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

CITY OF ELLIOT LAKE, TOWN OF BLIND RIVER, TOWNSHIP OF THE NORTH SHORE AND TOWN OF SPANISH, ONTARIO

APM-REP-06144-0091

NOVEMBER 2014

This report has been prepared under contract to the NWMO. The report has been reviewed by the NWMO, but the views and conclusions are those of the authors and do not necessarily represent those of the NWMO.

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

October 2014

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

City of Elliot Lake, Town of Blind River, Township of The North Shore, and Town of Spanish, Ontario

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

NWMO Report Number: APM-REP-06144-0091

REPORT

Report Number: 12-1152-0245 (1000)

Distribution:

PDF copy: NWMO

PDF copy: Golder Associates Ltd.

Golder Associates

Executive Summary

In November and December 2012, the communities of Elliot Lake, Blind River, The North Shore and Spanish expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process and requested that preliminary assessments be conducted to assess potential suitability of the City of Elliot Lake, the Town of Blind River, the Township of The North Shore, the Town of Spanish and surrounding areas for safely hosting a deep geological repository (Step 3). These requests followed the successful completion of initial screenings conducted during Step 2 of the site selection process (Geofirma, 2012a,b,c,d). 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, 2014a,b,c,d).

This report presents the results of a geoscientific desktop preliminary assessment to determine whether the communities of Elliot Lake, Blind River, The North Shore, Spanish and surrounding 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 City of Elliot Lake, the Town of Blind River, the Township of The North Shore, the Town of Spanish and their periphery, which are referred to as the "area of the four communities".

The geoscientific preliminary assessment was conducted using available geoscientific information and key geoscientific characteristics that can be realistically assessed at this early stage of the site evaluation process. These include geology, structural geology, interpreted lineaments, distribution and thickness of overburden deposits, surface conditions and the potential for economically exploitable natural resources. The geoscientific desktop preliminary assessment of potential suitability 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 the characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess factors such as overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification and evaluation of general potentially suitable areas based on key geoscientific characteristics and the systematic application of NWMO's geoscientific site evaluation factors.

The geoscientific desktop preliminary assessment showed that the area of the four communities contains at least four general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. All four general areas are located within the Ramsey-Algoma granitoid complex in the northern half of the area of the four communities, north of the municipal boundaries of Elliot Lake and Blind River.

The Ramsey-Algoma granitoid complex containing the four identified potentially suitable general areas appears to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. The bedrock within this granitoid complex is estimated to have sufficient depth and extend over large areas. The bedrock within the four potentially suitable areas has good exposure, although the bedrock has not been mapped in detail in these areas and some lithological heterogeneity has been found. All four potentially suitable areas have low potential for natural resources; are easily accessible using the existing secondary and logging road network; contain limited surface constraints; and are amenable to site characterization.

No general potentially suitable areas were identified within the municipal boundary of Blind River. This area is located almost entirely within rocks of the Huronian Supergroup that were not considered suitable because of their mineral potential and structural complexity. In addition, a large portion of the municipal area is occupied by the Blind River and Matinenda Provincial Parks and the Mississagi Delta Provincial Nature Reserve.

No general potentially suitable areas were identified within the municipal boundary of Elliot Lake. This area is located largely within rocks of the Huronian Supergroup that were considered to be not suitable. The portion of the municipal boundary that occurs within the Ramsey-Algoma granitoid complex, north of Elliot Lake, is in close proximity to the rocks of the Huronian Supergroup that have high mineral potential. Several past producing mines are located close to this area . In addition, the Ramsey-Algoma granitoid complex south of Elliot Lake is lithologically heterogeneous. A portion of the municipal area is occupied by the Matinenda Provincial Park and the Glenn N. Crombie Conservation Reserve.

No general potentially suitable areas were identified within the municipal boundary of The North Shore. This area is located largely within rocks of the Ramsey-Algoma granitoid complex. However, in this location, the granitoid complex is crosscut by numerous mafic dykes, exhibits a high apparent lineament density and is lithologically heterogeneous. This area is also in close proximity to the regional Murray fault system, which runs from Sault Ste. Marie to Sudbury, and corresponds to a marked change in metamorphic grade.

No general potentially suitable areas were identified within the municipal boundary of Spanish. About half of this area is within rocks of the Huronian Supergroup that were not considered suitable. About half of the municipality is located within the rocks of the Ramsey-Algoma granitoid complex. However, in this area the lithology is heterogeneous and it is in close proximity to the Murray fault and mineral occurrences.

While the four general potentially suitable areas identified 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 low resolution of available geophysical data, proximity to the Murray and Flack Lake faults, and the potential geological, structural and hydrogeological significance of the four known dyke swarms in the area of the four communities.

The four potentially suitable areas are located in areas of lower density of geophysical and surficial lineaments. However, the interpreted lower density of geophysical lineaments is likely due to the low resolution of available geophysical data. In the high resolution data area of the Seabrook Lake intrusion, the spacing between geophysical lineaments range from 200 to 800 m. It is possible that such a high density of geophysical lineaments exists across the area of the four communities.

The area of the four communities contains numerous dykes that are associated with major regional dyke swarms. While the spacing between mapped and interpreted dykes and lineaments within the four potentially suitable areas appears to be favourable, the low resolution of available geophysical data, and the strong magnetic signature of the dykes could be masking the presence of smaller scale dykes and fractures not identifiable from available data. In areas where higher resolution geophysical data are available, the frequency of dykes is much higher.

Should the area of the four communities 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 area of the four communities 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

APPENDIX A
Geoscientific Factors

APPENDIX B
Geoscientific Data Sources

SUPPORTING DOCUMENTS

Terrain and Remote Sensing Study, City of Elliot Lake, Town of Blind River, Township of The North Shore and Town of Spanish, Ontario (JDMA, 2014a)

Processing and Interpretation of Geophysical Data, City of Elliot Lake, Town of Blind River, Township of The North Shore and Town of Spanish, Ontario (PGW, 2014)

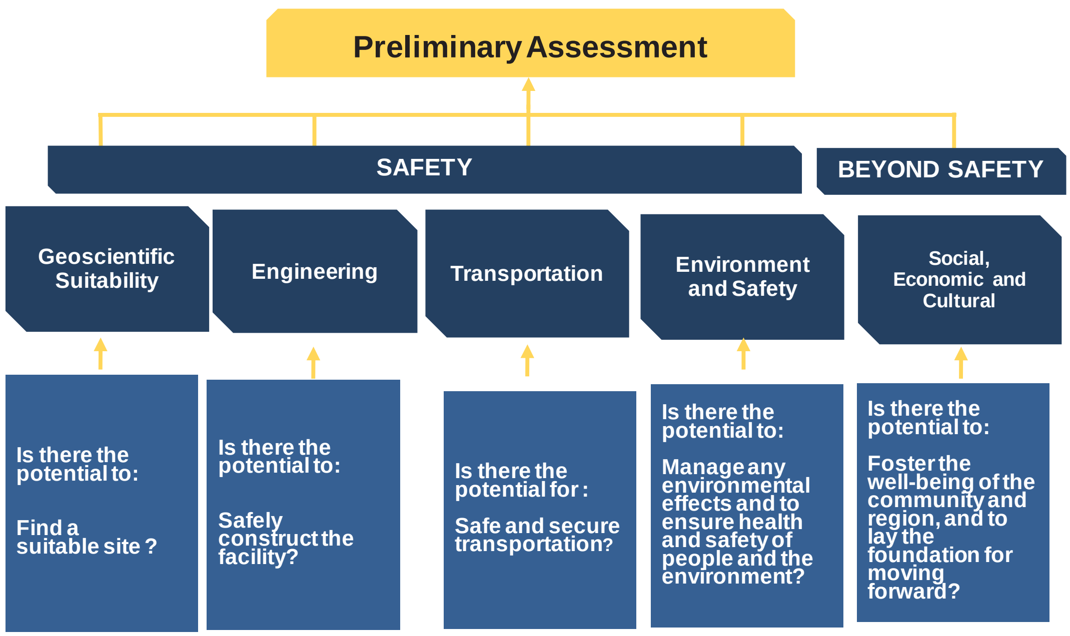
Lineament Interpretation, City of Elliot Lake, Town of Blind River, Township of The North Shore and Town of Spanish, Ontario (JDMA, 2014b)

1.0 INTRODUCTION

1.1 Background

In November and December 2012, the communities of Elliot Lake, Blind River, The North Shore and Spanish expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess their potential suitability for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process (Geofirma, 2012a,b,c,d).

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



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

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

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

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

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

1.2 Geoscientific Desktop Preliminary Assessment Approach

The objective of Phase 1 of the geoscientific preliminary assessment is to assess whether the communities of Elliot Lake, Blind River, The North Shore, Spanish and surrounding area contain general areas that have the potential to satisfy the geoscientific evaluation factors outlined in the NWMO site selection process (NWMO, 2010). The location and extent of identified potentially suitable areas would be confirmed during subsequent site evaluation stages.

The geoscientific desktop preliminary assessment built on the work previously conducted for the initial screening (Geofirma, 2012a,b,c,d) and focused on the City of Elliot Lake, the Town of Blind River, the Township of The North Shore, the Town of Spanish and their periphery, which are referred to as the "area of the four communities" in this report (Figure 1.1). The boundaries of the area of the four communities were defined to encompass the main geological features within the four communities and their surroundings. Phase 1 of the Geoscientific Desktop Preliminary Assessment of Potential Suitability included the following review and interpretation activities:

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

The details of these various studies are documented in three supporting documents: terrain analysis (JDMA, 2014a), geophysical interpretation (PGW, 2014), and lineament interpretation (JDMA, 2014b). Key findings from these studies are summarized and integrated into 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 area of the four communities 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 area of the four communities 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 geoscientific preliminary assessment studies and to identify general potentially suitable areas in the area of the four communities. 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 area of the four communities 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, 2011).

Satellite Pour l'Observation de la Terre (SPOT) multispectral (20 m resolution) and panchromatic (10 m resolution) orthoimagery were used for identifying surficial lineaments and exposed bedrock within the area (GeoBase, 2011). 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). Fourteen SPOT images (scenes) provided complete coverage for the area of the four communities with acquisition dates from 2006 and 2007. The scenes are from the SPOT 4 and 5 satellites. Ten of the images were captured during the summer (July or August), two in the spring (May) and two in the fall (September). SPOT 5 images were acquired using the High Resolution Geometric (HRG) sensor. Each image covers a ground area of 60 km by 60 km.

Cloud-free Landsat 2 coverage for the area of the four communities was acquired from the NASA Landsat Program (2013). One scene, dated from September 28th, 1976, covered the entire area. The sensor onboard the Landsat 2 satellite was the Multispectral Scanner (MSS). The MSS data consist of four multispectral bands with a pixel size of 60 m. The Landsat MSS data was processed to provide a preliminary bedrock outcrop map (JDMA, 2014a).

For the area of the four communities, geophysical data were obtained from available public domain sources, particularly the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC). Data obtained from GSC (Ontario #13, #16, #17) were flown at a terrain clearance of 305 m and flight line spacing of 805 m, providing it with a relatively low spatial resolution. A fourth survey (Ontario #04) was flown at a terrain clearance of 305 m and flight line spacing of 402 m, providing improved spatial resolution. The GSC flew one high-resolution survey in the area of the four communities (East Bull Lake (RA-7)), flown at a lower terrain clearance (150 m) compared to the older GSC surveys, and with tighter flight line spacing (300 m). Additional magnetic and electromagnetic surveys obtained from the OGS (2003; 2011b) and one GSC magnetic survey provided higher resolution coverage over approximately 5% of the area. Additional geophysical data were also found in the OGS Assessment File (AFRI) database in the form of maps. Of these, eight files provided images of magnetic data, as well as radiometric (four files), time-domain electromagnetic (two files), frequency-domain electromagnetic (one file) and very low frequency (VLF) (four files). These files were chosen due to the quality of the images and scatter of locations across the area of the four communities.

Gravity data coverage for the area of the four communities (GSC, 2013) consists of an irregular distribution of station measurements within the area of the four communities, comprising roughly a station every 5 to 15 km, with denser concentrations to the south and east, as well as over the Seabrook Lake and East Bull Lake intrusions. Spacing between gravity stations over the East Bull Lake intrusion range from 25 m to 200 m near its center, expanding to 1 km around the margins.

The GSC radiometric data provide complete coverage of the area of the four communities (GSC, 2013) with the exception of Lake Huron. The GSC radiometric data were flown at 5,000 m line spacing at a terrain clearance of 120 m above the surface over most of the area of the four communities. Along the eastern boundary, the resolution improves where the line spacing is 1,000 m. In the Elliot Lake area, higher resolution coverage at 500 m line spacing (and 123 m line spacing over a smaller block) improves the resolution further.

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

Table 1.1: Summary of Digital Elevation, Satellite and Geophysical Data Sources for the Communities of Elliot Lake, Blind River, The North Shore and Spanish, and Surrounding Area

Dataset	Product	Source	Resolution	Coverage	Date	Additional Comments
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	20 m	Entire area of the four communities	1978 - 1995	Hillshaded and slope rasters used for mapping
Satellite Imagery	Spot 4/5; Orthoimage, multispectral/ panchromatic	Geobase	10 m panchromatic 20 m multispectral	Entire area of the four communities	2006 and 2007 (east)	
	Landsat 2 MSS	NASA	60 m multispectral	Entire area of the four communities	1976	
Geophysics	East Bull Lake (RA-7) Fixed wing vertical gradiometer magnetic, VLF	GSC	300 m line spacing/ 150 m sensor height	East central over the East Bull Lake and nearby intrusions	1981	Higher resolution over intrusions
	Ontario #4 Fixed wing magnetic	GSC	402 m line spacing/ 305 m sensor height	West central	1956	Moderate resolution dataset
	Ontario #13 Fixed wing magnetic	GSC	805 m line spacing / 305 m sensor height	Northeast	1960	Lowest resolution dataset
	Ontario #16 Fixed wing magnetic	GSC	805 m line spacing / 305 m sensor height	East	1959	Lowest resolution dataset
	Ontario #17 Fixed wing magnetic	GSC	805 m line spacing/ 305 m sensor height	Most of area of the four communities	1963	Lowest resolution dataset
	GDS1017 Benny Helicopter magnetic, FDEM, VLF	OGS	200 m line spacing/ 30 m sensor height	East central over Benny greenstone belt	1990	4-frequency Aerodat system, higher resolution over Benny greenstone belt
	GDS1236 Elliot Lake-River aux Sables Helicopter magnetic, TDEM	OGS	100 m E, 50 m W line spacing/ 67 m mag 47 m TDEM sensor height	South central over Whiskey Lake greenstone belt	2008	VTEM system, higher resolution
	Sudbury Fixed wing magnetic, radiometric, VLF	GSC	1000 m line spacing/120 m sensor height	East	1989	Utilized for its radiometric and VLF coverage only
	Elliot Lake Fixed wing radiometric	GSC	500 m line spacing /124 m sensor height	South central over Huronian Supergroup	1970	Higher resolution over Huronian Supergroup
	Elliot Lake (detail) Fixed wing radiometric	GSC	123 m line spacing/ 115 m sensor height	South central over Huronian Supergroup	1977	Higher resolution over Huronian Supergroup

Dataset	Product	Source	Resolution	Coverage	Date	Additional Comments
	GSC Gravity Coverage Ground gravity measurements	GSC	5-15 km, 25 m to 1 km locally	Entire study area of the four communities	1945-1989	Station spacing somewhat variable overall with more detailed data over East Bull Lake and Seabrook Lake intrusions
Geophysics (AFRI File)	20000850 Fixed wing horizontal gradiometer magnetic, radiometric, VLF	North American Gem	100 m line spacing / 70 m sensor height	Northwest	2008	
	20003244 Fixed wing magnetic, TDEM	Canada Enerco	200 m line spacing / 73 m sensor height	North of Elliott Lake	2007	MEGATEM system
	20004445 Fixed wing horizontal gradiometer magnetic, radiometric, VLF	Delta Uranium	100 m line spacing / 70 m sensor height	North central	2006	
	200005757-1 to -3 Helicopter magnetic, TDEM	Carina Energy	100 m line spacing / 47 m sensor height	West central over the Huronian Supergroup	2007	AeroTEM II system
	20005762 Helicopter magnetic, radiometric	Carina Energy	150 m line spacing / 30 m sensor height	West central over the Huronian Supergroup	2007	
	20006243 Fixed wing horizontal gradiometer magnetic, radiometric, VLF	North American Gem	100 m line spacing/ 70 m sensor height	Northwest	2008	
	20006734 Helicopter magnetic, radiometric, VLF	Hawk Uranium	100 m line spacing /30 m sensor height	North central	2007	
	41I12SW2002 Helicopter vertical gradiometer magnetic, FDEM	Mustang Minerals	100 m line spacing / 45 m sensor height	Southeast over the East Bull Lake and nearby intrusions	2000	Dighem V system

1.4.2 Geology

Geological mapping in the area began in the 1840s when copper was discovered at Bruce Mines to the west of the area of the four communities. The Proterozoic metasedimentary rocks in the Blind River area were recognized as distinct from the underlying Archean rocks and termed the Huronian Series by Logan (1863). Subsequent mapping on a regional scale includes Coleman (1908; 1914), Collins (1914; 1925), and Quirke (1917). The area was subject to intensive exploration with the discovery of uranium deposits in the 1950s which spurred detailed mapping of the Huronian Supergroup in the 1960s and 1970s (Robertson, 1961; 1962; 1963a;

1963b; 1964; 1968; 1970; 1977a; 1977b; Wood, 1975; Siemiatkowska, 1977; Siemiatkowska, 1981). More recently, detailed mapping has been carried out over the East Bull Lake intrusive suite and the Whiskey Lake greenstone belt and surrounding area (Ejeckam et al., 1985; Rogers, 1992: 1993; Jensen, 1994; Easton, 2009; 2010; 2013; Easton et al., 2011).

Geological syntheses and interpretations are given by Giblin and Leahy (1979), Johns et al. (2003), and the Ontario Geological Survey's province-wide seamless geological map coverage (OGS, 2011a). Surficial geology mapping includes a regional reconnaissance study of surficial geology by Boissonneau (1965; 1968) as well as more detailed studies of the Quaternary geology of portions of the area of the four communities (Henderson and Halstead, 1992; Ford, 1993).

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

In addition to the above publications, Golder made extensive use of Ontario Ministry of Northern Development and Mines (MNDM, 2013) Assessment Files (AFRI) and industry publications.

1.4.3 Hydrogeology and Hydrogeochemistry

Hydrogeologic information for the area of the four communities 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, NRC) of the area of the four communities. These data sources contain hydrogeological information on the overburden and shallow bedrock aquifers for portions of the area of the four communities where development has taken place.

Information on the deep hydrogeology of the Huronian Supergroup and East Bull Lake intrusive suite was obtained from Golder (various studies dating from 1982 to the late 1990s); Robertson (1968); McCrank et al. (1982; 1989); Paillet and Hess (1986) and Raven et al. (1987). This area-specific information was augmented by inferences based on studies in similar geologic settings elsewhere in the Canadian Shield including: Frape et al. (1984); Gascoyne et al. (1987); Gascoyne (1994; 2000; 2004); Everitt et al. (1996); Farvolden et al. (1988); Singer and Cheng (2002) and Rivard et al. (2009).

1.4.4 Natural Resources – Economic Geology

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

1.4.5 Geomechanical Properties

Little information is available regarding the rock geomechanical properties for the Ramsey-Algoma granitoid complex in the area of the four communities. 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 East Bull Lake and Atikokan research areas in Ontario (Stone, 1984; Brown et al., 1989; 1995; Brown and Rey, 1989; Stone et al., 1989).

2.0 PHYSICAL GEOGRAPHY

2.1 Location

The communities of Elliot Lake, Blind River, The North Shore and Spanish are situated on the north shore of Lake Huron in northern Ontario (LIO, 2013). Highway 17 (Trans-Canada Highway) crosses through the communities and connects to Sudbury (100 km to the east) and Sault Ste. Marie (145 km to the west)), based on road distances to the boundary of the area of the four communities. Figure 2.1 presents a composite of panchromatic, SPOT-5 satellite image for the area taken in 2006 and 2007. The four communities and the surrounding area measure approximately 114 km by 126 km in size, encompassing an area of about 14,450 km^2.

2.2 Topography and Landforms

A detailed terrain analysis was completed as part of the preliminary assessment of potential suitability for the area. The results of this analysis are discussed in detail in JDMA (2014a). This section presents a brief summary of topography and landforms from the JDMA study.

The four communities lie within the Penokean Hills physiographic region. This area is south of the Abitibi Upland and is bordered to the east by the Cobalt Plain and the Laurentian Highlands according to Thurston (1991). The Penokean Hills are composed of folded Proterozoic stratified rocks while the north part of the area of the four communities lies within the Abitibi Upland, a broadly rolling surface of Canadian Shield bedrock that occupies most of north-central Ontario (NRCan, 1997).

The digital elevation model (DEM) of the area of the four communities is presented on Figure 2.2. Topography is an important aspect of the terrain, as it plays a role in controlling surface water and groundwater flow directions and it is an important factor to consider in the routing of roads or the siting of surface structures. The topography in this area is largely bedrock-controlled (Ford, 1991; Henderson and Halstead, 1992), with bedrock hills and ridges and structurally-controlled valleys acting as the main landscape elements, and, as a result, it can reveal much about the bedrock structure and distribution of overburden deposits.

Overall, the northern and central parts of the area are highlands and the southern part is a lowland. Boissonneau (1968) described the narrow lowland along this part of the north shore of Lake Huron as one characterized by wave-washed bedrock knolls interspersed with local pockets of glaciolacustrine sediments. The elevation gradient from north to south is from 612 to 176 m, with this elevation drop occurring over an approximately 90 km distance (Figure 2.2). The highest point in the area of the four communities is within the highlands north of the Aubinadong River. The lowest point is defined by the surface of Lake Huron, which has a chart datum of 176.0 m (Canadian Hydrographic Service, 2014).

The northeast quadrant of the area of the four communities features a large contiguous area of high elevation with local summits reaching elevations of 530 to 560 m or more. This major highland divides flow between three of the four tertiary watersheds included within the area of the four communities, known as the Spanish, Upper Mississagi and Lower Mississagi watersheds. It forms the headwaters of many watercourses, including the Boland, Little White, Wakonassin, Mozhabong rivers and the River aux Sables.

The northwest quadrant of the area of the four communities also contains abundant areas of high elevation, but the areas are distributed as isolated blocks of high ground rather than as a large contiguous area as in the northeast quadrant. One of the larger highlands in the northwest quadrant is the oval-shaped area west of the

Kindiogama River. Another is located in the northwest corner of the area of the four communities, forming a highland around the Aubinadong and Little Aubinadong rivers.

Topographic relief is influenced by the distribution and thickness of surficial deposits. Areas of sharp local relief are expected to represent bedrock hills, such as the cuestas and hogback ridges around the Boland and Little White rivers formed by the Nipissing diabase intrusions as described by Ford (1991). None of the surficial deposits in the area of the four communities display topographic prominence of this magnitude. The surficial deposits that display the greatest relief in the area of the four communities are eskers and recessional moraines, and Henderson and Halstead (1992) found that these deposits rarely display more than 5 m of topographic prominence in the Elliot Lake area. As a result, the hills at least 15 m high are expected to delineate the places where overburden deposits are most likely to be thin or absent.

Overburden deposits in the area of the four communities have been mapped at the scale of 1:100,000 as part of the Northern Ontario Engineering Geology Terrain Studies (Figure 2.3). Except for the narrow lowland along the north shore of Lake Huron, which was mapped as wave-washed bedrock with local pockets of glaciolacustrine deposits, Boissonneau (1968) mapped the rest of the area of the four communities as moderately rolling terrain characterized by thin till deposits over bedrock with local morainal and outwash deposits. Morainal, glaciolacustrine and alluvial deposits make up small percentages of the area, and a disproportionate amount of these deposits are located over the Proterozoic rocks.

Northern Ontario Engineering Geology Terrain Studies in the area of the four communities (e.g., Gartner, 1980a; Roed and Hallett, 1980a,b; VanDine, 1980a) suggest that the bedrock surface is generally mantled by ground moraine in the areas mapped as bedrock (Figure 2.3). The till in these areas is expected to be generally less than 1 m over the crest of hills, but it can increase to several metres on the flanks of hills or in the lows between hills. The till is silty to sandy in texture and generally contains cobbles and boulders. Local depressions within the areas mapped as bedrock commonly contain organic, ground moraine, outwash, esker or ice-contact deposits that were too small to map explicitly. Areas mapped as bedrock within the area of the four communities amount to 76% of the area not covered by Lake Huron. Within these areas, drift deposits are thinnest on the bedrock hills and ridges scattered throughout the landscape. The total extent of bedrock outcrops suggested by the Landsat MSS interpretation is about 8% of the portion of the area of the four communities not covered by Lake Huron (JDMA, 2014a). It is suspected that dense vegetation masks the bedrock surface in some areas where drift deposits are virtually absent.

The terrain analysis shows the area of the four communities to be dominated by exposed bedrock or bedrock having only a thin mantle of unconsolidated sediments. Quaternary mapping (1:1,000,000) in the area of the four communities (Figure 2.3) indicates that Quaternary deposits are predominantly located in bedrock-controlled valleys.

2.3 Watersheds and Surface Water Features

The area of the four communities is contained entirely within the St. Lawrence drainage area, which drains towards the Atlantic Ocean through the St. Lawrence River. The St. Lawrence drainage area covers parts of the provinces of Ontario and Quebec, and the states of Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Vermont and Wisconsin.

Drainage within the area of the four communities is directed towards the Northern Channel of Lake Huron through the Mississagi, Blind, Serpent and Spanish rivers. The inset map on Figure 2.4 shows the division of the area of the four communities into tertiary watersheds, illustrating how the Mississagi River in this area contains upper and lower watersheds.

The Mississagi River drains the northwest and west parts of the area of the four communities. Within the Lower Mississagi watershed, the Mississagi River is fed by the Little White, Little Rapid and Sharpsand rivers, of which the Little White River is the major tributary. The Boland, Sister, Kindiogama, and West Little White rivers are the main tributaries to the Little White River. Within the Upper Mississagi watershed, the Aubinadong, Wenebegon, Maskuti and Abinette rivers are the main tributaries to the Mississagi River. The Aubinadong River is fed by the West Aubinadong and Little Aubinadong rivers. The West Aubinadong is located just west of the northwest corner of the area of the four communities. The Wenebegon River is fed by the Burntwood and Embarrass rivers. The Abinette River receives flow from the North and West Abinette rivers.

The Serpent watershed drains the south-central part of the area of the four communities. This watershed is drained by the Blind and Serpent rivers. The Blind River flows through the Matinenda and Chiblow lakes before being fed by the Potomac River. The Serpent River flows through Quirke and Whiskey lakes, controlled by the Quirke Lake syncline, before receiving flow from the Marshland and Little Serpent rivers.

The Spanish watershed drains the eastern part of the area of the four communities and areas further to the east. The Spanish River receives flow from the River aux Sables and the Vermillion, Wakonassin, Agnes, Mogo, East Spanish and Mozhabong Rivers. The Vermillion and Mogo rivers are located east of the area of the four communities. In the northeast corner of the area of the four communities, surface flow directions are towards the north. However, surface water flows through Ramsay and Biscotasi Lakes beyond the area of the four communities, prior to joining the Spanish River that flows south towards the North Channel.

The Upper Mississagi watershed is the only tertiary watershed underlain entirely by Archean rocks. A mix of Proterozoic and Archean rocks underlies the Lower Mississagi and Serpent watersheds. Watersheds feeding the Blind River are underlain almost entirely by Proterozoic rocks, whereas a greater proportion of Archean rocks exist in watersheds feeding the Serpent River. Apart from the southern portion of the watershed, Archean rocks underlie much of the Spanish watershed in the area of the four communities.

