of sufficient size to host a deep geological repository. However, this would need to be confirmed during future site evaluation stages, as the observed low density of geophysical lineaments is likely due the low resolution of available geophysical data and the low magnetic susceptibility of the metasedimentary rocks.

Also, some of the identified potentially suitable areas are less than 10 km from the Sydney Lake fault zone which runs through the Ear fall area. The potential impact of this major regional structure on the suitability of identified potentially suitable areas would need to be further assessed during subsequent site evaluation stages. The impact of the variable degree of metamorphism and migmatization that the metasedimentary rocks have undergone in the geological past on the homogeneity of the metasedimentary rocks underlying four of the identified potentially suitable areas would need to be further assessed.

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

9.0 REFERENCES

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

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

Asudeh, I; White, D; Roberts, R; Forsyth, D; Kay, I; Cartwright, T; Carroll, P; Hajnal, Z; Koperwhats, B; Musacchio, G; Farrell, D. 1996. LITHOPROBE Western Superior seismic refraction survey: field acquisition and processing report; Geological Survey of Canada, Open File 3583, 1999, 223 pages, doi:10.4095/210198

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

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

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

Beakhouse, G. P., 1977. A subdivision of the western English River Subprovince; Canadian Journal of Earth Sciences 14, 1481-1489.

Beakhouse, G P, C. E. Blackburn, F. W. Breaks, J. Ayer, D. Stone, G.M. Stott, 1995. Western Superior Province, Field Guidebook; Geological Survey of Canada, Open File 3138

Bell, R., 1873. Report on the country between Lake Superior and Lake Winnipeg, Geological Survey of Canada, Report of Progress, 1872-1873, 87-111.

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

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

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

Bethune, K.M., Helmstaedt, H.H., Hrabi, R.B., 1999. Structural analysis of faults in the apical region of the Wabigoon Subprovince. In Western Superior Transec 5th Annual Workshop, Ottawa, Ont. Feb. 1-3, 1999. Edited by R.M. Harrap and H.H. Helmstaedt. Lithoprobe Secretariat, The University of British Columbia, Vancouver, B.C., Lithoprobe Report 70, pp. 5-14.

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

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

Bokelmann, G.H.R., 2002. Convection-driven motion of the North American craton: Evidence from P-wave anisotropy: Geophysical Journal International, 148, p. 278-287.

Bokelmann, G.H.R. and P.G. Silver, 2000. Mantle variation within the Canadian Shield: Travel times from the portable broadband Archean-Proterozoic Transect 1989: Journal of Geophysical Research, Vol 105, No. B1, p. 579-605.

Borowik, A., 1998. Structural Analysis in the Footwall of The Uchi-English River Subprovince Boundary, Red Lake Region, Northwestern Ontario; Master of Science thesis, University of Toronto, 1998

Breaks, F.W., W.D. Bond, N. Harris, and C. Westerman, 1975. Operation Kenora-Ear Falls, District of Kenora; in Summary of field work 1975, Ontario Geological Survey, Miscellaneous Paper 63, 158p.

Breaks, F. W., W. D. Bond, D.W. Desnoyers, D. Stone and N. Harris, 1976. Operation Kenora-Ear Falls, Bruce-Bluffy Lakes Sheet, District of Kenora; Ontario Div. Mines, Prelim. Map P.1199, scale 1:63,360 or 1 inch to 1 mile. Geology 1975.

Breaks, F.W. and W.D. Bond, 1977. English River Subprovince (Marchington Lake Area), District of Kenora; p.18-28 in Summary of Field Work, 1977, by the Geological Branch, edited by V.G. Milne, O.L. White, R.B. Barlow, and J.A. Robertson, Ontario Geological Survey Misc. Paper 75, 208p.

Breaks, F.W., W.D. Bond, and D. Stone 1978. Preliminary geological synthesis of the English River Subprovince, northwestern Ontario and its bearing upon mineral exploration; Ontario Geological Survey-Miscellaneous Paper 72, 55p.

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

Breaks, F. W., 1991. English River Subprovince in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, pp. 239-277.

Breaks, F.W., J.B. Selway and A.G. Tindle, 2003. Fertile peraluminous granites and related rare-element mineralization in pegmatites, Superior Province, northwest and northeast Ontario: Operation Treasure Hunt; Ontario Geological Survey, Open File Report 6099, 179p.

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

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

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

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

Brown, A., R.A. Everitt, C.D. Martin and C.C. Davison, 1995. Past and Future Fracturing In AECL Research Areas in the Superior Province of the Canadian Precambrian Shield, with Emphasis on The Lac Du Bonnet Batholith; Whiteshell Laboratories, Pinawa, Manitoba; AECL Report 11214, COG-528, 133p.

Bruce, E. L., 1924. Geology of the Upper Part of the English River Valley; Part 4 of the Thirty-third Annual Report of the Ontario Department of Mines, 11p.

Burwash, E.M., 1920. A geological reconnaissance into Patricia; Ontario Department of Mines 29, Part 1, 157-192.

Calvert, A.J., A.R. Cruden, and A. Hynes, 2004. Seismic evidence for preservation of the Archean Uchi granite-greenstone belt by crustal-scale extension. Tectonophysics, 388, 135-143.

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

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

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

Chipera, S. J., and D. Perkins, 1988. Evaluation of biotite-garnet geothermometers: application to the English River Subprovince, Ontario: Contributions to Mineralogy and Petrology January 1988, Volume 98, Issue 1, pp 40-48

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

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

Corfu, F., G.M. Stott and F.W. Breaks, 1995. U-Pb Geochronology and evolution of the English River Subprovince, an Archean low P-highT metasedimentary belt in the Superior Province; Tectonics, Vol. 14, No. 5, 1220-1233, Corfu, F. and D.W. Davis, 1992. A U/Pb geochronological framework for the western Superior Province, Ontario; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part II, p.1335-1348.

Corfu, F., and G. M. Stott, 1993. U-Pb geochronology of the central Uchi Subprovince, Superior Province; Canadian Journal of Earth Science 30

Corfu, F., and G. M. Stott, 1996. Hf isotopic composition and age constraints on the evolution of the Archean central Uchi Subprovince, Ontario, Canada; Precambrian Research Volume 78, Issues 1–3, May 1996, Pages 53–63

Davies, J.C. and Pryslak, A.P., 1967. Kenora-Fort Frances sheet, Kenora, Rainy River Districts; Ontario Department of Mines Map 2115.

de Lima Gomes, A. J. and V. Mannathal Hamza, 2005. Geothermal Gradient and Heat Flow in the State of Rio de Janeiro. Revista Brasileira de Geofisicaisica 23(4): 325-347.

Dome Exploration (Canada) Limited, 1957. Diamond Drill Logs for the Karas Lake Magnetic Anomaly.

Dowling, D.B., 1894. Report on the country in the vicinity of Red Lake and part of the basin of Berens River, Keewatin; Geological Survey of Canada 7, part F, 5-54.

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

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

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

Eberhardt, E., D. Stead and B. Stimpson, 1999. Effects of sample disturbance on the stress induced microfracturing characteristics of brittle rock; Canadian Geotechnical Journal, 1999, 36(2): 239-250

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

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

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

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

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

Fenwick, K.G., 1973. Geology of the Fredart-Whitemud Lakes area. District of Kenora (Patricia Portion); Ontario Department of Mines Open,File Report 5095, 131p.

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

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

Ford, M.J., 1981. Quaternary Geology of the Ear Falls and Pakwash Areas (52 K/ll, 52 K/14) District of Kenora (Patricia Portion) in Summary of Field Work, 1981, by the Ontario Geological Survey, Edited by John Wood, O.L. White, R.B. Barlow, and A.C. Colvine, Ontario Geological Survey, Miscellaneous Paper 100, 255p.

Ford, M.J., 1983. Quaternary Geology of the Far Falls Area. Kenora District (Patricia Portion); Ontario Geological Survey, Map P.2585, Geological Series-Preliminary Map. scale 1:50,000, Geology 1981.

Forte, A.M., R. Moucha, N.A. Simmons, S.P. Grand and J.X. Mitrovica, 2010. Deep-mantle contributions to the surface dynamics of the North American continent; Tectonophysics 481 p. 3–15.

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

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

Fronteer Development Group Inc., 2004. Airborne geophysical report of assessment work performed on the Dixie Lake property, OGS AFRI 52K13NE2008, 57p

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

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

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

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

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

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

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

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

Golder (Golder Associates Ltd.), 2011. Initial screening for siting a deep geological repository for Canada's used nuclear fuel. Township of Ear Falls, Ontario; 33p.

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

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

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

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

Grandcru Resources Corp., 2005. Assessment report on the high resolution airborne magnetic survey, Dixie East/South Properties , OGS AFRI 20001087, 32p.

Grandview Gold Inc., 2012. http://www.grandviewgold.com/ Accessed: June 2012

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

Gupta, V.K. and R.B. Barlow, 1984. A Detailed Gravity Profile across the English River subprovince, Northwestern Ontario; Canadian Journal of Earth Sciences, 21, pp.145-151

Gupta, V.K. and D.R. Wadge, 1980. Gravity Study of the Red Lake – Birch Lake Area, District of Kenora: Ontario Geological Survey Open File Report 5278, 249p. Accompanied by 4 plates, scale 1:250 000.

Gupta, V.K. and D.R. Wadge, 1986. Gravity Study of the Birch, Uchi, and Red Lakes Area, District of Kenora (Patricia Portion); Ontario Geological Survey Report 252, 98p. Accompanied by Maps 2492, 2493, 2494 and 2495, Scale 1:250 000.

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

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

Hall, D.H. and W. C. Brisbin, 1982. Overview of regional geophysical studies in Manitoba and northwestern Ontario; .Canadian Journal of Earth Sciences 19, 2049-2059.

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

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

Harris, N. B. W., and A. M. Goodwin, 1976. Archean rocks from the eastern Lac Seul region of the English River Gneiss Belt, northwestern Ontario, part 1. Petrology, chemistry, and metamorphism: Canadian Journal of Earth Sci. 13. 1201-1211

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

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

Hayek S.J., J.A. Drysdale, J. Adams, V. Peci, S. Halchuk and P. Street, 2011. Seismic Activity in the Northern Ontario Portion of the Canadian Shield: Annual Progress Report for the Period January 01 – December 31, 2010, NWMO TR-2011-26, 30p.

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

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

Heidbach, O., Tingay, M., Barth, A., Reinecker, J., Kurfeß, D., Müller, B., 2009. The World Stress Map based on the database release 2008, equatorial scale 1:46,000,000, Commission for the Geological Map of the World, Paris, doi:10.1594/GFZ.WSM.Map 2009..

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

Hillaire-Marcel, C., 1976. La déglaciation et le relèvement isostatique sur la côte est de la baie d'Hudson; Cahiers des Géographies de Québec. Vol. 20, numéro 50, p. 285-220

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

Hrabi, R.B. and A.R. Cruden, 2006. Structure of the Archean English River subprovince: Implications for the tectonic evolution of the western Superior Province, Canada; Canadian Journal of Earth Sciences. 43: pp. 947-966

Hynes, A., 1997. Constraints on the tectonic evolution of the English River Subprovince from studies in western Lac Seul. In Western Superior Transec 3rd Annual Workshop, Toronto, Ont. April 11-12, 1997. Edited by R.M. Harrap and H.H. Helmstaedt. Lithoprobe Secretariat, The University of British Columbia, Vancouver, B.C., Lithoprobe Report 63, pp. 37-45.

Hynes, A., 1998. Evidence for fault kinematics at the English River/Winnipeg River boundary. In Western Superior Transec 4th Annual Workshop, Toronto, Ont. March 23-24, 1998. Edited by R.M. Harrap and H.H. Helmstaedt. Lithoprobe Secretariat, The University of British Columbia, Vancouver, B.C., Lithoprobe Report 65, pp. 17-20.

JDMA (J.D. Mollard and Associates Ltd.), 2013. Phase 1 Geoscientific Desktop Preliminary Assessment, Terrain and Remote Sensing Study, Township of Ear Falls, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0020

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

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

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

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

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

Kenora Granite Company Limited, 2000. Assessment report for the work performed late summer and fall of 1998 on the Kenora Granite Company Limited; technical report prepared by Maria Gabriel and dated October 12, 2000; 12p.

Kiex Consulting Limited, 2011. NI 43-101 Report on The Griffith Property Ontario, Canada: prepared For: Northern Iron Corp by Christopher Hutchings, P. Geo., 75p.

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

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

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

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

Laurentian Goldfields Ltd., 2010. Goldpines South Property; Ear Falls Area, Ontario, Canada; Assessment Report prepared by Melissa Render, Steven R. Meade, and J.W. Patrick Lengyel, 1191p.

Laurentian Goldfields Ltd, 2012. Press Release dated Feb 1, 2012. http://www.laurentiangoldfields.com/s/NewsReleases.asp?ReportID=504714&_Type=News-Releases&_Title=Laurentian-Goldfields-Completes-Drill-Program-at-Goldpines-South

Liebel, H.T., K. Huber, B.S. Frengstad, R. Kalskin Ramstad and B. Brattli, 2010. Rock Core Samples Cannot Replace Thermal Response Tests - A Statistical Comparison Based On Thermal Conductivity Data

From The Oslo Region (Norway). Zero emission buildings - Proceedings of Renewable Energy Conference 2010, Trondheim, Norway.

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

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

MNR (Ontario Ministry of Natural Resources), 2013. Fish ON-Line. Ontario Ministry of Natural Resources., http://www.web2.mnr.gov.on.ca/fish_online/fishing/fishingExplorer_en.html (Accessed on 29 January, 2013).

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

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

Maloney, S., and P. K. Kaiser, 2005. Review of Ground Stress Database for the Canadian Shield Report No: 06819-REP-01300-10107-R00; 41p.

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

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

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

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

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

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

MMAH (Ministry of Municipal Affairs and Housing), 2004. Official Plan for the Township of Ear Falls. Approved June 26, 2006. 75 p.

Mira (Mira Geoscience Ltd.), 2013. Phase 1 Geoscientific Desktop Preliminary Assessment, Processing and Interpretation of Geophysical Data, Township of Ear Falls, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0021.

MOE (Ontario Ministry of Environment), 2012. Water Well Database – Water Well Records Data (Accessed August, 2012).

Monenco Ontario Limited, 1986. Open File Report 5544 Peat and Peatland Evaluation of the Dryden-Lac Seul Area prepared for the Ontario Geological Survey by Monenco Ontario Limited, Summary Volume

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

NWMO, 2005. Choosing a Way Forward. The Future Management of Canada’s Used Nuclear Fuel. Nuclear Waste Management Organization Final Study Report. (Available at www.nwmo.ca).

NWMO, 2013. Preliminary Assesment for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel - Township of Ear Falls, Ontario - Findings from Phase One Studies. NWMO Report Number APM-REP-06144-0017.

Nitescu, B., A.R. Cruden and R.C. Bailey, 2003. Topography of the Crust-Mantle Interface under the Western Superior Craton from Gravity Data. Canadian Journal of Earth Sciences, 40, pp.1307-1320.

Nitescu, B., A.R. Cruden, R.C. Bailey, 2006. Integrated potential-field and seismic constraints on the structure of the Archean metasedimentary English River belt, Western Superior craton, Canada; Precambrian Research 144 (2006), pp.261–277OGS, 2004 [shapefile].

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

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

OGS (Ontario Geological Survey), 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release---Data 126-Revision 1. ISBN 978-1-4435-5704-7 (CD) ISBN 978-1-4435-5705-4 [zip file] Ontario Parks, 2010. Provincial Park Profiles. http://www.ontarioparks.com/. Accessed May 2012.

OGS (Ontario Geological Survey), 2002a. Ontario airborne geophysical surveys, magnetic and electromagnetic data, Pakwash Lake area; Ontario Geological Survey, Geophysical dataset 1218 - Revised.

OGS (Ontario Geological Survey), 2002b. Ontario airborne geophysical surveys, magnetic and electromagnetic data, Troutlake River area; Ontario Geological Survey, Geophysical dataset 1222 - Revised.

OGS (Ontario Geological Survey), 2003, Uchi-Bruce Lakes Area, Ontario airborne magnetic and electromagnetic surveys, processed data and derived products, Archean and Proterozoic greenstone belts; Geophysical Dataset CD-ROM 1026-Revised

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

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

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

Parks Canada. 2012a. Canada's Historic Places. http://www.historicplaces.ca/en/pages/register-repertoire/search-recherche.aspx. Accessed May 15, 2012.

Parks Canada, 2012b. National Historic Sites. http://www.pc.gc.ca/progs/lhn-nhs/index.aspx. Accessed May 15, 2012.

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

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

Percival, J.A. and R.M. Easton, 2007. Geology of the Canadian Shield in Ontario: an update; Ontario Geological Survey, Open File Report 6196, Geological Survey of Canada, Open File 5511, Ontario Power Generation, Report 06819-REP-01200-10158-R00, 65p.

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

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

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

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

Posiva, 2011. Thermal Properties of Rocks in Olkiluoto: Results of Laboratory Measurements 1994-2011: Working Report 2011 – 17 by Kukkonen, I., L. Kivekäs, S. Vuoriainen, M. Kääriä, Posiva Oy.

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

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

Prest, V.K., 1982. Quaternary geology of the Madsen area, Kenora District (Patricia Portion). Ontario Geological Survey, Map P2484, scale 1:50,000.

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

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

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

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

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

SRK (SRK Consulting Inc.), 2013. Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Interpretation, Township of Ear Falls, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0022.

Sanborn-Barrie, M. 1991. Structural geology and tectonic history of the eastern Lake of the Woods greenstone belt, Kenora district, Ontario Geological Survey, Open File Report 5773,137p.

Sanborn-Barrie, M., N. Rogers, T. Skulski, J. Parker, V. McNicoll and J. Devany, 2004. Geology and Tectonostratigraphic Assemblages, East Uchi Subprovince, Red Lake and Birch-Uchi belts, Ontario; Geological Survey of Canada, Open File 4256. Ontario Geological Survey, Preliminary Map P.3460, 1:250,000

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

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

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

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

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

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

Shklanka, R., 1970. Geology of the Bruce Lake Area District of Kenora By R. Shklanka, Geological Report 82, 26p.

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

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

Stone, D., 1981. The Sydney Lake Fault Zone in Ontario and Manitoba; Unpublished Ph.D. Thesis, University of Toronto, 146p.

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

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

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

Stott, G.M. and F. Corfu, 1991. Uchi Subprovince in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, pp.145-236.

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

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

Sutcliffe, R.H, 1991. Proterozoic Geology of the Lake Superior Area; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, pp. 3-25.

Symons, D.T.A., I.A. Osmani, and M. Stupavsky, 1983. Magnetization characteristics of the Algoman iron formation and host rocks at the Griffith Mine, Red Lake, Ontario. Ontario Geological Survey, Open File Rept. 5447, p. 19-57.

Thomas, M.D., and J.G. Hayles, 1988. A review of geophysical investigations at the site of Chalk River Nuclear Laboratories, Ontario. Geological Survey of Canada Paper 88-13.

Thurston, P.C. and D. Paktunc, 1985. Western Uchi Subprovince Stratigraphy (Troutlake River Area), Pakwash Lake Sheet. District of Kenora (Patricia Portion); Ontario Geological Survey, Geological Series Preliminary Map, P.28S8, scale 1:50,000.

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

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

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

van de Kamp, P.C. and G. P. Beakhouse, 1979. Paragneisses in the Pakwash Lake area, English River gneiss belt, northwestern Ontario; Canadian Journal of Earth Sciences 16, 1753-1763.

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

Westerman, C.J., 1977. Tectonic evolution of a part of the English River Subprovince, Northwestern Ontario; unpublished PhD thesis, McMaster University, Hamilton, Ontario, 292p. http://digitalcommons.mcmaster.ca/cgi/viewcontent.cgi?article=1875&context=opendissertations

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

Zeng, F., and A. J. Calvert, 2004. A Combined Seismic Tomographic and Reflection Imaging Across the Red Lake Greenstone Belt Using LITHOPROBE Line 2B; CSEG National Convention Proceedings; 3p.