The area of the four communities contains a large number of lakes of various sizes, twenty-four of which are larger than 10 km^2 and ten of which are larger than 20 km^2, with 21% (3,049 km^2) of the area occupied by water bodies, 11% of which is represented by Lake Huron (Figure 2.4 and Table 2.1). Thus, 11.5% of the portion of the area of the four communities not contained within Lake Huron is covered by water bodies. The large lakes are sufficiently large to conceal geological structures up to about 5 km in length, and clusters of small lakes can conceal structures, especially when the lakes are located in areas covered by overburden.

Wetlands depicted on Figure 2.4 are from the Wetland Unit map file produced by the Ministry of Natural Resources. The wetlands contained in this file are from two main sources: Forest Resource Inventory (FRI) and Ontario Base Maps (OBM). Wetlands cover 738 km^2 (or 5.1%) of the area of the four communities, or 5.7% of the portion not covered by Lake Huron.

The paucity of extensive wetlands in much of the area of the four communities is associated with a general absence of thick and extensive overburden deposits over much of the area. The largest wetland complexes in the area are expected to be associated with some of the thickest overburden deposits.

A large (7.4 km^2) wetland complex exists in the low-relief basin surrounding the West Abinette River near the north boundary of the area of the four communities. Another large (5.3 km^2) wetland complex exists within the Boland River watershed south of Rawhide Lake. This wetland complex is located within the drift-filled bedrock basin formed between the Boland Hill and the escarpment of the Flack Lake fault. The floodplain and terraces of a lower 16 km-long reach of the Potomac River contain a large (9.3 km^2) wetland complex. The glaciolacustrine delta formed at the mouths of the Blind and Mississagi rivers supports a large (3.1 km^2) wetland known as the Marshy Bay wetland complex, which is designated as a provincially significant wetland. Another large (3.5 km^2) provincially significant wetland is located on the islands at the mouth of the Spanish River, also associated with a glaciolacustrine delta.

Table 2.2: Dimensional Characteristics of Selected Lakes in the Communities of Elliot Lake, Blind River, The North Shore and Spanish, and Surrounding Area[1]

Lake	Perimeter (km)	Area (km^2)	Max depth (m)	Mean depth (m)
Ten Mile Lake	52.7	10.4	117.4	31.2
Dunlop Lake	61.9	10.3	...	...
White Owl Lake	70.1	10.4	...	...
Sinaminda Lake	108.1	10.5	...	...
Birch Lake	51.0	10.6	27.4	10.3
Kirkpatrick Lake	65.1	11.2	...	...
La Cloche Lake	57.2	11.7	30.5	16.2
Lac aux Sables	59.9	11.7	...	...
Bright Lake	27.3	12.2	...	...
Tunnel Lake	74.6	15.8	...	...
Aubrey Lake	139.7	17.2	...	...
Indian Lake	178.9	18.1	...	...
Mozhabong Lake	134.9	18.7	45.7	12.1
Bark Lake	135.3	18.9	...	...
Chiblow Lake	50.9	20.0	...	...
Quirke Lake	60.0	20.7	...	...
Lauzon Lake	101.6	22.1	...	...
Wakomata Lake	46.0	24.9	73.2	31.1
Basswood Lake	48.8	27.0	73.0	38.6
Agnew Lake	196.4	27.4	...	...
Matinenda Lake	156.8	41.4	33.5	19.4
Rocky Island Lake	280.8	45.0	...	...
Ramsey Lake	373.6	48.2	...	...
Lake Huron[2]	1202.9	1567.8	...	...

[1]Metrics obtained from LIO OHN Waterbody file and MNR

[2] 2Metrics reported for portion of Lake Huron within the area of the four communities

... - information not available

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 is 117.4 m, which was measured in Ten Mile Lake which is located in the center of the area of the four communities (JDMA, 2014a). Lake Huron reaches about 60 m depth near the southwest boundary of the area of the four communities.

2.4 Land Use and Protected Areas

Figure 2.5 shows a summary of land disposition and ownership within the area of the four communities, 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 largest single land-use. The region has more than 60% productive forest and a number of private timber companies are currently managing forestry operations. The area of the four communities contains portions of two Forestry Management Units (FMUs): the Northshore Forest (FMU 680), and the Spanish Forest (FMU 210) (Forest Branch, 2013). The Northshore Forest FMU, managed by Northshore Forest Inc., is located in the western part of the area of the four communities. The Spanish Forest FMU, managed by Domtar Inc., covers the northeastern region of the area of the four communities. The Northshore Forest FMU contains approximately 734,372 ha of crown land, of which 79% is managed for eastern white pine, red pine, eastern hemlock and yellow birch in the east along with other tolerant hardwoods in the west (Domtar, 2010a). The Spanish Forest FMU contains approximately 994,625 ha of crown land, of which 92% is managed for comprised of jack pine, black spruce, poplar and white birch (Domtar, 2010b).

2.4.2 Parks and Reserves

There are 15 provincial parks, 12 conservation reserves and four forest reserves in the area of the four communities (Figure 2.5). Those within the boundaries of the four communities include: Blind River Provincial Park, Matinenda Provincial Park, Mississagi Delta Provincial Park, Glenn N. Crombie Conservation Reserve and Brennan Harbour Conservation Reserve.

Blind River Provincial Park encompasses part of the Blind River and its tributaries, and covers an area of approximately 44 km^2. Downstream of the Blind River Provincial Park is the Matinenda Provincial Park. The Matinenda Provincial Park has an area of 294 km^2 and vegetation conditions found within this park are provincially significant. The Mississagi Delta Provincial Park is a nature reserve class park approximately 2.4 km^2 in size containing a variety of aquatic and terrestrial vegetation. The Glenn N. Crombie Conservation Reserve is partially located in the City of Elliot Lake, and extends beyond the eastern boundary of the City. The reserve has an area of approximately 70 km^2. This conservation reserve protects the best known example of diverse vegetative growth on rugged terrain for the region. The Brennan Harbour Conservation Reserve is the only protected area within the Town of Spanish and occupies a very small area (approximately 2 km^2).

Other Provincial Parks in the surrounding area include: The Chutes, La Cloche, Aubinadong River, Wenebegon, Aubrey Falls, Spanish River, Mississagi, Mississagi River, Little White River, North Channel Islands, River au Sables and Rushbrook Provincial Parks. Other conservation reserves in the area of the four communities include: Rawhide Lake, Basswood Lake, Wagong Lake, Mozhabong Lake, Archambeau Lake Forest, Old Colleagues, Flat Creek Old Pine, Gough Outwash Forest, Shakespeare Forest and La Cloche Ridge. The four forest reserves are: Rawhide Lake, Glen N. Crombie, River aux Sables and Shakespeare.

2.4.3 Heritage Sites

The cultural heritage screening examined known archaeological and historic sites in the area of the four communities, using the Ontario Archaeological Sites Database, the Ontario Heritage Trust Database and the National Historic sites Database. There are 85 registered archaeological sites in the the area of the four communities (von Bitter, 2013, personal communication).

Of these 85 archaeological sites, three are located within the municipal boundary for the City of Elliot Lake; four are within the municipal boundary of the Town of Blind River, and five within the Township of The North Shore. Of note, there is a series of registered archaeological sites located along the shores of the Mississagi River, within Mississagi River Provincial Park. Of the 16 sites recorded within the provincial park boundary, all are pre-contact aboriginal sites with the exception of one being a historic fur trade post. The number and types of sites recorded along the Mississagi River give evidence that this was a major transportation route for both Aboriginal and Euro-Canadians.

There is a second concentration of archaeological sites within the Mississagi Delta Provincial Nature Reserve. These sites were recorded in the 1970s and there is no information on the age of these archaeological sites, their cultural affiliation, or the type of site.

Four sites have been identified as historical Aboriginal cemeteries and one site has been identified as a single burial of a Euro-Canadian. Of the historic Aboriginal cemeteries, two are located along the north shore of Lake Huron and the remaining two are located along the Mississagi River system. A search on recent archaeological assessments within the last 20 years has identified approximately 11 background (Stage 1) or background and property survey (Stage 1 and 2) assessments within the municipal boundary of the City of Elliot Lake (von Bitter, 2013, personal communication).

A search of Parks Canada’s Directory of Federal Heritage Designations (Parks Canada, 2012a,b) revealed that there are no federally recognized heritage designations within the area of the four communities. Parks Canada also administers a database, the Canadian Register of Historic Places (CRHP), which includes federal, provincial and territorial historic sites. A search of this database indicated that there are no additional designated historic sites in close proximity to the the area of the four communities (Parks Canada, 2012c).

The presence of locally protected areas and heritage sites would need to be further confirmed in discussion with the community and First Nation and Métis communities in the vicinity during subsequent evaluation stages, if the community is selected by the NWMO and remains interested in continuing with the site selection process.

3.0 GEOLOGY

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

The area of the four communities, situated on the north shore of Lake Huron, is underlain by early Proterozoic rocks of the Southern Province and Archean rocks of the westernmost portion of the Abitibi Subprovince of the Superior Province of the Canadian Shield. The Abitibi Subprovince is bounded to the west by the Kapuskasing structural zone (KSZ) and Wawa Subprovince and to the north by the Opatica Subprovince (Figure 3.1). The southern boundary of the Abitibi Subprovince is overlain by metasedimentary and metavolcanic rocks of the Huronian Supergroup of the Southern Province. The Southern Province is bounded to the southeast by the Proterozoic Grenville Province. Numerous mafic dyke swarms and mapped faults transect the bedrock in the area of the four communities. Figures 3.2 and 3.3 show the regional and local-scale geology for the area of the four communities and the surrounding area.

The Abitibi Subprovince is exposed in the northern half and much of the eastern side of the area of the four communities (Figures 3.2 and 3.3). The Abitibi Subprovince is a granite-greenstone-gneiss terrane that was developed between 2.8 and 2.6 billion years ago (Thurston, 1991). It is composed of low metamorphic grade volcanic rocks and granitoid plutonic and gneiss-dominated domains, the latter of which are predominant in the area of the four communities and are represented by the Ramsey-Algoma granitoid complex (e.g., Jackson and Fyon, 1991). The Ramsey-Algoma granitoid complex is a large heterogeneous group of granitic bodies that intruded the older metavolcanic and subordinate metasedimentary rocks of the Whiskey Lake and Benny Lake greenstone belts. Several smaller intrusive bodies are distributed throughout the area of the four communities, including the Cutler pluton, the Seabrook Lake intrusion, the Parisien Lake syenite, and the East Bull Lake intrusive suite, among others (Figure 3.3).

The Huronian Supergroup underlies the southern portion of the area of the four communities (Figure 3.2 and 3.3) and consists of a group of metasedimentary rocks (stratigraphically youngest) and lesser (stratigraphically oldest) metavolcanic rocks ranging in age from 2.5 to 2.2 billion years old. The Southern Province also includes the Sudbury Igneous Complex (ca. 1.85 billion years old) located to the east of the area of the four communities, and the metasedimentary and metavolcanic rocks of the Animikie and Sibley Groups that are exposed further to the west, beyond the assessment area, towards Thunder Bay.

The general bedrock geology and main structural features of the area of the four communities are shown on Figures 3.3 and 3.4. Figure 3.5 shows a conceptual north-south geological cross section through the central portion of the area of the four communities based on Zolnai et al. (1984). The location of the conceptual cross section is shown on Figure 3.3.

3.1.2 Geological History

The geological and structural history of the area of the four communities spans almost 3 billion years and includes both Archean and Proterozoic orogenic events, periods of intense felsic and mafic intrusive activity, and complex brittle deformation. The geological history is moderately well understood in the south where the Huronian Supergroup is exposed, but is less well constrained for the underlying Archean Ramsey-Algoma granitoid complex further to the north and east. The geologic and structural history is discussed below and summarized in Table 3.1. The discussion integrates the results from studies undertaken mainly within and proximal to the Huronian Supergroup, augmented by studies within the Swayze area (van Breemen et al., 2006), approximately 120 km north of Elliot Lake, to present an integrated geological and structural history for the area of the four communities.

The oldest rocks in the area of the four communities include the isolated greenstone belt slivers of the ca. 2.725 to 2.686 billion year old Whiskey Lake and Benny Lake greenstone belts, which are themselves intruded by and deformed with the Ramsey-Algoma granitoid complex. Geochronology for the Ramsey-Algoma granitoid complex spans the period between ca. 2.716 and ca. 2.651 billion years (Corfu and Grunsky, 1987; Easton, 2010), indicating that these rocks were emplaced and deformed during the same cratonization event that is characteristic of the regional scale deformation history of the Superior Province.

At the beginning of the Proterozoic Eon, approximately 2.5 billion years ago, an Archean supercontinent (Williams et al., 1991) began fragmentation into several continental masses, including the Superior craton, caused by a widespread and voluminous magmatic event that took place in the Lake Superior region (Heaman, 1997). This magmatic event is associated with rifting and intracratonic development of basins in many areas across the Lake Superior region. Major regional-scale faults such as the Murray and Flack Lake faults were likely formed during the rifting event or represent pre-existing structures reactivated during rifting.

Continental extension at the southern margin of the Superior craton, particularly in the Lake Huron area, allowed intrusion of coeval and comagmatic, mafic-ultramafic geological units such as the ca. 2.49 to 2.47 billion year old Agnew Lake and East Bull Lake intrusions, and contemporaneous to slightly younger (ca. 2.473 billion year old) Matachewan dyke swarm (Vogel et al., 1998; Buchan and Ernst, 2004; Easton, 2009). The timing of intrusion of the mafic and ultramafic units is also approximately contemporaneous with deposition of the basal volcanic rocks of the Huronian Supergroup (Rainbird et al., 2006) upon the Archean basement. The current areal extent of the intrusions likely represents the deformed and erosional remnants of one or more sill-like bodies that may originally have formed an extensive and interconnected mafic sheet (Vogel et al., 1998); similarly, the original extent of the volcanic rocks was much greater than that which is exposed today (Easton, 2010).

The area of the four communities was overprinted by a poorly understood tectonic event, the Blezardian Orogeny, during deposition of the metavolcanic and overlying metasedimentary rocks of the basal portion of the Huronian Supergroup from source regions to the east and northeast (Rainbird et al., 2006). The Blezardian event is interpreted to represent a short-lived orogenic pulse within a larger extensional tectonic setting (Schneider and Holm, 2005). The Blezardian Orogeny is interpreted to have been underway between ca. 2.47 and 2.4 billion years ago (Riller et al., 1999), and ended before ca. 2.30 billion years ago (Raharimahefa et al., 2011; Hoffman, 2013). It was characterized by the development of rifted and structurally-controlled depressions that themselves controlled the deposition of the basal portion of the Huronian Supergroup (Riller et al., 1999; Young et al., 2001). The Blezardian Orogeny is also thought to have initiated the map-scale thick-skinned folding of the Archean basement and rocks within the basal portion of the Huronian Supergroup (Riller et al., 1999).

The rift setting ultimately evolved into a passive margin setting, reflective of a more advanced stage of ocean-opening conditions of a Wilson cycle (Young et al., 2001; Bekker et al., 2005) during deposition of the remainder of the Huronian Supergroup. Deposition continued until between ca. 2.22 and 2.10 billion years ago (Corfu and Andrews, 1986) when rocks of the Archean basement and the Huronian Supergroup were pervasively intruded by the ca. 2.2 to 2.1 billion year old Nipissing intrusions (Lightfoot et al., 1993).

The area of the four communities was subsequently overprinted by the Penokean Orogeny that occurred ca. 1.89 to 1.84 billion years ago (Sims et al., 1989). At the regional scale, the Penokean Orogeny is marked first by the beginning of ocean closure and development of the Pembina-Wasau volcanic arc terrane ca. 1.889 to 1.860 billion years ago (Sims et al., 1989), which was later accreted to the southern margin of the Superior craton in the Lake Superior area (ca. 1.860 billion years ago). This was followed by indentation of the Marshfield terrane ca. 1.840 billion years ago in what is today part of Wisconsin and Illinois (Sims et al., 1989; Schulz and Cannon, 2007). Whether either the Pembina-Wasau terrane or the Marshfield terrane extended to the Lake Huron area, or whether in this latter area the oceanic crust was subducted, remains unknown (Riller et al., 1999). In the Lake Huron area, the Penokean Orogeny involved the reactivation of pre-existing listric normal faults, such as the Murray and Flack Lake faults, enhancement of the pre-existing (Blezardian) folds in the basement and cover rocks, and the northward thrust of rocks of the Huronian Supergroup. Together, these deformation events produced burial depths of up to 15 km for the basal rocks of the Huronian Supergroup (Zolnai et al., 1984). An associated metamorphic overprint was insignificant to the north of the Murray fault, where sub-greenschist facies assemblages are preserved. Amphibolite facies were reached southward of the Murray fault (Piercey, 2006), but seem to be associated with younger tectonothermal pulses such as the Yavapai Orogeny, which occured ca. 1.75 billion years ago (Piercey, 2006).

In addition, there may be structural overprinting along the eastern part of the area of the four communities resulting from the ca. 1.85 billion year old emplacement of the Sudbury Igneous Complex. The Sudbury Igneous Complex is generally considered to represent the scar of a meteorite impact event that occurred during the Penokean Orogeny (Young et al., 2001). Breccias within metamorphosed argillites of the Huronian Supergroup are known from the Whitefish Falls area approximately 70 km southwest of Sudbury and slightly to the southeast of the area of the four communities. These are attributed (Parmenter et al., 2002) to the Sudbury impact event and their distance suggests a diameter in excess of 200 km for the entire impact ring structure. Similar estimates are given by Thompson and Spray (1996) who inferred an original diameter of as much as 250 km for the Sudbury structure based on the distribution of pseudotachylyte. This distance encompasses the eastern third of the area of the four communities and structures related to the Sudbury impact may therefore be present within the area.

Around 1.238 to 1.235 billion years ago, a swarm of dykes intruded the bedrock in the area of the four communities. These are the Sudbury swarm mafic dykes which crosscut all bedrock units in the area of the four communities. The effects of later orogenic events, such as the Grenville Orogeny (ca. 1.250 to 0.980 billion years ago), remain unknown in the area of the four communities; although, towards the Grenville Front (the northwesternmost boundary of the area defining the Grenville Orogeny), the pre-existing mafic dykes are deformed and disrupted from their through-going nature further away from this young orogenic belt.

Around ca. 1.1 billion years ago, a continental-scale rifting event in the Lake Superior area produced the Midcontinent Rift structure (Van Schmus, 1992) that extends southward via an eastern branch down through Minnesota, and via a western branch from Sault Ste. Marie to central Michigan. The rifting event included deposition of large volumes of volcanic rocks and voluminous emplacement of mafic intrusions (Heaman et al., 2007).

Uplift and erosion of bedrock occurred over a protracted period following the rifting event such that at the end of the Precambrian Eon (ca. 540 million years ago), the folded and faulted terrain of the area of the four communities had been eroded to a peneplain roughly approximating the bedrock surface seen today over much of the area. Resistant strata of the Huronian Supergroup formed topographic ridges that persist to the present time, such as the La Cloche Mountains near Espanola. During the Paleozoic Era, commencing in the late Cambrian to early Ordovician Periods, most, perhaps all, of the area of the four communities was submerged beneath shallow seas and overlain by flat-lying carbonate and shale formations. Subsequent uplift and erosion during the late Paleozoic/Mesozoic eras stripped the Paleozoic cover from the area of the four communities. Weathering and erosion of the re-exposed Precambrian surface continued throughout the Cenozoic Era.

The area of the four communities was glaciated during the Pliocene-Pleistocene ice ages when a series of continental ice sheets moved southward across the area (Barnett et al., 1991; Reid, 2003). The advance of the ice sheets and subsequent outwash of meltwaters during glacial retreat scoured the bedrock surface, removing residual soil and weathered rock, and exposing fresh polished bedrock surfaces. Glacial erosion may have enhanced the numerous geological linear features that characterize the area of the four communities where deeper residual soils and weathered rock occurred in association with faults, dykes and formational contacts (e.g., greenstone/granite contacts) of contrasting hardness. This erosion established drainage patterns and lakes which tend to follow the various structural lineaments.

Table 3.1: Summary of the Geological and Structural History of the Communities of Elliot Lake, Blind River, The North Shore and Spanish, and Surrounding Area

Approximate Time Period (billion years ago)	Geological Event
2.72 to 2.651	Kenoran Orogeny: • Emplacement and deformation of the ca. 2.72 to 2.68 billion year old Whiskey Lake and Benny Lake greenstone belts and ca. 2.716 to 2.651 billion year old Ramsey-Algoma granitoid complex. Intrusion of the ca. 2.665 billion year old Parisien Lake syenite. • Development of folds and east-trending foliation in the greenstone belts (ca. 2.72 to 2.70 billion years ago). [D_1]
<2.651 to 2.5	• Early (re)activation of NE-, ENE-, WNW- and NW-striking faults (e.g., Murray and Flack Lake faults) [D_2]
2.497 to 2.47	Onset of continental break-up [D_3]; rifting in many areas across Lake Superior. • Deposition of volcanic rocks and basal sedimentary rocks of the Huronian Supergroup. • Reactivation, or continued activity, of WNW- to NW- and E-striking faults. Widespread mafic magmatism, and emplacement of: • Agnew Lake intrusion and East Bull Lake intrusion 2.49 to 2.47 billion years; ca. 2.473 billion years Matachewan dyke swarm.
2.47 to > 2.3	Blezardian Orogeny. [D_4] • Thick-skinned folding of Archean basement and basal rocks of the Huronian Supergroup. Initiation of Quirke Lake syncline and Chiblow anticline.
< 2.3 and > 2.1	Transition to passive margin setting; • Continued deposition of sedimentary rocks of Huronian Supergroup. • Emplacement of ca. 2.2 to 2.1 billion year old Nipissing diabase intrusions and ca. 2.17 to 2.15 billion year old Biscotasing dyke swarm.
2.10 to 1.89	Denudation of bedrock and formation of peneplain.
1.89 to 1.84	Penokean Orogeny. [D_5]

Approximate Time Period (billion years ago)	Geological Event
	• Crustal shortening and development of thrust-and-fold belt in rocks of the Huronian Supergroup, buckling and faulting of Archean basement. • Subgreenschist and amphibolite grade metamorphic overprint to north and south of Murray fault, respectively. • Emplacement of the Sudbury Igneous Complex ca. 1.85 billion years ago.
1.75 to 1.7	Emplacement of ca. 1.7 billion years Cutler pluton and metamorphic overprint south of Murray fault. Ca. 1.75 to 1.7 billion years ago, a metasomatic event of the Huronian Supergroup (Fedo et.al., 1997).
1.238 to 1.235	Emplacement age of Sudbury dyke swarm and related intrusions of unclassified olivine diabase dykes.
1.25 to 0.98	Grenville Orogeny (overprint in area of the four communities is unclear) • Development of Midcontinent Rift (ca. 1.1. billion years ago) (D_6)
< 1.1 to present	ca. 1.1 to 0.54 billion years ago: denudation of bedrock, formation of peneplain (continuation of D_6). Post-0.54 billion years ago: sedimentation, erosion, ingression and regression of sea water, shallow sea, glaciations. Exhumation of peneplain.

3.1.3 Structural History

As illustrated in the north-south cross section on Figure 3.5, the structural history in the area of the four communities is complex. Recent geologic investigations within the area of the four communities and its vicinity conclude that the region has undergone complicated polyphase deformation (e.g., Card et al., 1972; Young, 1983; Riller et al., 1999; Jackson, 2001; Easton, 2005). The most comprehensive studies on the structural geology of the area of the four communities and its vicinity have been carried out by Zolnai et al. (1984), Riller et al. (1999) and Jackson (2001). These and other investigations documenting the structural geology of particular portions of the area of the four communities (e.g. Easton, 2005) support the existence of two main deformation events which have overprinted all bedrock lithologies. These have been assigned to the aforementioned Blezardian and Penokean orogenies. It should be noted, however, that the occurrence of the Penokean Orogeny in the area of the four communities remains controversial with some authors (e.g. Davidson et al., 1992; Piercey et al. 2003).

It is understood that there are potential problems in applying a regional deformation numbering (D_x) system into a local geological history. Nonetheless, the following summary offers an initial interpretation for the area of the four communities, which may be modified in future if site-specific information is collected.

The earliest deformation phase (D_1) is associated with ca. 2.72 to 2.7 billion year old penetrative deformation of rocks of the Whiskey Lake greenstone belt. According to Jensen (1994), this penetrative deformation is represented by foliation closely paralleling the strike and dip of the metavolcanic and metasedimentary strata composing the greenstone belt. The foliation was likely developed concurrent with folding which is expressed by a west-northwest-trending, isoclinal syncline that strikes about 110°E and dips approximately 70°NE. Recently, Easton (2010) reported the existence of an east-trending shear zone apparently overprinting only the greenstone rocks. Later truncation of the foliation by plutonic material indicates that much of this deformation occurred prior to at least the youngest phase of emplacement of the ca. 2.716 to 2.651 billion year old Ramsey-Algoma granitoid complex (Jensen, 1994).

Subsequent to emplacement of the Ramsey-Algoma granitoid complex, a series of northeast-striking sinistral strike-slip faults and later subvertical, east-northeast-striking faults exhibiting sinistral-oblique movement were formed along the margins of the greenstone belts. The earliest activation along regional east-trending faults, such as the Murray and Flack Lake faults, is attributed to this deformation. This early faulting episode, defined herein as the D_2 event, is poorly constrained to have occurred between ca. 2.651 and 2.5 billion years ago.

Subsequently, a large-scale rifting event (D_3) overprinted the area of the four communities in association with the ca. 2.497 to 2.47 billion year old break-up of the Superior Craton (Williams et al., 1991). This deformation event also involved continued activation along regional faults, including the Murray and Flack Lake faults, and overlapped in time with the deposition of the basal volcano-sedimentary rocks of the Huronian Supergroup (Jensen, 1994). These faulting episodes also involved dextral, west-northwest- to northwest-striking fault reactivation crosscutting the earlier formed structures throughout the Huronian Supergroup (Jackson, 2001). These younger faults also cut the Archean basement and the Murray fault (Jackson, 2001). Alternatively, Jensen (1994) and Jackson (2001) suggested that some of the faults in the area of the four communities may have initiated as Archean structures that subsequently experienced a long history of reactivation during and post-dating the Penokean Orogeny.

D_3 also overlaps in time with the widespread emplacement of mafic intrusions such as the Agnew Lake intrusion and the East Bull Lake intrusive suite (Vogel et al., 1998; Easton, 2009), as well as the pervasive Matachewan dyke swarm. Numerous, narrow, discontinuous shear zones that range from east-northeast to east-southeast in strike, cut the volcanic rocks of the Huronian Supergroup suggesting that east-trending faulting continued during the period of volcanism (Jensen, 1994). As well, the Flack Lake fault and the Murray fault continued as down-to-the-south syn-sedimentary growth faults during the formation of the Huronian Supergroup (Zolnai et al., 1984) while the Neoarchean dextral, west-northwest to northwest faults were reactivated.

The Blezardian Orogeny is assigned as the fourth deformation event, D_4, in the area of the four communities. The Blezardian Orogeny produced steeply south-dipping reverse faults and upright, kilometre-scale folds (Zolnai et al., 1984). Riller et al. (1999) interpreted the initial development of the Quirke Lake syncline and the Chiblow anticline to be attributed to the Blezardian event. As mentioned, the timing of the Blezardian Orogeny is poorly constrained. It is thought to have occurred between ca. 2.4 (possibly as early as 2.47 billion years ago), and 2.3 billion years ago (Riller et al., 1999; Raharimahefa et al., 2011).