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

Report Signature Page

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CWM/GWS/wlm

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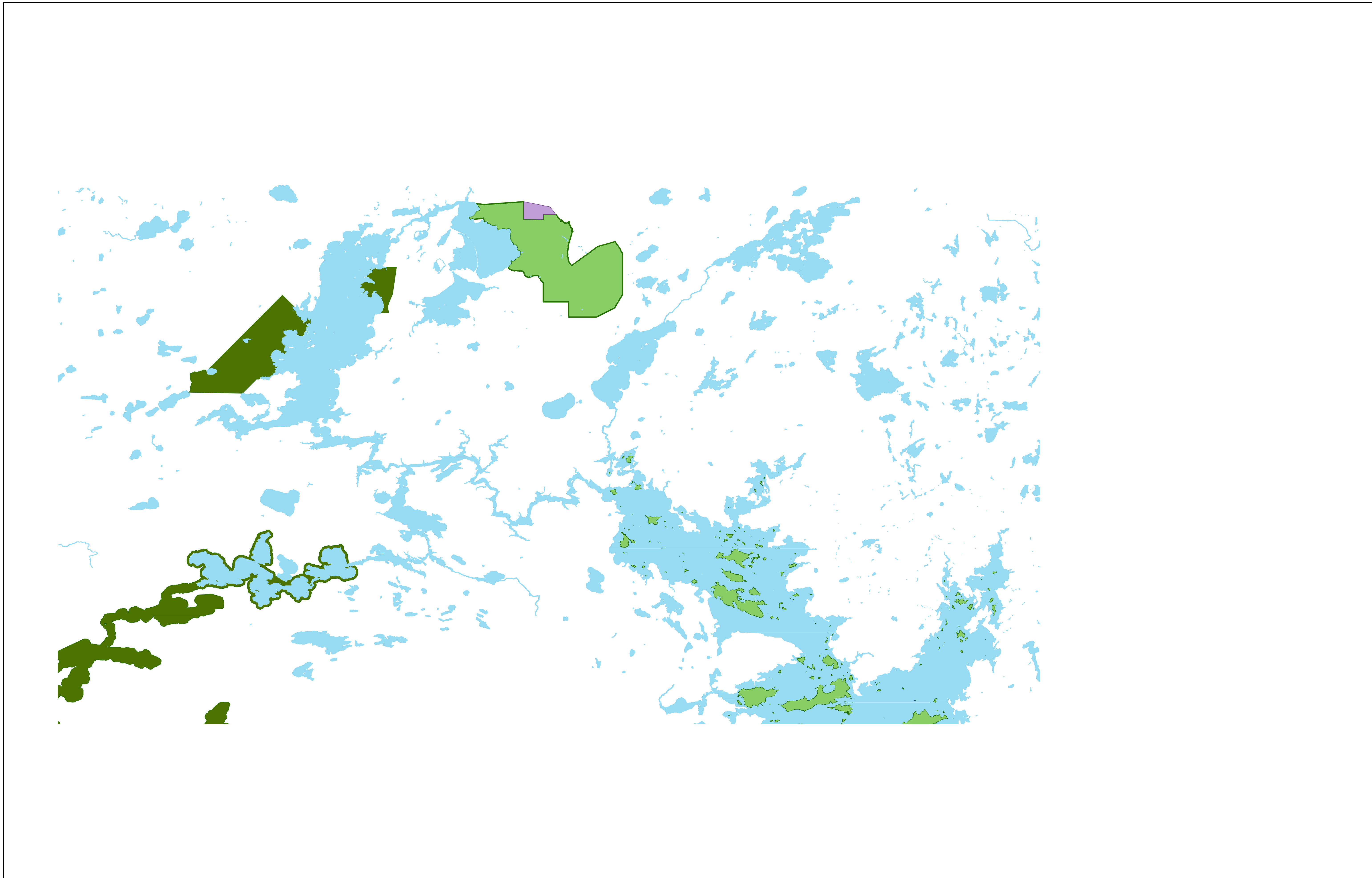
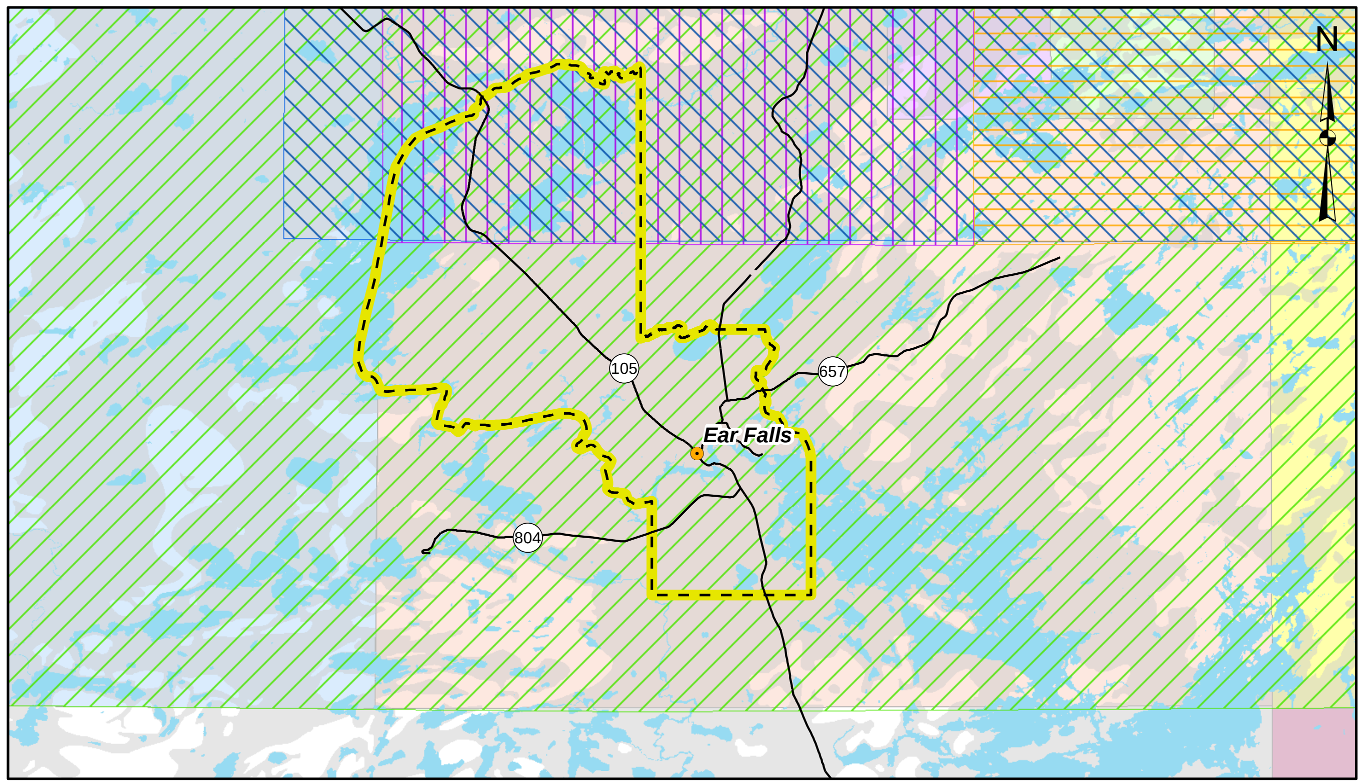
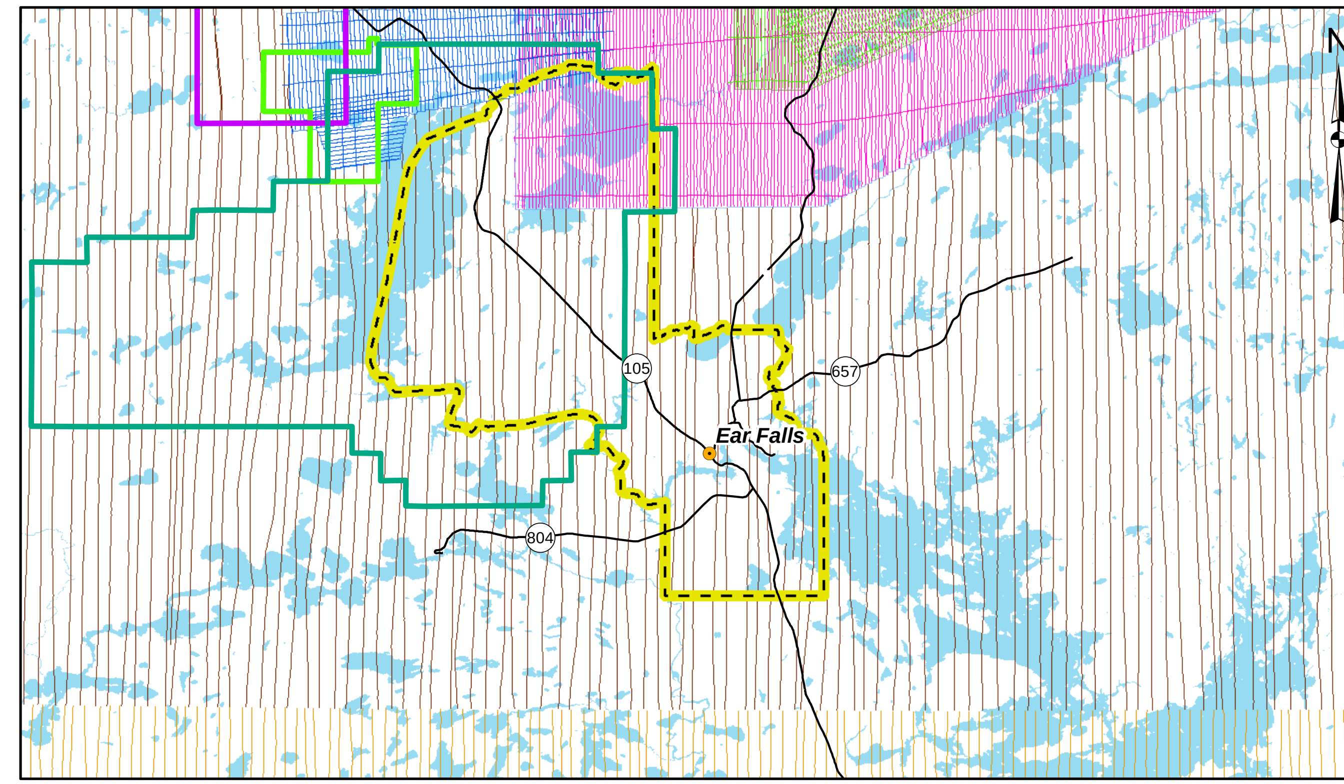
FIGURES



Geology Mapping Coverage



Geophysics Mapping Coverage



LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Ear Falls
- Main Road
- Water Area, Permanent
- Overburden Cover

Bedrock Geology Coverage

- Fenwick, 1967 (P0410)
- Fenwick, 1967 (P0411)
- Breaks et al., 1975 (P1027)
- Breaks et al., 1975 (P1200)
- Breaks et al., 1976 (P1202)
- Breaks et al., 1976 (P1199)
- Thurston and Paktunc, 1981 (P2386)
- Thurston and Paktunc, 1985 (P2858)
- Thurston and Paktunc, 1985 (P2859)
- Sanborn-Barrie et al., 2004 (P3460)

Full Geology Coverage

Breaks et al., Western English River Subprovince, 1978 (P1971)
OGS Quaternary Geology of Ontario (Data Set 14)
OGS Bedrock Geology of Ontario 2011 (MRD 126)

Full Geophysics Coverage

GSC Gravity 1946-1974
GSC Radiometric 1975, 1979, 1996
OGS Ontario #7, 1965-1979 (800 m spacing)

REFERENCE

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

LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Ear Falls
- Main Road
- Water Area, Permanent

Geophysical Survey Extent

- Uchi, Bruce Lake (GDS1026)
- Pakwash Lake (GDS1218)
- Troutlake River (GDS1222)
- Ontario #6
- Ontario #7
- Grancru Survey
- Fronteer Survey
- Laurentian Survey

10 5 0 10 20 30
SCALE 1:450,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geoscience Mapping and
Geophysical Coverage of the Ear Falls Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	19 Oct. 2012		
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		

FIGURE: 1.2

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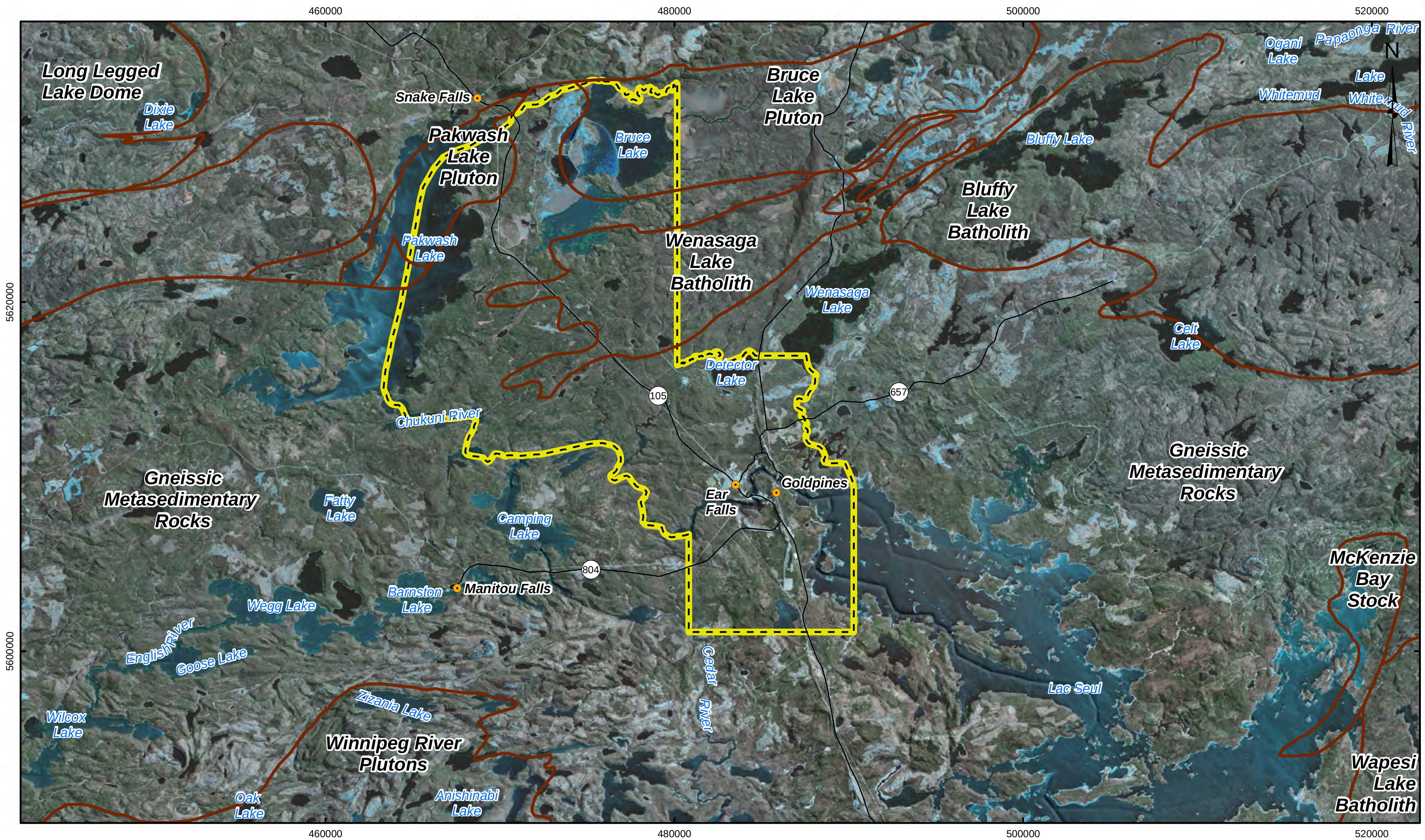
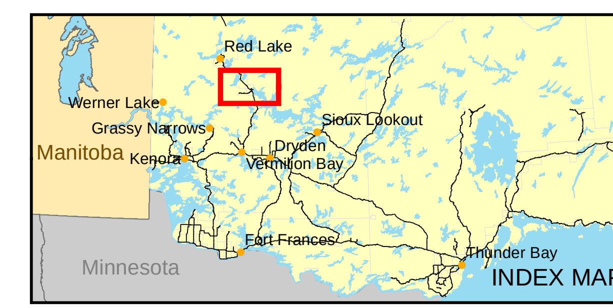
LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Community
- Main Road
- Major Geological Contact





REFERENCE

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

5 2.5 0 5 10 15

SCALE 1:275,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Satellite Imagery of the Ear Falls Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	30 Aug. 2010	FIGURE: 2.1	
GIS	PM/JB	18 Oct. 2013		
CHECK	CM	18 Oct. 2013		
REVIEW	GWS	18 Oct. 2013		

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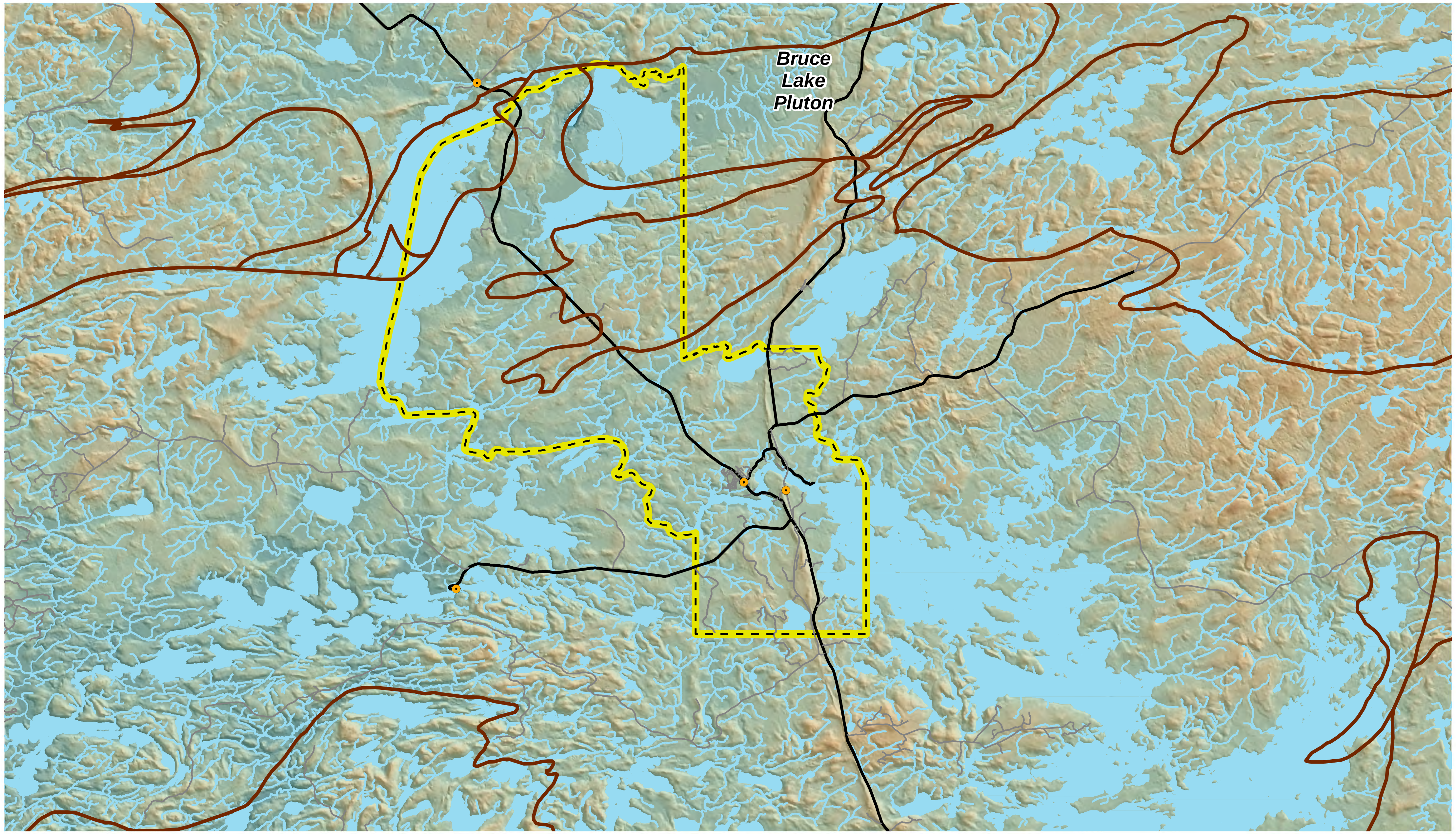
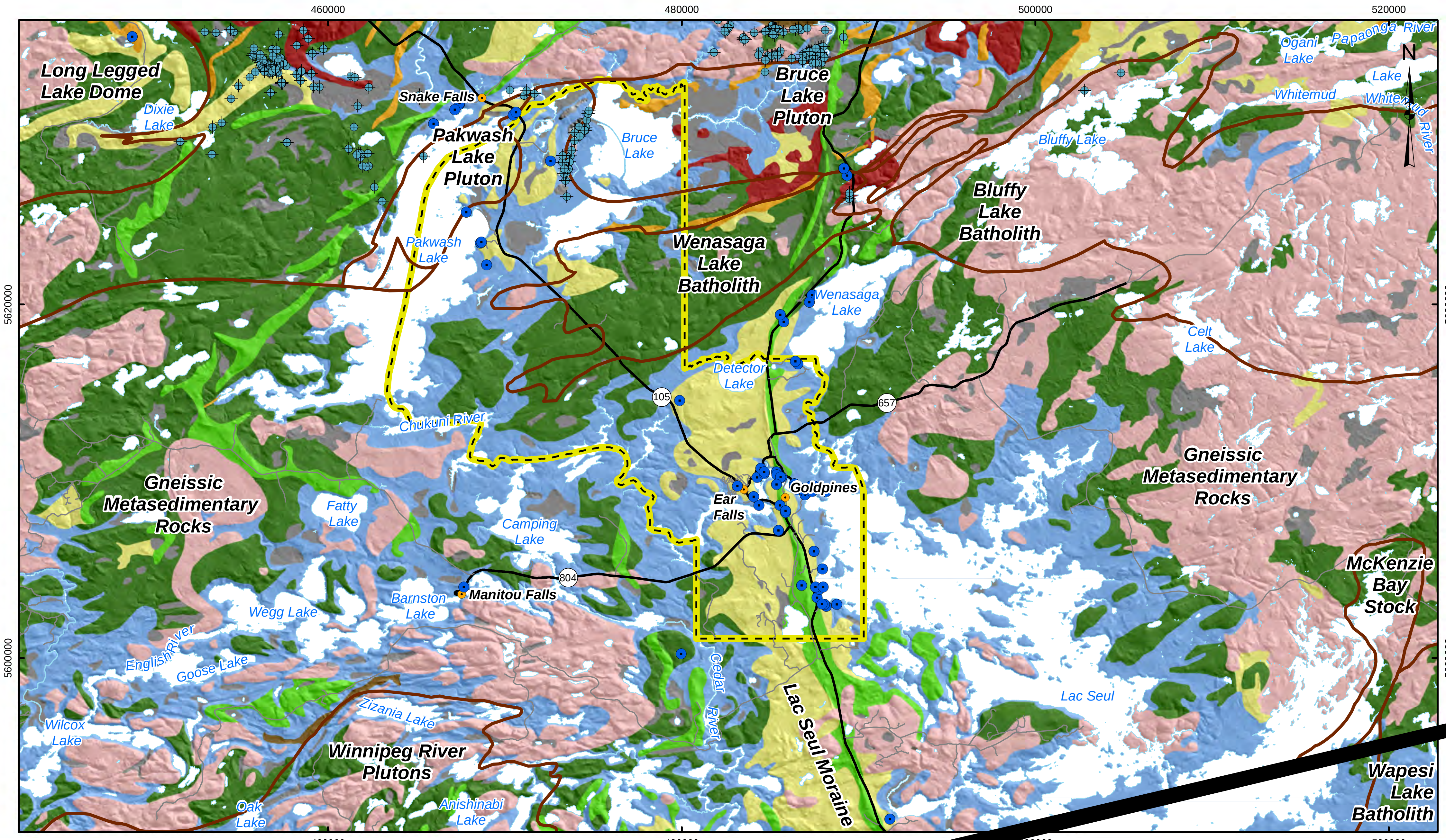