The ca. 1.89 to 1.84 billion year old Penokean Orogeny represents a fifth deformation event, D_5. Riller et al. (1999) contended that the Penokean Orogeny in the area of the four communities involved dextral shearing and horizontal shortening. Jensen (1994) also noted that east-northeast faults in the Archean basement and Huronian Supergroup near the Whiskey Lake greenstone belt were reactivated at this time. Crustal shortening and fault reactivation enhanced the previously buckled (Blezardian) structure of the Archean basement and further compressed, folded and faulted rocks of the Huronian Supergroup, so that overlapping thrusted blocks stacked up to possibly 15 km in burial thickness (Zolnai et al., 1984; Figure 3.5). Penetrative deformation features, included cleavage, stretching lineation and rotation of tectonic fabric to a near-vertical orientation, and development of medium to high grade metamorphic assemblages (south of the Murray fault) were developed at this time (Zolnai et al., 1984). Northwest-trending strike-slip faults such as the Spanish American, Pecors Lake and Horne Lake faults that cut the Huronian Supergroup sequence and the parallel Nook Lake fault within the

Archean basement directly north of the Quirke Lake syncline (Robertson, 1968), may have been formed during the Penokean Orogeny, or they may be reactivated Archean faults as suggested by Jackson (2001). The effect that the syn-Penokean meteorite impact, which produced the Sudbury Igneous Complex, had on the geological and structural evolution of the area of the four communities is unclear.

Deformation associated with the Grenville Orogeny, ca. 1.250 to 0.98 billion years ago, is considered the next major deformation episode, D_6, in the area of the four communities. In spite of the scarcity of evidence and problems of deformation overprinting and fault reactivation, it seems that the Murray fault remained active or was reactivated during this orogeny (Robertson, 1970; Card, 1978; McCrank et al., 1989; Piercey, 2006). The Midcontinent Rift (ca. 1.1 to 1.0 billion years ago) was developed contemporaneously with the long-lived Grenville Orogeny and is also included as part of D_6, although its effect on the area of the four communities is not known. There is poor control on any subsequent fault reactivation in the area of the four communities. Therefore all possible post-Grenville fault reactivation is included as part of a protracted D_6 event.

3.1.4 Mapped Regional Structures

Mapped structures in the area of the four communities include large-scale folds, several mafic dyke swarms of different age and orientation, and a mosaic of brittle faults (Figures 3.2 and 3.3.). Their complex present day geometrical arrangement is attributed to the protracted history of tectonic events that has overprinted the area, as described in Section 3.1.3. At the broader regional scale, additional prominent structures include the Sudbury Igneous Complex, the Kapuskasing structural zone and the Grenville Front tectonic zone (Figure 3.2). The following paragraphs provide additional details on these structural features.

During the Penokean Orogeny and earlier deformational periods, both the Archean basement and Huronian Supergroup were affected by different degrees of folding, deformation and faulting. The synformal structure of the Whiskey Lake greenstone belt and its belt-parallel foliation is evidence of early structural overprinting related to the Archean amalgamation of the Superior Province. The development of the Quirke Lake syncline, Chiblow anticline and Flack Lake syncline (Figure 3.3) occurred between approximately 2.219 and 1.8 billion years ago in response to northward compression that included tectonic events attributed to the Penokean Orogeny (e.g., Zolnai et al., 1984; Easton, 2013). The regional scale folding is also evident in the map pattern of the gneissic tonalite suite of the Ramsey-Algoma granitoid complex wrapping around a massive granodioritic to granitic core (e.g., Figure 3.3).

Several distinct mafic dyke swarms are some of the most prominent geological features within the area of the four communities and surrounding region (Figures 3.2 and 3.3). These include the northwesterly trending intrusions corresponding to the ca. 2.473 billion year old Matachewan dyke swarm (Buchan and Ernst, 2004). Volumetrically, these are the most prominent dyke swarms in the region and their mapped spacing of about 1 to 3 km may not be indicative of their detailed distribution, as suggested by detailed mapping studies undertaken elsewhere (e.g., Halls, 1982). The Matachewan dykes are orthogonally crosscut by the approximately east-west trending ca. 2.22 billion year old Nipissing intrusions (Corfu and Andrews, 1986); the younger, less frequent, northeasterly trending ca. 2.167 billion year old Biscotasing dykes (Buchan et al., 1993); and the east-northeast trending 2.1 billion year old Kapuskasing/Marathon dykes (not mapped within the area of the four communities). Later emplacement of the ca. 1.238 billion year old Sudbury dyke swarm (Krogh et al., 1987), and a suite of mafic dykes of uncertain affinity and unknown age (ca. 2.5 to 1.6 billion years old) referred to as the North Channel dyke swarm (OGS, 2011a), provide evidence of the long and complicated crustal deformation that has occurred in the area of the four communities.

The various mafic dyke swarms are associated with, and overprinted by, regional and local scale brittle fractures or fault systems that are also evident throughout the area of the four communities. The faults include northwest-trending strike-slip faults (e.g., the Spanish American, Pecors Lake and Horne Lake faults) that cut the Huronian Supergroup, and the parallel Nook Lake fault within the Archean basement directly north of the Quirke Lake syncline (Robertson, 1968). These faults locally offset diabase dyke intrusions across some fault traces (Spanish American and Horne Lake faults), and offset diabase sills across others (Pecors Lake fault). Thrust faults also occur in the sedimentary sequence parallel to the axis of the syncline and over-thrusting toward the north such as the Quirke Lake fault (Robertson, 1968).

The regional scale arcuate east-trending Flack Lake fault (Figure 3.3) extends for about 150 km and transects both the Huronian Supergroup rocks and the Ramsey-Algoma granitoid complex. The Flack Lake fault is interpreted as a north-directed listric thrust that reactivated an earlier normal fault. Its movement history may be related to post-Nipissing and Penokean events (Bennett et al., 1991).

The Murray fault (referred to in the literature by some as the Murray fault zone) is a major east-trending structure that can be traced a few hundred kilometres from Sault Ste. Marie to Sudbury (Robertson, 1967). Within the area of the four communities, the Murray fault parallels the shoreline of Lake Huron (Figure 3.3) where it is a steeply south-dipping fault zone with approximately 15 to 20 km of reverse sense offset (Zolnai et al., 1984). It records both dextral (Bennett et al., 1991), and sinistral (Abraham, 1953) movement. The Murray fault appears to have been initiated prior to deposition of the Huronian Supergroup, but periodic reactivation occurred synchronous with and after sediment deposition (Reid, 2003; Dyer, 2010). As discussed in Section 3.1.3, the most recent movement of the Murray fault was during the Grenville Orogeny (Robertson, 1970; Card, 1978; McCrank et al., 1989; Piercy, 2006). North of the fault, the Huronian Supergroup deposits are largely fluvial and accumulated to depths of about 5 km, while south of the fault the deposits are dominated by turbidites that accumulated to depths of 15 to 20 km as reflected by their higher metamorphic grade (Bennett et al., 1991). North of the Murray fault, the Huronian Supergroup is considered largely unmetamorphosed, ranging from sub-greenschist to lower greenschist (Bennett et al., 1991). South of the Murray fault, metamorphism increases to middle greenschist and upward to amphibolite facies (Bennett et al., 1991; Jackson, 2001).

Detailed mapping at the East Bull Lake pluton (Ejeckam et al., 1985) highlights the northwest-trending Folson Lake and East Bull Lake faults, and the east-trending Parisien Lake deformation zone. The Folson Lake fault offsets the East Bull Lake intrusion with approximately 3 km of dextral movement and the fault lineament is traceable for approximately 45 km trending northwest (McCrank et al., 1989). Cataclastic zones up to 10 m wide associated with various episodes of movement and dyke injection were identified and drilling difficulties were experienced where these zones were intersected at depth (McCrank et al., 1989). Some evidence gained from dyke-fault relationships suggests that the Folson Lake fault may have been active prior to the injection of the East Bull Lake intrusion while potassium feldspar (adularia) from a hydrothermal vein suggests reactivation ca. 940 million years ago during a later stage of the Grenville Orogeny. Additional fractures and minor faults occur in several preferred orientations, the most common being subparallel to the Folson Lake fault, to mafic dykes and to topographic lineaments (McCrank et al., 1989). The contact between the East Bull Lake pluton and the Huronian Supergroup seems to be faulted, but this has not been confirmed (Easton et al., 2004). In the Whiskey Lake area, at least some of these faults have been inactive since the Archean Eon as shear zones are cut by Archean granitoid rocks that do not appear to be affected by subsequent deformation (Easton, 2010).

Proximal to the area of the four communities, there are several tectonic features of importance. The north-northeast-trending KSZ is an approximately 150 km wide by 500 km long fault-bounded block, located to the northwest of the area of the four communities, which subdivides the Superior Province into eastern and western halves (Percival and West, 1994). The KSZ consists of Archean granulite facies metasedimentary rocks derived from a lower crustal environment (high pressure and temperature) that was brought to higher levels in the crust along the major westward dipping thrust fault and shear zones during the Penokean Orogeny (Percival and West, 1994). The maximum uplift along the fault zone is in the order of 30 to 40 km based on the granulite metamorphic facies of the zone being brought into juxtaposition with greenshist facies rock. Continued tectonic activity in proximity to the KSZ is evidenced by the emplacement of alkalic complexes as recently as ca. 1.1 billion years ago (Sage, 1991). The ca. 1.85 billion year old Sudbury Igneous Complex, located east of the area of the four communities, is generally considered to represent the scar of a meteorite impact event that occurred during the Penokean Orogeny (Young et al., 2001). The Grenville Front tectonic zone, located to the southeast of the area of the four communities represents the mapped northwestern boundary of rocks affected by the Grenville Orogeny. While acknowledging their existence, it is unclear what effect the development of these regional structures had on the local structural complexity of the area of the four communities.

3.1.5 Metamorphism

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in several publications, including Fraser and Heywood (1978), Kraus and Menard (1997), Menard and Gordon (1997), Berman et al. (2000), Easton (2000a,b), Holm et al. (2001) and Berman et al. (2005). The thermochronologic record for major parts of the Canadian Shield is 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). Overall, most of the Canadian Shield, outside of unmetamorphosed late tectonic plutons, contains a complex episodic history of tectonometamorphism largely of Neoarchean age with broad tectonothermal overprints extending from the Paleoproterozoic to the end of the Grenville Orogeny approximately 0.95 billion years ago.

The Superior Province largely preserves low pressure – low to high temperature Neoarchean metamorphism from ca. 2.710 to 2.640 billion years ago, but there is a widespread tectonothermal overprint of the Archean crust by Paleoproterozoic deformation 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 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).

Subgreenschist 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 ca. 2.50 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.

Metamorphic grade in the area of the four communities is largely of subgreenschist facies north of the Murray fault, east and north of Blind River. South of the fault (Piercey, 2006), metamorphism increases to localized lower amphibolite facies extending eastward between Blind River, Sudbury and the Grenville Front (Riller et al., 1999). Most authors (e.g., Zolnai et al., 1984) have considered the medium grade metamorphism reached south of the Murray fault to be a product of tectonothermal burial. However, Jackson (2001) pointed out that the high temperature-low pressure metamorphism reached could not be solely the result of burial, and he advanced the alternative of a second period of crustal extension in the area of the four communities. This hypothesis would not only account for the required heat for medium grade metamorphism but would also explain the emplacement of Nipissing intrusions. Holm et al. (2001) suggested that peak Penokean Orogeny metamorphism occurred ca.1.835 billion years ago, based on monazite ages. More recently, Piercey (2006) pointed out that the Penokean Orogeny was only the first of several accretionary events that impinged on the southern Laurentide margin and presented evidence of a younger and more significant, ca. 1.7 billion year old, metamorphic event possibly related to the Yavapai tectonothermal pulse. This event may have affected the metamorphic conditions in the area of the four communities and possibly increased the metamorphic overprint to greenschist facies, at least in the area proximal to the Cutler pluton, on the north side of the Murray fault. Also north of the Murray fault, Fedo et. al. (1997) pointed out that a ca. 1.7 to 1.75 billion years ago metasomatic event is evident in potassic and sodic alterations of the Huronian Supergroup. This event is probably what replaces most metamorphic minerals in the Huronian Supergroup with white mica and is presumably related to fluid-flow driven by post-orogenic uplift of the Penokean Orogeny. Minor contact metamorphism exists in the metavolcanic rocks of the greenstone belt near some of the large Proterozoic mafic intrusions (Rogers, 1992).

3.1.6 Erosion

During the Archean, following the Kenoran Orogeny, the terrain was reduced by erosion to a peneplain with varying degrees of rolling relief prior to the onset of deposition of the sedimentary sequence of the Huronian Supergroup. Following the Penokean-Hudsonian Orogeny the terrain was again eroded to near its current peneplain configuration before a Paleozoic marine transgression deposited sedimentary strata over much or all of the area of the four communities. These sedimentary strata were dominated by carbonate and shale deposits presumably similar to those preserved on Manitoulin Island and in the Hudson Bay Lowlands. The deposits were subsequently removed from the area of the four communities by erosion during uplift in the late Paleozoic/Mesozoic eras.

There is no site-specific information on erosion rates for the area of the four communities. However, studies reported by McMurry et al. (2003) and Hallet (2011) provide general information on erosion rates for the Canadian Shield. The average Quaternary 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) with higher erosion rates associated with periods of glaciation. The depth of glacial erosion depends on several regionally specific factors, such as the ice geometry, topography, and local geological conditions, such as overburden thickness, rock type and pre-existing weathering.

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

In summary, the area of the four communities is thought to have undergone sequential periods of uplift and erosion followed by crustal depression. The area was largely emergent until the development of the Michigan Basin submerged the area of the four communities and vicinity in an Ordovician-age sea, followed by carbonate deposition continuous with the formations on Manitoulin Island directly to the south. The area was again emergent in the Mesozoic and Cenozoic eras, during which time the Paleozoic strata were eroded from the area. The current Precambrian bedrock topography likely compares closely to that upon which the Huronian Supergroup strata were deposited. This submergence and emergence was of a flexural rather than orogenic nature, though it may have been associated with reactivation of pre-existing fault structures (Easton, 2009).

The most recent period of depression of the crustal sequence beneath the area of the four communities was associated with isostatic adjustments due to loading by the continental ice sheet of the last glaciation which depressed the land surface approximately 200 to 300 m below its current level (Lewis et al., 2005).

3.2 Local Bedrock and Quaternary Geology

3.2.1 Bedrock Geology

Approximately two-thirds of the area of the four communities is underlain by the Ramsey-Algoma granitoid complex, which extends beyond this area to the east, west, and north (Figure 3.2). The bedrock in the southern third of this area is dominated by metasedimentary rocks and subordinated metavolcanic rocks of the Huronian Supergroup, and an inlier of the Ramsey-Algoma granitoid complex. Rocks of the Huronian Supergroup extend beyond this area to the east and west. Less areally extensive lithologies include thin slivers of greenstone belt affinity (Whiskey Lake and Benny Lake greenstone belts) distributed within the gneissic portion of the granitoid complex. In addition, mafic to ultramafic units of the East Bull Lake intrusive suite, the Parisien Lake syenite, and the Cutler pluton, among other small geological units, are present in the southern third of this area. As well, several generations of mafic dykes and brittle faults crosscut the area of the four communities with the former comprising a volumetrically significant portion of the total bedrock area. All mapped dykes post-date the older Archean rocks; however, as discussed further below, not all dykes post-date the metasedimentary rocks of the overlying Huronian Supergroup.

Information on local bedrock geology for the area of the four communities was obtained from the various published reports for the area, geological maps (Section 1.5), and the geophysical interpretation of the area carried out as part of this preliminary assessment (PGW, 2014). The regional and local bedrock geology of the area of the four communities is shown on Figures 3.2 and 3.3, respectively, while a conceptual cross section across the Huronian Supergroup is shown on Figure 3.5. The total magnetic field and the first vertical derivative of the residual magnetic field over the area of the four communities are shown on Figures 3.6 and 3.7, respectively. The regional Bouguer gravity data is shown on Figure 3.8.

In general, the aeromagnetic data shows regional magnetic highs to the north and east predominantly associated with the mapped distribution of massive granodiorite to granite, and to a lesser extent the gneissic tonalite suite of the Ramsey-Algoma granitoid complex. Regional magnetic low response to the southwest is associated with the weakly magnetized bedrock of the Huronian Supergroup. Smaller discrete magnetic highs are located throughout the area, reflecting intrusions of different ages and lithologies, as well as the Benny Lake and Whiskey Lake greenstone belts and smaller greenstone fragments. The boundaries of the geological units are not always well-defined in the aeromagnetic data, largely due to the low resolution of the data.

Gravity data reveal a large arcuate gravity high anomaly present within the area of the four communities that underlies much of the Huronian Supergroup units in an east-southeast direction, and continues in a northeast direction through the central portion of the Ramsey-Algoma granitoid complex. In the Ramsey-Algoma granitoid complex, this gravity anomaly is roughly coincident with the trend of the mapped gneissic tonalite suite, although gravity stations are sparse in this area. The arcuate nature of the gravity anomaly extending through the Ramsey-Algoma granitoid complex and into the Huronian Supergroup rocks appears to spatially correlate to a large scale fold structure with east-west-trending axial surface traces in the area of the four communities.

The gravity high underlying much of the Huronian Supergroup reflects the highest values in the area of the four communities. It is speculated that this gravity high anomaly may reflect the distribution and increased thickness of high density metavolcanics and metasedimentary rocks and the presence of mineralization located within the core of a regional fold (i.e. Quirke Lake syncline), or may reflect the presence of an intrusion at depth. Similarly, this high gravity anomaly broadly extends to the southeast where it is coincident with the mapped distribution of the Elliot Lake Group metasedimentary rocks exposed to the south of the Murray fault, near the North Channel of Lake Huron.

In the north-central portion of the Ramsey-Algoma granitoid complex there is broad correlation between a gravity low and the mapped distribution of massive granodiorite to granite. A similar low gravity response occurs in the northwestern corner of the area of the four communities, which is also broadly correlative with a massive granodiorite to granite unit.

Card et al. (1984) described the high gravity responses along the Murray fault, correlating with the boundary between the Superior and Southern provinces, as being part of a regional anomaly that extends 350 km to the east. Hearst and Morris (2001) interpreted it to reflect an uplifted block of Huronian Supergroup volcanic rocks.

Gravity measurements locally show a higher density of sampling over some of the smaller intrusions and greenstone belts in the area of the four communities, including the Benny Lake greenstone belt, Whiskey Lake greenstone belt, East Bull Lake intrusion, Agnew Lake intrusion and Seabrook Lake intrusion. These units are predominantly characterized by anomalies with relatively high gravity values and may reflect rock units that are higher density than the surrounding bedrock. Although the gravity data is still relatively sparse, the last two intrusions appear areally more extensive in the gravity data compared to their response in the magnetic data and the bedrock geology map.

Interpretation of radiometric data was hindered by the generally low resolution of the data. The mapped massive granodiorite to granite of the Ramsey-Algoma granitoid complex correlates well with a broad regional response that is relatively high in all three radioelements (U, Th, and K). The gneissic tonalite within the complex is also relatively high in potassium but low in uranium and thorium. The Huronian Supergroup show a mixture of responses, with higher values north and east of Elliot Lake, despite the low resolution of the data. Radiometric data over the Benny Lake greenstone belt shows low concentrations of thorium and uranium, and elevated concentrations of potassium. In contrast, the Whiskey Lake greenstone belt tends to be dominated by thorium, with lesser amounts of potassium and uranium, in spite of the lower resolution data acquired over this greenstone belt.

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

3.2.1.1 Whiskey Lake Greenstone Belt

The Whiskey Lake greenstone belt (Figure 3.3) consists of Archean metavolcanic and subordinated metasedimentary rocks that form an arcuate, easterly-striking, 10 km by 30 km, synclinal greenstone belt (Rogers, 1992). The greenstone belt has been subdivided into the Whiskey Lake greenstone belt for the portion south of the Folson Lake fault and a northern component named the Ompa greenstone belt (Easton, 2010) for the portion north of the Folson Lake fault. In the interest of simplicity and consistency with earlier nomenclature, the name Whiskey Lake refers to both components in this assessment. Radiometric ($^{207}Pb/^{206}Pb$) dating from greenstone rocks in the Joubin Township area, located 15 km west of the East Bull Lake intrusion, yielded ages of ca. 2.686 and 2.725 billion years, for upper and lower metavolcanic sequences (Easton, 2010; Easton and Heaman, 2011), while a similar age of 2.689 billion years was obtained from felsic metavolcanic rock of the northern portion of the greenstone belt (Easton, 2010). Drill holes in the Whiskey Lake greenstone belt in the vicinity of Folson Lake (AFRI # 41J08NW0001) indicate a thickness of at least 400 m for the greenstone rocks.

The Whiskey Lake greenstone belt is mostly composed of metavolcanic rocks in its eastern half. Metasedimentary rocks are more abundant in the western part of the greenstone belt. Although the greenstone belt is partly overlain by rocks of the Huronian Supergroup, there are large exposures of Archean greenstone rocks southeast and northwest of the easternmost portion of the Huronian Supergroup located in the vicinity of the City of Elliot Lake (Roscoe, 1969).

The eastern half of the Whiskey Lake greenstone belt consists of inter-layered tholeiitic and calc-alkalic metavolcanic rocks and rare, narrow horizons of bedded chert (Rogers, 1992). The tholeiitic rocks consist of massive and pillow basalt flows usually about 15 m thick. Mafic to felsic pyroclastic rocks, composing the calc-alkalic suite, occur as generally thin, less than 100 m thick, units of fine-grained tuff, exhibiting penetrative schistosity parallel to bedding (Rogers, 1992). These rocks are intruded by Archean gabbro dykes, sills, and stocks across the southern portion of the greenstone belt.

The mafic to intermediate metavolcanic portions of the greenstone belt are well-defined by discrete magnetic highs with a roughly east-west orientation; although, the widespread dyke activity makes it difficult to differentiate the more subtle responses of any felsic metavolcanic and metasedimentary rocks from adjacent rocks of the Ramsey-Algoma granitoid complex or the Huronian Supergroup. A slight gravity high is associated with the greenstone belt, which has a low radiometric response.

3.2.1.2 Benny Lake Greenstone Belt

The Benny Lake greenstone belt (Figure 3.3) consists of Archean metavolcanic and metasedimentary rocks that form an east-striking 40 km long by 5 km wide greenstone belt that extends from the Geneva Lake area to the Mink Lake area, some 70 km northeast of the City of Elliot Lake. The greenstone belt extends approximately 10 km into the area of the four communities to its mapped termination south of Mink Lake. Card and Innes (1981) described the central part of the belt as consisting of intercalated mafic flows and pyroclastic rocks with intermediate tuffs and tuff-breccia with some volcanogenic metasedimentary rocks including tuffaceous greywake and siltstone, chert, and iron formation. The stratigraphic sequence in this part of the belt comprises cyclic repetitions of mafic, intermediate, and felsic metavolcanics, plus sulphide-bearing tuffs and tuffaceous metasedimentary rocks that commonly lie along contact zones between the metavolcanic units. Outliers of the Huronian Supergroup have also been mapped in the area south of the greenstone belt.

Felsic plutonic rocks are noted to surround and intrude the greenstone rocks. Card and Innes (1981) subdivided these rocks into an older gneissic, granodioritic complex that occurs mainly to the north of the greenstone belt and a younger, relatively massive, homogeneous quartz monzonite that forms most of the terrain to the south, based on mapping carried out in 1973-74. Quartz monzonite, as used in 1973-74, may overlap with a number of fields in the currently used International Union of Geological Sciences (IUGS) classification. Although there is no published information on the age of this greenstone belt, Easton (2010) noted that the ages obtained for the Whiskey Lake greenstone belt mentioned above were consistent with 2.690 to 2.685 billion year old volcanism in the southern part of the Abitibi Subprovince, including the Benny Lake greenstone belt and other greenstone belts in the subprovince.

The greenstone sequence dips steeply to the south with a schistosity subparallel to the primary stratification. Movements on major northwest and north-northwest trending faults such as those along the Spanish River have resulted in progressive northward displacement of the Benny Lake belt from east to west.

The Benny Lake greenstone belt exhibits a similar aeromagnetic response to that of the Whiskey Lake greenstone belt, with the mafic to intermediate metavolcanic portions of the greenstone belt defined by magnetic highs with a roughly east-west orientation. A slight gravity high is associated with the Benny Lake greenstone belt.

3.2.1.3 Ramsey-Algoma Granitoid Complex

The Ramsey-Algoma granitoid complex is a large complex of granitoid and gneissic rocks divided in three large domains: Chapleau gneiss domain, Ramsey gneiss domain and Algoma plutonic domain (Jackson and Fyon, 1991). In the area of the four communities, the granitoid complex is dominated by the Algoma plutonic domain. Although some portions of the Algoma plutonic domain have been mapped in detail (e.g., Robertson, 1965a,b,c; Robertson and Johnson, 1965; Giblin, 1976; Giblin et al.,1977), the Algoma plutonic domain is generally not well studied. The Ramsey-Algoma granitoid complex is generally described in the literature as largely consisting of a massive to foliated granite-granodiorite suite intruding a tonalite-granodiorite suite. In addition, several narrow slivers of metavolcanic rock are mapped within the gneissic tonalite portion of the Ramsey-Algoma granitoid complex in the north part of the area of the four communities.

The Algoma plutonic domain consists of granitic and granodioritic rocks and granitic gneisses with numerous greenstone enclaves and massive to foliated granite, granodiorite, and syenite intrusions (Card, 1979); although, a variety of facies have been observed throughout the granitoid complex in the area of the four communities. For example, in the area of Rawhide Lake, about 15 km north of Elliot Lake, the Algoma plutonic domain consists generally of uniform, massive, medium to coarse-grained, equigranular granite (Ford, 1993). About 45 km northwest of Elliot Lake, in the area of Kirkpatrick Lake, the plutonic complex is reported to be predominantly composed of massive to foliated biotite-bearing to hornblende-bearing granitic rock with up to 30% amphibole. Minor, more leucocratic phases are typically quartz monzonite to granodiorite and trondhjemite. Further westward in the Wakomata Lake area, outcrops of pink to grey, equigranular, fine- to coarse-grained trondhjemite, quartz monzonite and granodiorite have been reported, of which grey, medium- to coarse-grained, leucocratic trondhjemite predominates (Siemiatkowska, 1977). Sage (1988) described granitic rock in the Seabrook Lake area as massive, medium- to coarse-grained, red to red-brown, leucocratic, granodiorite to quartz monzonite. In the area of East Bull Lake, Easton et al. (2004) reported mixtures of strongly foliated granitic gneiss and migmatitic facies enclosing mafic gneiss, whereas McCrank et al. (1989) described that area as comprising weakly to moderately foliated granodiorite and porphyroblastic granite. Lastly, Gordon (2012) noted massive, homogeneous syenogranite as the main plutonic phase in Otter Township, located just west of the area of the four communities.

The geophysical interpretation by PGW (2014), based largely on the aeromagnetic data, subdivides the Ramsey-Algoma granitoid complex into distinct anomalies with strongest magnetic responses predominantly associated with areas of mapped granite to granodiorite units, and slightly weaker response associated with the mapped gneissic tonalite units. The geophysical interpretation also identifies low magnetic response where the gneissic tonalite surrounds the Huronian Supergroup. Some of the contacts between the massive granodiorite to granite and the gneissic tonalite, based on the geophysical interpretation, are discordant relative to their mapped surface location. There is also uncertainty in the true location of contacts due to the presence of dykes masking the bedrock response, and the limitation of the data set resolution.

Geochronology for the Algoma plutonic domain includes an age of 2.716 billion years old in the Batchawana area, about 60 km west of the area of the four communities (Corfu and Grunsky, 1987), and 2.662 billion years for the area south of Ramsey, about 20 km northeast of the area of the four communities (van Breemen et al., 2006). Heather et al. (1995) reported a preliminary age of ca. 2.727 billion years for biotite tonalite from immediately south of the Swayze greenstone belt to the northeast of the area of the four communities. More recently, Easton (2010) obtained preliminary dates of 2.675 and 2.651 billion years for two samples of granite and granodiorite near Elliot Lake. The wide range of dates suggests that the Algoma-Ramsey granitoid complex contains distinct plutonic and gneissic lithologies emplaced over a period of 75 million years and possibly longer. This interpretation is supported by van Breemen et al. (2006) who subdivided granitic rocks in the Swayze area, around 120 km north of Elliot Lake, into the following five broad categories:

- Synvolcanic diorite and hornblende tonalite intrusions ranging in age from ca. 2.740 to 2.696 billion years old;
- A transitional suite of tonalite and quartz monzonite intrusions ranging from ca. 2.695 to 2.686 billion years old;
- Syntectonic hornblende granodiorite intrusions ranging from ca. 2.685 to 2.686 billion years old;
- A younger transitional suite of tonalite and quartz monzonite intrusions ranging from ca. 2.680 to 2.665 billion years old; and
- Non-foliated ca. 2.665 billion year old post-tectonic granite intrusions occurring within areas of synvolcanic and syntectonic intrusions.

Although the Swayze area is located further north, it shares a similar tectonic setting to the northern part of the area of the four communities. Van Breeman et al. (2006) may therefore offer an interpretative framework for the largely unmapped Ramsey-Algoma granitoid complex within the northern part of the area of the four communities. Heather et al. (1995) also described a large body of massive Algoma biotite granite in the area southwest of Ramsey that extends into the area of the four communities.

There is only limited data on the thickness of the Ramsey-Algoma granitoid complex in the area of the four communities. Cruden (2006) used gravity and seismic measurements to estimate the regional thickness of late Archean granites to be on the order of 1 to 3 km thick, with the lower value assuming wedge-shaped plutons and the higher value corresponding to a tabular morphology.

3.2.1.4 Seabrook Lake Intrusion

The Seabrook Lake carbonatite intrusion is located within the northwest part of the area of the four communities some 80 km northwest of the City of Elliot Lake. Sage (1988) described the carbonatite as tadpole-shaped in plan-view, tapering to the south, and occupying an area of approximately 1.5 km^2. The northern portion is dominated by sovite and silicocarbonatite, while rocks of the ijolite suite dominate to the south. The intrusion occurs at the intersection of several regional lineaments, and Sage (1988) speculated that it may represent the southern limit of alkalic magmatism associated with faulting in the Kapuskasing structural zone which lies further to the north.

The carbonatite and ijolite are enclosed within an envelope of brecciated and fenitized granitic rock, which grades outward to an unbrecciated halo of fenitized granitic rocks up to 300 m wide. The granitic rocks are mapped as part of the Ramsey-Algoma granitoid complex and are described at this location (Sage, 1988) as typical of the late Archean granite diapirs found throughout the Canadian Shield. Texturally, the granite is massive, medium- to coarse-grained, red to red-brown, leucocratic, granodiorite to quartz monzonite with modal composition estimated as 35% quartz, 40 to 50% plagioclase, trace to 25% potassium feldspar, and up to 5% biotite. No petrographic evidence of recrystallization and/or metamorphism was noted by Sage (1988).

The granitic rocks enclosing the Seabrook Lake intrusion are crosscut by northwesterly-trending diabase dykes (Matachewan and Sudbury) but these dykes do not crosscut the carbonatite. The intrusion has been dated by K-Ar isotopic techniques at 1.109 and 1.107 billion years old (Gittins et al., 1967).

This intrusion is characterized by a central, east-northeast-striking, magnetic high and spotty magnetic highs beyond its mapped margin.

3.2.1.5 Parisien Lake Syenite

The Parisien Lake syenite is a late Archean, 2.665 billion year old (Krogh et al., 1984), elliptical intrusive stock located about 15 km east of the City of Elliot Lake, adjacent to the East Bull Lake intrusion. It measures approximately 13.5 km east-west and 3.3 km at its widest point north-south. The intrusion is composed of medium- to coarse-grained, pink, equigranular monzodiorite, monzonite and syenite (Rogers, 1992). Predominant minerals are K-feldspar phenocrysts, with interstitial amphibole, biotite, sphene, and magnetite, with a distinctive, locally developed K-feldspar alignment (McCrank et al., 1989). The Parisien Lake syenite is shown on Figure 3.3 as a diorite-monzonite-granodiorite suite. There is no readily available information on the thickness of this intrusion.

The Parisien Lake syenite, with its strong magnetic response, is clearly differentiated from the weakly magnetic East Bull Lake intrusion immediately to the north.

3.2.1.6 East Bull Lake Intrusive Suite

The East Bull Lake intrusive suite is located east of the City of Elliot Lake. It consists of a series of east-northeast-trending, elongated gabbro-anorthosite intrusions that were emplaced into Archean metavolcanic and metaplutonic rocks of the Superior Province during the early Proterozoic ca. 2.490 to 2.470 billion years ago

(Easton et al., 2004). These intrusions are shown as mafic and ultramafic intrusive rocks on Figure 3.3. The East Bull Lake intrusive suite comprises three intrusions: 1) the East Bull Lake intrusion, which includes the East Bull Lake pluton and the intrusions to the north of the pluton; 2) the Agnew Lake intrusion; and 3) the May Township intrusion, located near Highway 17 east of the Town of Spanish, which is a thin sheet-like intrusion near the contact between Archean granitic rocks and the Huronian Supergroup.

The elliptical East Bull Lake pluton, about 15 km east of the City of Elliot Lake, has surface dimensions of at least 13.5 km east to west, and a maximum north-south extent of 3.5 km (Figure 3.3). It is about 780 m thick in its central part (McCrank et al., 1989). The East Bull Lake pluton has a U-Pb isotopic age of 2.480 billion years old (Krogh et al., 1984), and it is divided into several large composite rock units distinguishable by variations in mineral composition, texture, and style of internal layering (McCrank et al., 1982; James et al., 1985; Ejeckam et al., 1985). Within the composite units, mineralogical grading produced layers that grade from gabbro to leucogabbro, rhythmic layers that grade upwards from clinopyroxenite and gabbro, to anorthosite layers and thin, centimetre-sized laminations of clinopyroxenite within gabbroic rock (McCrank et al., 1989).

The main mass of the Agnew Lake intrusion is located about 35 km east of the City of Elliot Lake. It is similar in age and size to the East Bull Lake intrusion, with an estimated U-Pb isotopic age of approximately 2.491 billion years old (Krogh et al., 1984), a thickness of 1 to 2.1 km, and an area of 50 km^2 (Vogel et al., 1998). The primary axis of the Agnew Lake intrusion is east-west, similar to the East Bull Lake intrusion, and is thought to reflect the orientation of the rift structure that permitted magma intrusion (Easton et al., 2004), and would have shaped the Agnew Lake and the East Bull Lake intrusions originally into funnel-like bodies (Vogel et al., 1998). The Agnew Lake intrusion is linked to the East Bull Lake intrusive suite on its northwest side by the Streich dyke, a 200 to 300 m wide gabbronoritic body with a strike length of approximately 10 km (not shown on Figure 3.3). The Agnew Lake intrusion is a product of four major magma pulses that produced an internal layered distribution of gabbronorite, olivine gabbronorite and leucogabbronorite in the intrusive body, each ranging in thickness from a few tens of metres to hundreds of metres. The Camp Eleven fault bisects the intrusion and exhibits 600 m of dextral displacement of this internal layering (Vogel et al., 1998). The Agnew Lake intrusion was wholly emplaced in granitoid rocks of the Algoma plutonic domain, while the top of this intrusion corresponds to a major disconformity separating the Agnew Lake intrusion from the Huronian Supergroup (Vogel et al., 1998). Also, potentially related to the East Bull Lake suite is the Tennyson sill (Prevec, 1993), an approximately 650 m thick body of medium-grained gabbro north of Massey. The Tennyson sill intruded Archean granodiorite, but is crosscut by Matachewan dykes. Easton (2010) interpreted the Tennyson sill to be a primitive phase of the East Bull Lake intrusive suite.

The East Bull Lake intrusion generally shows a low magnetic response, with some areas of higher intensity towards its west end, reflecting some internal inhomogeneity (Figures 3.6 and 3.7). The northern two lobes mapped for this intrusion show no magnetic contrast with the host rock and have not been separated in the interpretation. The Agnew Lake intrusion shows a local magnetic high in its southeast corner, but otherwise cannot be differentiated from the surrounding massive granodiorite to granite. Local gravity highs (Figure 3.8) are associated with both the East Bull Lake and Agnew Lake intrusions.

3.2.1.7 Cutler Pluton

The Cutler pluton is located south of the City of Elliot Lake (Figure 3.3) and extends west into Lake Huron (Giblin and Leahy, 1979). The pluton is an elongated muscovite-biotite granitic body with dimensions of approximately 3 km by 28 km. The pluton intrudes both metamorphosed rocks of the Huronian Supergroup and Nipissing intrusive rocks south of the Murray fault (Robertson, 1970; Card, 1978) along the axis of the doubly plunging Spanish anticline (Robertson, 1970). The pluton consists of different intrusive phases, medium- to coarse-grained, foliated quartz monzonite, granodiorite and tonalite. The Cutler pluton was emplaced approximately 1.75 billion years ago after the Penokean Orogeny (Wetherill et al., 1960). There is no readily available information on the thickness of this intrusion.

3.2.1.8 Huronian Supergroup

The Huronian Supergroup (Figures 3.2 and 3.3) is a stratigraphic sequence that extends for about 450 km from the east shore of Lake Superior to northwest Quebec, with varying thickness of up to 12 km southwest of Sudbury, thinning northward against rocks of the Ramsey-Algoma granitoid complex (Bennett et al., 1991). The Huronian Supergroup surrounds the City of Elliot Lake and overlies rocks of both the Whiskey Lake greenstone belt and the Ramsey-Algoma granitoid complex over large areas. Deposition of the thick Huronian stratigraphic package in a rift setting started approximately 2.497 billion years ago (Rainbird et al., 2006), influenced by Archean tectonic activity and possibly an early Proterozoic extension event, and was later succeeded by a passive-margin setting (Bennett et al., 1991; Young et al., 2001). Deposition ceased sometime before 2.219 billion years ago (Corfu and Andrews, 1986).

The Huronian Supergroup consists of a succession of four lithostratigraphic groups: the Elliot Lake Group is at the base and is overlain, in ascending order, by the Hough Lake, Quirke Lake and Cobalt groups. The Elliot Lake Group forms an eastward-thinning volcano-sedimentary package of uranium-bearing conglomerate beds and sandstone sequences associated with the extensional rifting events (Bennett et al., 1991). The other three groups represent three sedimentary cycles deposited in a continental passive-margin setting, intercalated by periods of Neoproterozoic glaciations (Bennett et al., 1991; Young et al., 2001). Each metasedimentary cycle typically consists of conglomerate, overlain by either mudstone, siltstone or carbonate, and is capped by coarse, cross-bedded sandstone (Roscoe, 1969).

The Huronian Supergroup sequence underwent subgreenschist facies metamorphism that resulted in highly indurated, non-porous quartzite and arkose-greywacke strata. The sequence was gently folded through north–south compression prior to the emplacement of Nipissing diabase intrusions (2.2 to 2.1 billion years ago). The Huronian Supergroup is also intruded by the Cutler pluton (Bennett et al., 1991) and several groups of mafic dykes such as Nipissing, Sudbury and unclassified dykes (Lewis, 2013) described in the section below.

The Huronian Supergroup strata are generally magnetically transparent. The southern part of the Huronian Supergroup shows a slightly higher magnetic response than the northern part, corresponding to the shallower and deeper underlying basement reflected by the Chiblow anticline and the east-west Quirke Lake syncline axes respectively (Johns et al., 2003). Two prominent, broadly north-west trending magnetic highs are observed east of Elliot Lake. The larger of the two anomalies is referred to as the Pecors magnetic anomaly, known to exhibit resource potential. The north-west orientation of these anomalies tends to be broadly coincident with the strike of the Matachewan dyke swarm through the area. Magnetic inversion modelling suggests that the source of the magnetic anomaly is located within the Archean bedrock underlying the Huronian Supergroup units (Hawke, 2011). The east-southeast oriented gravity high, previously described, occurs near the center of the Huronian Supergroup and is aligned with the Quirke Lake syncline. The Huronian Supergroup strata show a mixture of radiometric responses, with higher responses in the Quirke Lake syncline, particularly north and east of Elliot Lake.

3.2.1.9 Mafic Dykes

Mafic dykes and intrusions of diabase and gabbroic composition are widespread in and around the area of the four communities (Figures 3.3 and 3.4). Although the similar composition and texture of these intrusions has hampered the determination of their age and character, most of the studies carried out in the area of the four communities have historically assigned the mafic intrusions and dykes either to the Matachewan or Nipissing suites. More recent studies (Osmani, 1991; Phinney and Halls, 2001) indicate the presence of at least four distinct generations of mafic dyke emplacement: Matachewan swarm, Nipissing intrusions, Biscotasing swarm, Sudbury swarm, North Channel swarm, and younger unclassified dykes (in addition to the local occurrence of highly deformed unclassified mafic dykes of Archean age). The determination of age relationships is further hampered by the widespread occurrence of composite dykes, resulting from multiple injections of magma into the same fracture system (Easton, 2009). Finally, Easton (2010) noted that south of approximately 46°42′N, the Matachewan swarm diabase dykes lose their magnetic character, making their identification based on aeromagnetic response problematic.

The main generations of mafic dykes in the area of the four communities are described in the following subsections.

Matachewan Dykes

Matachewan diabase dykes are early Proterozoic intrusions ca. 2.473 billion years old (Buchan and Ernst, 2004). These dykes form the oldest and most extensive dyke swarm, cutting the Archean Superior Province rocks, and are characterized by a north-northwest orientation and the display of large phenocrysts of plagioclase in an epidote-rich matrix (Robertson, 1977b). Variations can be found in particular areas; for example, in the area of Albanel Township, located approximately 35 km northwest of Elliot Lake, these dykes are equigranular, fine- to medium-grained, composed predominantly of hornblende and plagioclase, and vary in width from 2 to 20 m (Lewis, 2013). In the Pecors-Whiskey Lake area, Easton (2010) noted dyke widths of up to 150 m and identified two compositional groups: non-phyric and plagioclase-phyric with phenocrysts up to 3 mm in size. The majority of the mafic dykes cutting the Archean terrane beneath the northern half of the area of the four communities and south and east of the Quirke Lake syncline are considered to be Matachewan dykes, which have also been related to the East Bull Lake intrusive event and may be related to the basal Thessalon Formation basaltic flow deposits (Vogel et al., 1998; Easton, 2009). The Matachewan dykes in the East Bull Lake area trend northwestward through the Archean terrain of the northern half of the assessment area (Figure 3.3). Easton (2010) noted that in the area south of Elliot Lake, Matachewan dykes constitute roughly 60 to 75% of the mafic dykes exposed in outcrop with this percentage rising to approximately 90% in the Whiskey Lake area. The Matachewan dykes predate the deposition of the sedimentary rocks of the Huronian Supergroup, but they may have served as feeders for the volcanic rocks of the Huronian Supergroup (Buchan and Ernst, 2004), given their similar age and geochemical affinity (Vogel et al., 1998).

Nipissing Intrusions

The Nipissing intrusions consist of early Proterozoic mafic bodies of irregular sill-like and dyke-like geometry, approximately 2.21 billion years old (Corfu and Andrews, 1986; Palmer et al., 2007). These intrusions post-date the Matachewan dykes and cut both the Archean basement and the folded Huronian Supergroup. In the area of the four communities, mapped Nipissing intrusions are confined to the Huronian Supergroup and adjacent crystalline rocks of the Ramsey-Algoma granitoid complex. These undulating sill-like intrusions are up to around 460 m thick, and roughly parallel the regional east-west structural-stratigraphic trends (Lovell and Caine, 1970;

Card and Pattison, 1973; Card, 1976), predominating over much less frequent dyke-like intrusions of tens of metres wide, and other intrusive bodies interpreted as cone sheets (Palmer et al., 2007).

Most of the Nipissing intrusions consist of uniform, undifferentiated quartz diabase; nevertheless, more differentiation exists in the area of the four communities, as quartz diabase and two-pyroxene gabbro appear to be the most common Nipissing intrusive rock type (Lightfoot et al., 1993). Other varieties of Nipissing intrusive rocks consist of olivine gabbro, hornblende gabbro, feldspathic pyroxenite, leucogabbro, granophyric gabbro and granophyre (Card and Pattison, 1973). In the Iron Bridge area (at the intersection of Highway 17 and Highway 546), steeply dipping, metagabbro bodies are dominant (Bennett et al., 1991). The gabbros are massive, but commonly display weak foliations near their contacts with other rocks. Some sills are altered mainly by hydrous fluids produced by the elevated temperature and pressure of regional metamorphism (Card, 1964).

The Nipissing intrusions seem to have been emplaced during at least two magmatic pulses from approximately 2.209 to 2.218 billion years ago (Buchan et al. 1989; Palmer et al., 2007). No major tectonic event has been identified to be the source of the Nipissing intrusive rocks (Bennett et al., 1991), but subduction of oceanic crust with some continental crustal contribution could possibly account for their emplacement (Lightfoot et al., 1993), or a second extensional event (Jackson, 2001). More recently, however, Palmer et al. (2007) suggested that coeval Seneterre dykes acted as feeders for the Nipissing intrusions, mostly based on measurements of anisotropy of magnetic susceptibility and age correlation, but apparently also supported by geochemical affinities.

Biscotasing Dykes

Biscotasing dykes are prominent, regional northeasterly-trending vertical features that have been identified within the northern half of the assessment area, where they cut rocks of the Archean basement, and further south where they transect the Huronian Supergroup. At the regional scale these dykes extend from the Flack Lake syncline northeast several hundred kilometres to the Lake Abitibi area. The dykes have been dated at 2.167 billion years old (Buchan et al., 1993). These dykes, also formerly referred to as the Preissac dykes, are quartz tholeiitic features usually 50 to 100 m in width, with fine-grained chilled margins and medium- to coarse-grained interiors (Buchan et al., 1993; Halls et al., 2008), which were emplaced along fault structures that possibly pre-date the dykes. Compositionally, the Biscotasing dykes are composed of approximately 50% plagioclase, 30% pyroxene, up to 10% quartz, and several percent magnetite–ilmenite intergrowths. Alteration of the dykes is highly variable from one dyke to another and within individual dykes (Buchan et al., 1993).

Sudbury Dykes

Archean rocks in the area of the four communities in the vicinity of East Bull Lake intrusive suite are themselves intruded by Proterozoic, post-Nipissing mafic dykes that correlated with the 1.238 to 1.235 billion year old Sudbury dyke swarm (Krogh et al., 1987). These younger dykes typically range in composition from olivine diabase, amphibole diabase, diabase, magnetite-bearing diabase to lamprophyre diabase. All have in common a narrow width, generally less than 10 m, and a west-northwest orientation; they appear to have filled the space of older northwest-trending faults (Easton, 2009). Dykes of this age and composition are scarce or absent within a prism-shaped area of approximately 150 km^2 centered on Elliot Lake (Robertson, 1968; Easton, 2009).

North Channel Dykes

A suite of west-northwest striking mafic dykes occurs along the southern portion of the area of the four communities. Previously mapped as part of the Nipissing dyke swarm, these dykes are now considered to represent a separate phase of intrusion and they are mapped separately in the most recent seamless geology coverage of Ontario (OGS, 2011c) which gives an age range from 1.6 to 2.5 billion years old.

Younger Dykes

Archean rocks in the area of the four communities are also intruded by younger post-Sudbury dykes including olivine lamprophyres (Siemiatkowska, 1977). These late intrusions were mapped crosscutting the Seabrook carbonatite intrusion (Sage, 1988) suggesting an emplacement age that post-dates ca. 1.1 billion years ago. Easton (2010) also recognized several intrusions in the area of the four communities that could not be confidently assigned to the extensive Nipissing intrusions, one of which seem to correlate with that observed more recently by Lewis (2013) in the Albanel Township area.

3.2.2 Quaternary Geology

The Quaternary geology of the area of the four communities 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 ago, at which time the glacial ice front extended south of Ontario into what is now Ohio and Indiana (Barnett, 1992).

The area of the four communities is dominated by exposed bedrock or bedrock having only a thin mantle of unconsolidated sediments. Quaternary deposits are predominantly located in bedrock-controlled valleys. Figure 2.3 illustrates the extent and type of Quaternary deposits in the area of the four communities. Overburden deposits within this area were also mapped as part of the Northern Ontario Engineering Terrain Study (NOEGTS), a program undertaken between 1977 and 1981 (Gartner, 1978a,b,c; 1980 a,b; Roed and Hallet, 1979a,b,c,d; 1980a,b; VanDine, 1979a,b,c,d; 1980a,b,c,d; Gartner et al., 1981). These studies divided the landscape into a set of distinct terrain units within which the engineering characteristics are broadly predictable. Major landforms mapped by the NOEGTS program are shown on Figure 2.3.

Data on ice flow direction compiled from the literature (Karrow, 1987) reveal that glacial ice flowed in a generally southwesterly direction across the area of the four communities from the Hudson Bay basin. Ford (1993) recognized two dominant orientations in glacial striations, lunate fractures, drumlinoid features, and till flutings in the Rawhide Lake area to the north of the City of Elliot Lake. These are recorded as 175° (165° to 180°) and 195° (190° to 210°). At three sites, older 100° to 120° striations were found intersecting either the 175° or 195° sets.

The most widely occurring and oldest known stratigraphic unit in the area is a silty sand to sandy silt till found overlying bedrock in low relief areas and along the flanks of topographic lows. It is typically thin and discontinuous and is coarse-textured, unsorted, and boulder-rich, although there are some areas of compact, massive to fissile and gravelly to silty and sandy till (Barnett et al., 1991). Glaciolacustrine sediments have more limited distribution and are limited to only very small mappable surficial units (Ford, 1993) largely along river valleys. These units, typically composed of laminated silt and fine sand and silt-clay rhythmites, may be related to the series of postglacial lakes of the Lake Huron basin.

Deposits of glaciofluvial outwash and ice-contact stratified drift are commonly encountered along valleys in the area of the four communities. Ice contact deposits are composed of variable quantities of sand, gravel, and boulders, locally with minor silt and/or till in the form of small moraines. Glaciofluvial outwash is common in low-lying areas and occasionally in esker ridges with the local formation of terraces related to changing lake levels in the Lake Huron basin. Thick deposits of alluvial sand and gravel are found along many of the rivers in the region. Recent swamp, lake, and stream deposits are also common throughout the area.

The northward retreat of the ice sheet in the area of the four communities started approximately 12,000 years ago between the Onaway Advance (11,800 years ago) and the Marquette Advance (10,000 years ago). Ice retreat took place as Lake Algonquin spread northward, leaving a series of shorelines during isostatic uplift and opening of the sequence of outlets near North Bay, Ontario. The high water level associated with Lake Algonquin has been mapped between 309 and 312 m above present day sea level (Cowan, 1976; 1985). Lower strand sequences are interpreted as recessional strands representing falling Lake Algonquin water levels as the retreating Laurentide ice sheet exposed a series of outlets south of North Bay. These recessional beaches are believed to have formed between about 10,400 and 10,000 years ago, and some strands may actually represent single storm events (Cowan and Bennett, 1998). After the opening of a very low-level outlet at North Bay after 10,000 years ago, water levels in the Huron-Michigan basin dropped to more than 100 m below present levels, creating two smaller water bodies: Lake Stanley in the main Huron basin and Lake Hough in Georgian Bay (Eschman and Karrow, 1985).

Over time, isostatic uplift continued to raise the North Bay outlet, and by about 7,500 years ago, the Huron-Michigan and Superior basins became confluent again. The St. Marys River thus became the St. Marys Strait connecting the three upper Great Lakes. Ongoing uplift closed the North Bay outlet around 5,500 years ago, restoring high-level outlets at Chicago and Port Huron and initiating the Nipissing phase in the upper Great Lakes. The Nipissing transgression is marked by buried wood and peat 7,300 to 5,900 years old and by the development of a prominent shoreline above the present lake level.

Information on the thickness of Quaternary deposits in the area of the four communities was largely derived from a small number of water well records for rural residential properties, a small number of water well records along the highways, and from diamond drill holes. A more detailed accounting of recorded depths to bedrock in the area of the four communities is provided by JDMA (2014a). Diamond drill hole records and water well records in the area show overburden thickness to be between 0 and 137 m. The reported overburden thicknesses from the diamond drill holes and water wells are from localized pockets of overburden that may not be evident at the 1:1,000,000 scale of the mapping shown on Figure 2.3.

3.2.3 Lineament Investigation

A lineament investigation was conducted for the area of the four communities using multiple datasets that included satellite imagery (SPOT and Landsat), digital elevation model data (CDED) and geophysical (aeromagnetic) survey data. The lineament investigation identified interpreted brittle (including brittle-ductile) and dyke structures in the area of the four communities, and evaluated their relative timing relationships within the context of the local and regional geological setting. A detailed analysis of interpreted lineaments is provided by JDMA (2014b) and key aspects of the lineament investigation are summarized in this section.

For each dataset, brittle and dyke lineaments were interpreted by two independent experts using a number of attributes, including certainty and reproducibility. 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 to the rock units (including sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation) were classified as ductile lineaments. This category also includes recognizable penetrative shear zone fabric.
- **Brittle lineaments**: Features interpreted as fractures (joints or joint sets, faults or fault zones, and veins or vein sets), including those that offset the continuity of the ductile fabric described above, were classified as brittle lineaments. This category also includes brittle-ductile shear zones, and brittle partings interpreted to represent discontinuous re-activation parallel to the ductile fabric. At the desktop stage of the investigation, this category also includes features of unknown affinity. This category does not include interpreted dykes, which are classified separately (described below).
- **Dyke lineaments**: For this preliminary desktop interpretation, any features which were interpreted, on the basis of their distinct character, e.g., scale and composition of fracture in-fill, orientation, geophysical signature and topographic expression to be dykes, were classified as dyke lineaments. Dyke interpretation is largely made using the aeromagnetic data set, and is often combined with pre-existing knowledge of the bedrock geology of the area of the four communities.

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

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 area (JDMA, 2014b). The CDED dataset is at a 1:50,000 scale, with a uniform 20 m resolution over the entire area of the four communities (JDMA, 2014b). 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. Aeromagnetic datasets (Figures 3.6 and 3.7) were used to identify linear geophysical anomalies indicative of bedrock structures.

The majority of the area of the four communities is covered by low-resolution aeromagnetic data published by the Geological Survey of Canada (GSC, 2013) (Figure 1.2). Three higher resolution magnetic/electromagnetic surveys, one published by the Geological Survey of Canada (GSC, 2013) and two published by the Ontario Geological Survey (OGS 2003; 2011b), were also available for use in the lineament interpretation. These include the East Bull Lake (RA-7) fixed-wing survey that covers the East Bull Lake and Parisien Lake intrusions in the east central part of the area of the four communities with a flight line spacing of 300 m and a sensor height of 150 m, the Benny Lake helicopter survey (OGS, 2003) that covers the Benny Lake greenstone belt across the eastern boundary of the area of the four communities with a flight line spacing of 200 m and a sensor height of 30 m, and the Elliot Lake-River aux Sables helicopter survey (OGS, 2011b) that covers the Whiskey Lake greenstone belt in the south central part of the area of the four communities with a flight line spacing of 100 m and sensor height of 67 m.