Bruce
Lake
Pluton



LEGEND

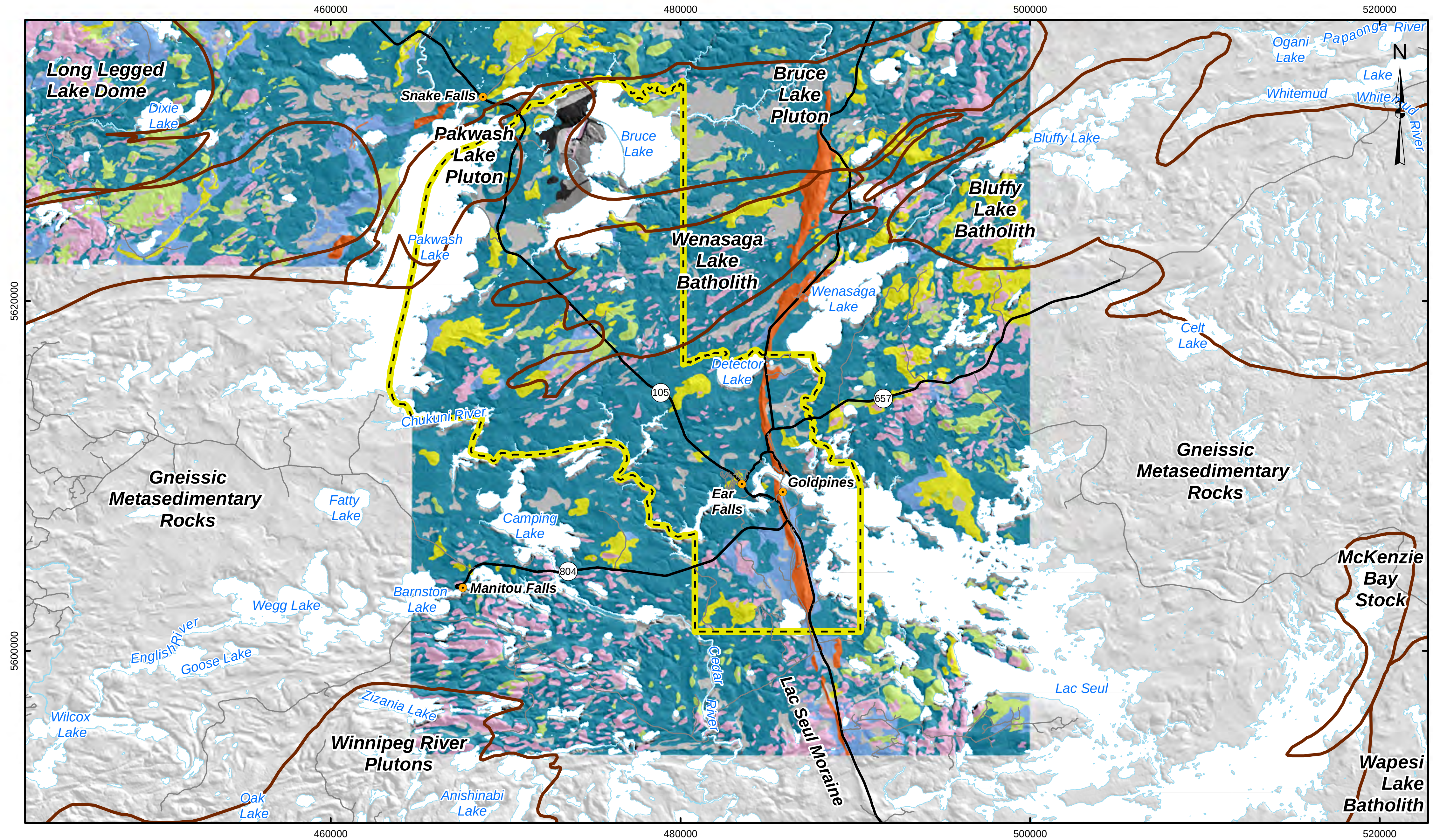
Base ... LIO, obtained 2009-2012
...M - CDED elevation (1:50,000)
Landform - OGS, MND Mines, and Northeast Science and Information Section, MNR 2005
Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Geology/Drillholes - MRD126-Bedrock Geology of Ontario, 2011
Water Wells - Ministry of the Environment, last accessed October 18, 2012
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Terrain Features of the Ear Falls Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 2.3	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		

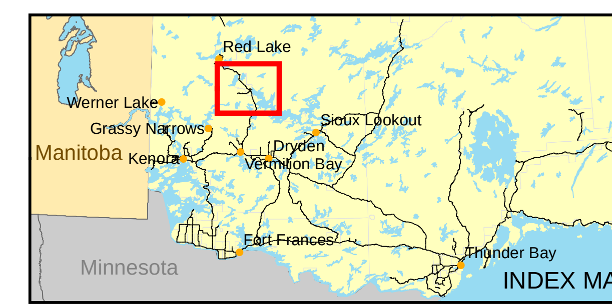


LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Community
- Main Road
- Local Road
- Water Area, Permanent
- Major Geological Contact

Surficial Geology

- 1 - Bedrock
- 2 - Glacial deposit
- 3 - Glacial and glaciofluvial deposit
- 4 - Glaciofluvial deposit
- 5 - Deep-water glaciolacustrine deposit
- 6 - Nearshore glaciolacustrine deposit
- 7 - Organic deposit
- 8 - Mine waste



REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
DEM - CDED elevation (1:50,000)
Surficial Geology - OGS P2484 2572 2585 (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:275,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Surficial Geology of the Ear Falls Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 2.4	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		

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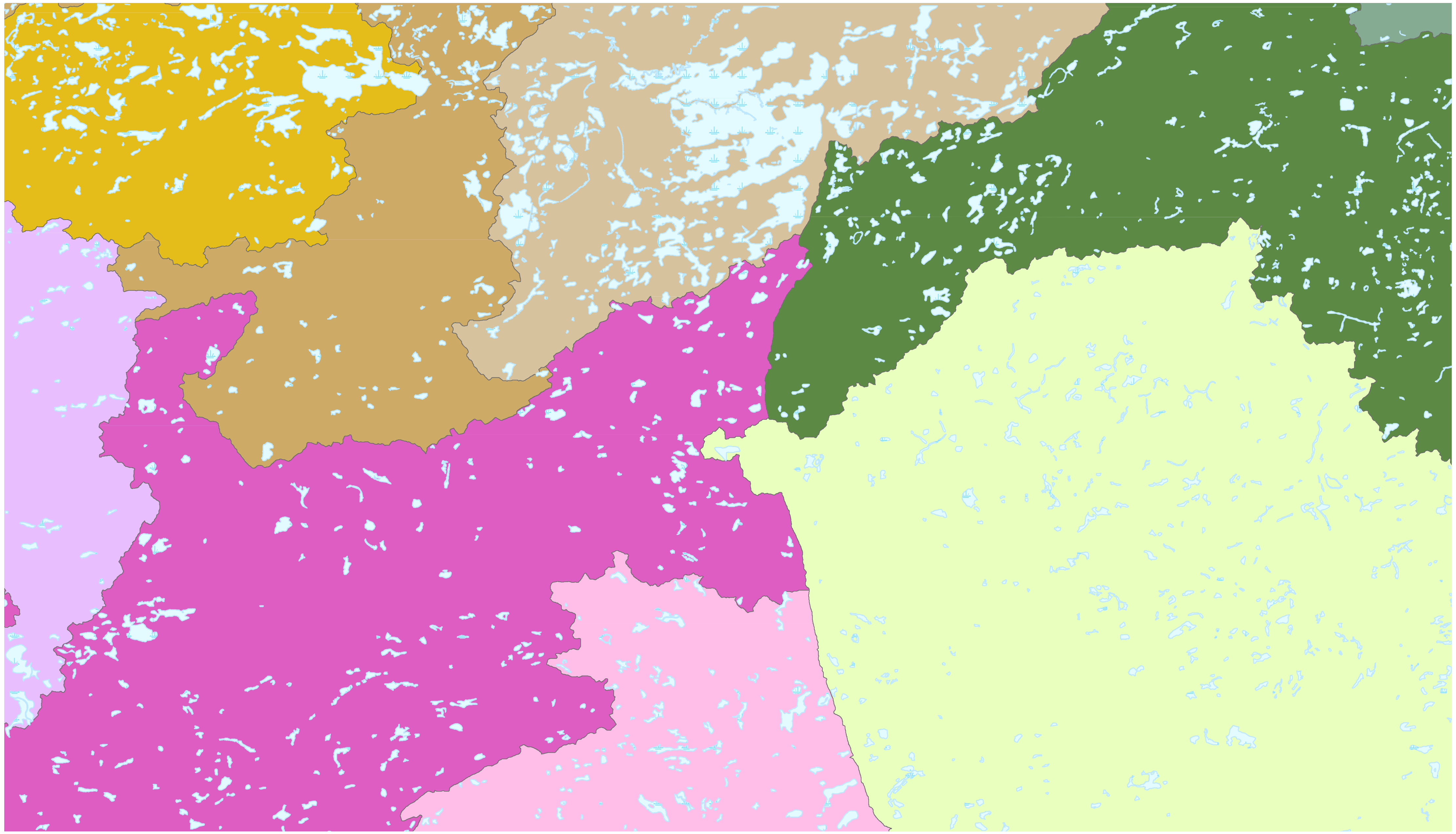

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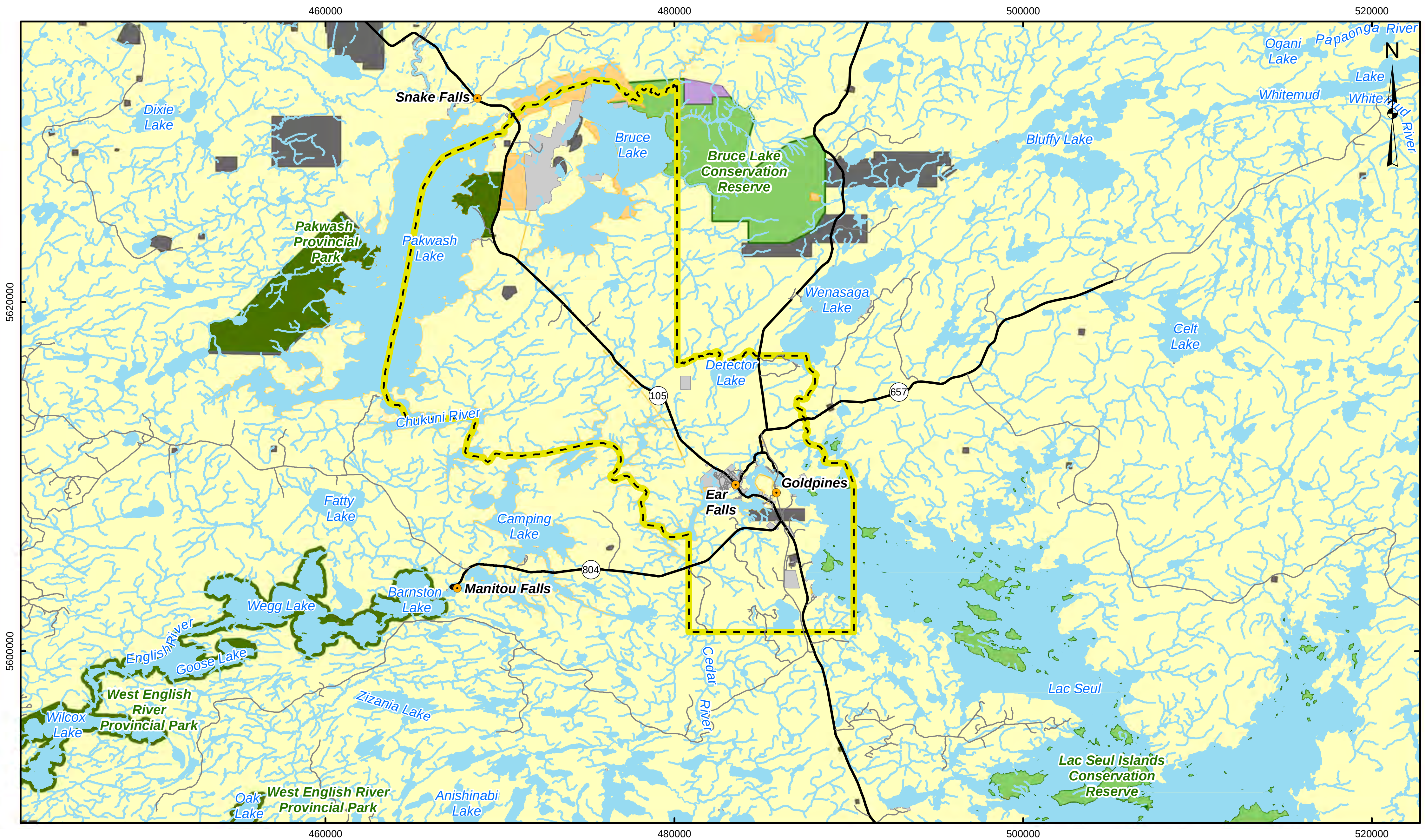

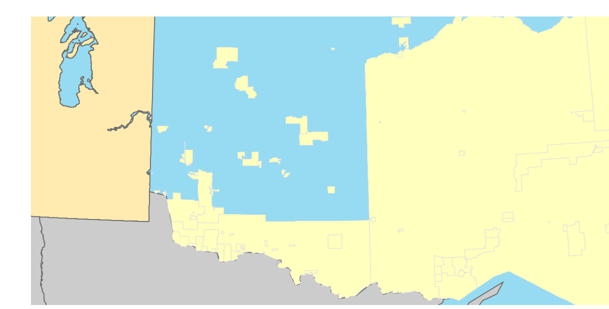

Base Data - MNR NRVIS, obtained 2009-2012, CANMAP v2006.4
Claims - Ministry of Northern Mines and Development November 30, 2012
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Land Disposition and Ownership within the Ear Falls Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	30 Aug. 2010	FIGURE: 2.6	
GIS	PM/JB	18 Oct. 2013		
CHECK	CM	18 Oct. 2013		
REVIEW	GWS	18 Oct. 2013		

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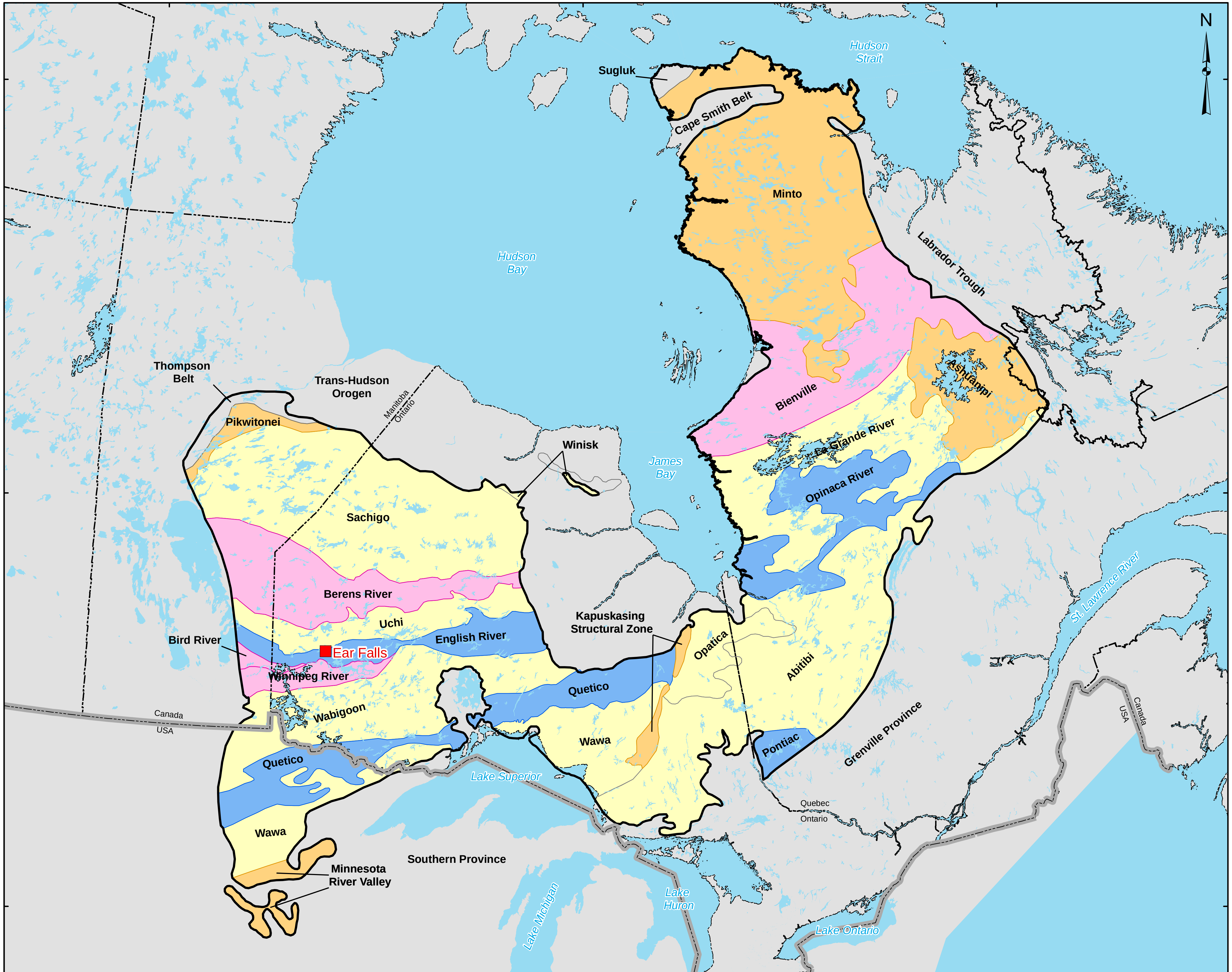
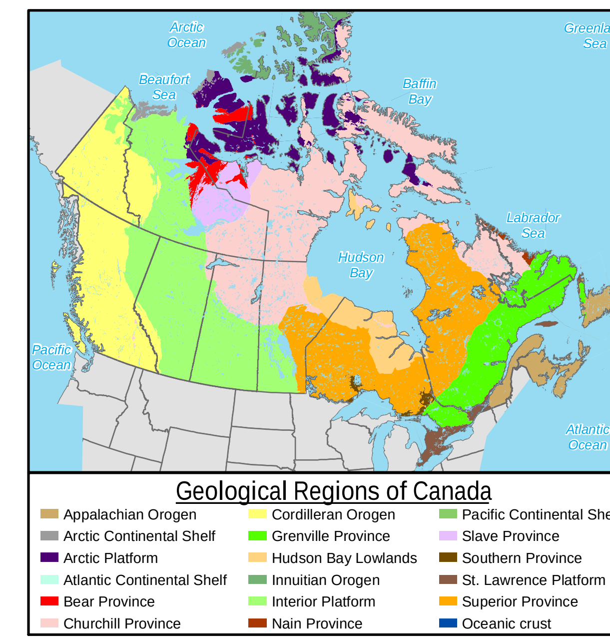


LEGEND

- Township of Ear Falls
- Provincial Boundary
- International Boundary
- Limit of Exposed Archean Rock

Superior Province (Archean)

- Sub-Province Gneissic - Plutonic
- Sub-Province Plutonic
- Sub-Province Metasedimentary
- Sub-Province Volcanic-Plutonic



REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
Archean Geology of Ontario - Thurston, P. C. 1991 in Geology of Ontario, OGS, Special Volume 4, Part 1, p.73-78
Geology - Geological Map of Canada 1996, Map D1860A
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2009
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

200 100 0 200 400

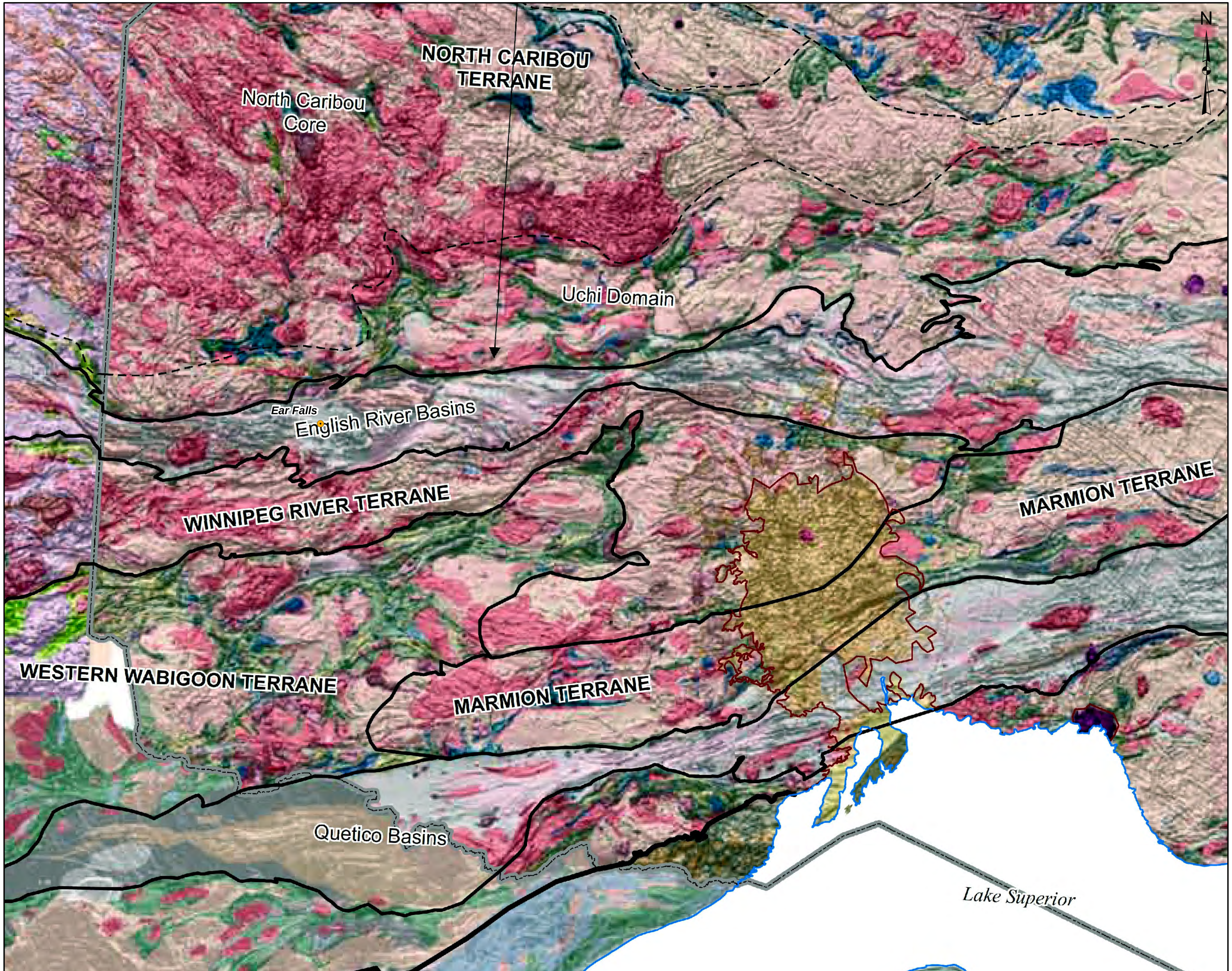
SCALE 1:9,500,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Subdivision of the Superior Province of the Canadian Shield

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	11 May. 2012	FIGURE: 3.1	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		



LEGEND

- Ear Falls
- Provincial Boundary
- Domain Boundary
- Terrane Boundary
- Trans Hudson Orogen Extent

Bedrock Geology

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

REFERENCE

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

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SCALE 1:2,500,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Terrane Subdivision of the
Northwest Superior Province

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	30 Apr. 2012	FIGURE: 3.2	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		

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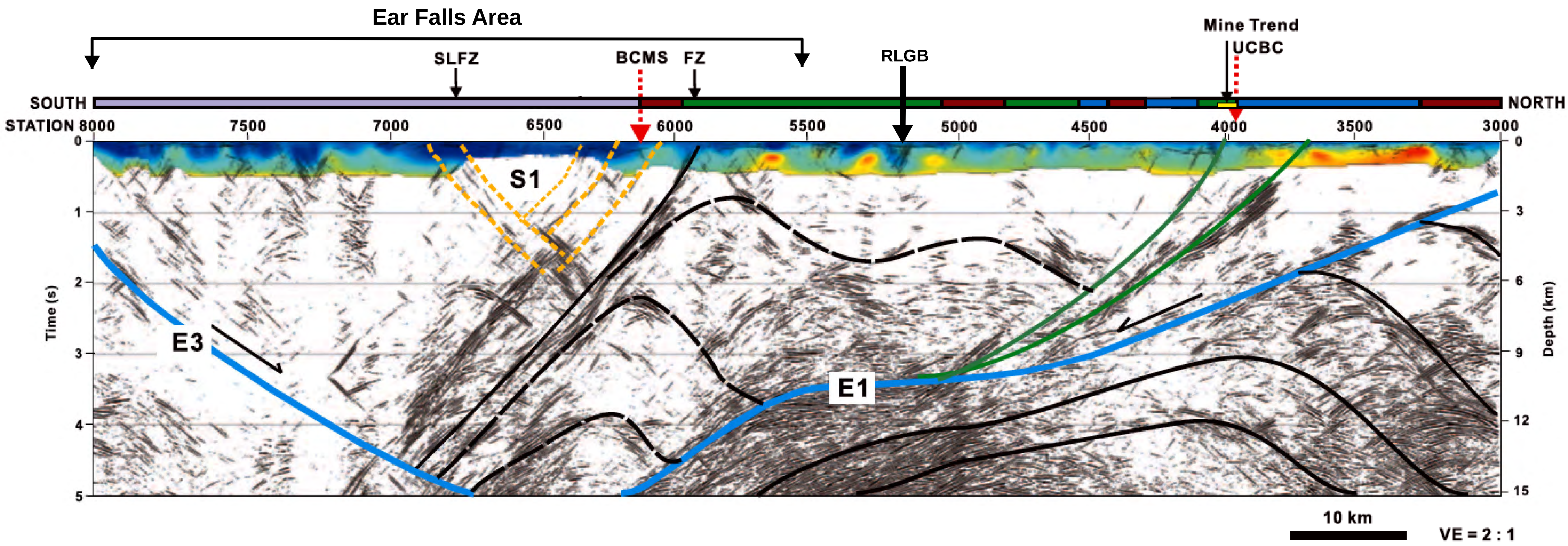


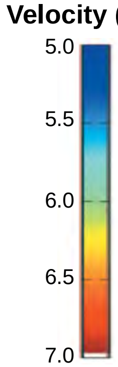
LEGEND

- Reflector Truncations
- Interpreted Reflectors
- Strike-slip
- Extensional Fault
- Reflections Associated with Shear Zones

- Metasedimentary Rocks
- Felsic-Intermediate Volcanics
- Mafic Volcanics
- Granite, Granodiorite

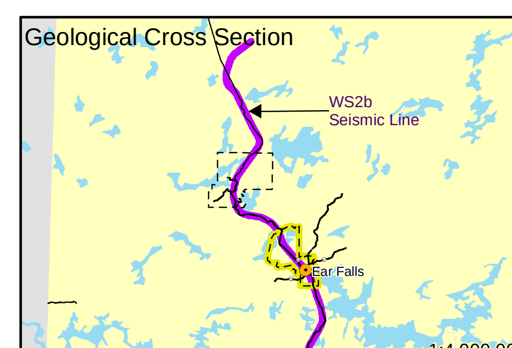
SLFZ - Sydney Lake Fault Zone
BCMS - boundary between the Confederation Assemblage
FZ - fault zone
RLGB - Red Lake Greenstone Belt
UCBC - unconformity between the Balmer and the Confederation assemblages

Velocity (km/s)



REFERENCE

Zeng, F., and A.J. Calvert, 2006. Imaging the upper part of the Red Lake greenstone belt, northwestern Ontario, with 3-D traveltime tomography: Canadian Journal of Earth Science 43: 849-863



PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

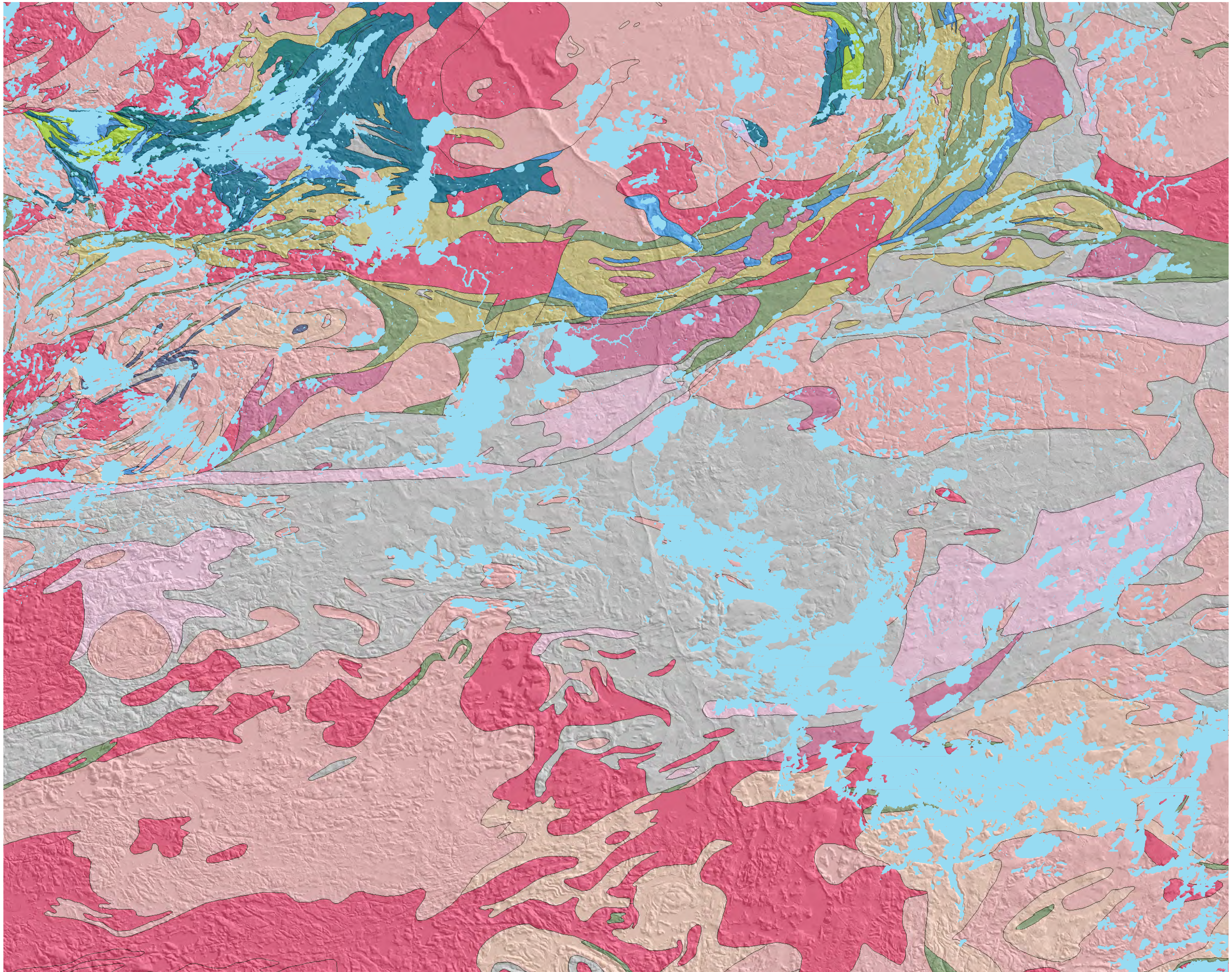
Interpreted Lithoprobe Section

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026		
DESIGN	PM	6 Nov. 2012
GIS	PM/JB	23 Aug. 2013
CHECK	CM	23 Aug. 2013
REVIEW	GWS	23 Aug. 2013

SCALE AS SHOWN
REV. 0.0

FIGURE: 3.3



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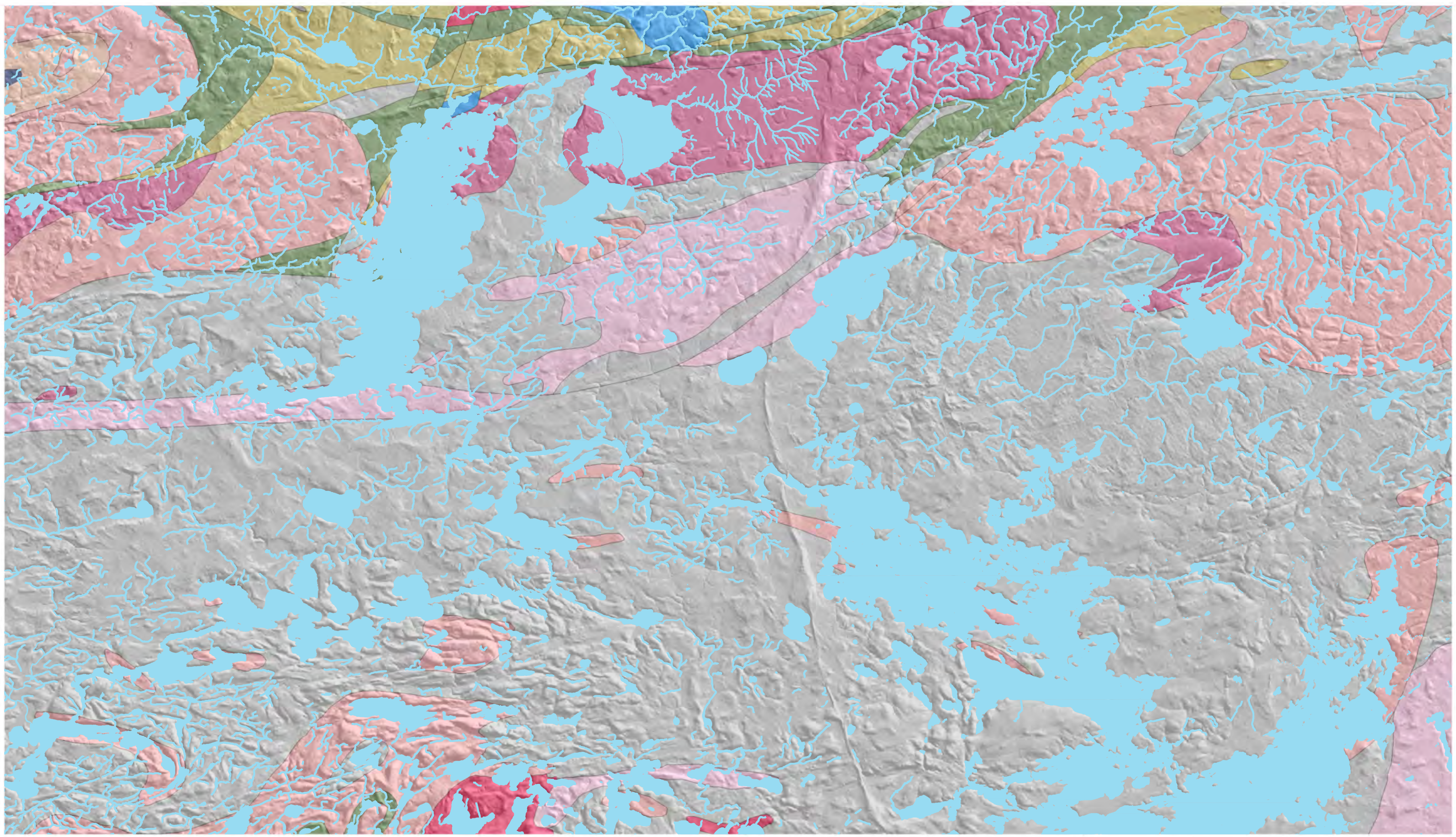

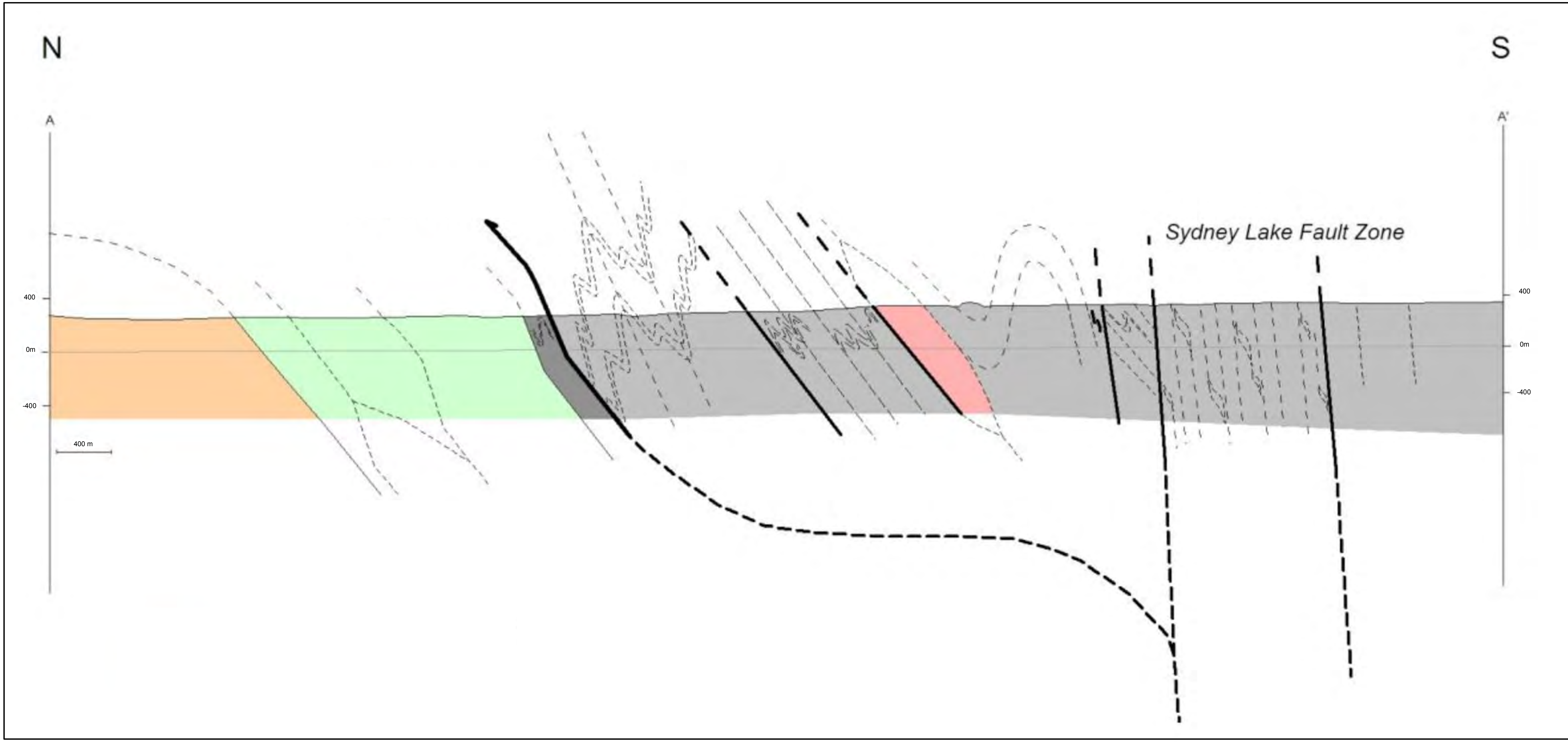

LEGEND

- Granodiorite
- Mafic/Intermediate Volcanic
- Metasediment
- Conglomerate
- Tonalite

REFERENCE

Laurentian Goldfields Limited, 2010. Goldpines South Property; Ear Falls Area, Ontario, Canada; Assessment Report - Figure 18: Cross section AA', prepared by Melissa Render, Steven R. Meade, and J.W. Patrick Lengyel

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Conceptual Geological Section

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	6 Nov. 2012	FIGURE: 3.6	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		