Eight additional datasets were retrieved as maps extracted from assessment file reports downloaded from the Ontario Geological Survey's AFRI database. The surveys were acquired in 2000 and from 2006 to 2008 by various mining companies, mainly involved in exploration for uranium or nickel-PGE. The images were retrieved from the assessment files are presented in the geophysical interpretation report (PGW, 2014). The eight surveys were acquired with flight line spacings ranging from 100 to 200 m, and sensor heights ranging from 30 to 73 m.

Figure 3.9 shows the RA_1 surficial lineament interpretation for both SPOT and CDED combined, distinguished on the basis of length. A total of 2,494 lineaments comprise the dataset of merged lineaments identified by the two interpreters from the CDED digital elevation data. These lineaments range in length from 803 m to 94.5 km, with a geometric mean length of 4.99 km and a median length of 4.35 km. The most notable feature of the CDED lineament orientations when plotted on a rose diagram weighted by length are the dominant west-northwest and north-northwest trends (Figure 3.9 inset). There is also a notable east-west trend. It is also evident that no dominant trend emerges among the lineaments oriented toward the northeast.

The SPOT lineament dataset compiled from the merger of lineaments identified by the two interpreters yielded a total of 7,509 lineaments (Figure 3.9). The length of the SPOT lineaments ranges from 900 m to 139.8 km, with a geometric mean length of 2.2 km and a median length of 1.8 km. When the azimuths of the lineaments are plotted on a rose diagram weighted by length (Figure 3.9 inset), there appear to be two diffuse orientation clusters, one ranging from west to north-northwest and one ranging from north-northeast to east-northeast. Within this broad array, there are slightly more distinct peaks towards west-northwest, north-northwest and east-northeast, roughly matching the trends seen in the CDED data. Neither of the surficial datasets show a strong northerly trend.

The aeromagnetic dataset yielded a total of 2,146 lineaments (Figure 3.10). Of these geophysical lineaments, 460 are interpreted as brittle lineaments, while 1,686 are interpreted as dykes. Among the geophysical lineaments interpreted as brittle lineaments, most (390) did not exhibit relative displacement, but brittle lineaments with both dextral (46) and sinistral (24) relative offsets were identified. The length of these brittle lineaments ranged from approximately 200 m to 144.3 km, with a geometric mean length of 4.2 km and a median length of 4.3 km. Azimuth data, weighted by length, for the brittle fracture lineaments exhibit several distinct trends towards the north-northeast and east, as well as a notable west-northwest peak and multiple distinct northeasterly trends (Figure 3.10 inset).

Geophysical lineaments include a total of 1,686 interpreted as dykes, belonging to the Biscotasing, Matachewan, North Channel, and Sudbury dyke suites. The length of these dyke lineaments ranged from approximately 200 m to 48.7 km, with a geometric mean length of 2.9 km and a median length of 3.1 km. Sharp trends allow that each dyke suite can be distinguished by orientation. Biscotasing dykes are represented by 266 lineaments oriented strongly toward the northeast at 045º and clustered mostly in the felsic gneiss. Matachewan dykes are represented by 396 lineaments that trend dominantly toward the north-northwest. The distribution of these dykes appears clustered in the northwest and northeast quadrants of the area of the four communities. North Channel dykes comprise 346 lineaments and exhibit a strong east-west orientation and appear mostly in the area of the Huronian Supergroup. Sudbury dykes, comprising 678 lineaments, trend strongly to the northwest, with a distinctly more northerly orientation than the Matachewan dykes. Interpreted Sudbury dykes are distributed throughout the area of the four communities.

Although each dyke suite has a relatively well defined orientation in the area of the four communities, the overwhelming number of northwest-trending dykes (Matachewan and Sudbury swarms) dominates the length-weighted rose diagram plot and subdues the other individual dyke orientations (Figure 3.10 inset). The number of interpreted dykes in particular areas is related to the resolution of the geophysical surveys, with more dykes mapped in the areas of high resolution aeromagnetic surveys around the Seabrook Lake and East Bull Lake intrusions and in the area east of White Owl Lake (Figure 3.10).

Aeromagnetic features interpreted as ductile lineaments (i.e. magnetic form lines) have been mapped separately and are shown on Figure 3.11. Such features are useful in identifying the stratigraphy and ductile structure within the greenstone belts. In this report, the ductile lineaments are shown to provide context to our understanding of the tectonic history of the area of the four communities, but were not included in the statistical analysis undertaken with the dataset.

Figure 3.12 shows the distribution of both merged surficial and geophysical brittle (including brittle-ductile) lineaments and dyke lineaments interpreted for the area of the four communities, classified by length. The merged lineament dataset contains a total of 9,351 lineaments. The merged lineaments range in length from 109 m to 144.3 km. The geometric mean length of these lineaments is 2.5 km and the median length is 2.3 km. Lineaments in the >10 km and 5-10 km length bins represent 7% and 14% of the merged lineaments, respectively, while lineaments in the 1-5 km and <1 km length bins represent 71% and 8% of the merged lineaments, respectively.

Orientation data for the merged lineament dataset (inset of Figure 3.12) exhibit a fairly broad and uniform distribution of trends toward the east-northeast and the west-northwest. Subsidiary peaks in the broadly uniform data spread are towards the northwest, north-northwest and east-west. Notably, there is a relative paucity of lineaments oriented north-south. It should be noted that the rose diagram on Figure 3.12 is weighted by lineament length, and thus these orientations are influenced by longer lineaments.

Results from the reproducibility assessment RA_2 (coincidence) for the combined geophysical and surficial (CDED and SPOT) datasets show that 257 lineaments (3%) were identified and coincident on all three datasets (RA_2 = 3), and that 1,883 lineaments (20%) were coincident with a lineament from one other dataset (RA_2 = 2). A total of 7,211 lineaments (77%) lacked a coincident lineament from the other two datasets (RA_2 = 1). There is greater coincidence between surficial lineaments (interpreted from digital elevation data and satellite imagery) than between the geophysical lineaments and either of the surficial datasets. Of the geophysical dataset, about 12% (59 out of 504) of the interpreted faults were coincident with a mapped surficial lineament, and 22% of the dykes were coincident with a mapped surficial lineament (406 out of 1,874).

Merged lineament rose diagrams are presented for the bedrock units that are considered potentially suitable for a geological repository (Figure 3.13). The Ramsey-Algoma granitoid complex has been subdivided into northern and southern domains for the purpose of this description. The northern part of the Ramsey-Algoma granitoid complex (Unit 15 on Figure 3.13) consists of massive granodiorite to diorite that covers approximately 1,350 km^2 in the northwest corner of the area of the four communities. Most of the area is exposed bedrock or thin drift over bedrock that offers well-expressed bedrock lineaments, resulting in relatively high lineament density.

Surficial cover partially obscures bedrock structures along the northern boundary of the area of the four communities (OGS, 2005). Lineaments interpreted on the northern portion of the Ramsey-Algoma granitoid complex total 1,125 with orientations, weighted by length, trending strongly toward the northwest to north-northwest and north-northeast to northeast (rose diagram A on Figure 3.13). Matachewan and Sudbury dykes contribute to the northwest-trending lineaments, while Biscotasing dykes contribute to the northeast-trending lineaments. Few North Channel dykes (trending east-west) are interpreted to have intruded the area.

The Ramsey-Algoma granitoid complex (southern part) consists of massive granodiorite to granite from which a total of 3,163 lineaments were mapped. This part of the granitoid complex spans approximately 4,150 km^2 of the area of the four communities across a region that mostly exhibits exposed bedrock or thin drift over bedrock. Given these conditions, bedrock features are well-expressed and lineament density is relatively high. Azimuth data, weighted by length, for lineaments from the southern part of the Ramsey-Algoma granitoid complex exhibit a dominant northwesterly trend and a diffuse northeast to east trend (rose diagram B on Figure 3.13). While each of the four dyke suites identified in the area of the four communities are evident in the dataset for the southern portion of the Ramsey-Algoma granitoid complex, the Sudbury dykes are most pervasive and contribute to the strong northwest trend in the orientation data.

The area of the four communities features an extensive (2,950 km^2) gneissic tonalite suite (Unit 11 on Figure 3.13) that, at the surface, separates the Ramsey-Algoma granitoid complex from the Huronian Supergroup. A total of 2,781 lineaments were mapped from the gneissic tonalite and lineament density is relatively high. Bedrock structures are well-expressed because of extensive bedrock exposure and thin drift cover. Surficial cover is increased mostly along the northern boundary of the area of the four communities between White Owl Lake and Ramsey Lake, and in the area south of the Huronian Supergroup. Rose diagram C on Figure 3.13, weighted by length, for lineament azimuths from the gneissic tonalite shows a dominant trend to the west-northwest, a secondary east-trending peak, and a generally diffuse pattern in other orientations. Each of the four dyke suites identified in the area of the four communities intrude the gneissic tonalite, but the Matachewan and Sudbury dykes are the most pervasive swarms in this unit.

In order to gain insight into the influence of various lineament lengths on lineament density for the combined geophysical and surficial datasets, Figures 3.14 to 3.17 illustrate how lineament density varies across the area of the four communities 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 a better depiction of the longer lineaments. The figures show that filtering out the shorter lineaments greatly increases the spacing between lineaments, including within areas having a high percentage of exposed bedrock and high resolution aeromagnetic data. Within the Ramsey-Algoma granitoid complex, lineaments longer than 5 km and 10 km are spaced on the order of between 0.5 and 14.9 km and between 1.1 and 24 km apart, respectively.

Figure 3.18 shows the combined geophysical and surficial lineament datasets (including interpreted dykes), interpreted ductile features and mapped regional faults and dyke swarms. The known mapped faults in the area of the four communities include the east-west-trending Murray fault and the largely northeast-trending Flack Lake fault, as well as northwest-trending Spanish American fault, Pecors Lake fault, Folson fault and Webwood fault. Several unnamed mapped faults, trending mostly west to northwest, occur through the Huronian Supergroup. Another set of unnamed mapped faults, trending northwest to north, occur in the northeast corner of the area of the four communities. Based on the compilation of interpreted lineaments, there appears to be a close relationship with known mapped faults. Each of the named mapped faults are represented by interpreted lineaments. Even many of the smaller unnamed mapped faults correspond closely to interpreted lineaments. Figure 3.18 also shows there is very good coincidence of mapped dykes and dykes interpreted as part of the lineament assessment, in terms of orientation, length and location throughout the area of the four communities. Such coincidence is expected, as mapped and interpreted dykes are derived from the same aeromagnetic surveys.

One aspect of uncertainty associated with the interpretation of dyke lineaments is the likelihood that thin dykes, while known to be present in the host rock, are too small to be identified with any confidence from the geophysical data. For example, Halls (1991) characterized the Matachewan dykes as having a median width of approximately 20 m, but also described minor dykelets as narrow as several centimetres in width that were recognized during detailed field mapping. West and Ernst (1991) suggested further that narrow dykes may produce anomalies of insufficient magnetic intensity to be traced with any confidence. In addition, Halls (1982) discussed the bifurcating and branching geometry of the Matachewan dykes which was also determined based on detailed field mapping. One particularly well-mapped area within the Matachewan swarm highlights the complex nature of the dyke distribution in the field (Halls, 1982), which further indicates that the detailed geometrical arrangement of the dykes at the outcrop scale cannot be resolved with any confidence from the available geophysical data. This latter point is important with regard to uncertainty in understanding the extent of potential damage to the host rock as a result of dyke emplacement. It is well understood, but not easily quantifiable from geophysical data alone, that dyke propagation will induce damage to the host rock within an envelope around the dyke that varies with the size of the intrusion (e.g., Meriaux et al., 1999).

Another aspect of uncertainty associated with the high density of diabase dykes observed/interpreted in the area of the four communities relates to the likelihood that the dominance of the dyke signal in the geophysical data will mask evidence of ductile and brittle structure within the host rock. For example, in areas of high dyke density, and where the dykes are offset by brittle faults, the true fault offset is ambiguous in the aeromagnetic dataset (West and Ernst, 1991). Dyke spacing on the order of 10’s to 100’s of metres in several locations across the area of the four communities (e.g., Figure 10 of the lineament interpretation; JDMA (2014b)) suggests that underlying structure in the host rock may be under-identified in these areas of increased dyke density.

3.2.4 Relative Age Relationships of Lineaments

The structural history of the area of the four communities, outlined in Section 3.1.3, provides a framework that may aid in constraining the relative age relationships of the interpreted bedrock lineaments. Six main regionally distinguishable deformation episodes (D_1-D_6) are inferred to have overprinted the bedrock geological units of the area of the four communities. Kenoran orogenesis is associated with D_1-D_2 deformation. D_1 deformation produced folds and an east-trending foliation in the greenstone belts between ca. 2.72 and 2.70 billion years ago. No lineaments were assigned to this early deformational episode. Development of northeast, east-northeast, northwest and west-northwest striking faults, including the Murray and Flack Lake faults occurred between ca. 2.651 and 2.497 billion years ago, during D_2. Lineaments associated with the Murray and Flack Lake faults are the oldest identified in the area of the four communities. Despite an interpreted early age of formation, the Flack Lake fault appears to offset a Sudbury dyke, suggesting reactivation more recently than 1.2 billion years ago.

Rifting during D_3 reactivated northwest, west-northwest, and east striking faults and induced emplacement of the Matachewan dykes ca. 2.473 billion years ago. Deformation associated with the Blezardian Orogeny (D_4)

initiated development of the east-west-trending Quirke syncline and Chiblow anticline and map-scale folding evident in the Archean basement, followed by emplacement of ca. 2.2 to 2.1 billion year old Nipissing diabase intrusions and the ca. 2.17 to 2.15 billion year old Biscotasing dyke swarm. The North Channel dyke swarm is poorly constrained in terms of emplacement age to between ca. 2.5 and 1.6 billion years ago. These ages suggest that the North Channel dykes are younger than the Matachewan dykes and may be coeval with the Nipissing and Biscotasing swarms. The orientation of the North Channel dykes trends strongly east-west, but there are weaker trends to the west-northwest and to the northeast. The northeast trend follows that of the Biscotasing dykes. Given the wide range in age and the differing orientations, the North Channel dykes may consist of more than one generation of intrusions that correspond to the Nipissing and Biscotasing swarms. Dykes identified in the geophysical data as either North Channel or Biscotasing are assigned to the D_4 episode.

Penokean orogenesis corresponds to the D_5 deformational episode that includes enhancement of pre-existing (Blezardian) folds and final development of the present day fold-and-thrust belt geometry of the Huronian Supergroup. Continued activation of basement-seated faults is also attributed to the Penokean event. Many of the brittle surficial lineaments (i.e. those that do not correspond to dykes) may be associated with this deformational episode and were subsequently reactivated by stresses produced by more recent orogenies and isostatic adjustment to formation of a peneplain and glaciation. Emplacement of the Sudbury dykes followed at ca. 1.238 billion years ago. Because the Sudbury dykes post-date D_5 deformation and pre-date D_6 deformation, the relative age of these lineaments was designated D_5+.

The most recent episode of deformation (D_6) includes the Grenville Orogeny, development of the Midcontinent Rift, and the formation of a peneplain. The overprint of the Grenville Orogeny in the area of the four communities is unclear, but this episode may have reactivated existing structures produced during D_5. The Cutler pluton, emplaced ca. 1.7 billion years ago, is cut by brittle fractures of various orientation, demonstrating that many of the surficial lineaments formed or were reactivated during D_6.

It is difficult at the desktop stage of the preliminary assessment of potential suitability to assign temporal relationships with any degree of confidence to the identified surficial lineaments, though it is reasonable to suggest that most brittle features were either formed or reactivated during the most recent episodes of deformation (D_5-D_6). These lineaments may have been subsequently reactivated by stresses associated with more recent orogenies, isostatic adjustment to erosion of a peneplain, and recent glaciations. In addition, the low resolution of the available geophysical data, although sufficient to recognize four differently oriented generations of dyke swarms, is insufficient as a means of indicating any systematic fracture crosscutting relationships above and beyond what can be determined from the surficial data sets. Apparent offsets of some segment of the north-east-trending dykes may be due to the en echelon nature of their emplacement.

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

The area of the four communities has recorded only one moderate earthquake since 1985, according to the National Earthquake Database (NRCan, 2013) (Figure 3.19). The seismic event was a magnitude m_N 2.1 in August of 1991 and was located 28 km northeast of Elliot Lake, as shown on Figure 3.20. The next closest earthquake was recorded in 2001, at a magnitude m_N 3.1 and was located 65 km southeast of Elliot Lake, on Manitoulin Island.

A significant portion of the seismicity measured in the area of the four communities is due to mining activities near Sudbury. Natural Resources Canada has documented several hundred seismic events of magnitude 2 or smaller, identified as being anthropogenic (man-made), resulting from rock bursts associated with mining activities for their period of active monitoring, 1985 through present. Studies of mining associated rock bursts in the area of the Denison Mine (Pritchard and Hedley, 1993) and Quirke II Mine (Johnston, 1988) near Elliot Lake confirm the sources of the low magnitude seismic events.

In summary, the available literature and recorded seismic events indicate that the area of the four communities is located within an area of low seismicity.

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 neotectonic activity of the area of the four communities appears to be principally due to post-glacial isostatic rebound resulting from melting of the Laurentide ice sheet (Adams and Clague, 1993).

The Quaternary geology of the area of the four communities 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). This estimate is 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 area of the four communities would likely be slightly greater than that of the Minnesota/North Dakota area due to its closer proximity to the main center of Wisconsinan 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 to 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 post-glacial rebound models, which in turn indicated that present day rebound rates in the area of the four communities 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 changed. These post-glacial stress changes overprinted onto the existing tectonic stress regime could lead to paleo-seismic events associated with 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 area of the four communities. 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 northwestern 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.

4.0 HYDROGEOLOGY

4.1 Groundwater Use

Information concerning groundwater for the area of the four communities was obtained from the Ontario Ministry of the Environment (MOE) Water Well Record (WWR) database and is shown on Figure 4.1 (MOE, 2013). The majority of wells have been drilled along Highways 17 and 108, with a significant number of wells also drilled around the City of Elliot Lake and in the area north of La Cloche Provincial Park.

The WWR database contains a total of 785 water well records for the area shown on Figure 4.1. Of the 785 records, 538 records had information on lithology, well yield and / or depth to static water level. Table 4.1 summarizes the water well record data for the area of the four communities. Note that a negative value for the depth to water table indicates the water level above ground surface under artesian conditions. The water well records show the overburden thickness in the region to be between 0 and 136.8 m, with an average of 13.2 m.

Table 4.1: Water Well Record Summary for the Communities of Elliot Lake, Blind River, The North Shore, Spanish and Surrounding Area

Water Well Type	Number of Wells	Total Well Depth (m)	Static Water Level (m below surface)	Tested Well Yield (L/min)	Depth to Top of Bedrock (m)
Overburden	181	2.4 to 136.8	-0.9 to 44.8	4.5 to 1,137	N/A
Bedrock	357	3 to 216	0.3 to 28.2	4.5 to 341	0 to 136.8

4.2 Overburden Aquifers

There are 181 water well records in the area of the four communities that can be confidently assigned to the overburden aquifers (Table 4.1). The wells depths range between 2.4 to 136.8 m and have measured pumping rates of 4.5 to 1,137 L/min. These well yields reflect the purpose of the wells (private residential supply, dewatering, etc.) and do not necessarily reflect the maximum sustainable yield that might be available from the overburden aquifers.

The overburden well records are concentrated within bedrock controlled valleys and along the main roadways, which limits the available information regarding the extent and characteristics of the overburden aquifers in the area of the four communities. However, as several of these water wells are located within till, glaciolacustrine, glaciofluvial terrains, it is likely that similar terrain mapped in the area (Figure 2.3) will host overburden aquifers.

4.3 Bedrock Aquifers

Limited information was found on deep groundwater conditions in the area of the four communities at a typical repository depth of approximately 500 m. In the area of the four communities there are 357 well records that can be confidently assigned to the shallow bedrock aquifer. These wells range from 3 to 216 m in depth with measured pumping rates variable and ranging from 4.5 to 341 L/min. These well yields reflect the purpose of the wells (private residential supply, dewatering, etc.) and do not necessarily reflect the maximum sustainable yield that might be available from the bedrock aquifers. Long-term groundwater yield in fractured bedrock will depend on the number and size of fractures, their connectivity, transmissivity, storage and on the recharge properties of the fracture network in the wider aquifer.

The MOE (2013) WWRs shows no potable water supply wells which exploit aquifers at typical repository depths in the area of the four communities or anywhere else in northern Ontario.

Heat-pulse flow meter testing was carried out at East Bull Lake in two deep boreholes (EBL-2 and 4) which are 850 and 480 m deep, respectively, as part of a larger suite of geophysical testing carried out by the USGS in 1984 (Paillet and Hess, 1986). These two boreholes are located mainly within the East Bull Lake mafic intrusion except for a few tens of metres at the bottom of the holes, which intersected the underlying granitic basement (Paillet and Hess, 1986). The flow meter testing indicated that water was entering the boreholes at numerous fractures above a depth of 200 m, with flow exiting through isolated fractures below a depth of 400 m to 700 m, noting that this pathway was created by the drilling of the borehole and does not represent a natural flow path. Previous hydraulic conductivity packer testing carried out at East Bull Lake for AECL in boreholes EBL-1 to 4 provided a characterisation of hydrogeologic conditions within the rock to depths of 850 m (Raven et al., 1984) as outlined below.

4.4 Regional Groundwater Flow

Geotechnical drilling investigations carried out for the mines in Elliot Lake (e.g., Golder, various studies dating from 1982 to the late 1990s) have demonstrated that the water table within the bedrock is typically near the ground surface and conforms to the general configuration of the surface topography. This is consistent with the low to moderate permeability of the upper bedrock that also supports the numerous lakes within the area under the comparatively humid net precipitation conditions. Groundwater flow-divides parallel surface water drainage-divides following topographic highs and groundwater discharge zones conform to topographic lows such as valleys, streams and lakes. A more detailed discussion of shallow groundwater flow in the area of the four communities is provided in JDMA (2014a).

The groundwater levels seasonally fluctuate up to a few metres between the periods of recharge associated with snowmelt and major precipitation events. Accordingly, within bedrock dominated terrains, shallow groundwater flow systems are considered to consist of localized, topographically controlled basins directly reflected by the surface water drainage basins. These influences are directly seen in groundwater baseflow contributions supporting surface streams during drier periods of the year.

Estimates of groundwater recharge rates and baseflow were developed for the Elliot Lake area as part of the groundwater model developed for the Stanleigh Mine/Crotch Lake tailings basin (Golder, 1996) and the Denison Mines Long Lake tailings basin (Golder et al., 1992a,b). The estimates of recharge were made based upon the calibration of the models to groundwater levels and stream baseflows and ranged from 76 to 80 mm/yr of the annual precipitation (Golder et al., 1992a,b).

The deep hydrogeological conditions encountered in the area of the four communities are similar to those from other areas in the Canadian Shield, where investigations have shown that active groundwater flow is generally confined to shallow localized systems, where the flow tends to be dependent on the secondary permeability created by fractures (Singer and Cheng, 2002). An example exists in Manitoba's Lac du Bonnet batholith, where groundwater movement is largely controlled by a fractured zone down to approximately 200 m depth (Everitt et al., 1996).

In deeper regions, rock mass hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth (Herget and Arjang, 1990) tend to close or prevent fractures, thereby reducing permeability (Stevenson et al., 1996; McMurry et al., 2003). Rock mass hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell and Atikokan research areas range from approximately 10^{-10} to 10^{-15} m/s (Stevenson et al. 1996; Ophori and Chan, 1996). Data reported by Raven et al. (1987) show that the rock mass hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400 to 500 m.

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

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

4.5 Groundwater Observations from the Elliot Lake Mines

This section presents groundwater observations made as part of geotechnical investigations carried out at a number of the Elliot Lake mines, as well as observations made during the construction of underground mine workings. These observations are limited to the rocks of Huronian Supergroup and the Archean-age rocks situated unconformably immediately beneath them. These rocks are not considered to be potentially suitable for a deep geological repository (Section 7.1).

Shallow bedrock was extensively investigated to depths of approximately 50 m (Golder, various studies dating from 1982 to the late 1990s) as part of the geotechnical design investigations for the Elliot Lake mine tailings basins. Packer testing encountered low to moderate permeability conditions (10^{-8} to 10^{-5} m/s) associated with bedrock fractures that typically decreased in frequency with depth.

At depth in the bedrock, the occurrence of groundwater is limited to the occasional seepage associated with fracture zones, faults or dyke margins based upon the experience of the very extensive underground mine openings beneath the Quirke Lake syncline (R. Blair, 2013, personal communication). The mines developed laterally using extensive room and pillar mining of the uraniferous conglomerate reefs within the Matinenda Formation at the base of the syncline, extending from near surface along the north and south rims of the syncline (Quirke Mine and Nordic Mine, respectively) to depths of approximately 1,000 m in the Stanleigh Mine located centrally beneath the syncline. The mines were generally known to be "dry" with respect to groundwater seepage although some seepage did occur from open fractures associated with faulting.

During the sinking of Stanleigh Shafts 1 and 2 in 1956 and 1957, seepage inflows requiring grouting control were experienced in the Bruce limestone horizon encountered at comparatively shallow depths of 100 to 120 m, and at various other depths including three zones between 975 to 1,000 m in Shaft No 2, requiring 470 bags of cement grout to seal (Stanleigh Mine drawing No. 557 annotated by L.C. Harper). During the decade of mine shutdown prior to the redevelopment of the Stanleigh Mine in the late 1970s, the mine experienced partial flooding. The Stanleigh, Milliken and Lacnor mines are interconnected and closure studies estimated that the combined mine flooding to the point of surface discharge at Milliken would take approximately 60 to 70 years. Much of the inflow was attributed to the intersection of shallow seepage zones draining into the Milliken and Lacnor mines.

The Spanish American Mine located on the southwest shore of Quirke Lake experienced groundwater inflow during shaft sinking in the vicinity of "bad" ground associated with the intersections of the Spanish American fault and Quirke Lake thrust fault at depths of approximately 1,000 m (Robertson, 1968). The surface expression of the Spanish American fault was exposed during construction of the Denison Mines tailings basin, where the fault-sheared nature of the infilling diabase dyke was observed at Dam 9 (Golder, various studies dating from 1982 to the late 1990s).

The Quirke Lake thrust fault was intersected at a depth of 381 m in the Denison Mines Shaft No 2. The fault was associated with 15 m of blocky ground and considerable groundwater inflow that delayed shaft sinking for 3 months (Robertson, 1968). The thrust fault was also exposed in the Dam K1 foundation at the west end of the Quirke Mine tailings basin 7.5 km west of Denison Mines, where Bruce conglomerate was thrust over Mississagi quartzite associated with a 30 to 40 cm wide chlorite schist infilling and fracturing of the adjacent rock (Golder and Senes, 1982).

4.6 Hydrogeochemistry

Existing literature has shown that groundwater within the Canadian Shield can be subdivided into two main hydrogeochemical regimes: a shallow, generally fresh groundwater flow system, and a deep, saline to brine groundwater flow system (Singer and Cheng, 2002). Gascoyne et al. (1987) investigated the saline groundwater to brines found within several Precambrian plutons and identified a general chemical transition at around 300 m depth marked by a uniform, rapid rise in total dissolved solids 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. 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 et al., 1987; 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 values of total dissolved solids (TDS) ranging from 3 to 90 g/L (Gascoyne 2000; 2004). However, total dissolved solids exceeding 250 g/L have been reported in some regions of the Canadian Shield at depths below 500 m (Frape et al., 1984; Frape and Fritz, 1987).

Hydrogeochemical data are available for the East Bull Lake pluton, located in the area of the four communities. Raven et al., (1987) reported that the groundwater in the East Bull Lake pluton transitions from fresh in the near surface to saline water below a depth of approximately 400 m. Frape et al. (2003) reported that water samples taken from 460 m and 429 m at East Bull Lake had chloride concentrations in groundwater of 1 g/L and 2.5 g/L, while Bottomley et al. (2003) reported that a seep in the Stanleigh Mine at 960 m had chloride concentrations in groundwater of 28 g/L.

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 assessed during subsequent site evaluation stages.

5.0 NATURAL RESOURCES — ECONOMIC GEOLOGY

There are currently no active mines in the area of the four communities, but the region has a long history of mining and mineral exploration continues there today. Figure 5.1 shows the areas of active exploration in the area of the four communities based on mining claims and known mineral occurrences identified in the Ontario Geological Survey's Mineral Deposit Inventory (OGS, 2011c). The historical and ongoing interest in the Whiskey Lake greenstone belt, the Huronian Supergroup, and the East Bull Lake intrusive suite is evident from the relative densities of mineral occurrences recorded and active mining claims.

There is extensive mineral exploration ongoing within the Huronian Supergroup, including a total of 252 active mining claims throughout the area as shown on Figure 5.1. The Huronian Supergroup is known for uranium and thorium mineralization in quartz-pebble conglomerates (Witwatersrand-type deposits) of the Matinenda Formation. There are also metallic minerals other than uranium (e.g. gold, nickel, copper) typically associated with the intrusion of Nipissing diabase (Reid, 2003). There are numerous mineral occurrences and discretionary occurrences in the Huronian Supergroup (Figure 5.1), a full description of which is beyond the scope of this assessment.

Mineral exploration in the Whiskey Lake and Benny Lake greenstone belts has focused on base metal sulphide-bearing units of banded iron formations and mafic intrusive rocks (Jensen, 1994). There are 44 active mining claims and a number of discretionary occurrences of iron in the greenstone belts. The more northerly Benny Lake greenstone belt has also been the focus of sporadic exploration efforts over the years.

The East Bull Lake intrusive suite has platinum group elements (PGE) and copper-nickel sulphide mineralization and contains economically significant platinum, palladium and gold (Peck and James, 1991). There are 134 active mining claims in total in the East Bull Lake, Lake Agnew and May Township intrusions, as well as mineral occurrences and discretionary occurrences of copper, nickel, platinum and palladium.

The mineral potential in the Ramsey-Algoma granitoid complex is relatively low compared to the other rocks listed above, based on the relatively few mineral occurrences and active mining claims shown on Figure 5.1. Despite covering a large area, there are only 134 active claims throughout the Ramsey-Algoma granitoid complex. However, many of the 134 claimed areas overlap rocks from the Whiskey Lake greenstone belt, East Bull Lake intrusive suite, or the Huronian Supergroup, which are likely the targeted rocks for mineral exploration. There are some mineral occurrences and/or discretionary occurrences for niobium, iron, copper, lead, uranium, gold, molybdenum, and silica in the Ramsey-Algoma granitoid complex, but none are known to be economically viable.

5.1 Metallic Mineral Resources

Base Metals

There are numerous occurrences of copper within the area of the four communities and at least seven former copper mines within or on the margin of the area. The largest of these was the Pater Mine which produced approximately 32,000 tonnes of copper with minor gold and silver from a mineralized shear zone in mafic metavolcanics along the Murray fault in Long and Spragge townships. There are several occurrences of zinc and nickel recorded within the area of the four communities with most of these associated with the Huronian Supergroup or the metavolcanic greenstones. There are also magmatic segregation deposits, nickel, copper, and PGE deposits associated with the intrusion of Nipissing diabase (Reid, 2003). Similar mineralization has been identified in the East Bull Lake intrusive suite (Peck and James, 1991). Also associated with the diabase sills and dykes and mafic intrusions are vein deposits containing lead, zinc, copper, cobalt, arsenic, and bismuth, as well as minor amounts of gold, silver and uranium. The volcano-sedimentary assemblages of the greenstone belts have potential to contain volcanic massive sulphide (VMS) deposits of zinc, copper, and lead, while molybdenum deposits occur locally within granite-hosted hydrothermal veins and stockwork zones (MDI 41J08SE00002, MDI 41J08NW00028).

Gold

In the area of the four communities, potential for gold mineralization is mostly associated with silicified banded iron formation and shear zones in the metavolcanic rocks of the Whiskey Lake and Benny Lake greenstone belts and within brecciated or sheared zones of late granitic rocks near geological contacts (i.e. Côte Lake style mineralization). One former gold mine (Shakespeare/Foley) operated within the area of the four communities (Shakespeare Township) and produced small amounts of gold from a narrow quartz vein between 1903 and 1905.

Iron

Iron deposits occur as oxide and sulphide facies iron formation within volcanic and metasedimentary rock assemblages. None of these deposits are known to be economically viable.

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. There are no mineral occurrences or discretionary occurrences for rare earth metals recorded in the Ontario Geological Survey inventory apart from the Seabrook Lake carbonatite in the northern part of the area of the four communities which has received significant exploration interest over the years as a potential source of niobium. Rare metals and REE were also recovered in secondary production in several of the uranium mines in the Elliot Lake area.

Despite some exploration activity over the years, no economic deposits of rare metals or REE have been identified within the area of the four communities.

Uranium

The Elliot Lake area is famous as an area of uranium mining, and at its peak in 1960 it hosted thirteen active mines including: Pronto, Buckles, Lacnor, Nordic, Spanish American, Quirk I&II, Stableigh I&II, Panel, Can Met, Denison 1&2, Stanrock, Milliken I&II and Pater mines. Together these mines produced approximately 140,000 tonnes of U_3O_8 from the beginning of production in 1955 to the closure of the last mine in 1996. Economic uranium mineralization in the area of the four communities is limited to quartz pebble conglomerate horizons deposited within paleochannels of the Matinenda Formation. Brannerite, uranite and monazite formed the most common uranium ore minerals with minor amounts of uranothorite. While grades of 1% or more were found locally, average grades were 0.1% (Jackson and Fyon, 1991). Minor production of cerium, neodymium, yttrium, rare earth elements and thorium occurred through secondary recovery processes at several of the mines, with a minor amount of gold (Robertson, 1983).

In addition to the uranium mines, there are numerous documented mineral occurrences of uranium within the Huronian Supergroup in the area of the four communities as well as a small number within the Archean granitic terrain outside the Huronian Supergroup. The area continues to be the focus of uranium exploration and the potential for economically viable uranium deposits exists within the Huronian Supergroup, including the Matinenda Formation which hosted the past mine production. Some potential may also exist for Rössing-style mineralization within the granitoid complex, though no economically viable deposits are known to occur.

Platinum

The mafic intrusive bodies of the East Bull Lake intrusive complex contain PGE-enriched nickel and copper sulphide mineralization and are the focus of active mineral exploration programs by a number of companies. Peck et al. (1995) reported up to 10 mg/kg combined Pt-Pd in sulphides within the anorthosite zone of the East Bull Lake intrusion. Elevated levels of PGE have also been reported in association with Cu-Ni sulphides in diabase sills (Reid, 2003).

5.2 Non-Metallic Mineral Resources

Known non-metallic mineral resources in the area of the four communities include sand and gravel, stone, and silica, while other potential non-metallic mineral resources include diamonds, peat, mica, lime and a variety of other commodities.

Sand, Stone, and Gravel

There are numerous sand and gravel pits within the area of the four communities. These are typically shallow pits of limited surface extent exploiting glaciofluvial outwash or lacustrine beach deposits. An alternative source of aggregate is the bedrock, of which Nipissing diabase is considered the best suited for crushed stone production.

There are two discretionary occurrences for building stone (granite) reported within the Ramsey-Algoma granitoid complex, near the mouth of the Blind River. There is also a building stone quarry on the border of Cadeau and Tennyson townships, about 20 km east of the City of Elliot Lake. The property is owned by Sudbury Canadian Granite Inc. and the target rock is described as a fine-grained black gabbro referred to as Massey “black granite” that forms a circular plug 3 km in diameter, which intrudes early Precambrian felsic granite of the Birch Lake batholith (Lacey, 1991).

Peat

Peat exists in low-lying portions of the area of the four communities; however, the generally rugged relief of the area precludes the formation of extensive peatlands. The potential for economic peat extraction is considered low and restricted to the near surface.

Diamonds

There are no mineral occurrences or discretionary occurrences of diamonds in the area of the four communities. A regional survey for the types and distribution of kimberlite indicator minerals was conducted for a portion of the area (Reid, 2003). The report did not identify any mineral occurrences, but indicated that there may be some potential based on indicator parameters and more work would be required to assess this potential. Recent work by the OGS in the nearby Cobalt-New Liskeard area found microdiamonds recovered from 6 of 45 samples taken from late Archean lamprophyre dyke-like intrusions (Meyer et al., 2006). Macrodiamonds were found in one of the samples.

Industrial Minerals

Industrial minerals include graphite, diopside, clays, mica, silica and limestone. There are no mineral occurrences or discretionary occurrences for these industrial minerals in the area of the four communities, although there is good potential for industrial silica production from the quartzites of the Lorrain Formation (Vos, 1978). As with aggregates, industrial mineral extraction is generally restricted to the near surface pits and quarries.

5.3 Petroleum Resources

The area of the four communities 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 PROPERTIES

Geomechanical information including intact rock properties, rock mass properties and *in situ* stresses are needed to design stable underground openings and to predict the subsequent behaviour of the rock mass around these openings. 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 geological units in the area of the four communities. Table 6.1 summarizes some available geomechanical information from bedrock formations elsewhere in the Canadian Shield with rock types similar to those of interest in the area of the four communities (granitic plutons). 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

Site-specific, geomechanical information on the granitic intrusions in the area of the four communities is lacking. At this early stage of the site assessment process, it is useful to look at the geomechanical properties of similar intact crystalline rocks such as the Lac du Bonnet batholith, Eye-Dashwa pluton and similar rock types elsewhere. The rock property values presented in Table 6.1 are based on laboratory testing of rock core specimens from boreholes from Pinawa and Atikokan and 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 (Golder, 2012a,b). The table also includes rock properties such as density, porosity, uniaxial compressive strength and tensile strength for use in engineering design and structural analyses. These parameters feed into rock mass classification schemes.

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

Property	Lac du Bonnet Granite	Eye-Dashwa Granite
Uniaxial Compressive Strength (MPa)	185 ± 24[a]	212 ± 26[c]
Split Tension Strength (Brazilian) (MPa)	4 to 9[b]	NA
Porosity (%)	0.35[a]	0.33[a]
P-wave velocity (km/s)	3.220 - 4.885[c]	NA
S-wave velocity (km/s)	2.160 – 3.030[c]	NA
Density (Mg/m^3)	2.65[a]	2.65[a]
Young's Modulus (GPa)	66.8[a]	73.9[a]
Poisson's Ratio	0.27[a]	0.26[a]
Thermal Conductivity (W/(mK))	3.4[a]	3.3[a]
Coef. Thermal Expansion (x10^{-6}/ □C)	6.6[a]	15[a]

NA = Not Available
[b]Stone et al., 1989
[c]Annor et al., 1979
[d]Eberhardt et al. 1999

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 area of the four communities is a brief description of joint orientation and spacing contained in some assessment files.

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

Rock mass properties for the area of the four communities would 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.

Within the area of the four communities, *in situ* stress conditions are known from the Stanleigh and Denison uranium mines. The minimum principal stress data available from the Denison and Stanleigh mines yields an average value of 15 MPa, dipping at an average angle of ca. 70° at depths ranging from 300 to 1,066 m (Kaiser and Maloney, 2005).

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. Herget and Arjang (1990), Arjang (1991) and Arjang and Herget (1997) indicate pre-mining, major horizontal compressional stress directions of about northeast-southwest, based on stress testing and analyses completed at the nearby underground mines at Wawa, Elliot Lake and Sudbury that are situated in the Superior and Southern provinces. These regional horizontal stress results are similar to directions for other parts of the Canadian Shield in eastern North America, and have been interpreted by Herget (1972) as stable and preserved in relative magnitude for close to a billion years.

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.

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 a depth of 270 m (referred to as Fracture Zone 2, or FZ2 at the site), the magnitude was close to the average value for the Canadian Shield and the orientation of the maximum horizontal stress was consistent with the average predicted by the World Stress Map (i.e., southwest) (Heidbach et al., 2009). Below the same thrust fault, the stress magnitudes are much higher than the average data for the Canadian Shield, and the maximum principal stress rotates approximately 90° to a southeast orientation (Martino et al., 1997). The principal maximum horizontal stress magnitude below the Fracture Zone 2 thrust fault remains relatively constant around 55 to 60 MPa, which is more typical of the values found at greater depths. The southeast orientation of the maximum principal horizontal stress is consistent with the data presented by Herget (1980) for the area which indicates maximum compression clustered in the southwest and southeast for the Canadian Shield.

In addition to loading history and geologic structure, *in situ* stress conditions are further influenced by rock mass complexity (i.e., jointing, heterogeneities and mineral fabric). As such, local stresses may not resemble the average stress state for a region (Maloney et al., 2006). The conceptual model presented by Maloney et al. (2006) is considered appropriate for sub-regional scale modelling activities. Due to wide scatter in the data (Figure 6.1), site-specific measurements would be 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 composed of higher quartz content generally having higher thermal conductivities. The thermal conductivity of quartz (7.7 W/(m˚K)) is greater than that of other common rock-forming minerals such as feldspars (1.5 to 2.5 W/(m˚K)) or mafic minerals (2.5 to 5 W/(m˚K)) (Clauser and Huenges,1995).

There are no site-specific thermal conductivity values or detailed quantitative mineral compositions for the area of the four communities. The quartz mineral content of the granitic rocks that are of interest as a potential repository host are likely to range from approximately 20% to 60% by volume (Streckeisen, 1976), a range in agreement with the quartz contents reported for granitic rocks similar to those of the Ramsey-Algoma granitoid complex. The range of measured thermal conductivity values for plutonic rock types found in the literature are presented in Table 6.2.

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

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

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

Although no thermal conductivity values are available for the area of the four communities, 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, during the collection of site-specific information.

7.0 DESKTOP PHASE 1 GEOSCIENTIFIC SUITABILITY EVALUATION

7.1 Approach

The objective of the Phase 1 geoscientific desktop preliminary assessment is to assess whether the communities of Elliot Lake, Blind River, The North Shore, Spanish and surrounding area contain general areas that have the potential to meet the geoscientific site evaluation factors outlined in NWMO's site selection 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, 2014). The actual underground footprint at any particular site would depend on a number of factors, including the characteristics of the rock, the final design of the repository and the inventory of used fuel to be managed. For the purpose of this preliminary assessment, it is assumed that the repository would require a footprint in the order of 2 x 3 km.

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

- ***Geological Setting:*** Areas of unfavourable geology identified during the initial screening (Geofirma, 2012a,b,c,d) were not considered. Such areas include metasedimentary rocks and subordinated metavolcanic rocks of the Huronian Supergroup, and metavolcanic-dominated greenstone belts (Figure 3.3). These geological units were considered not suitable due to their lithological heterogeneity, structural complexity and mineral potential. Plutons that are too small to be a viable host (such as the Cutler Pluton) were also avoided. Potentially suitable geological units in the area of the four communities include the Archean Ramsey-Algoma granitoid complex and gneissic rocks. In the area of the four communities, the granitoid complex generally consists of granitic, granodioritic and granitic gneiss with numerous greenstone enclaves and massive to foliated granite, granodiorite, and syenite intrusions.

- ***Structural Geology:*** Spatial distribution, character and history of relative movement of local and regional scale faults in area of the four communities were considered. There are two large-scale faults mapped in the area of the four communities: the Murray and Flack Lake faults. While there is no evidence to suggest that the Murray fault had been tectonically active within the past 1.250 to 0.98 billion years (Robertson, 1970; Card, 1978; McCrank et al., 1989; Piercy, 2006) and the Flack Lake fault within the past 1.8 billion years (Bennett et al., 1991), they were avoided in selecting general potentially suitable areas. The potential host rock unit thickness is estimated to be 1 to 3 km, based on geophysical data. This thickness was considered sufficient for repository siting purposes. The potential for groundwater movement at repository depth within an area is in part controlled by the fracture frequency, their degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of infilling. At this stage, factors that could affect groundwater movement at depth within the Ramsey-Algoma granitoid complex could not be assessed, due to lack of site specific information.

Factors potentially influencing groundwater movement at repository depth are assessed at a generic level in Section 7.3.

- ***Lineament Analysis:*** In the search for general potentially suitable areas, there was a preference to select areas that have a relatively low density of lineaments, particularly a low density of longer lineaments, as they are more likely to extend to greater depth than shorter lineaments (Section 3.2.3). For the purpose of this assessment, all interpreted lineaments (fractures and dykes) were conservatively considered as conductive (permeable) features. In reality, many of these interpreted features may be sealed due to higher stress levels at depth and the presence of infilling minerals.

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

- ***Protected Areas:*** All provincial and federal parks and other protected areas as identified in Section 2.4 were excluded from consideration. There are 15 provincial parks, 12 conservation reserves and four forest reserves in the area of the four communities (Figure 2.5). The provincial parks and reserves occupy a combined area of approximately 1,700 km^2. Several of these parks and reserves occur within the Ramsey-Algoma granitoid complex, which is the geological unit of interest.

- ***Natural Resources:*** The potential for natural resources in the area of the four communities is shown on Figure 5.1. The rocks of the Huronian Supergroup, the Benny Lake and Whiskey Lake greenstone belts, and the Seabrook Lake, Parisien Lake and East Bull Lake intrusions all have known potential for natural resources, are internally heterogeneous and are, in some cases, too small in size; therefore they were not considered as favourable. In contrast, the Ramsey-Algoma granitoid complex in the area of the four communities has low potential for economically exploitable natural resources. At this stage of the assessment, areas of active mining claims were not systematically excluded if the claims were located in geologic environments judged to have low mineral resource potential.

- ***Surface Constraints:*** Areas of obvious topographic constraints (density of steep slopes), and large waterbodies (i.e., wetlands, lakes) were considered in the identification of general potentially suitable areas. While areas with such constraints were not explicitly excluded at this stage of the assessment, they were considered less preferable, all other factors being equal. Much of the Ramsey-Algoma granitoid complex has rugged topography (Figure 2.2). The majority of the area of the four communities is accessible by existing highways, secondary roads and/or logging roads.

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the above geoscientific evaluation factors and constraints revealed that the area of the four communities contains at least four general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. All four general areas are all located within the Ramsey-Algoma granitoid complex in the northern half of the area of the four communities, north of the municipal boundaries of Elliot Lake and Blind River. These four general areas are discussed in detail in Section 7.2.1.

No general potentially suitable areas were identified within the municipal boundaries of the four communities. Figure 7.1 shows features illustrating some of the key characteristics and constraints used to identify the general potentially suitable areas, including: bedrock geology, protected areas, areas of thick overburden cover, existing road network, natural resource potential 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 potentially suitable areas were identified in the area of the four communities using a systematic and step-wise approach. Areas containing parks and natural reserves and areas with unsuitable rock types were eliminated. The resulting general potentially suitable areas were then refined using the magnetic data to avoid areas with obvious magnetic anomalies interpreted to represent lithological heterogeneity. The areas were further refined by favouring areas with lower geophysical and surficial lineament densities. Identified potentially suitable areas were finally refined by favouring areas away from known structural heterogeneities such as mapped regional faults.

No potentially suitable general areas were identified within the municipal boundary of Blind River. This area is located almost entirely within the rocks of the Huronian Supergroup that were not suitable because of their mineral potential and structural complexity. In addition, a large portion of the municipal area is occupied by the Blind River and Matinenda Provincial Parks and the Mississagi Delta Provincial Nature Reserve.

No general potentially suitable areas were identified within the municipal boundary of Elliot Lake. This area is located largely within the rocks of the Huronian Supergroup that are considered to be not suitable. The portion of the municipal boundary that occurs within the Ramsey-Algoma granitoid complex, north of Elliot Lake, is in close proximity to the rocks of the Huronian Supergroup that have high mineral potential. Several past producing mines are located close to this area and several current mineral claims are present (Figure 5.1). The Ramsey-Algoma granitoid complex south of Elliot Lake is lithologically heterogeneous, with metavolcanic, amphibolites and ultramafic rocks encountered in several boreholes in the area (Figure 4.1). A portion of the municipal area is occupied by the Matinenda Provincial Park and the Glenn N. Crombie Conservation Reserve.

No general potentially suitable areas were identified within the municipal boundary of The North Shore. This area is located largely within the rocks of the Ramsey-Algoma granitoid complex. However, in this location, the granitoid complex is crosscut by numerous mafic dykes, exhibits a high apparent lineament density (Figure 3.14) and is lithologically heterogeneous, with metavolcanic, amphibolites and ultramafic rocks encountered in several boreholes in the area (Figure 4.1). The area is also in close proximity to the regional Murray fault, which runs from Sault Ste. Marie to Sudbury, and corresponds to a marked change in metamorphic grade.

No general potentially suitable areas were identified within the municipal boundary of Spanish. About half of this area is within the rocks of the Huronian Supergroup that were not suitable. About half of the municipality is located within the rocks of the Ramsey-Algoma granitoid complex. However, the area the lithology is heterogeneous and it is in close proximity to the Murray fault and mineral occurrences (Figure 5.1).

The following section provides more details on how the key geoscientific factors and constraints discussed above were applied to the Ramsey-Algoma granitoid complex to identify 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 Ramsey-Algoma Granitoid complex

As discussed in Section 3.2.1, the Ramsey-Algoma granitoid complex is a large heterogeneous granitoid complex that intruded the older metavolcanic and metasedimentary rocks of the Whiskey Lake and Benny Lake greenstone belts and other unnamed greenstone belts. In the area of the four communities, this complex varies in composition from granodiorite to granite to gneissic tonalite, and extends for about 6,320 km^2 within the area of the four communities. The granitoid complex has an estimated thickness greater than 1 km.

The granodiorite to gnessic tonalite rocks in the area of the four communities generally have excellent bedrock exposure, low potential for natural resources, are well drained, and contain large areas that are outside of protected areas and surface constraints (i.e., large water bodies and wetlands), although the terrain is modest to rugged. There are a number of mapped faults as well as four known dyke swarms that have affected the area of the four communities. The main constraining factors used in the selection of general potentially suitable siting areas within the granitoid complex were protected areas, surface constraints, structural geology and lineament density.

The assessment of key geoscientific characteristics allowed for the identification of four general potentially suitable areas within the Ramsey-Algoma granitoid complex in the northern half of the area of the four communities, north of the municipal boundaries of Elliot Lake and Blind River. The general locations of these four general areas are shown on Figures 7.2 to 7.5. The inset map on each of these figures show the area of each map relative to Figure 7.1. Key geoscientific characteristics shown on these maps include: bedrock geology, protected areas, areas of thick overburden cover, surficial and geophysical lineaments, existing road network, natural resources potential and mining claims.

North-Eastern Ramsey-Algoma (Figure 7.2)

The first general potentially suitable area occurs within the north-eastern portion of the Ramsey-Algoma granitoid complex (Figure 7.2). The general area is bounded by the Mississagi River Provincial Park to the west and the Mozhabong Conservation Reserve to the east. The general area is accessible via Highway 553 and local roads directly access the area.

Bedrock in this general area is mapped as massive granodiorite to granite. Bedrock exposure is very good. The area is 11.5 km north of the Flack Lake fault and 71 km north of the Murray fault. Though these faults are far from the area, their potential impact on the suitability of the area would need to be further assessed. No smaller-scale faults were mapped within the area. The Sudbury and Matachewan dykes are the predominant mapped dykes present in the area. The geophysical data interpretation found variable magnetic responses in the area. Given the low resolution of the geophysical data in the area, lithological homogeneity is uncertain at this stage and would need to be further investigated in subsequent stages of the site evaluation process.

Additional insight into the potential suitability of this area is provided by the analysis of interpreted lineaments (Section 3.2.3). The identified potentially suitable area encompasses an area of lower density of lineaments. The lineament filtering process by length, as described in Section 3.2.3 and presented on Figures 3.15 to 3.17, was also used to guide the selection of general potential areas. The figures show that filtering out the shorter lineaments greatly increases the spacing between lineaments, including within areas having a high percentage of exposed bedrock.

The distribution of lineament density as a function of lineament length is strongly influenced by the amount of exposed bedrock and resolution of available geophysical data. Figures 3.10 and 7.2 show interpreted geophysical lineaments in this general potentially suitable area have a spacing of 1.4 to 6.6 km for lineaments greater than 5 km, and 1.9 to 14.3 km for lineaments greater than 10 km. The low geophysical lineament density is likely due to the low resolution of the aeromagnetic dataset, and would need to be further investigated during subsequent stages of the site evaluation process. In areas where higher resolution geophysical data are available, the density of geophysical lineament is much higher. For example, in the high resolution data area of the Seabrook Lake intrusion (NW part on Figure 3.10), the spacing between geophysical lineaments range from 200 to 800 m. It is possible that such a high density of geophysical lineaments exists across the area of the four communities.

The surficial lineament density (Figures 3.9 and 7.2) in this general area is moderate, which is a consequence of the extensive bedrock exposure in the general area identified. The interpreted surficial lineaments in this general potentially suitable area have a spacing of 0.6 to 3.3 km for lineaments greater than 5 km, and 1.1 to 4.4 km for lineaments greater than 10 km.

As discussed in Section 3.2.1, the area of the four communities contains numerous mapped and interpreted dykes, as it lies within regional dyke swarms. As previously mentioned, in areas where higher resolution geophysical data are available, the frequency of dykes is much higher. Although a large number of these dykes are identifiable in the aeromagnetic data in the area of the four communities, there remain some uncertainties regarding the distribution and structural impact of the dykes. Main uncertainties are related to: the potential for smaller-scale dykes to be present between interpreted dykes; the potential underestimation of geophysical brittle (fractures) and ductile lineaments due to the predominance and masking effect of the dyke signatures in the geophysical dataset; and the potential damage that may have been caused to the host rock during dyke emplacement.

This general potentially suitable area is Crown land (Figure 2.5) and lies outside of protected areas (Figure 7.2). It is free of active mining claims (Figures 5.1 and 7.2) and free of mineral known occurrences.

North-Central Ramsey-Algoma - North of Mississagi River (Figure 7.3)

The second general potentially suitable area occurs within the north-central portion of the Ramsey-Algoma granitoid complex, north of the Mississagi River (Figure 7.3). The general area is bounded by the Mississagi River Provincial Park to the south and the Wagong Lake Forest Reserve to the north. The area is generally accessible via logging roads.

Bedrock in this general area is mapped as massive granodiorite to granite and gneissic tonalite. Bedrock exposure is moderate to good. The area is 48 km northwest of the Flack Lake fault and 93 km north of the Murray fault; however, the potential impact of these regional features on the suitability of the area needs to be further assessed. No smaller-scale faults were mapped within the area. The Sudbury, Matachewan and Biscotasing dykes are the predominant mapped dykes present in the area. The geophysical data interpretation found magnetically quiet responses in the area. Given the low resolution of the geophysical data in the area, lithological homogeneity is uncertain at this stage and would need to be further investigated in subsequent stages of the site evaluation process.

The identified potentially suitable area encompasses an area of lower density of lineaments. The lineament filtering process by length, as described in Section 3.2.3 and presented on Figures 3.15 to 3.17, was also used to guide the selection of general potential areas. The figures show that filtering out the shorter lineaments greatly increases the spacing between lineaments, including within areas having a high percentage of exposed bedrock.