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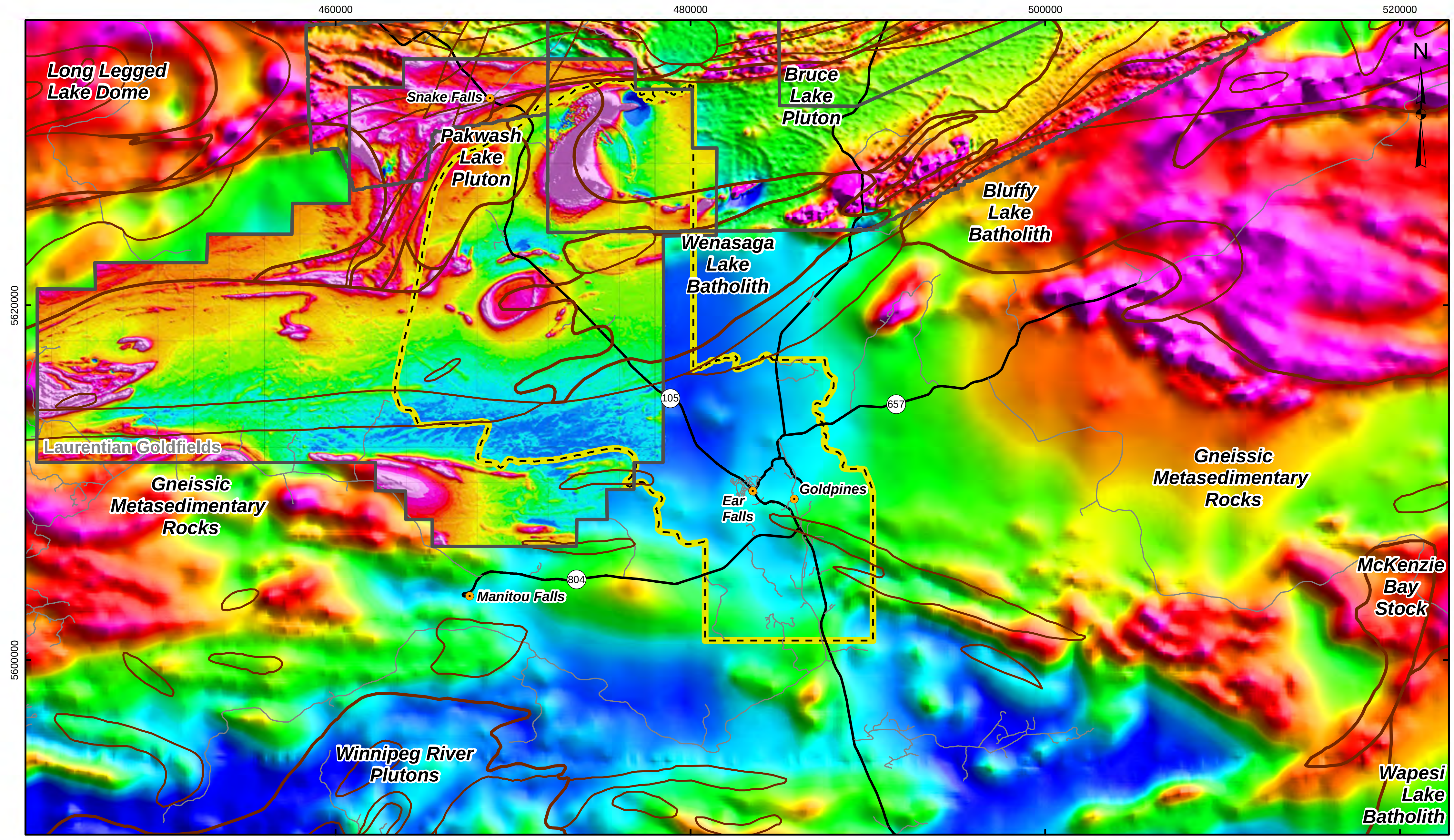


LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Community
- Main Road
- Local Road
- Geologic Contact
- Major Geological Contact
- Higher Resolution Geophysical Surveys

Residual Total Magnetic Field (nT)

OGS	Laurentian Goldfields
1077.4	58590
254.0	58300
98.8	58180
-27.7	58100
-141.5	58040
-292.6	58000
-477.5	57960
	57940
	57910
	57890
	57870
	57850
	57830
	57820
	57800
	57780
	57770
	57750
	57740
	57730
	57720
	57710
	57770
	57690
	57680
	57670
	57660
	57650
	57640
	57630
	57620
	57610
	57600
	57590
	57580

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Geophysics - GSC Canada 200m Compilation, Aug 2010; OGS Uchi-Bruce Lakes Area, GDS1026; OGS Red Lake Area Survey, GDS1028; OGS Pakwash Lake Area Survey, GDS1218; Laurentian Goldfields Ltd., Goldpines South Property, total magnetic field not GSC-Levelled
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:275,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

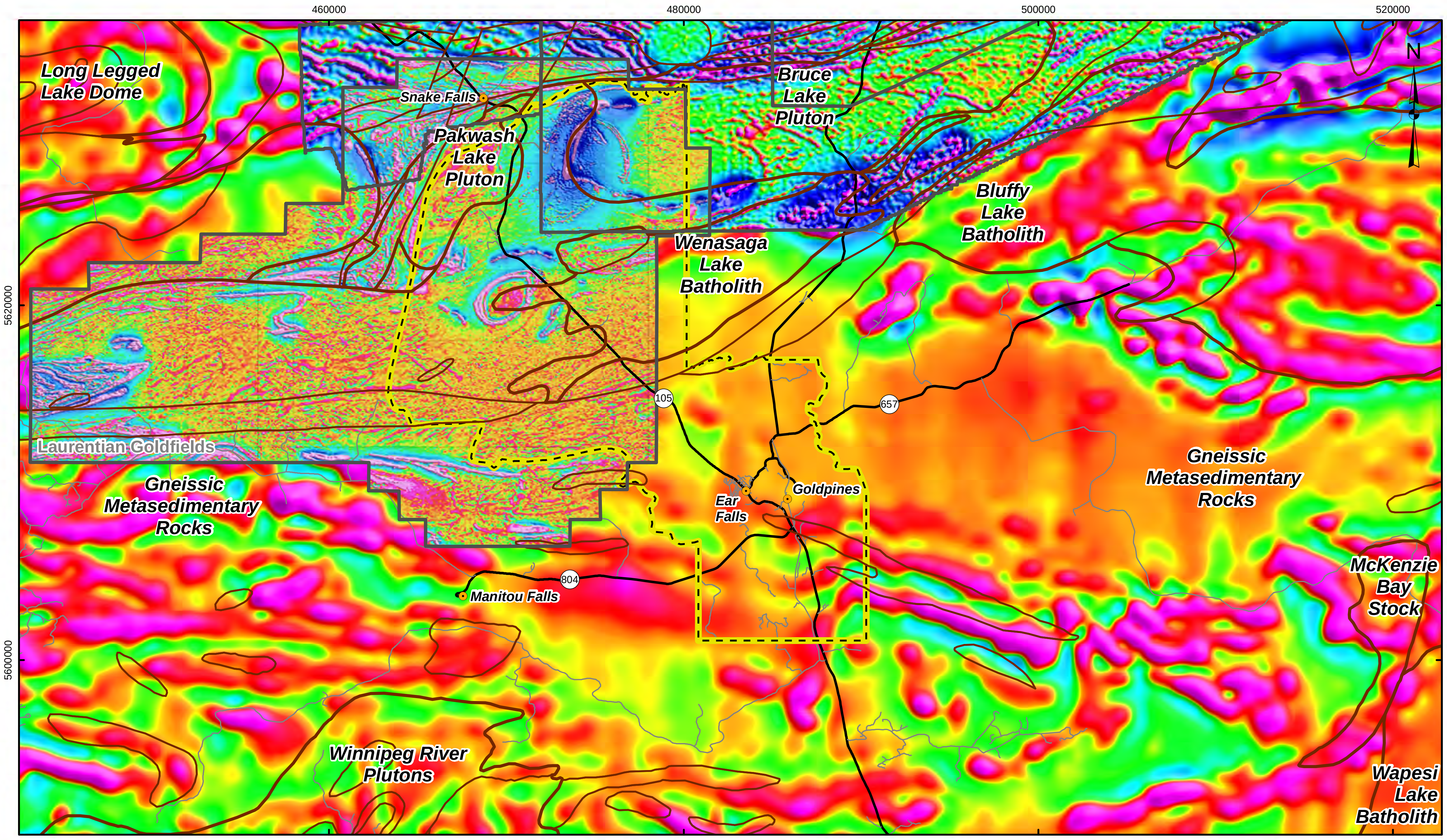
TITLE
Total Magnetic Field (Reduced to Pole) of the Ear Falls Area

Golder Associates
Mississauga, Ontario

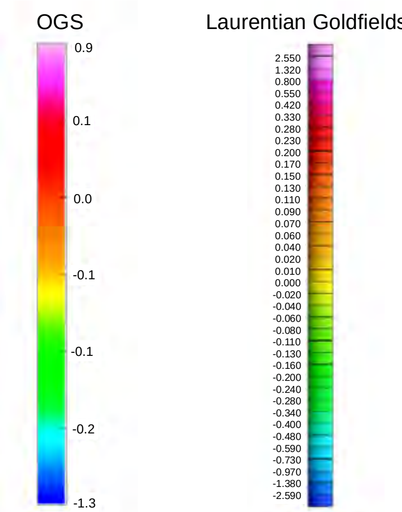
PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	11 May. 2012	FIGURE: 3.7	
GIS	PM/JB	18 Oct. 2013		
CHECK	CM	18 Oct. 2013		
REVIEW	GWS	18 Oct. 2013		

LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Community
- Main Road
- Local Road
- Geologic Contact
- Major Geological Contact
- Higher Resolution Geophysical Surveys



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



REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Geophysics - GSC Canada 200m Compilation, Aug 2010; OGS Uchi-Bruce Lakes Area, GDS1026: OGS Red Lake Area Survey, GDS1028; OGS Pakwash Lake Area Survey, GDS1218; Laurentian Goldfields Ltd., Goldpines South Property, total magnetic field not GSC-Levelled
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:275,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

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

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	11 May. 2012	FIGURE: 3.8	
GIS	PM/JB	18 Oct. 2013		
CHECK	CM	18 Oct. 2013		
REVIEW	GWS	18 Oct. 2013		

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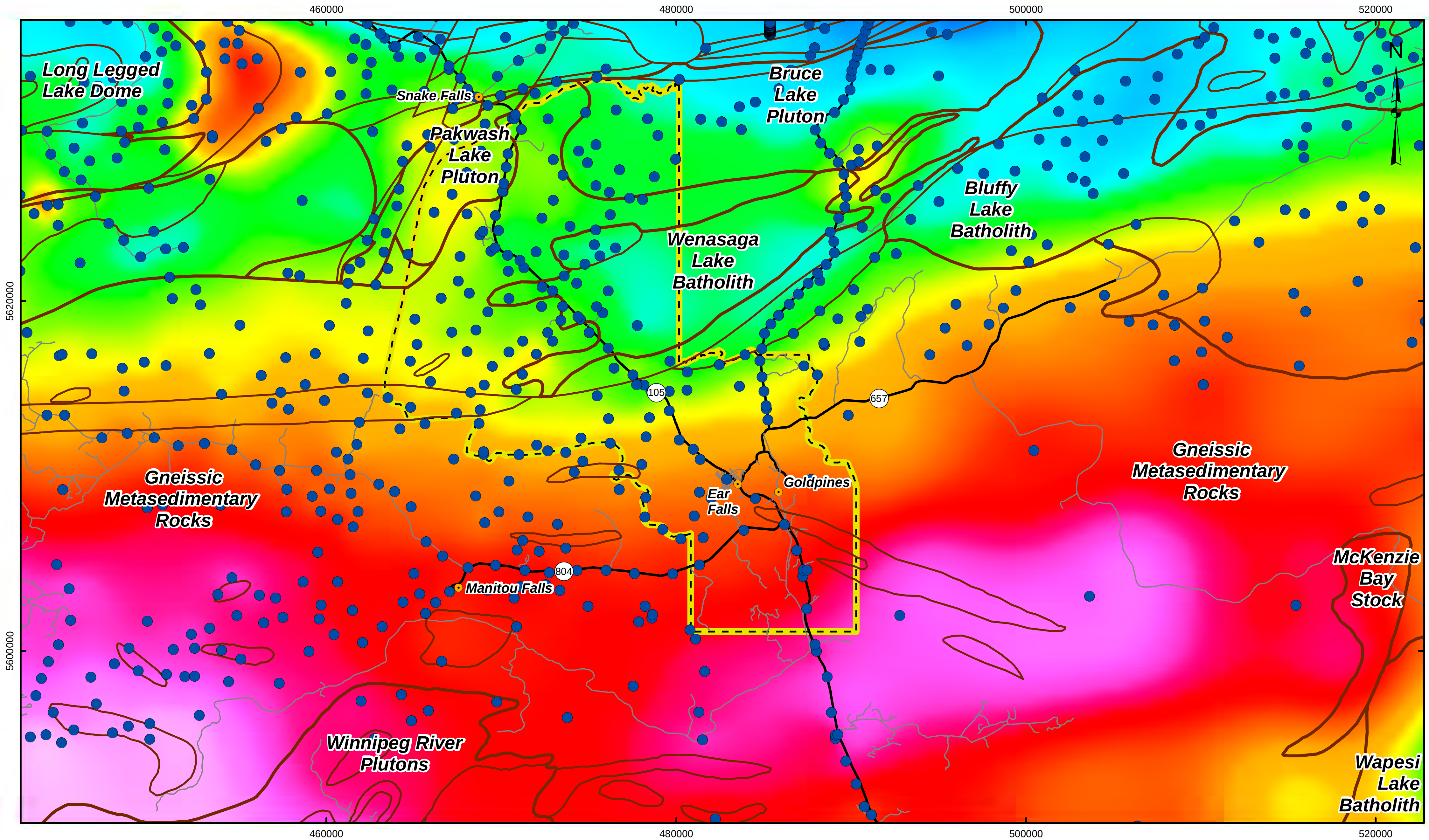
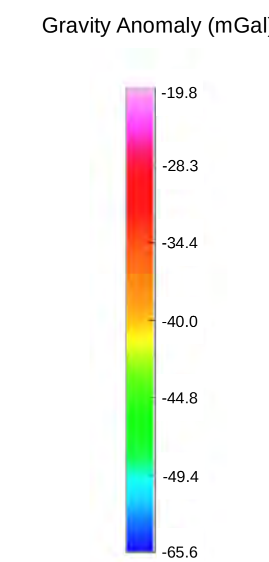


LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Community
- Main Road
- Local Road
- Gravity Station
- Geologic Contact
- Major Geological Contact



REFERENCE

Base Data - MNR LIO, obtained 2009-2012
Geophysics - GSC Canada - 2km resolution - Gravity Anomalies, 2010;
Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada Division, Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:275,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Bouguer Gravity of the Ear Falls Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	11 May. 2012		
GIS	PM/JB	18 Oct. 2013		
CHECK	CM	18 Oct. 2013		
REVIEW	GWS	18 Oct. 2013		

FIGURE: 3.9

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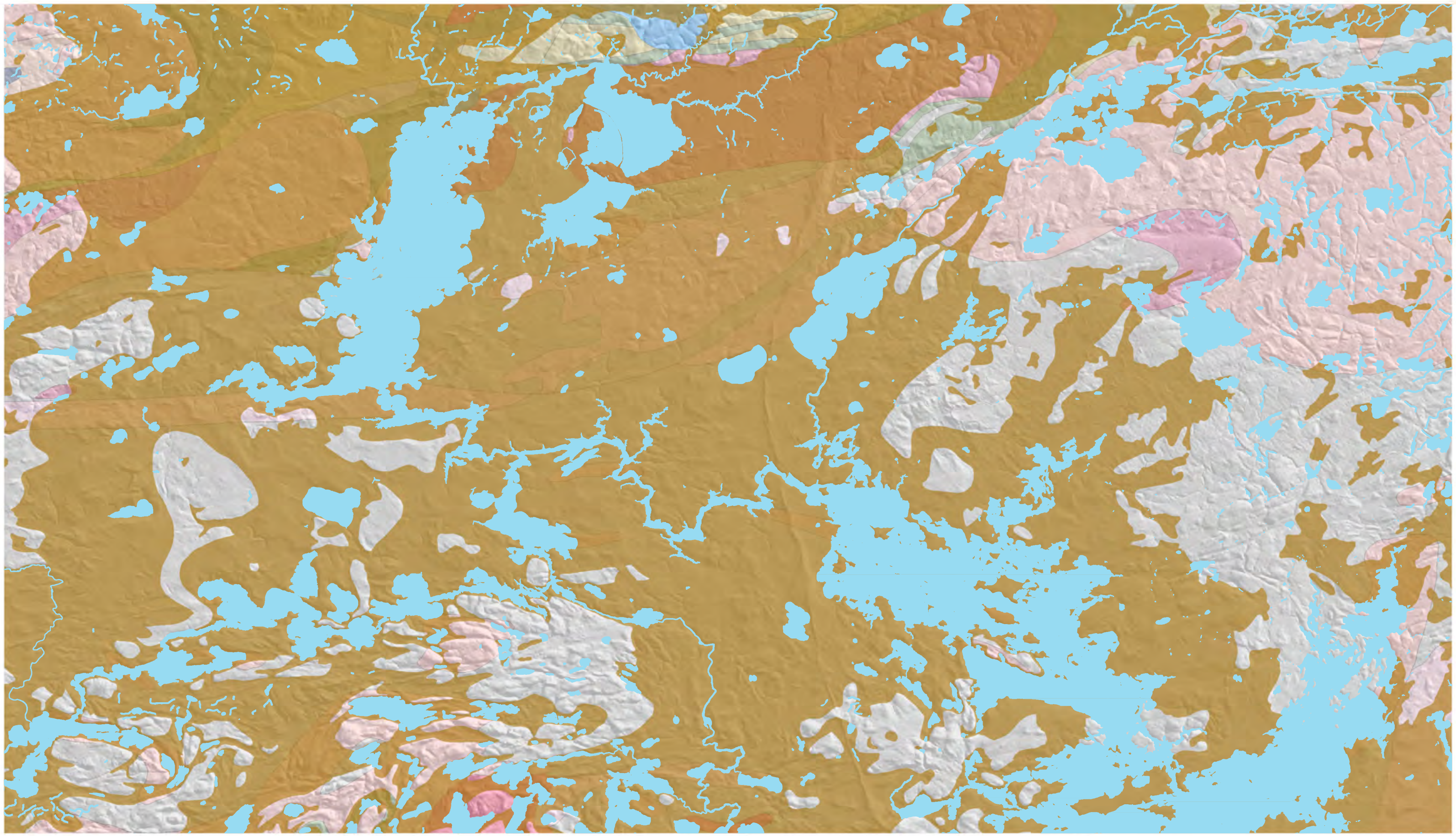
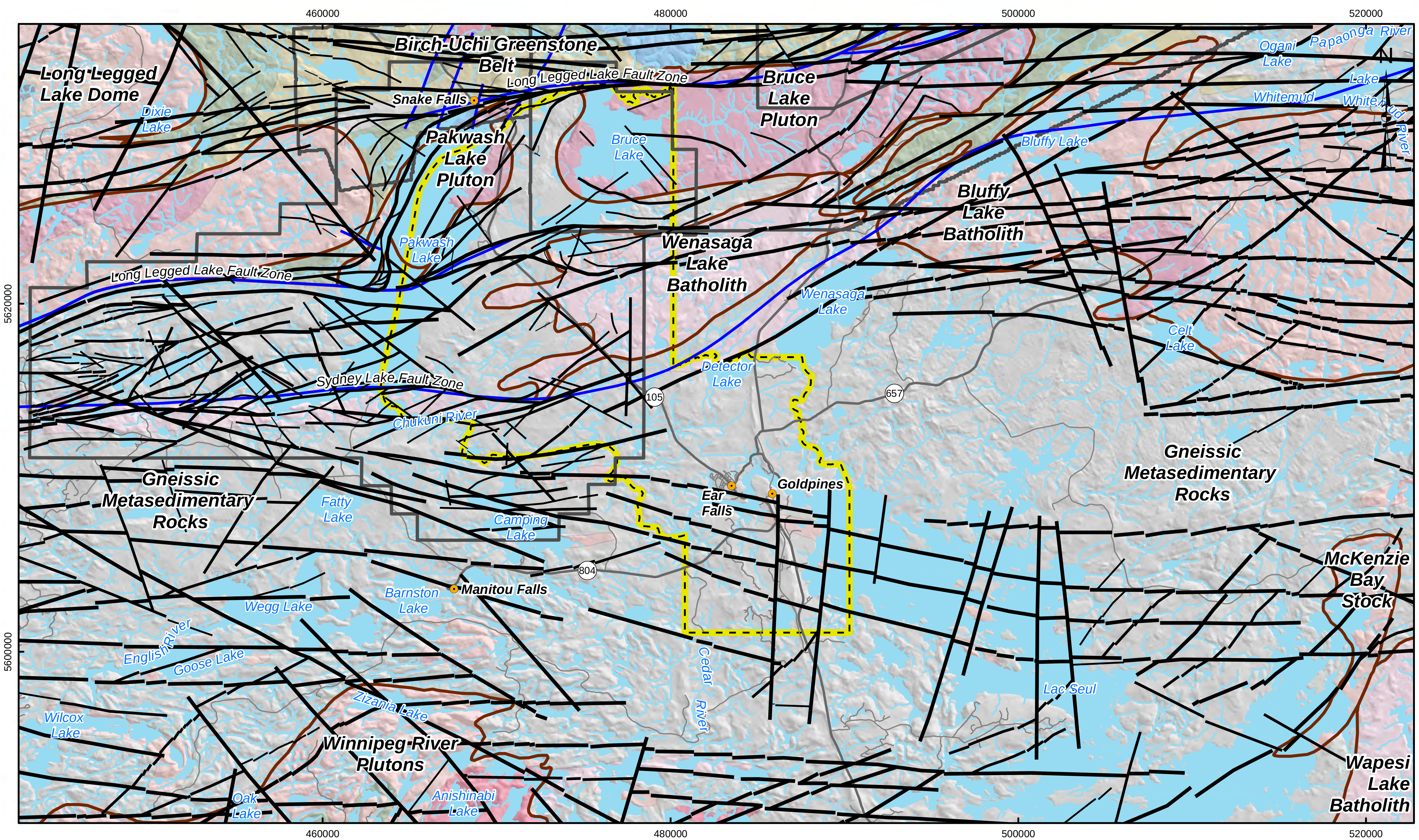




LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Community
- Main Road
- Local Road
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Major Geological Contact
- Mapped Fault
- Higher Resolution Geophysical Surveys

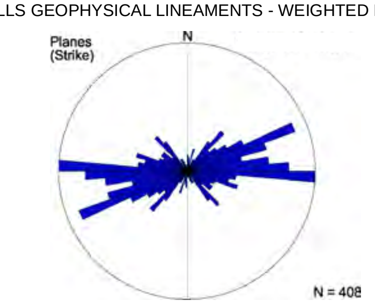
Geophysical Lineament

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

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 10a Gabbro
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
- 7d Conglomerate and arenite
- 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks

EAR FALLS GEOPHYSICAL LINEAMENTS - WEIGHTED HISTOGRAM



REFERENCE

Base Data - MNR LIO, obtained 2009-2012
DEM - CDED elevation (1:50,000)
Lineaments - Lineament Investigation for the Ear Falls Area, Ontario (SRK, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15
SCALE 1:275,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geophysical Lineaments of the Ear Falls Area

Golder Associates
Mississauga, Ontario

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

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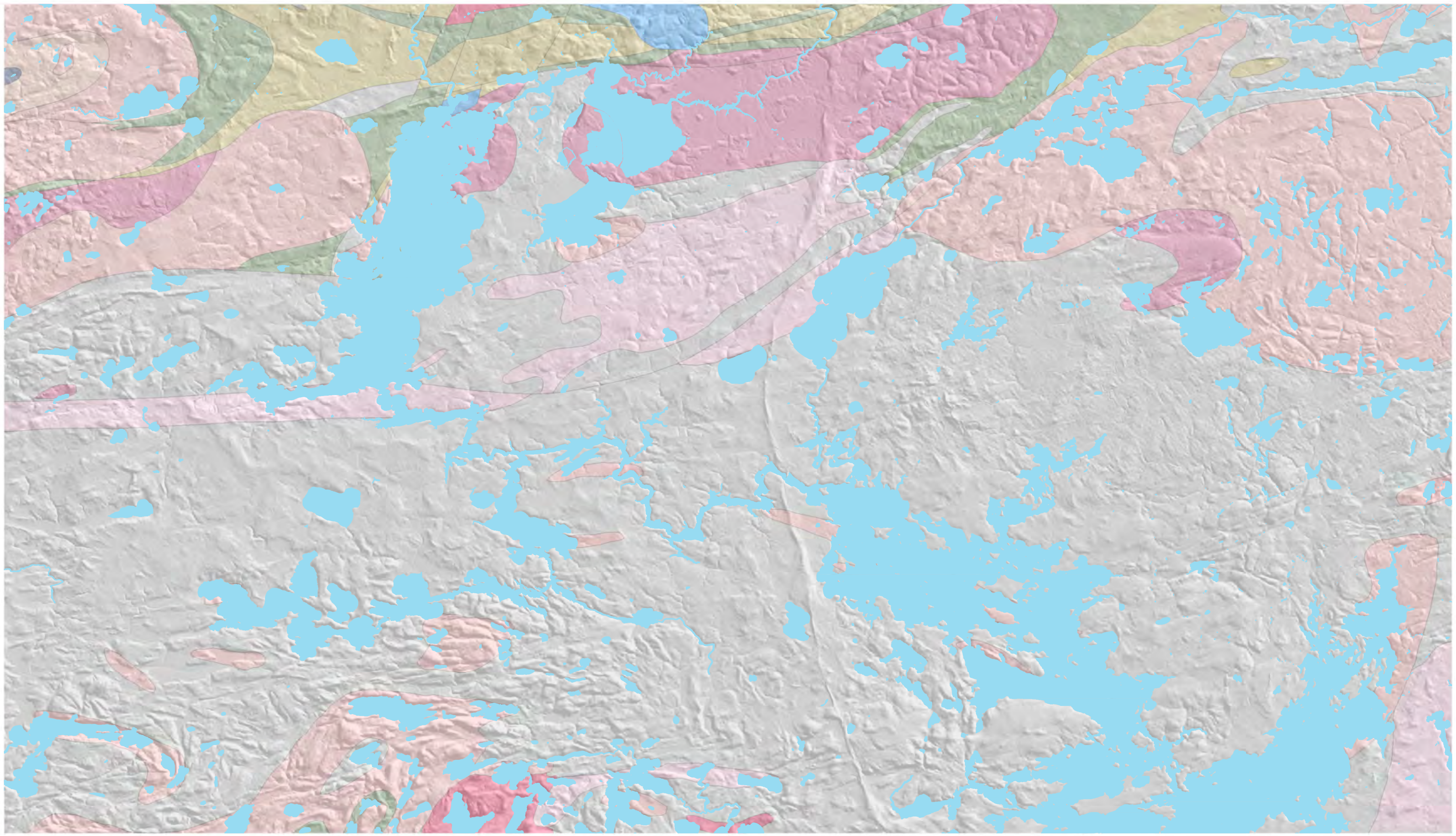


LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Community
- Main Road
- Local Road
- Watercourse, Permanent
- Watercourse, Intermittent
- Water Area, Permanent
- Mapped Fault
- Major Geological Contact

Brittle Lineament (Surficial and Geophysical)

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

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 10a Gabbro
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
- 7d Conglomerate and arenite
- 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks

REFERENCE

Base Data - MNR LIO, obtained 2009-2012
DEM - CDED elevation (1:50,000)
Lineaments - Lineament Investigation for the Ear Falls Area, Ontario (SRK, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:275,000 KILOMETRES

PROJECT

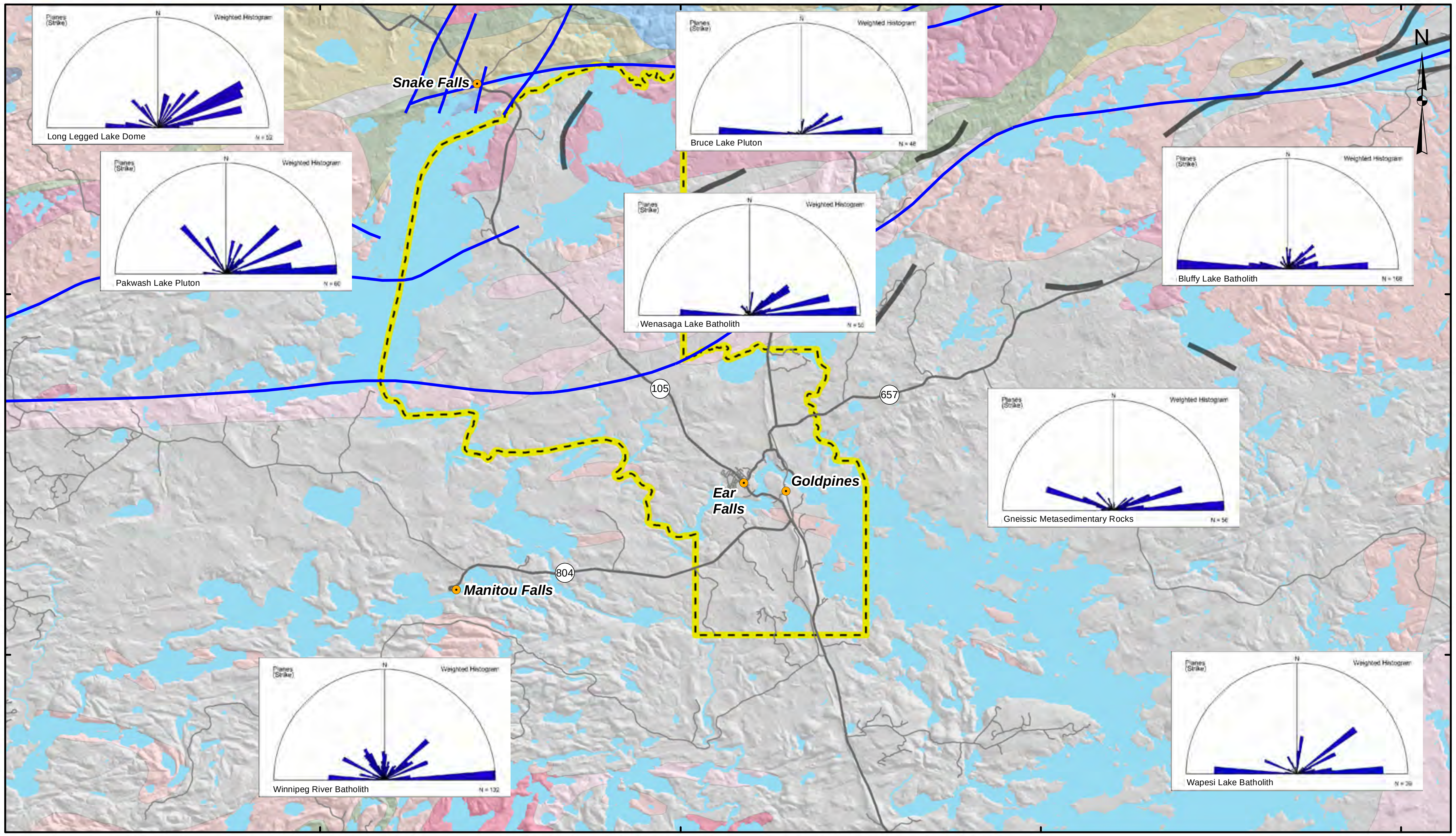
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Merged Lineaments of the Ear Falls Area

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012		
GIS	PM/JB	18 Oct. 2013		
CHECK	CM	18 Oct. 2013	FIGURE: 3.13	
REVIEW	GWS	18 Oct. 2013		

Golder Associates
Mississauga, Ontario



LEGEND

- Municipal Boundary (Township of Ear Falls)
- Municipal Boundary
- Community
- Main Road
- Local Road
- Water Area, Permanent
- Mapped Fault
- Iron Formation

Bedrock Geology

- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 10a Gabbro
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
- 7d Conglomerate and arenite
- 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
DEM - CDED elevation (1:50,000)
Lineaments - Lineament Investigation for the Ear Falls Area, Ontario (SRK, 2012)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15N

5 2.5 0 5 10 15

SCALE 1:275,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Lineament Orientations of Principal Geological Units of the Ear Falls Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN REV. 0
DESIGN	PM	17 May. 2012	FIGURE: 3.14
GIS	PM/JB	23 Aug. 2013	
CHECK	CM	23 Aug. 2013	
REVIEW	GWS	23 Aug. 2013	

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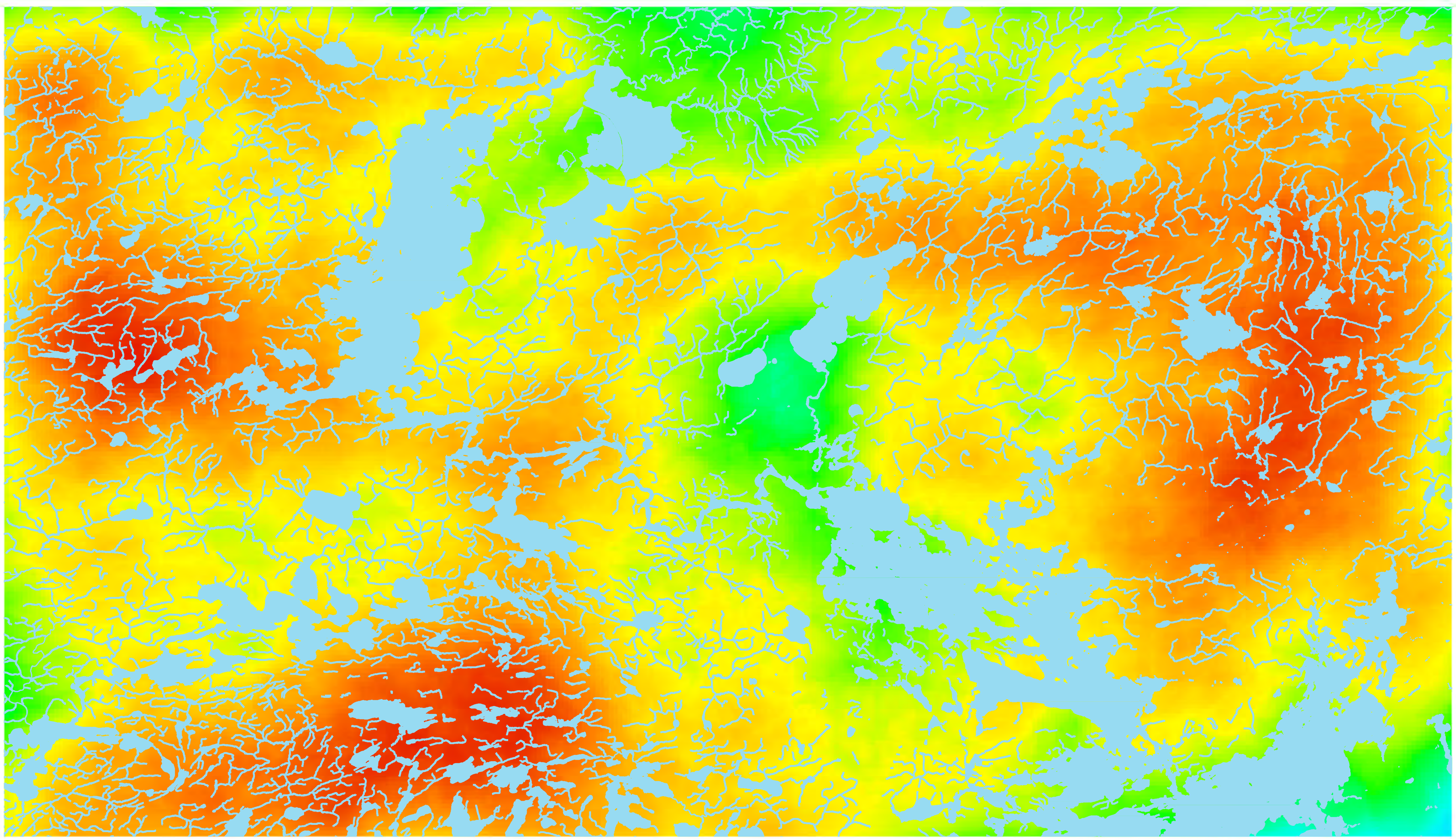