The distribution of lineament density as a function of lineament length is strongly influenced by the amount of exposed bedrock and resolution of available geophysical data. Figures 3.10 and 7.2 show interpreted geophysical lineaments in this general potentially suitable area have a spacing of 0.6 to 7.2 km for lineaments greater than 5 km, and 2.6 to 7.2 km for lineaments greater than 10 km. As discussed earlier, the low geophysical lineament density is likely due to the low resolution of the aeromagnetic dataset, and would need to be further investigated during subsequent stages of the site evaluation process. In areas where higher resolution geophysical data are available, the density of geophysical lineament is much higher. It is possible that such a high density of geophysical lineaments exists across the area of the four communities.

The surficial lineament density (Figures 3.9 and 7.2) in this general area is moderate, which is a consequence of the extensive bedrock exposure in the general area identified. The interpreted surficial lineaments in this general potentially suitable area have a spacing of 1.1 to 4.4 km for lineaments greater than 5 km and 1.4 to 6.6 km for lineaments greater than 10 km.

As discussed in Section 3.2.1, the area of the four communities contains numerous mapped and interpreted dykes as it lies within regional dyke swarms. As previously mentioned, in areas where higher resolution geophysical data are available, the frequency of dykes is much higher. Although a large number of these dykes are identifiable in the aeromagnetic data in the area of the four communities, there remain some uncertainties regarding the distribution and structural impact of the dykes. Main uncertainties are related to: the potential for smaller-scale dykes to be present between interpreted dykes; the potential underestimation of geophysical brittle (fractures) and ductile lineaments due to the predominance and masking effect of the dyke signatures in the geophysical dataset; and the potential damage that may have been caused to the host rock during dyke emplacement.

This general potentially suitable area is Crown land (Figure 2.5) and lies outside of protected areas (Figure 7.3). It is free of active mining claims (Figures 5.1 and 7.3) and free of known mineral occurrences.

North-Central Ramsey-Algoma - South of Mississagi River (Figure 7.4)

The third general potentially suitable area also occurs within the north-central portion of the Ramsey-Algoma granitoid complex, south of the Mississagi River (Figure 7.4). The general potentially suitable area is bounded by the Mississagi River Provincial Park to the north and the Rawhide Lake Conservation Reserve to the south. The general area is accessible via Highway 546 and directly via logging roads.

Bedrock in this general area is mapped as massive granodiorite to granite. Bedrock exposure is very good. The area is 24 km northwest of the Flack Lake fault and 66 km north of the Murray fault; however, the potential impact of these regional features on the suitability of the area needs to be further assessed. No smaller-scale faults were mapped within the area. The Sudbury, Matachewan and Biscotasing dykes are the predominant mapped dykes present in the area. The geophysical data interpretation found magnetically quiet responses in the area. Given the low resolution of the geophysical data in the area, lithological homogeneity is uncertain at this stage and would need to be further investigated in subsequent stages of the site evaluation process.

The identified potentially suitable area encompasses an area of lower density of lineaments. The lineament filtering process by length, as described in Section 3.2.3 and presented on Figures 3.15 to 3.17, was also used to guide the selection of general potential areas. The figures show that filtering out the shorter lineaments greatly increases the spacing between lineaments, including within areas having a high percentage of exposed bedrock.

The distribution of lineament density as a function of lineament length is strongly influenced by the amount of exposed bedrock and resolution of available geophysical data. Figures 3.10 and 7.2 show interpreted geophysical lineaments in this general potentially suitable area have a spacing of 1.1 to 6 km for lineaments greater than 5 km, and 5 to 11 km for lineaments greater than 10 km. As discussed earlier, the low geophysical lineament density is likely due to the low resolution of the aeromagnetic dataset, and would need to be further investigated during subsequent stages of the site evaluation process. In areas where higher resolution geophysical data are available, the density of geophysical lineament is much higher. It is possible that such a high density of geophysical lineaments exists across the area of the four communities.

The surficial lineament density (Figures 3.9 and 7.2) in this general area is moderate, which is a consequence of the extensive bedrock exposure in the general area identified. The interpreted surficial lineaments in this general potentially suitable area have a spacing of 0.6 to 3.3 km for lineaments greater than 5 km, and 1.1 to 3.3 km for lineaments greater than 10 km.

As discussed in Section 3.2.1, the area of the four communities contains numerous mapped and interpreted dykes as it lies within regional dyke swarms. As previously mentioned, in areas where higher resolution geophysical data are available, the frequency of dykes is much higher. Although a large number of these dykes are identifiable in the aeromagnetic data in the area of the four communities, there remain some uncertainties regarding the distribution and structural impact of the dykes. Main uncertainties are related to: the potential for smaller-scale dykes to be present between interpreted dykes; the potential underestimation of geophysical brittle (fractures) and ductile lineaments due to the predominance and masking effect of the dyke signatures in the geophysical dataset; and the potential damage that may have been caused to the host rock during dyke emplacement.

This general potentially suitable area is Crown land (Figure 2.5) and lies outside of protected areas (Figure 7.4). It is free of active mining claims (Figures 5.1 and 7.4) and free of known mineral occurrences.

North-West Ramsey-Algoma (Figure 7.5)

The fourth general potentially suitable area occurs within the north-western portion of the Ramsey-Algoma granitoid complex (Figure 7.5). The general area is bounded by the Seabrook Lake intrusion to the west and Highway 129 to the east. The area is generally accessible via Highway 129.

Bedrock in this general area is mapped as massive granodiorite to granite. Bedrock exposure is very good. The area is 35 km northwest of the Flack Lake fault and 80 km north of the Murray fault; however, the potential impact of these regional features on the suitability of the area needs to be further assessed. No smaller-scale faults were mapped within the area. The Sudbury and Matachewan dykes are the predominant mapped dykes present in the area. The geophysical data interpretation found magnetically quiet responses in the area. Given the low resolution of the geophysical data in the area, lithological homogeneity is uncertain at this stage and would need to be further investigated in subsequent stages of the site evaluation process.

The identified potentially suitable area encompasses an area of lower density of lineaments. The lineament filtering process by length, as described in Section 3.2.3 and presented on Figures 3.15 to 3.17, was also used to guide the selection of general potential areas. The figures show that filtering out the shorter lineaments greatly increases the spacing between lineaments, including within areas having a high percentage of exposed bedrock.

The distribution of lineament density as a function of lineament length is strongly influenced by the amount of exposed bedrock and resolution of available geophysical data. Figures 3.10 and 7.2 show interpreted geophysical lineaments in this general potentially suitable area have a spacing of 0.6 to 14.9 km for lineaments greater than 5 km, and 17.6 to 24 km for lineaments greater than 10 km. As discussed earlier, the low geophysical lineament density is likely due to the low resolution of the aeromagnetic dataset, and would need to be further investigated during subsequent stages of the site evaluation process. In areas where higher resolution geophysical data are available, the density of geophysical lineament is much higher. It is possible that such a high density of geophysical lineaments exists across the area of the four communities.

The surficial lineament density (Figures 3.9 and 7.2) in this general area is moderate, which is a consequence of the extensive bedrock exposure in the general area identified. The interpreted surficial lineaments in this general potentially suitable area have a spacing in the order of 0.6 to 7.7 km for lineaments greater than 5 km and 1.1 to 7.7 km for lineaments greater than 10 km.

As discussed in Section 3.2.1, the area of the four communities contains numerous mapped and interpreted dykes, as it lies within regional dyke swarms. As previously mentioned, in areas where higher resolution geophysical data are available, the frequency of dykes is much higher. Although a large number of these dykes are identifiable in the aeromagnetic data in the area of the four communities, there remain some uncertainties regarding the distribution and structural impact of the dykes. Main uncertainties are related to: the potential for smaller-scale dykes to be present between interpreted dykes; the potential underestimation of geophysical brittle (fractures) and ductile lineaments due to the predominance and masking effect of the dyke signatures in the geophysical dataset; and the potential damage that may have been caused to the host rock during dyke emplacement.

This general potentially suitable area is Crown land (Figure 2.5) and lies outside of protected areas (Figure 7.5). It is free of active mining claims (Figures 5.1 and 7.5) and free of mineral occurrences. However, the area is just east of the Seabrook Lake intrusion, where rare earth mineral occurrences have been identified. The effect that such occurrences could have on the potential suitability of this general area would need to be further assessed in future stages of the site selection process.

7.2.2 Other Areas

No prospective general potentially suitable areas were identified within the Huronian Supergroup, the metavolcanic rocks and the small intrusive bodies (Seabrook Lake, Parisien, East Bull Lake and Cutler), as these rock types were considered unfavourable rock units for siting a deep geological repository. General potentially suitable areas were identified within the massive granodiorite to granite and the gneissic tonalite using overburden cover, structural geology and lineament density to further refine the extent of the areas. Given the very large geographic extent of this rock type in the area of the four communities, it may be possible to identify additional general potentially suitable areas. However, the four general areas identified are those judged to best meet the preferred geoscientific characteristics outlined in Table 7.1, based on available information.

7.2.3 Summary of Characteristics of Areas within the Ramsey-Algoma Granitoid Complex

Table 7.1 provides a summary of the key geoscientific descriptive characteristics of the four general potentially suitable areas in the Ramsey-Algoma granitoid complex in the area of the four communities.

Table 7.1: Summary of Characteristics of the Areas within the Ramsey-Algoma Granitoid Complex, Communities of Elliot Lake, Blind River, The North Shore, Spanish and Surrounding Area

	General Area			
Geoscientific Descriptive Characteristic	***Ramsey-Algoma Granitoid Complex (North East) Figure 7.2***	***Ramsey-Algoma Granitoid Complex (North Central – north of Mississagi River) Figure 7.3***	***Ramsey-Algoma Granitoid Complex (North Central – south of Mississagi River) Figure 7.4***	***Ramsey-Algoma Granitoid Complex (North West) Figure 7.5***
Rock Type	Predominantly granodiorite	Mixture of gneissic tonalite and granodiorite	Predominantly granodiorite	Predominantly granodiorite
Age	ca. 2.6 to 2.7 billion years ago	ca. 2.6 to 2.7 billion years ago	ca. 2.6 to 2.7 billion years ago	ca. 2.6 to 2.7 billion years ago
Inferred host rock thickness	>1 km	>1 km	>1 km	>1 km
Extent of rock unit within the area	Ramsey-Algoma Granitoid Complex: 6,320 km^2	Ramsey-Algoma Granitoid Complex: 6,320 km^2	Ramsey-Algoma Granitoid Complex: 6,320 km^2	Ramsey-Algoma Granitoid Complex: 6,320 km^2
Relative proximity to mapped major geological features (regional faults/ shear zones, geological sub-province boundaries, etc.)	Murray fault – 70.9 km Kapuskasing SZ – 114.4 km Flack Lake fault – 11.5 km	Murray fault – 92.5 km Kapuskasing SZ – 80.2 km Flack Lake fault – 48.2 km	Murray fault – 66.4 km Kapuskasing SZ – 106.5 km Flack Lake fault – 24.4 km	Murray fault – 80.5 km Kapuskasing SZ – 63 km Flack Lake fault – 35.3 km
Structure: faults, foliation, dykes, joints	Moderate surface lineament density Lack of longer surficial lineaments Transected by high density of NW Sudbury and NNW Matachewan dykes, bounded by NE Biscotasing dykes	Moderate surface lineament density Lack of longer surficial lineaments Transected by high density of NW Sudbury and NNW Matachewan dykes, bounded by NE Biscotasing dykes	Moderate surface lineament density Lack of longer surficial lineaments Transected by high density of NW Sudbury and NNW Matachewan dykes, bounded by NE Biscotasing dykes	Moderate surface lineament density Lack of longer surficial lineaments Transected by high density of NW Sudbury and NNW Matachewan dykes, bounded by NE Biscotasing dykes

Geoscientific Descriptive Characteristic	***General Area***			
	Ramsey-Algoma Granitoid Complex (North East) Figure 7.2	***Ramsey-Algoma Granitoid Complex (North Central – north of Mississagi River) Figure 7.3***	***Ramsey-Algoma Granitoid Complex (North Central – south of Mississagi River) Figure 7.4***	***Ramsey-Algoma Granitoid Complex (North West) Figure 7.5***
Aeromagnetic characteristics and resolution	Magnetically variable, Low Resolution	Magnetically quiet Low Resolution	Magnetically quiet Low Resolution	Magnetically quiet Mixture of high and low resolution
Terrain: topography, vegetation	Rugged	Moderate relief	Rugged	Rugged
Access	Access to central portion via logging road	Good access throughout via logging roads	Good access throughout via logging roads	Good access along secondary road
Resource Potential	Low	Low	Low	Low
Bedrock exposure	75%	55%	75%	75%
Drainage	Generally good. Water cover: approx. 15%	Generally good. Some wetland. Water cover: approx. 15%	Generally good. Water cover: approx. 15%	Generally good. Water cover: approx. 15%

7.3 Evaluation of the General Potentially Suitable Areas

This section provides a brief description of how the identified general 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 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 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 general potentially suitable areas that would fail to satisfy the safety functions.

An evaluation of the four general potentially suitable areas in the Ramsey-Algoma granitoid complex within the area of the four communities 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's 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, a review of available information conducted as part of this preliminary assessment indicates the estimated thickness of the Ramsey-Algoma granitoid complex to be greater than 1 km, and therefore is expected to extend below typical repository depths (approximately 500 m), which would contribute to the isolation of the repository from human activities and natural surface events.

Analysis of lineaments interpreted during this preliminary assessment (Sections 3.2.3 and 7.1) indicate that the Ramsey-Algoma granitoid complex in the area of the four communities has 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 resolution of available geophysical data. By classifying the lineaments according to length, this local bias is greatly reduced and the area of the four communities exhibit lineament spacing between short brittle lineaments on the order of less than 0.5 km to 2.5 km, and spacing between longer lineaments (i.e., those longer than 10 km) on the order of 1.5 to 5 km, suggesting that there is a potential for there to be sufficient volumes of structurally favourable rock at typical repository depth. All four general potentially suitable areas are located away from known deformation zones or faults.

Numerous dykes have been mapped and interpreted in the area of the four communities, as it lies within a region of dyke swarms. Information from mines in the Canadian Shield (Raven and Gale, 1986) and other geological settings show that dykes may act as either pathways or barriers for groundwater flow in a host rock. Their hydraulic characteristics depend on a wide range of factors that include their frequency and location within a host rock, their orientation with respect to the direction of groundwater flow, their mineralogical composition, degree of alteration and their association with brittle deformation structures (e.g. SKB, 2010; Gupta et al., 2012; Holland, 2012), including both pre-existing structures and those developed as a result of dyke emplacement.

The hydrogeological regime at repository depth should exhibit low groundwater velocities and retard the movement of any potentially released radioactive material. As discussed in Section 4.4, there is limited information on the hydrogeologic properties of the deep bedrock in the area of the four communities in the Ramsey-Algoma granitoid complex. It is, therefore, not possible at this stage of the evaluation to predict the nature of the groundwater regime at repository depth. 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 from other areas in the Canadian Shield with similar rock types indicates that groundwater flow within structurally-bounded blocks tends to be generally limited to shallow fracture systems, typically less than 300 m. In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan range from approximately 10^{-10} to 10^{-15} m/s (Ophori and Chan, 1996; Stevenson et al., 1996). Data reported by Raven et al. (1987) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400-500 m.

Experience from other areas on the Canadian Shield with similar rock types also indicates that ancient faults, similar to those in the area of the four communities, 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 area of the four communities would need to be investigated at later stages of the site evaluation process through site characterization activities that include drilling and testing of deep boreholes.

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 area of the four communities. The review of available information from other locations with similar rock types did not reveal any obvious conditions that would suggest unfavourable mineralogical or hydrogeochemical characteristics of the rocks for the potentially suitable areas identified within the area of the four communities (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 granitic intrusions within the area of the four communities may resemble those of the Lac du Bonnet batholith and similar rock types elsewhere in the Superior Province (Section 6.0) with no obvious unfavourable conditions known at present; although these characteristics would need to be assessed during subsequent site evaluation stages.

In summary, the review of available geoscientific information for the the four general identified potentially suitable areas, including completion of a lineament analysis, did not reveal any obvious conditions that would fail 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 the above factors requires detailed site-specific data that would be typically collected and analyzed through detailed field investigations. The assessment would include understanding how the site has responded to past glaciations and geological processes and would entail a wide range of detailed studies involving disciplines such as seismology, hydrogeology, hydrogeochemistry, paleohydrogeology and climate change. At this desktop preliminary assessment stage of the site evaluation process, the long-term stability factor is evaluated by assessing whether there is any evidence that would raise concerns about the long-term stability of the four general potentially suitable areas identified in the area of the four communities. The remainder of this section provides a summary of the factors listed above.

Although a number of low magnitude seismic events have been recorded in the area of the four communities over the past 25 years, there are no recorded earthquakes of magnitude greater than 3.1 (Nuttli magnitude, m_N) occurring in the area of the four communities (Section 3.3). As discussed in Sections 3.1 and 3.2, major faults have been identified in the area, including the regional Murray fault and the Flack Lake fault; however, there is no evidence to suggest these faults have been tectonically active within the past 1.250 to 0.98 billion years (Section 3.1.3). The four identified general areas are located at sufficient distance from these faults.

The geology of the area of the four communities 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 have remained largely unaffected by past perturbations such as glaciation. Findings of a comprehensive paleohydrogeological study of the fractured crystalline rock at the Whiteshell Research Area, located within the Manitoba portion of the Canadian Shield (Gascoyne, 2004) have 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 ancient features. Subsequent geological processes such as plate movement and continental glaciation have typically caused reactivation of existing zones of weakness rather than the formation of large new zones of fractures.

Land in the area of the four communities 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 area of the four communities should be well below 10 mm/yr, and likely between 2 and 4 mm/yr. There is no site-specific information on erosion rates for the area of the four communities; but, 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 area of the four communities 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 area of the four communities would need to be further assessed through detailed multidisciplinary site specific geoscientific and climate change site investigations.

7.3.3 Safe Construction, Operation and Closure of the Repository

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

This requires that:

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

There are few surface constraints that would limit the construction of surface facilities in the four general potentially suitable areas identified in the area of the four communities. The areas have moderate to high topographic relief and contains enough surface land outside protected areas and major water bodies to accommodate the required repository surface facilities.

From a constructability perspective, there is limited site-specific information available on the local rock strength characteristics and *in situ* stresses for potentially suitable geologic units in the area of the four communities. Based upon the *in situ* stress conditions at the Stanleigh and Denison uranium mines, the minimum principal stress data available from these mines yields an average value of 15 MPa, dipping at an average angle of approximately 70°, at depths ranging from 300 to 1,066 m (Kaiser and Maloney, 2005).

There is also abundant information at other locations of the Canadian Shield that could provide insight into what might be expected for the area of the four communities in general. As discussed in Section 6, available information suggests that granitic and gneissic crystalline rock units within the Canadian Shield generally possess good geomechanical characteristics that are amenable to the type of excavation activities involved in the development of a deep geological repository for used nuclear fuel (Arjang and Herget, 1997; Everitt, 1999; McMurry et al., 2003; Chandler et al., 2004). The conceptual model developed by Kaiser and Maloney (2005) based on available stress measurement data, 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.

In summary, the Ramsey-Algoma granitoid complex in the area of the four communities has good potential to meet the safe construction, operation and closure function.

7.3.4 Isolation of Used Fuel from Future Human

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

This requires that:

- The repository should not be located within rock 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.

There are currently no active mines in the area of the four communities, but the region has a long history of mining, and mineral exploration continues there today. As shown on Figure 5.1, the historical and ongoing interest in the Whiskey Lake greenstone belt, the Huronian Supergroup, and the East Bull Lake intrusive suite is evident from the relative densities of mineral occurrences and active mining claims.

The review of available information did not identify any groundwater resources at repository depth within the area of the four communities. As discussed in Section 4.0, the MOE WWR database shows that all water wells known in the area obtain water from overburden or shallow bedrock sources ranging from 0.3 to 216 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). The MOE water well records indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the area of the four communities 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 area of the four communities 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 geologic conditions at a potential site must be amenable to site characterization and data interpretation. This would require that the host rock geometry and structure should be predictable and amenable to site characterization and site data interpretation.

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

As described in Section 3, the Ramsey-Algoma granitoid complex is interpreted to be relatively heterogeneous with a complex structural history and has undergone polyphase deformation. As discussed in Section 7.1, interpreted lineaments represent the observable two-dimensional expression of three-dimensional features. The ability to detect and map such lineaments is influenced by topography, the character of the lineaments (e.g., their width, orientation, age, etc.), and the underlying resolution of the data used for the mapping. Interpreted geophysical dyke lineaments in the area of the four communities, including the identified general areas, show distinct, very well defined orientations that can be assigned to specific generations of dykes. This aids the amenability to characterize these features. The area of the four communities has a high surficial lineament density, but this is likely due to the greater bedrock exposure. It is likely that unidentified lineaments exist and subtle unidentified structural features may also be expected. The orientation of lineament features in three dimensions represents another degree of structural complexity that will require assessment through detailed site investigations in future phases of the site selection process.

The identification and field mapping of structures is influenced by the extent and thickness of overburden cover and the presence of large lakes. The area of the four communities contains about 70% exposed bedrock, and a relatively small area (by percent land use) of large lakes and wetlands. The lack of extensive wetlands in much of the area is due to the generally rugged terrain and absence of extensive low-lying areas. The largest wetland complexes in the area are expected to be associated with thicker overburden deposits.

Information on the thickness of overburden deposits within the area of the four communities is largely derived from terrain evaluation and measured thicknesses of water well records for rural residential properties, and diamond drill holes. Overburden thickness, where overburden is present, is highly variable ranging from 0 to 137 m (JDMA, 2014a).

The Ramsey-Algoma granitoid complex in the area of the four communities is accessible using the existing logging road network and secondary roads, although some general potentially suitable areas have less extensive road access.

The review of available information did not indicate any obvious conditions which would make the rock mass in the Ramsey-Algoma granitoid complex in the area of the four communities unusually difficult to characterize.

8.0 GEOSCIENTIFIC DESKTOP FEASIBILITY STUDY FINDINGS

This report presents the results of a geoscientific desktop preliminary assessment to determine whether the area of the four communities contains general areas that have the potential to meet NWMO's geoscientific site evaluation factors. At this stage of the assessment, the intent is not to identify specific repository-scale sites, but rather to identify general areas that have the potential to satisfy the geoscientific site evaluation factors outlined in the site selection process document (NWMO, 2010). The location and extent of potentially suitable areas would need to be refined during subsequent site evaluation stages through more detailed studies and field evaluations.

The preliminary geoscientific assessment built on the work previously conducted for the initial screenings (Geofirma, 2012a,b,c,d) and focused on the City of Elliot Lake, the Town of Blind River, the Township of The North Shore, the Town of Spanish and their periphery, which were referred to as the "the area of the four communities" (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 area of the four communities was limited or not available, the assessment drew on information and experience from other areas with similar geological settings on the Canadian Shield. The geoscientific desktop preliminary assessment included the following review and interpretation activities:

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, 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 the characteristics such as location, orientation, and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess factors such as overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification and evaluation of general potentially suitable areas based on key geoscientific characteristics and the systematic application of NWMO's geoscientific site evaluation factors.

The geoscientific desktop preliminary assessment showed that the area of the four communities contains at least four general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. All four general areas are located within the Ramsey-Algoma granitoid complex in the northern half of the area of the four communities, north of the municipal boundaries of Elliot Lake and Blind River.

The Ramsey-Algoma granitoid complex containing the four identified potentially suitable general areas appears to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. The bedrock within this granitoid complex is estimated to have sufficient depth and extend over large areas. The bedrock within the four potentially suitable areas has good exposure, although the bedrock has not been mapped in detail in these areas and some lithological heterogeneity has been found. All four potentially suitable areas have low potential for natural resources; are easily accessible using the existing secondary and logging road network; contain limited surface constraints; and are amenable to site characterization.

No general potentially suitable areas were identified within the municipal boundary of Blind River. This area is located almost entirely within rocks of the Huronian Supergroup that were not considered suitable because of their mineral potential and structural complexity. In addition, a large portion of the municipal area is occupied by the Blind River and Matinenda Provincial Parks and the Mississagi Delta Provincial Nature Reserve.

No general potentially suitable areas were identified within the municipal boundary of Elliot Lake. This area is located largely within rocks of the Huronian Supergroup that were considered to be not suitable. The portion of the municipal boundary that occurs within the Ramsey-Algoma granitoid complex, north of Elliot Lake, is in close proximity to the rocks of the Huronian Supergroup that have high mineral potential. Several past producing mines are located close to this area. In addition, the Ramsey-Algoma granitoid complex south of Elliot Lake is lithologically heterogeneous. A portion of the municipal area is occupied by the Matinenda Provincial Park and the Glenn N. Crombie Conservation Reserve.

No general potentially suitable areas were identified within the municipal boundary of The North Shore. This area is located largely within rocks of the Ramsey-Algoma granitoid complex. However, in this location, the granitoid complex is crosscut by numerous mafic dykes, exhibits a high apparent lineament density and is lithologically heterogeneous. This area is also in close proximity to the regional Murray fault system, which runs from Sault Ste. Marie to Sudbury, and corresponds to a marked change in metamorphic grade.

No general potentially suitable areas were identified within the municipal boundary of Spanish. About half of this area is within rocks of the Huronian Supergroup that were not considered suitable. About half of the municipality is located within the rocks of the Ramsey-Algoma granitoid complex. However, in this area the lithology is heterogeneous and it is in close proximity to the Murray fault and mineral occurrences.

While the four general potentially suitable areas identified 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 low resolution of available geophysical data, proximity to the Murray and Flack Lake faults, and the potential geological, structural and hydrogeological significance of the four known dyke swarms in the area of the four communities.

The four potentially suitable areas are located in areas of lower density of geophysical and surficial lineaments. However, the interpreted lower density of geophysical lineaments is likely due to the low resolution of available geophysical data. In the high resolution data area of the Seabrook Lake intrusion, the spacing between geophysical lineaments range from 200 to 800 m. It is possible that such a high density of geophysical lineaments exists across the area of the four communities.

The area of the four communities contains numerous dykes that are associated with major regional dyke swarms. While the spacing between mapped and interpreted dykes and lineaments within the four potentially suitable areas appears to be favourable, the low resolution of available geophysical data, and the strong magnetic signature of the dykes could be masking the presence of smaller scale dykes and fractures not identifiable from available data. In areas where higher resolution geophysical data are available, the frequency of dykes is much higher.

Should the area of the four communities 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 area of the four communities 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

Abraham, E.M., 1953. Preliminary report on the geology of parts of Long and Spragge Townships, Blind River uranium area, District of Algoma. Ontario Department of Mines.

Adams, J. and J.J. Clague, 1993. Neotectonics and large-scale geomorphology of Canada, Progress in Physical Geography **17**, p. 248-264.

Annor, A., G. Larocque and P. Chernis, 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., 1991. Pre-mining stresses at some hard rock mines in the Canadian Shield. CIM Bulletin **84**, p. 80-86.

Arjang, B. and G. Herget, 1997. In situ ground stresses in the Canadian Hardrock Mines, An update. Int. J. Rock Mech. & Min. Sci., **34**, Paper No. 015.

Barnett, P.J., A.P. Henry and D. Babuin, 1991. Quaternary geology of Ontario, east-central sheet; Ontario Geological Survey, Map 2555, scale 1:1,000,000.

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

Bekker, A., A.J. Kaurfman, J.A. Karhu and K.A. Eriksson, 2005. Evidence for Paleoproterozoic cap carbonates in North America. Precambrian Research **137**, p. 167-206.

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

Bennett G, B.O. Dressler and J.A. Robertson, 1991. The Huronian Supergroup and Associated Intrusive Rocks. *in* Geology of Ontario. Ontario Geological Survey, Special Volume 4, Part 1, p. 549-591.

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

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 **43**, p. 409-442.

Blair, R., 2013. Personal communication.

Bleeker, W. and B. Hall, 2007. The Slave Craton: Geology and metallogenic evolution; *in* 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.