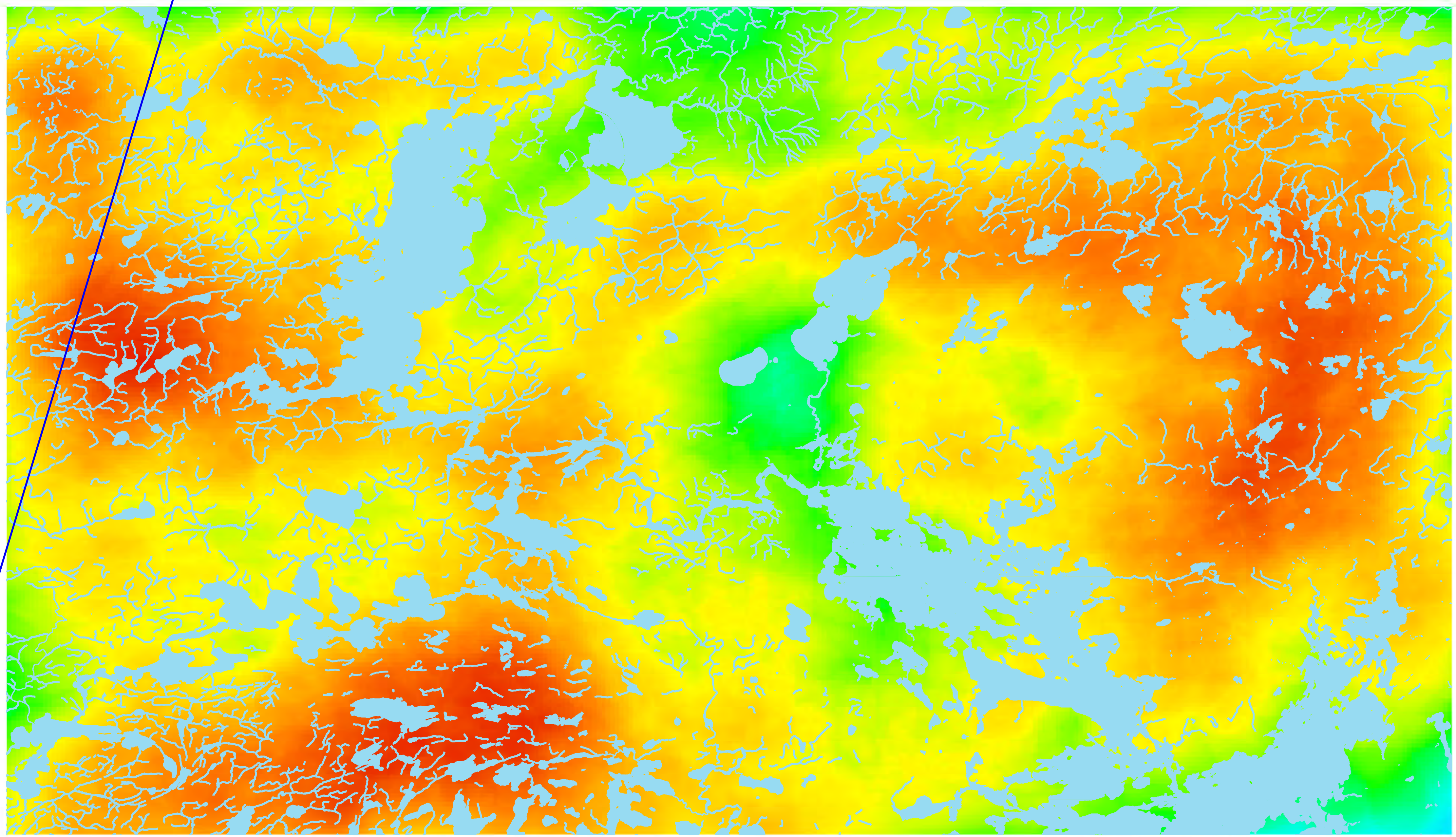

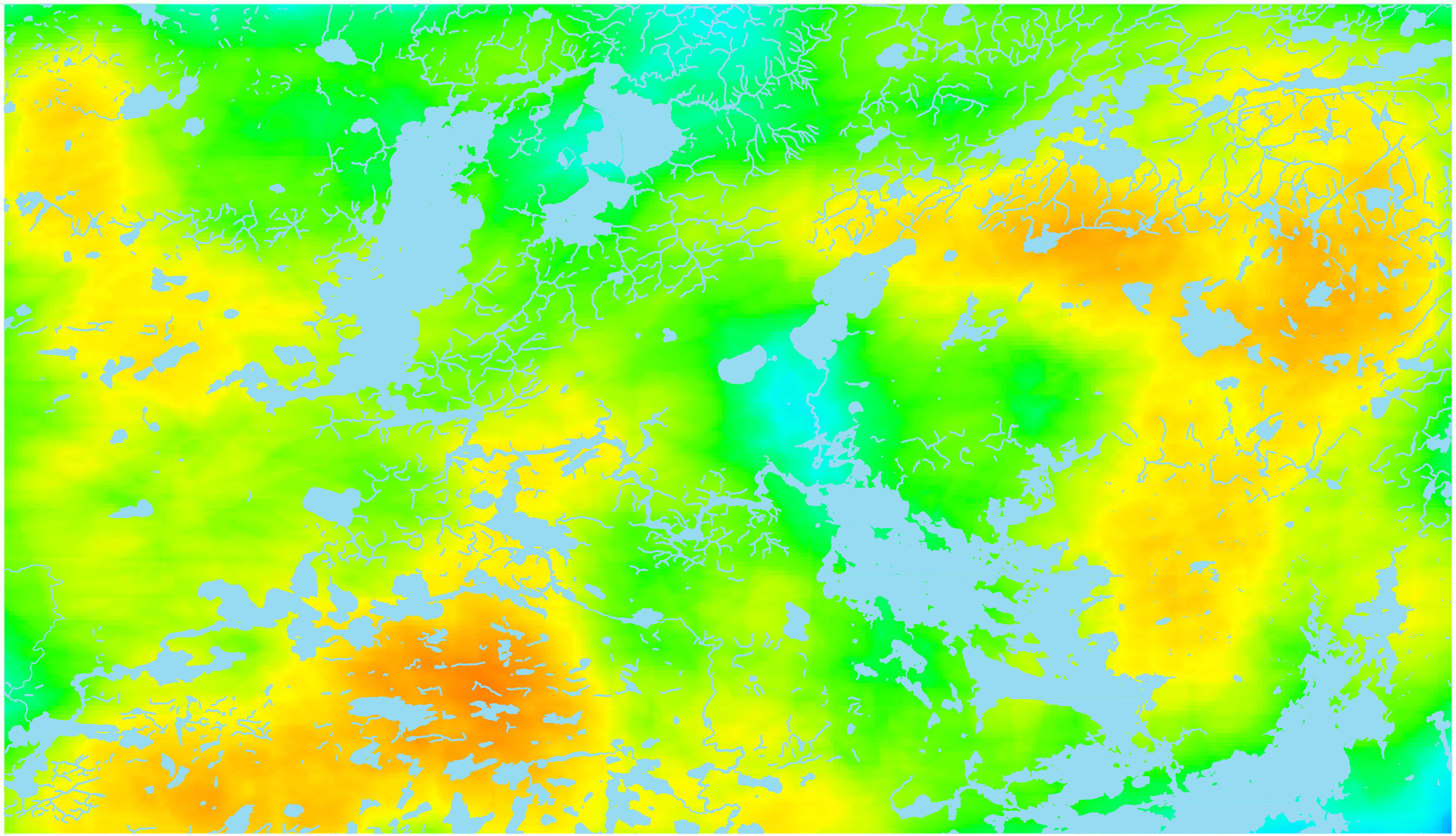

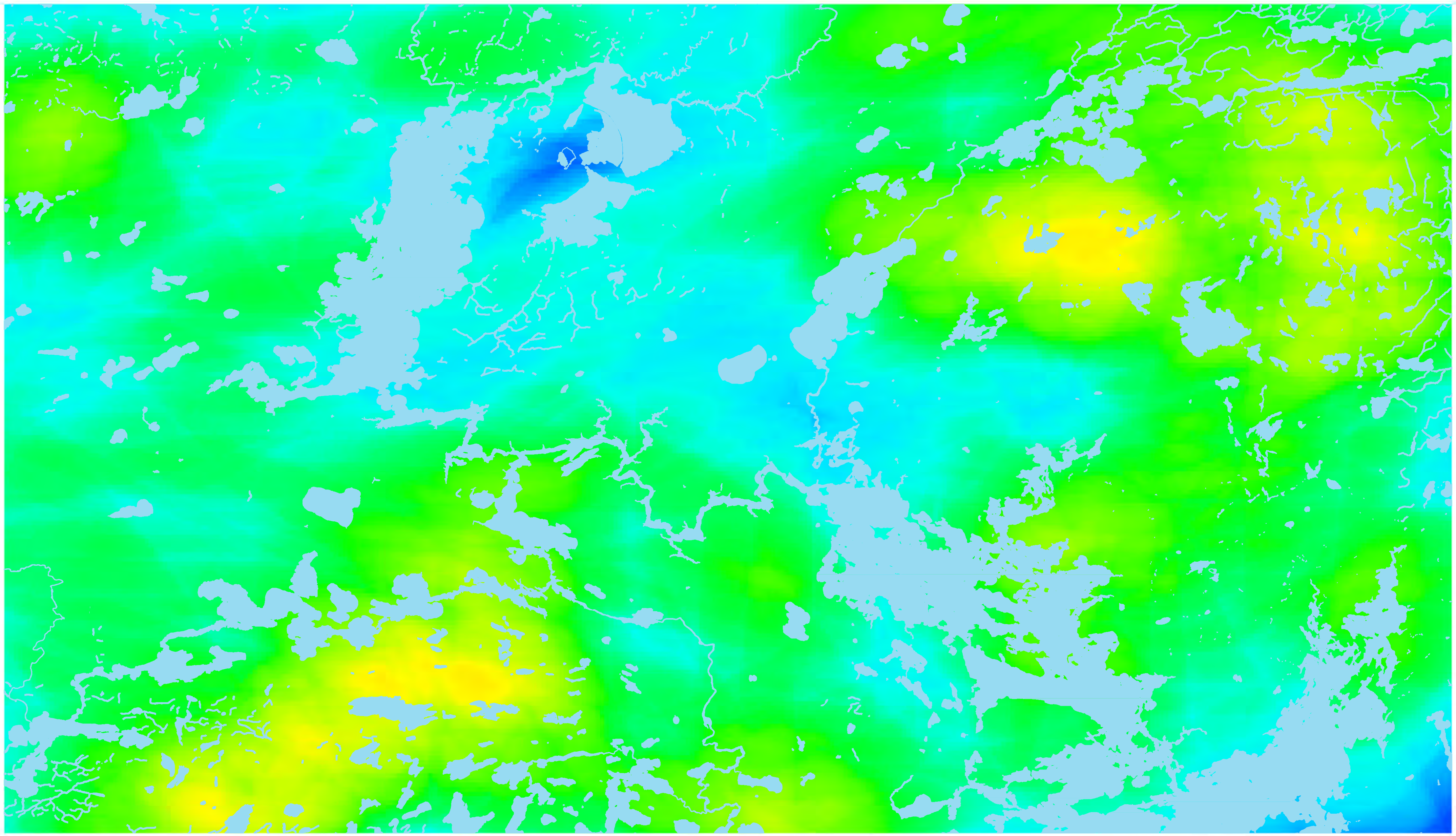

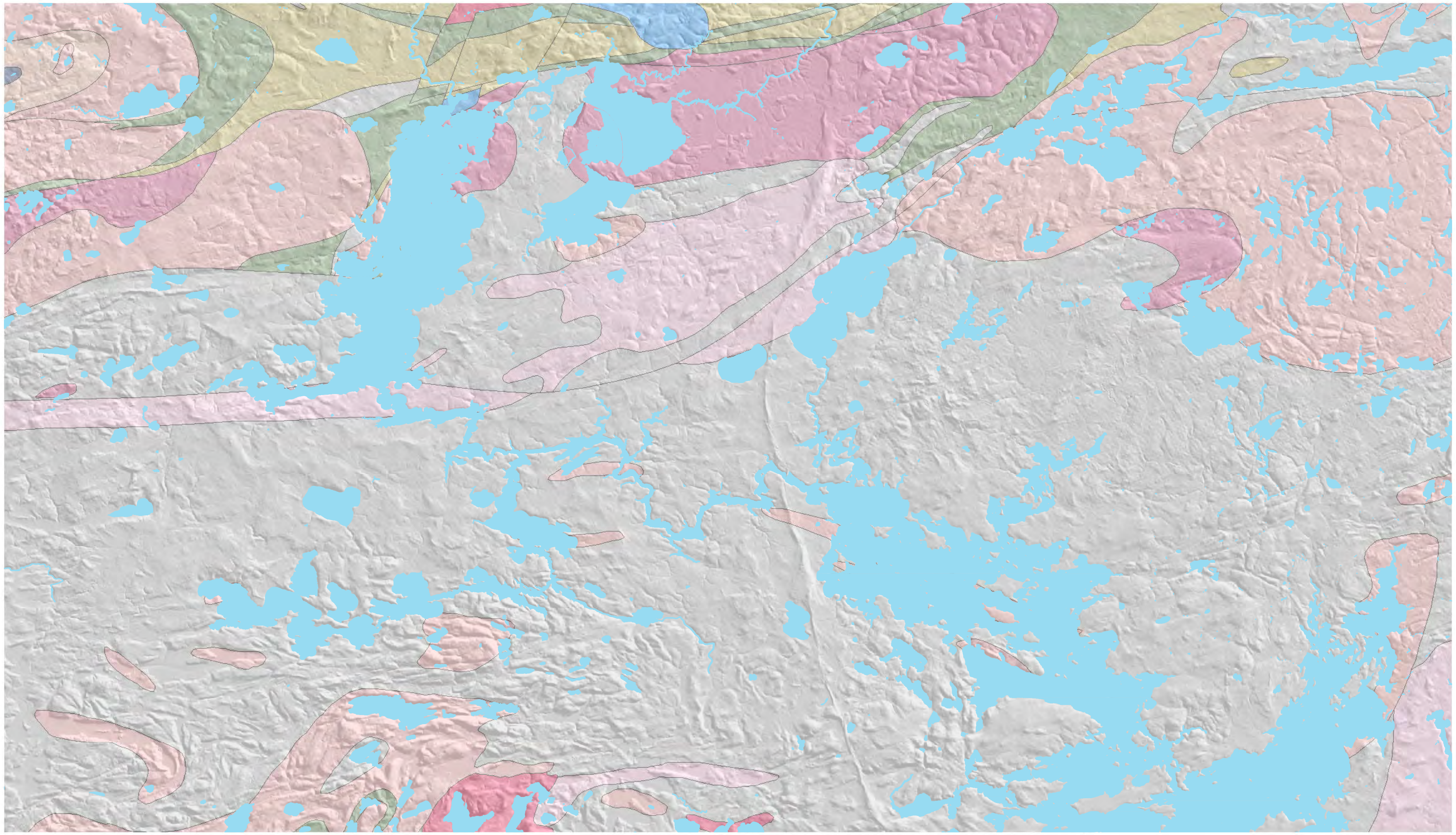

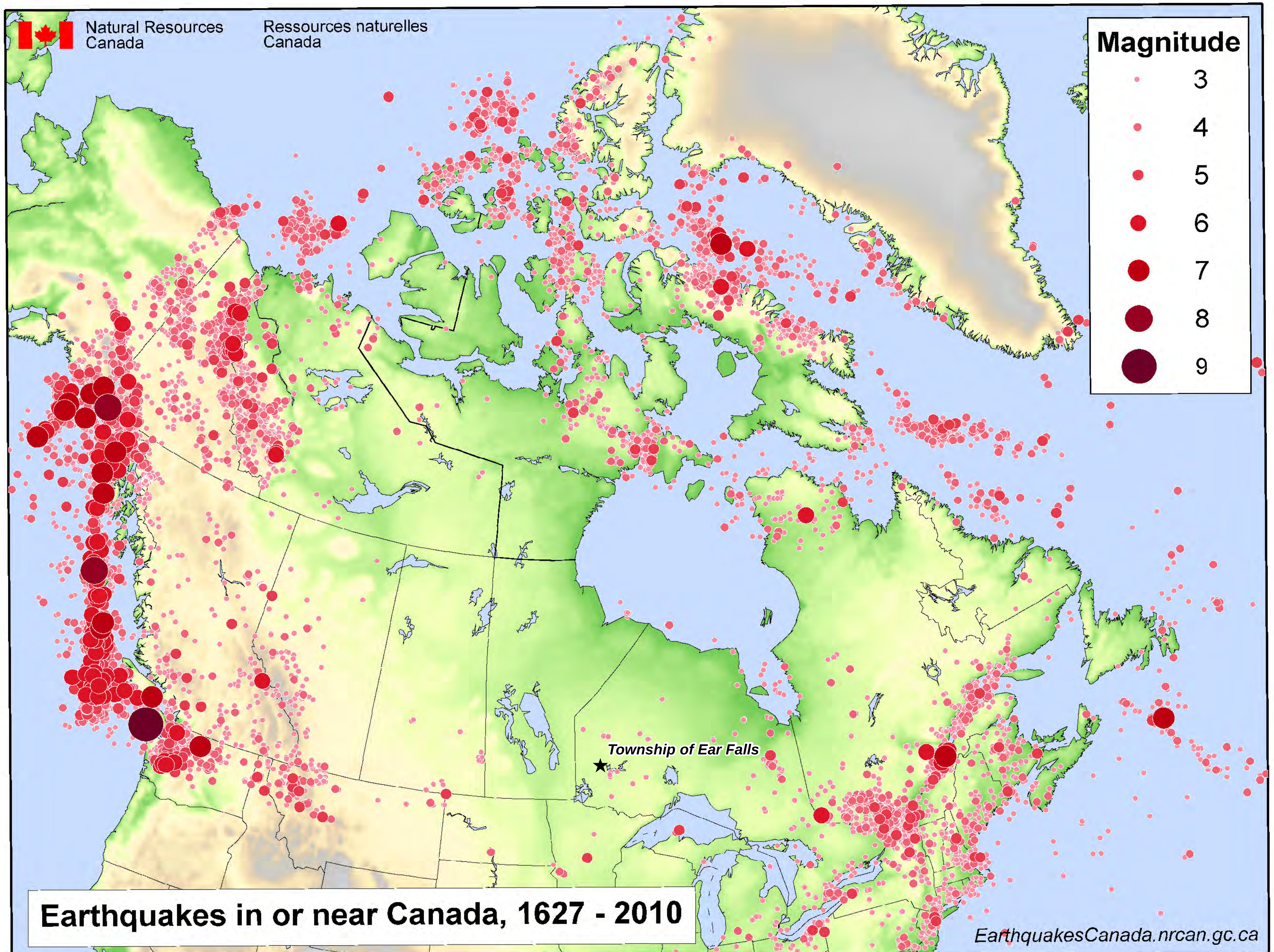

LEGEND

★ Township of Ear Falls

REFERENCE

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Earthquakes Map of Canada 1627-2010

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.20	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		

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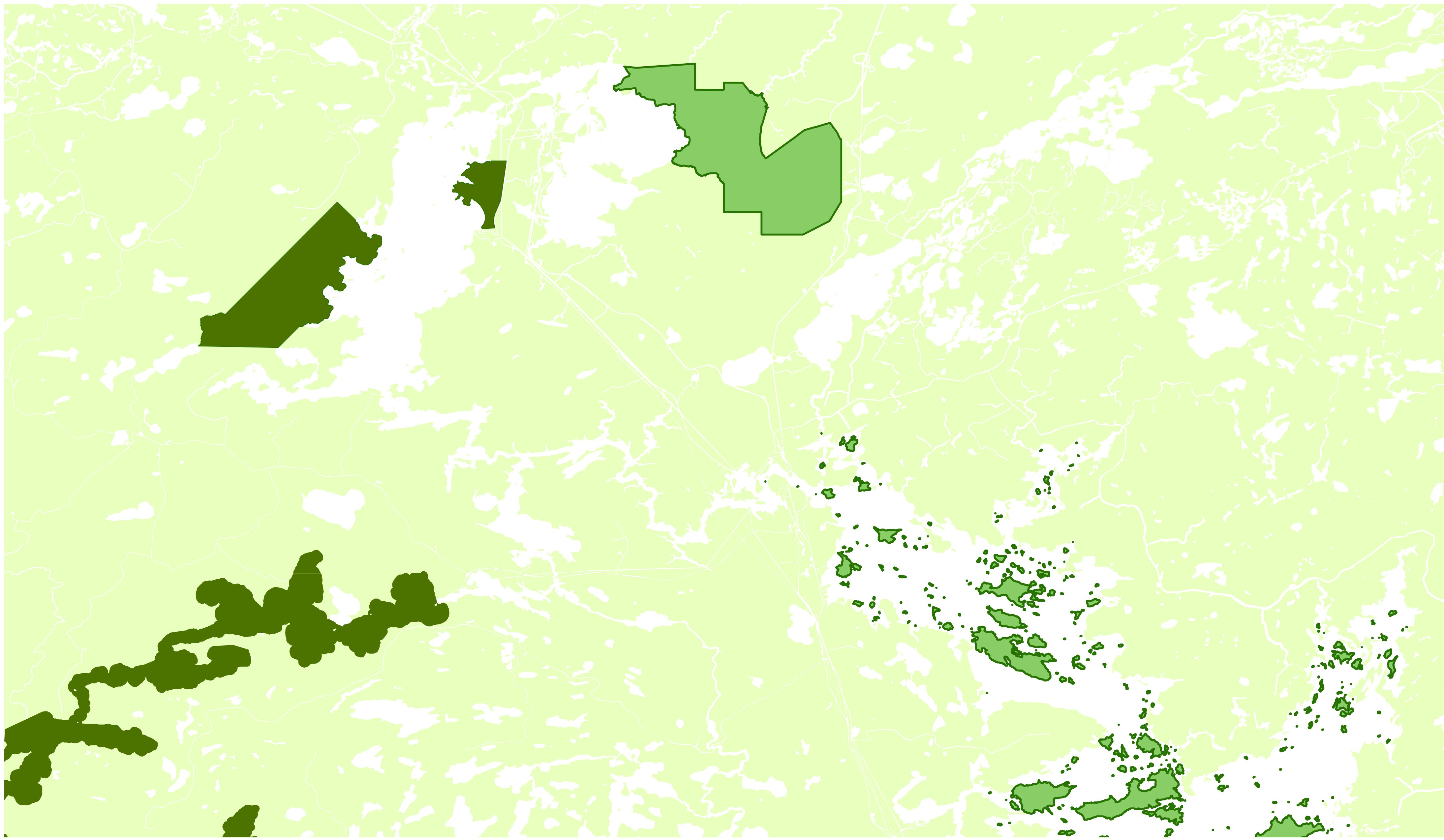

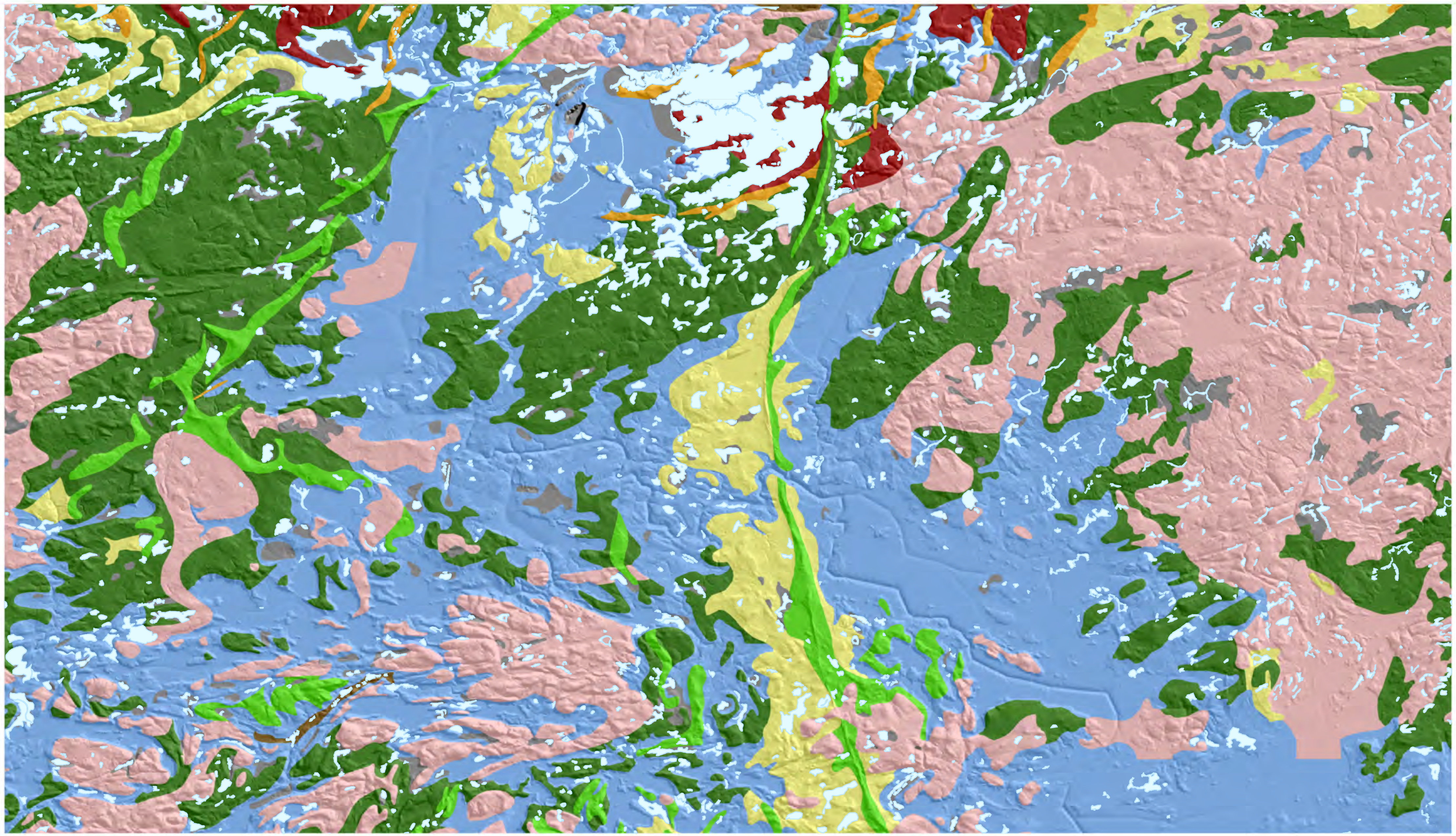

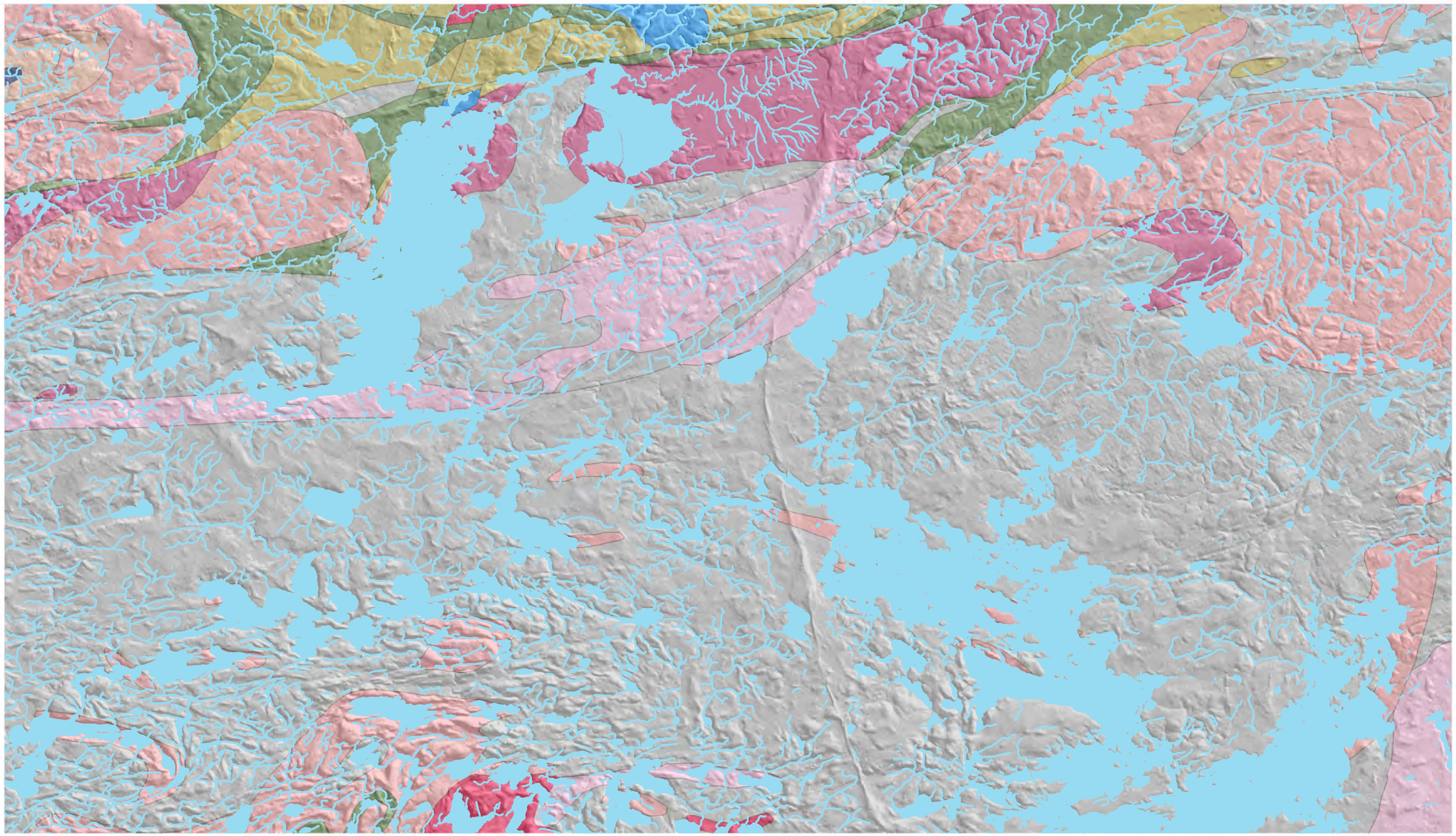

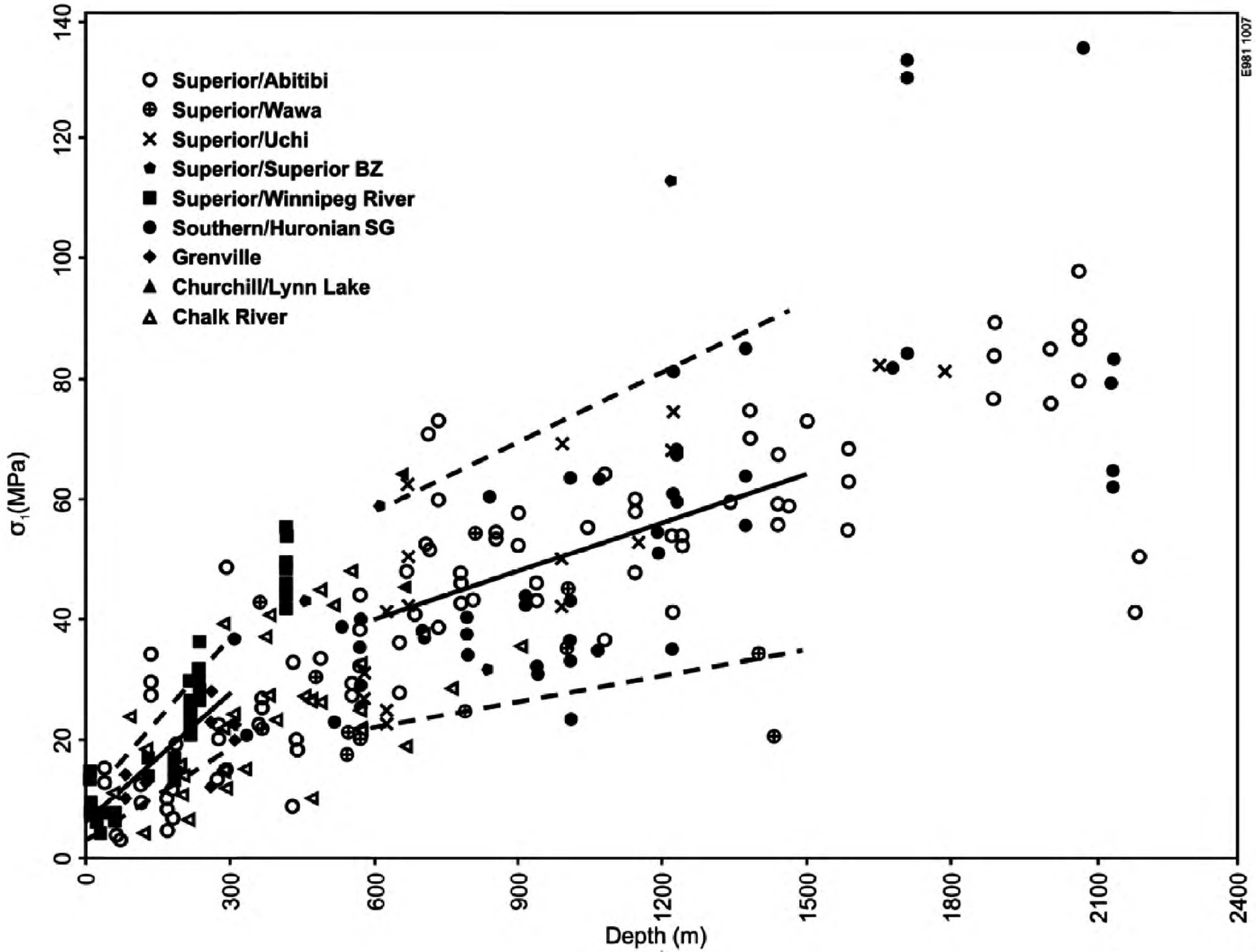

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REFERENCE

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

PROJECT

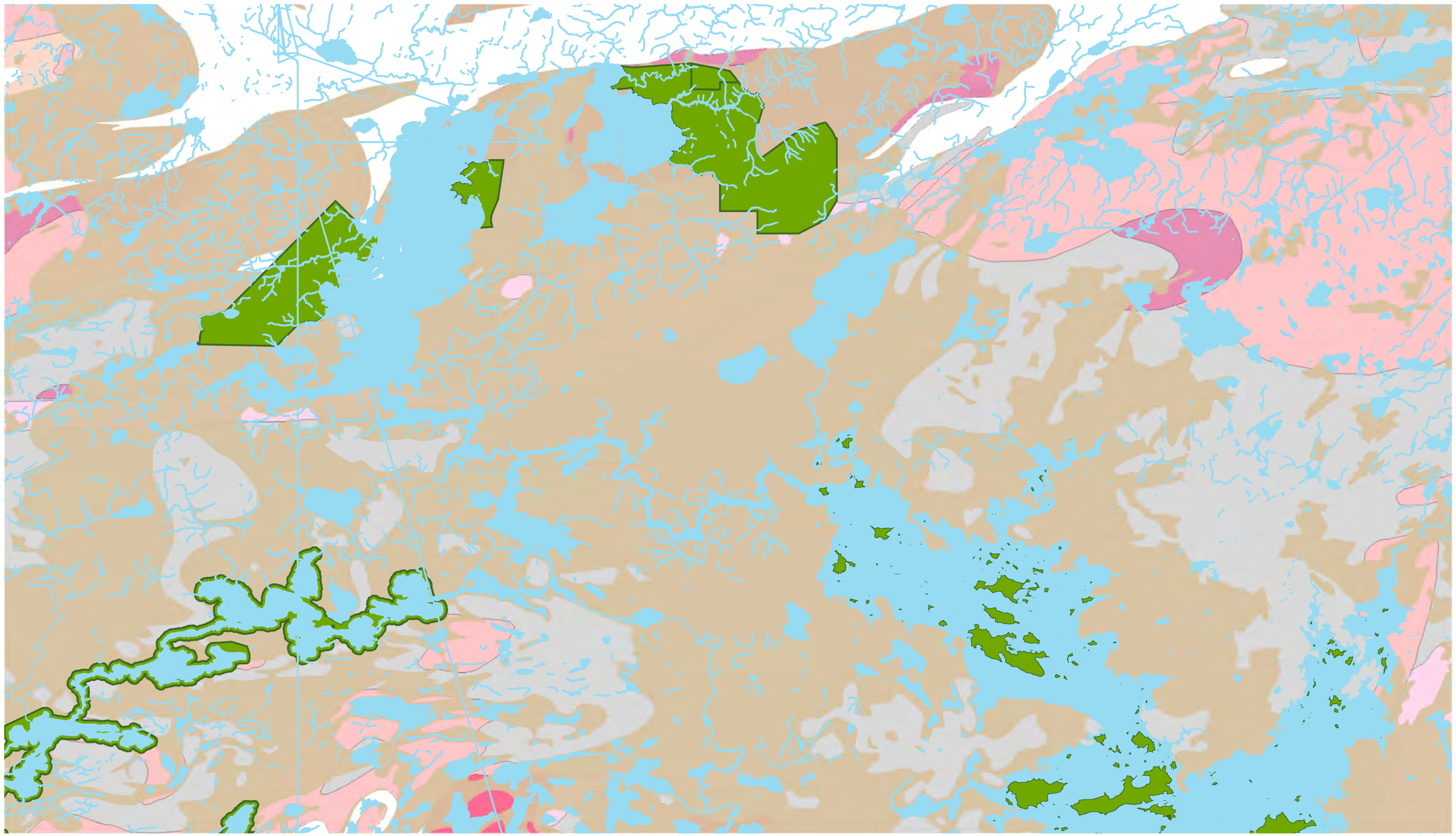
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

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

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	6 Nov. 2012	FIGURE: 6.1	
GIS	PM/JB	23 Aug. 2013		
CHECK	CM	23 Aug. 2013		
REVIEW	GWS	23 Aug. 2013		



APPENDIX A

Geoscientific Factors

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

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

Safety Factors	Performance Objectives	Evaluation Factors to be Considered
Repository construction, operation and closure	**3.** The surface and underground characteristics of the site should be favourable to the safe construction, operation, closure and long-term performance of the repository.	**3.1** The strength of the host rock and in situ stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities. **3.2** The soil cover depth over the host rock should not adversely impact repository construction activities. **3.3** The available surface area should be sufficient to accommodate surface facilities and associated infrastructure.
Human intrusion	**4.** The site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities.	**4.1** The repository should not be located within rock formations containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today. **4.2** The repository should not be located within geological formations containing exploitable groundwater resources (aquifers) at repository depth.
Site characterization	**5.** The characteristics of the site should be amenable to site characterization and site data interpretation activities.	**5.1** The host rock geometry and structure should be predictable and amenable to site characterization and site data interpretation.
Transportation	**6.** The site should have a route that exists or is amenable to being created that enables the safe and secure transportation of used fuel from existing storage sites to the repository site.	**6.1** The repository should be located in an area that is amenable to the safe transportation of used nuclear fuel. **6.2** The repository should be located in an area that allows appropriate security and emergency response measures during operation and transportation of the used nuclear fuel.

APPENDIX B

Geoscientific Data Sources

Table B-1: Summary of Geoscientific Databases for the Ignace Area

Database	Description	Scale (Regional/Local)	Used? (Yes/No)
AFRI	The AFRI database captures details on location, property ownership, type of work done and commodities sought for each Assessment File. It provides an index to the reports and maps that comprise the technical data as well as a link to complete digital images of that data. Spatial data is collected for each file in the form of polygons indicating property outlines.	Regional	Yes
AMIS (Abandoned Mines Information System Database)	AMIS is a database containing information on all known abandoned and inactive mine sites located on both Crown and privately held lands within the province of Ontario. There are currently 5,700 known abandoned mine sites scattered throughout the Province, which contain more than 16,400 mine features.	Regional	Yes
Bedrock Geology (MRD 126)	Bedrock Geology contains information about the solid rock underlying the Province of Ontario at a compilation scale of 1:250000. Data includes: bedrock units, major faults, dike swarms, iron formations, kimberlites and interpretation of the Precambrian bedrock geology underlying the Hudson Bay and James Bay lowlands Phanerozoic cover.	Regional	Yes
CLAIMaps	CLAIMaps contains active claims, alienations and dispositions. Data includes: links to further land tenure information.	Regional	Yes
Diabase Dykes (MRD 241)	Stott, G.M. and Josey, S.D. 2009. Post-Archean mafic (diabase) dikes and other intrusions of northwestern Ontario, north of latitude 49°30′; Ontario Geological Survey	Regional	Yes
Drill Holes	Drill Holes contains information on surface and underground drilling done as outlined by assessment files. Data includes: company name, company hole number, township and a link to the full drill hole record on Geology Ontario.	Regional	Yes
Earthquakes Canada (NEDB)	Geological Survey of Canada Earthquake Search (On-line Bulletin): http://www.earthquakescanada.nrcan.gc.ca/index-eng.php	Regional	Yes
Geochronology (MRD 75)	Geochronology Data for Ontario; Ontario Geological Survey. The compilation covers all isotopic ages greater than 10 Ma for Ontario, and adjacent areas of Manitoba, Michigan, Minnesota, New York and Quebec.	Regional	No (redundant)
Geotechnical Boreholes	Geotechnical Boreholes contains records of boreholes constructed during geotechnical investigations. Data includes: information on the Geological Stratum identified down each hole as well as the hole depth.	Regional	Yes
NOEGTS	Northern Ontario Engineering Geology and Terrain Study. Contains an evaluation of near-surface geological conditions such as material, landform, topography and drainage. Data includes: land form type, geomorphology, primary material, secondary material, topography and drainage condition, point features such as sand and gravel pits, sand dunes, drumlins, eskers, landslide scars and index maps to study areas.	Regional	Yes
Ontario Base Mapping	Land Information Ontario (LIO). Ontario Ministry of Natural Resources. Topography, roads, infrastructure, land cover and drainage. http://www.mnr.gov.on.ca/en/Business/LIO	Regional	Yes
Quaternary Geology	Ontario's Quaternary Geology at a compilation scale of 1:1000000. Ontario Geological Survey, 1997. Quaternary geology, seamless coverage of the province of Ontario: Ontario	Regional	Yes

Database	Description	Scale (Regional/Local)	Used? (Yes/No)
(Data Set 14)	Geological Survey, Data Set 14. This layer includes Quaternary geology units, point features such as drumlins and glacial striae and line features such as eskers, shore bluffs and moraines.		
WWIS (Water Wells)	Database containing water well records throughout Ontario from 1949 to present: http://www.ene.gov.on.ca/environment/en/mapping/index.htm	Regional	Yes

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

Product	Source	Line Spacing/ Sensor Height	Coverage	Date	Additional Comments
Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	20 m	Entire Ear Falls area	1978 - 1995	Hillshaded and slope rasters used for mapping
Spot 5; Orthoimage, multispectral/ panchromatic	Geobase	10 m panchromatic 20 m multispectral	Entire Ear Falls area	2006	
Dryden-Kenora, Dryden block	GSC	5000m/ 120m	Entire Ear Falls area	1996	Quality control and initial processing applied by GSC.
Ontario #06 (CADB27)	GSC	805m/152m	Ear Falls area north of 5,594,200mN	1960	Data digitized from contour maps along flight lines flown at a higher elevation than other datasets with a low spatial resolution.
Ontario #07 (CADB27)	GSC	805m/305m	Ear Falls area south of 5,594,200mN	1965	Data digitized from contour maps along flight lines flown at a higher elevation than other datasets with a low spatial resolution.
Canada - 200m - Compilation	GSC	n/a	Entire Ear Falls area	August 2010	Updated compilation of GSC magnetic surveys.
Uchi-Bruce Lakes Area (GDS1026)	OGS	200m/60m	Covers the north central part of the Ear Falls area	1991	Quality control and correction of bad data were applied by OGS.
Red Lake Area	OGS (GDS1028)	200m/122m	Outside, but located just north-northwest, of the Ear Falls area	1978	Quality control and correction of bad data were applied by OGS.
Single Master Gravity and Aeromagnetic Data for Ontario – XYZ and Grids	OGS (GDS1035 and GDS1036)	Various	Entire Ear Falls area	1944-2010	Reduced and levelled to common datum
Pakwash Lake Area	OGS	250m/40m	Covers a small area in the north northwest	1992	Quality control and initial processing

	(GDS1218-REV)		central part of the Ear Falls area.		applied by OGS.
Trout Lake River Area	OGS (GDS1222-REV)	200m/73m	Covers a small area in the north northeast central part of the Ear Falls area.	1997	Quality control and initial processing applied by OGS.
Red Lake, Dixie North Area	Fronteer Development Group Inc.	75m/100m	~62km^2 in the northwest corner of the Ear Falls area.	2008	No digital data available, only images files
Dixie East/South Properties	Grandcru Resources Corp.	75m/60m	~50km^2 in the northwest corner of the Ear Falls area.	2005	No digital data available, only images files
Goldpines South Property	Laurentian Goldfields Ltd.	100m/30m	~681km^2 in the northwest quarter of the Ear Falls area.	2009	No digital data available, only images files
Ground Gravity (CGDB, SEP 2010)	OGS	5-15km/surface	Stations sparsely located over entire Ear Falls area.	1944-Present	Good data quality but sparse coverage within Ear Falls area
Lithoprobe - Western Superior	GSC	Along roads or at stations/surface	Seismic line crossing central part of the Ear Falls area with a ~315°N azimuth. Two MT stations located within Ear Falls area.	1999	

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

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
	A Geological Reconnaissance into Patricia	Burwash, E.M	ODM	4 miles to the inch	1920	partial	Preliminary mapping along the Wenasaga River
P1202	Lac Seul Sheet	Breaks, F.W., W.D Bond, N.Harris, C.J Westerman,D. Stone, and D.W. Desnoyers	OGS	1:63,360	1976	partial	Detailed mapping with coverage in the extreme southeast corner of the Ear Falls area (Wapesi batholith)
P1199	Bruce-Bluffy Lakes Sheet	Breaks, F.W., W.D Bond, N.Harris, C.J Westerman,D.Stone, and D.W. Desnoyers	OGS	1:63,360	1976	partial	Detailed mapping of a large portion of the eastern part of the Ear Falls area.
P0410	Feaver Lake Area	Fenwick, K.G	OGS	1:15,840	1967	partial	Detailed mapping of a small area around Feaver Lake. Coverage overlaps with P1199
P0411	Bluffy Lake Area	Fenwick, K.G	OGS	1:15,840	1967	partial	Detailed mapping of a small area around Bluffy Lake. Coverage overlaps with P1199
P1027	Pakwash-Longlegged Lakes	Breaks, F.W., W.D Bond, N.Harris, C.J	OGS	1:63,360	1975	partial	Detailed mapping of the area

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
	Sheet	Westerman,D. Stone,and D.W. Desnoyers					surrounding Pakwash Lake and extending west of the Ear Falls area
P1200	Papaonga-Wapesi Lakes Sheet	Breaks, F.W., W.D Bond, N.Harris, C.J Westerman,D. Stone,and D.W. Desnoyers	OGS	1:63,360	1976	partial	Detailed mapping of lands along the eastern fringe of the Ear Falls area
P1971	Western English River Subprovince	Breaks, F.W., W.D. Bond, C.J. Westerman, C.F. Gower, D. Stone, D.W. Desnoyers, G.H. McWilliams, N. Harris, and D. Findlay	OGS	1: 253,440	1978	complete	Compilation map covering the Western English River Subprovince and all of the Ear Falls area.
P2386	Trout Lake-Birch Lake Sheet	Thurston P.C. and J. R. Bartlett .	OGS	1:126,720	1981	partial	Compilation map covering the Trout Lake-Birch Lake area. Includes lands from the upper part of Pakwash Lake and extending north and east of the Ear Falls area.
P2858	Pakwash Lake Sheet	Thurston. P.C., and D. Paktunc	OGS	1:50,000	1985	partial	Detailed map coverage in the north central part of the Ear Falls area (centred over the Bruce Lake pluton) and extending north of the Ear Falls area.
P2859	Bluffy Lake Sheet	Thurston. P.C., and D. Paktunc	OGS	1:50,000	1985	partial	Detailed map covering the Bluffy Lake area.
P3460	East Uchi Subprovince	Sanborn-Barrie, M., N. Rogers, T. Skulski, J. Parker, V. McNicoll and J. Devany	GSC/ OGS	1:250,000	2004	Nearly complete	Detailed compilation map covering most of the Ear Falls area. Includes geochronology and a tectonic and depositional history for the area.
P2484	Quaternary geology of the Madsen area	Prest, V.K.	OGS	1:50,000	1982	partial	Detailed quaternary geological mapping for a small area in the northwest part of the Ear Falls area.
P2585	Quaternary geology of the Ear	Ford, M.J.	OGS	1:50,000	1982	partial	Detailed quaternary geological mapping

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
	Falls area, Kenora District						for the Ear Falls area.
P2572	Quaternary geology of the Pakwash area, Kenora District (Patricia Portion)	Ford, M.J.	OGS	1:50,000	1983	partial	Detailed quaternary geological mapping for the Pakwash Lake area.

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