Boissonneau, A.N., 1965. Surficial geology, Algoma, Sudbury, Timiskaming and Nipissing, Ontario Department of Lands and Forests Map S465.

Boissonneau, A.N., 1968. Glacial history of Northeastern Ontario II. The Timiskaming-Algoma area. Can. J. Earth Sci. **5**, p. 97-109.

Bottomley D.J., L.H. Chan, A. Katz, A. Starinsky and I.D. Clark., 2003. Lithium Isotope Geochemistry and Origin of Canadian Shield Brines. Groundwater **41**, p. 847-856.

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, p. 1-483.

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**, p. 161–169.

Brown, P.A. and N.A.C. Rey, 1989. Statistical analysis of the geological-hydrogeological conditions within part of the Eye-Dashwa Pluton, Atikokan, northwestern Ontario. Can. J. Earth Sci. **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**, p. 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, 133 p.

Buchan, K.L., J.K. Mortensen and K.D. Card, 1993. Northeast-trending Early Proterozoic dykes of southern Superior Province: multiple episodes of emplacement recognized from integrated paleomagnetism and U - Pb geochronology. Can. J. Earth Sci. **30**, p. 1286-1296.

Buchan, K.L., K.D. Card and F.W. Chandler, 1989. Multiple ages of Nipissing diabase intrusion: paleomagnetic evidence from the Englehart area, Ontario. Can. J. Earth Sci. **26**, p. 427-445.

Buchan, K.L. and R.E. Ernst, 2004. Diabase dyke swarms and related units in Canada and adjacent regions. Geological Survey of Canada, Map 2022A, scale 1:5,000,000.

Byron, M, R.E. Whitehead and J.F. Davis, 1994. Lithogeochemical and geological compilation of the Archean rocks of the Whisdkey Lake greenstone belt, Algoma District, Ontario; applications to reconnaissance mineral exploration. Ontario Geological Survey, Open File Report 5902, 100 p..

Canadian Hydrographic Service, 2014. Water levels Great Lakes and Montreal Harbour. Monthly Bulletin prepared by the Canadian Hydrographic Service and Fisheries and Oceans Canada, January 2014, <http://www.waterlevels.gc.ca/c&a/bulletin_e.html>.

Card, K.D., 1964. Metamorphism in the Agnew Lake area, District of Sudbury, Ontario, Canada. Geological Society of America Bulletin **75**, p. 1011-1030.

Card, K.D., 1976. Geology of the Espanola-Whitefish Falls Area, District of Sudbury, Ontario. Ontario Geological Survey, Report 131, 70 p.

Card, K.D., 1978. Geology of the Sudbury-Manitoulin area, districts of Sudbury and Manitoulin. Ontario Geological Survey, Report 166, 238 p.

Card, K.D., 1979. Regional geological synthesis, Central Superior Province. Geological Survey of Canada, Paper 79-1A, p. 87-90.

Card, K. D., W.R. Church, J.M. Franklin, M.J. Frarey, J.A. Robertson, G.F. West, and G.M. Young, 1972. The Southern Province; *in* Variations in Tectonic Styles in Canada. Geological Association of Canada, Special Paper No. 11. P. 335-380.

Card, K.D., V.K. Gupta , P.H. McGrath, and F. S. Grant ,1984. The Sudbury Structure: Its Regional Geological and Geophysical Setting. OGS Special Volume 1, Chapter 2, 25 -43.

Card, K.D., and D.G. Innes, 1981. Geology of the Benny Area, District of Sudbury. Ontario Geological Survey Report 206, 117 p.

Card, K.D. and E.F. Pattison, 1973. Nipissing diabase of the Southern Province; *in* Huronian Stratigraphy and Sedimentation, Geological Association of Canada, Special Paper 12, p. 7-30.

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

Clauser, C. and E. Huenges, 1995. Thermal conductivity of rocks and minerals; *in* Rock Physics & Phase Relations: A Handbook of Physical Constants. American Geophysical Union, p. 105-126.

Coleman, A.P., 1908. The lower Huronian ice age. Journal of Geology **16**, p. 149-158.

Coleman, A.P., 1914. The Precambrian rocks north of Lake Huron with special reference to the Sudbury Series. Ontario Bureau of Mines, Annual Report, **23**, p. 202-236.

Collins, W.H., 1914. Huronian formations of the Temiskaming region, Canada. Geological Survey of Canada, Miscellaneous Bulletin 8, 31 p.

Collins, W. H., 1925. North shore of Lake Huron. Geological Survey of Canada, Memoir 143, 160 p.

Corfu, F., and A. Andrews, 1986. A U-Pb age for mineralized Nipissing diabase, Gowganda, Ontario. Can. J. Earth Sci. **23**, p. 107-112.

Corfu, F. and E.C. Grunsky, 1987. Igneous and tectonic evolution of the Batchawana greenstone belt, Superior Province: a U-Pb zircon and titanite study. Journal of Geology **95**, p. 87-105.

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 **14**, p. 1220-1233.

Corrigan, D., A.G. Galley and S. Pehrsson, 2007. Tectonic evolution and metallogeny of the southwestern Trans-Hudson Orogen; *in* 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.

Cowan, W.R., 1976. Quaternary Geology of the Sault Ste. Marie Area, District of Algoma; *in* Summary of Fieldwork, 1976. Geological Branch, Ontario Division of Mines, Miscellaneous Paper 67, p. 134-136.

Cowan, W. R., 1985. Deglacial Great Lakes Shorelines at Sault Ste. Marie, Ontario; *in* Quaternary Evolution of the Great Lakes. Geological Association of Canada Special Paper 30, p. 33-37.

Cowan, W. R., and G. Bennett, 1998. Urban Geology: City of Sault Ste. Marie, Ontario; *in* Urban Geology of Canadian Cities. Geological Association of Canada Special Paper 42, p. 197-205.

Cruden, A.R., 2006. Emplacement and growth of plutons: implications for rates of melting and mass transfer in continental crust; *in* Evolution and Differentiation of the Continental Crust. Cambridge University Press, Cambridge, UK, p. 455-519.

Davidson, A., O. van Breeman, R.W. Sullivan, 1992. Circa 1.75 Ga ages for plutonic rocks of the Southern Province and adjacent Grenville Province: what is the expression of the Penokean orogeny? *in* Radiogenic Age and Isotopic Studies: Report 6, Geological Survey of Canada, Paper 92-2, p.107-118.

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**, p. 325-347.

Domtar (Domtar Inc.), 2010a. Forest Management Plan for the The North Shore Forest. Ministry of Natural Resources Sault Ste. Marie and Sudbury Districts, Northeast Region, for the 10-year period from April 1, 2010 to March 31, 2020.

Domtar (Domtar Inc.), 2010b. Forest Management Plan for the Spanish Forest. Ministry of Natural Resources Sudbury District, Northeast Region, for the 10-year period from April 1, 2010 to March 31, 2020.

Dyer R.D., 2010. Lake Sediment and Water Geochemical Data from the Elliot Lake–Sault Ste. Marie Area, Northeastern Ontario, Miscellaneous Release-Data 267, released in conjunction with Open File Report 6251.

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

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

Easton, R. M., 2005, Geology of Porter and Vernon townships, Southern Province; *in* Summary of Field Work and Other Activities, 2005. Ontario Geological Survey, Open File Report 6172, p. 13–1 to 13–20.

Easton, R.M. 2009. Compilation Mapping, Pecors–Whiskey Lake Area, Southern and Superior Provinces; *in* Summary of Field Work and Other Activities 2010. Ontario Geological Survey, Open File Report 6240, 254 p.

Easton, R.M. 2010. Compilation Mapping, Pecors–Whiskey Lake Area, Southern and Superior Provinces; *in* Summary of Field Work and Other Activities 2010. Ontario Geological Survey, Open File Report 6260, p. 8-1 to 8-12.

Easton, R.M. 2013. Geological, geochemical and geophysical data from the Elliot Lake area, Southern and Superior provinces, Ontario. Ontario Geological Survey, Miscellaneous Release-Data 305.

Easton, R.M., L.S. John-Bevans and R.S. James, 2004. Geological Guidebook to the Paleoproterozoic East Bull Lake Intrusive Suite Plutons at East Bull Lake, Agnew Lake and River Valley, Ontario. Ontario Geological Survey, Open File Report 6315, 84 p.

Easton, R.M. and L.M. Heaman, 2011. Detrital zircon geochronology of Matinenda Formation sandstones (Huronian Supergroup) at Elliot Lake, Ontario: Implications for uranium mineralization; *in* Proceedings of the 57th ILSG Meeting, Ashland, Wisconsin, U.S., May 19-20, 2011.

Easton, R.M., S.D. Josey, E.I. Murphy, and R.S. James, 2011. Geological compilation, East Bull Lake and Agnew intrusions. Ontario Geological Survey, Preliminary Map P.3596, scale 1:50 000.

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

Ejeckam, R.B., R.I. Sikorsky, D.C. Kamineni and G.F.D. McCrank, 1985. Subsurface Geology of the East Bull Lake Research Area (RA 7) in Northeastern Ontario. AECL Technical Record, TR-348.

Eschman, D. F. and P. F. Karrow, 1985. Huron Basin Glacial Lakes: A Review; *in* Quaternary Evolution of the Great Lakes. Geological Association of Canada Special Paper 30, p. 79-93.

Evans, D. A. D., and H.C. Halls, 2010. Restoring Proterozoic Deformation within the Superior Craton, Precambrian Research 183, p. 474-489.

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.

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, Manitoba.

Farvolden, R. N., O. Pfannkuck, R. Pearson, P. Fritz, 1988. Region 12, Precambrian Shield; *in* The Geology of North America, Hydrogeology. Geological Society of America Special Volume 2, p. 102-114.

Fedo, C.M., G.M. Young, H.W. Nesbitt, and J.M. Hanchar, 1997. Potassic and sodic metasomatism in the Southern Province of the Canadian Shield: evidence from the Paleoproterozoic Serpent Formation, Huronian Supergroup, Canada. Precambrian Research **84**, p. 17-36.

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

Flint, R.F, 1947. Glacial Geology and the Pleistocene Epoch. 589 p.

Follin, S. and S. Stigsson, 2014. A transmissivity model for deformation zones in fractured crystalline rock and its possible correlation to in situ stress at the proposed high-level nuclear waste repository site at Forsmark, Sweden. Hydrogeology Journal 22, p. 299–311.

Ford, M.J. 1991. The Quaternary geology of the Rawhide Lake area, District of Algoma. Ontario Geological Survey, Miscellaneous Paper 157.026.

Ford, M.J., 1993. The Quaternary Geology of the Rawhide Lake area, District of Algoma. Ontario Geological Survey, Open File Report 5867, 10 p.

Forest Branch, 2013. Forest Management Plans. Ontario Ministry of Natural Resources. http://www.mnr.gov.on.ca/en/Business/Forests/2ColumnSubPage/STEL02_ 163549.html. Accessed March 2013.

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

Frape, S.K. and P. Fritz, 1987. Geochemical trends for groundwaters from the Canadian Shield; *in* Saline water and gases in crystalline rocks. Geological Association of Canada Special Paper 33, p. 19-38.

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 **48**, p. 1617-1627.

Frape, S.K., A. Blyth, R. Blomquist, R.H. McNutt, and M. Gascoyne, 2003. Deep Fluids in the Continents: II Crystalline Rocks. Treatise on Geochemistry **5**, p. 541-580.

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

GSC (Geological Survey of Canada), 2013. Geoscience Data Repository for Geophysical and Geochemical Data, gdr.nrcan.gc.ca. (data accessed 2013)

Gartner, J.F., 1978a. Northern Ontario Engineering Geology Terrain Study, data base map, Cartier, NTS 41I/NW. Ontario Geological Survey, Map M5000, scale 1:100,000.

Gartner, J.F., 1978b. Northern Ontario Engineering Geology Terrain Study, data base map, Espanola, NTS 41I/SW. Ontario Geological Survey, Map M5002, scale 1:100,000.

Gartner, J.F., 1978c. Northern Ontario Engineering Geology Terrain Study, general construction capability map, Cartier, NTS 41I/NW. Ontario Geological Survey, Map M5004, scale 1:100,000.

Gartner, J.F., 1980a. Cartier Area (NTS 41I/NW), Districts of Algoma and Sudbury. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 94, 18 p.

Gartner, J.F., 1980b. Espanola Area (NTS 41I/SW), Districts of Manitoulin and Sudbury. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 99, 14 p.

Gartner, J.F., J.D. Mollard and M.A. Roed, 1981. Ontario Engineering Geology Terrain Study User's Manual. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 1.

Gascoyne, M., 1994. Isotopic and geochemical evidence for old groundwaters in a granite on the Canadian Shield. Mineralogical Magazine **58A**, p. 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**, p. 519-560.

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. Geological Association of Canada Special Paper 33, p. 53-68.

Geobase, 2011. A federal, provincial and territorial government initiative that is overseen by the Canadian Council on Geomatics (CCOG). Retrieved from: http://www.geobase.ca/geobase/en/data/cded/description.html

Geofirma (Geofirma Engineering Ltd.) , 2012a. Initial Screening for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, Town of Blind River, Ontario: 39 p.

Geofirma (Geofirma Engineering Ltd.) , 2012b. Initial Screening for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, City of Elliot Lake, Ontario: 39 p.

Geofirma (Geofirma Engineering Ltd.) , 2012c. Initial Screening for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, Township of the The North Shore: 40 p.

Geofirma (Geofirma Engineering Ltd.) , 2012d. Initial Screening for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, Town of Spanish, Ontario: 40 p.

Giblin, P.E., 1976. Report of the Northeastern Regional Geologist and Sault Ste. Marie Resident Geologist; p. 91-99 in Annual Report of the Regional and Resident Geologist, 1975, edited by C.R. Kustra, Ontario Division of Mines, MP64, 146p.

Giblin, P.E., E.J. Leahy and J.A. Robertson, 1977. Geological Compilation of the Blind River-Elliot Lake Sheet, Districts of Algoma and Sudbury. Ontario Geological Survey Preliminary Map P.304, scale 126,720.

Giblin, P.E. and E.J. Leahy, 1979. Sault Ste. Marie-Elliot Lake, Geological Compilation Series, Algoma, Manitoulin and Sudbury Districts. Ontario Geological Survey, Map 2419, scale 1:253,440.

Gittins, J., R. M. Mcintyre, and D. York, 1967. The Ages of Carbonatite Complexes in Eastern Ontario. Can. J. Earth Sci. **4**, 651-655.

Golder (Golder Associates Ltd.) and Senes (Senes Consultants Ltd.), 1982. Quirke Mine Tailings Impoundment Hydrogeological Re-Assessment of West End of Tailings Basin. Prepared for Rio Algom Limited. October 1982. Report Number 821-1163.

Golder (Golder Associates Ltd.), (Senes) Senes Consultants Ltd. and Cumming (Cumming Cockburn Ltd.), 1992a. Geological and Hydrogeological Assessment: Supporting Document Volume 2 Decommissioning Study Stanrock Mine Tailings Management Area. Prepared or Denison Mines Limited. June 1992. Report Number 911-1817B-2.

Golder (Golder Associates Ltd.), (Senes) Senes Consultants Ltd. and Cumming (Cumming Cockburn Ltd.),, 1992b. Evaluation of Closure Options Decommissioning Study Denison Mine Tailings Management

Areas TMA-1 and TMA-2. Prepared for Denison Mines Limited. May 1992. Report Number 911-1817G-1.

Golder (Golder Associates Ltd.), 1996. Hydrogeological Modelling of the Stanleigh Mine Waste Management Area Post Closure Conditions. Prepared for Rio Algom Limited. September 1996. Report Number 961-1804.

Golder (Golder Associates Ltd.),2012a. Thermo-mechanical Analysis of a Single Level Repository for Used Nuclear Fuel. Prepared 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 for the Nuclear Waste Management Organization. NWMO TR-2012-19.

Gordon C.A., 2012 Preliminary Results from the Otter–Morin Townships Bedrock Mapping Project, Southern and Superior Provinces; *in* Summary of Field Work and Other Activities 2012. Ontario Geological Survey, Open File Report 6280, p. 17-1 to 17-10.

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

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 **48**, p. 569-581.

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

Halls, H.C., 1982. The importance and potential of mafic dyke swarms in studies of geodynamic processes; Geoscience Canada, 9: p.145-154.

Halls, H.C., 1991. The Matachewan dyke swarm, Canada: an early Proterozoic magnetic field reversal; Earth and Planetary Science Letters, 105 (1991), p.279-292.

Halls, H. C., H.C. Palmer, M.P. Bates and W.C. Phinney, 1994, Constraints on Nature of the Kapuskasing Structural Zone from the Study of Proterozoic Dyke Swarms, Can. J. Earth Sci. **31**, p. 1182-1196.

Halls, H.C., D.W. Davis, G.M. Stott, R.E. Ernst and M.A. Hamilton, 2008. The Paleoproterozoic Marathon Large Igneous Province: New evidence for a 2.1 Ga long-lived mantle plume event along the southern margin of the North American Superior Province. Precambrian Research **162**, p. 327-353.

Hawke, D.R., 2011. Report on a 3D magnetic interpretation for International Montoro Resources on Serpent River Project. AFRI no. 20009827.

Hay, W.W., C.A. Shaw and C.N. Wold. 1989. Mass-balanced paleogeographic reconstructions. Geologishce Rundschau **78**, p. 207-248.

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.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 of January 01 - December 31, 2010, Nuclear Waste Management Organization TR-2011-26, 30 p.

Heaman, L.M., 1997. Global mafic magmatism at 2.45 Ga: Remnants of an ancient large igneous province? Geology **25**, p. 299-302.

Heaman, L.M., R.M. Easton, T.R. Hart, P. Hollings, C.A. MacDonald, and M. Smyk, 2007. Further refinement to the timing of Mesoproterozoic magmatism, Lake Nipigon region, Ontario. Can. J. Earth Sci. **44**, p. 1055-1086.

Hearst, R.B. and W.A. Morris, 2001. Regional gravity setting of the Sudbury Structure. Geophysics **66**, p. 1680-1690.

Heather, K. B., G.T. Shore, and O. van Breeman, 1995. The convoluted “layer cake”, an old recipe with new ingredients for the Swayze greenstone belt, southern Superior Province, Ontario; *in* Current Research 1995-C, p. 1-10.

Heidbach, O., M. Tingay, A. Barth, J. Reinecker, D. Kurfe, B. Müller, 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.

Henderson, P.J. and J.M. Halstead, 1992. The Quaternary Geology of the Elliot Lake Area, District of Algoma. Ontario Geological Survey, Open File Map 193, 1:50,000.

Herget, G., 1972. Tectonic Fabric and Current Stress Field at an Iron Mine in the Lake Superior Region; *in* Proceedings of the 24th International Geological Congress, Section 13, p. 241-248.

Herget, G., 1980. Regional stresses in the Canadian Shield; *in* Proceedings 13th Canadian Rock Mechanics Symposium, CIM Bulletin 22, p. 9-16.

Herget, G. and B. Arjang, 1990. Update on ground stresses in the Canadian Shield; *in* Stresses in Underground Structures, CANMET, Ottawa, October 2-3, p. 33-47.

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

Hoffman, P.F., 2013. The Great Oxidation and a Siderian snowball Earth:MIF-S based correlation of Paleoproterozoic glacial epochs. Chemical Geology

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

Holm, D.K., D.A. Schneider,C. O'Boyle, M. A. Hamilton, M.J. Jercinovic and M. L. Williams, 2001. Direct timing constraints on Paleoproterozoic metamorphism, southern Lake Superior region: results from SHRIMP and EMP U-Pb dating of metamorphic monazites; Geological Society of America, Abstracts with Program, v.33, no.6, p.A-401.

JDMA (J.D. Mollard and Associates Ltd.), 2014a. Phase 1 Geoscientific Desktop Preliminary Assessment, Terrain and Remote Sensing Study, City of Elliot Lake, Town of Blind River, Township of The North

Shore, Town of Spanish, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0092.

JDMA (J.D. Mollard and Associates Ltd.), 2014b. Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Interpretation, City of Elliot Lake, Town of Blind River, Township of The North Shore, Town of Spanish, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0094.

Jackson, S.L. and J.A. Fyon, 1991. The Western Abitibi Subprovince in Ontario; *in* Geology of Ontario. Ontario Geological Survey, Special Volume 4, Part 1, p. 405-482.

Jackson, S.L., 2001. On the structural geology of the Southern Province between Sault Ste. Marie and Espanola, Ontario. Ontario Geological Survey, Open File Report 5995, 55 p.

James, R.S. and P. Born ,1985. Geology and Geochemistry of the East Bull Lake Intrusion, District of Algoma, Ontario. Can. J. Earth Sci. **22**, p. 968-979.

Jensen, L.S., 1994. Geology of the Whiskey Lake Greenstone Belt (West Half), Districts of Sault Ste. Marie and Sudbury. Ontario Geological Survey, Open File Report 5883, 101 p.

Johns, G. W., S. McIlraith, and T.L. Muir, 2003. Bedrock geology compilation map, Sault Ste. Marie-Blind River map sheet. Ontario Geological Survey, Map 2670, scale 1:250 000.

Johnston, J.C., 1988. A Survey of Mining Associated Rockbursts. Earth Sciences Division, Air Force Geophysics Laboratory, AFGL-TR-88-0050, Environmental Research Papers, NO. 998.

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.

Karrow, P.F., 1987. Glacial and glaciolacustrine events in northwestern Lake Huron, Michigan and Ontario Geological Society of America Bulletin **98**, p. 113-120.

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

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

Krogh, T.E., F. Corfu, D.W. Davis, G.R. Dunning, L.M. Heaman, S.L. Kamo, N. Machado, J.D. Greenough and E. Nakamura, 1987. Precise U-Pb isotopic ages of diabase dykes and mafic to ultramafic rocks using trace amounts of baddeleyite and zircon; *in* Mafic dyke swarms. Geological Association of Canada, Special Paper 34, p. 147-152.

Krogh, T.E., D.W. Davis and F. Corfu, 1984. Precise zircon and baddeleyite ages for the Sudbury area; *in* Geology and Ore Deposits of the Sudbury Structure. Ontario Geological Survey, Special Volume 1, p. 431-446.

Lacey, K., 1991. Building Stone Inventory of the Sudbury Resident Geologist's Area, Volume I. Ontario Geological Survey, Open File Report 5762, 35 p.

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**, p. 188–198.

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

LIO (Land Information Ontario), 2013. Ontario Ministry of Natural Resources. (Retrieved from http://www.mnr.gov.on.ca/en/Business/LIO/). Accessed April 2013.

Lewis, C.F. M. , S. M. Blasco and P. L. Gareau, 2005. Glacial Isostatic Adjustment of the Laurentian Great Lakes Basin: Using the Empirical Record of Strandline Deformation for Reconstruction of Early Holocene Paleo-Lakes and Discovery of a Hydrologically Closed Phase. Géographie physique et Quaternaire **59**, p. 187-210.

Lewis, D., 2013. Precambrian geology of Albanel Township, Southern and Superior Provinces. Ontario Geological Survey, Preliminary Map P.3773, scale 1:20 000.

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.

Lightfoot P.C., H. de Souza and W. Doherty, 1993. Differentiation and source of the Nipissing Diabase intrusions, Ontario, Canada. Can. J. Earth Sci. **30**, p. 1123-1140.

Logan, W.E. 1863. The geology of Canada; Dawson Brothers, Montreal, Quebec, 983 p.

Lovell, H.L. and T.W. Caine, 1970. Lake Timiskaming Rift Valley, Ontario. Department of Mines, Miscellaneous Paper 39, 16 p.

Mainville A. and M.R. Craymer, 2005. Present-day tilting of the Great Lakes region based on water level gauges. GSA Bulletin **117**, p. 1070-1080.

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, 9 p.

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.

McCrank, G.F.D., D. Stone, D.C Kamineni, B. Zayachkivsky, and G. Vincent, 1982. Regional geology of the East Bull Lake area, Ontario. Geological Survey of Canada, Open File 873 -1983 paper 83-1A, p. 457-464.

McCrank, G.F.D., D.C. Kamineni, R.B. Ejeckam and R. Sikorsky, 1989. Geology of the East Bull Lake gabbro-anorthosite pluton, Algoma District, Ontario. Can. J. Earth Sci. **26**, p. 357-375.

McFall, G. H., 1993. Structural Elements and Neotectonics of Prince Edward County, Southern Ontario, Géographie physique et Quaternaire **47**, p. 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 **35**, p. 1093-1115.

Meriaux, C., J.R. Lister, V. Lyakhovsky, A. Agnon, 1999. Dyke propagation with distributed damage of the host rock; Earth and Planetary Science Letters, 165 (1999), p.177-185.

Merrett, G.J. and P.A. Gillespie, 1983. Nuclear fuel waste disposal: Long-term stability analysis. Atomic Energy of Canada Limited Report AECL-6820, 49 p.

Meyer, G., G.P.B. Grabowski, D. L. Guindon, and E. C. Chaloux, 2006. Report of Activities 2005, Resident Geologist Program, Kirkland Lake Regional Resident Geologist Report: Kirkland Lake District; Ontario Geological Survey, Open File Report 6184, 50 p.

MNDM (Ontario Ministry of Northern Development and Mines), 2013. Assessment File Research Imaging (AFRI) Database. Accessed April, 2013.

MOE (Ontario Ministry of the Environment), 2013. Water Well Record Database. Accessed April 2013.

NASA Landsat Program, 2013. Landsat MSS scene p022r028_1dm19760908. United States Geological Survey, Global Land Cover Facility, http://glcf.umd.edu/.

NRCan (Natural Resources Canada), 2012. Geobase. Accessed April 2013.

NRCan (Natural Resources Canada), 2013. National Earthquake Database. Accessed April 2013.

NRCan (Natural Resources Canada), 1997. Geological Map of Canada - Map D1860A [CD-ROM].Geological Survey of Canada, Natural Resources Canada, Ottawa.

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

NWMO (Nuclear Waste Management Organization), 2014a. Preliminary Assessment for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, City of Elliot Lake, Ontario – Findings from Step 3, Phase One Studies. NWMO Report Number: APM-REP-06144-0097.

NWMO (Nuclear Waste Management Organization), 2014b. Preliminary Assessment for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, Town of Blind River, Ontario – Findings from Step 3, Phase One Studies. NWMO Report Number: APM-REP-06144-0089.

NWMO (Nuclear Waste Management Organization), 2014c. Preliminary Assessment for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, Township of The North Shore, Ontario – Findings from Step 3, Phase One Studies. NWMO Report Number: APM-REP-06144-0100.

NWMO (Nuclear Waste Management Organization), 2014d. Preliminary Assessment for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, Town of Spanish, Ontario – Findings from Step 3, Phase One Studies. NWMO Report Number: APM-REP-06144-0103.

OGS (Ontario Geological Survey), 2003. Benny Area, Ontario airborne magnetic and electromagnetic surveys, processed data and derived products, Geophysical Data Set 1017 - Revised.

OGS (Ontario Geological Survey), 2005. Digital Northern Ontario Engineering Geology Terrain Study (NOEGTS). Ontario Geological Survey, Miscellaneous Release of Data 160.

OGS (Ontario Geological Survey), 2011a. 1:250 000 Scale Bedrock Geology of Ontario, Miscellaneous Release – Data 126 – Revision 1. ISBN 978-1-4435-5704-7 (CD) ISBN 978-1-4435-5705-4 [zip file].

OGS (Ontario Geological Survey), 2011b. Ontario airborne geophysical surveys, magnetic and electromagnetic data, grid, profile and vector data, Elliot Lake–River aux Sables area - Purchased Data, Geophysical Data Set 1236.

OGS (Ontario Geological Survey), 2011c. Mineral Deposit Inventory-2011. Ontario Geological Survey.

OGS (Ontario Geological Survey), 2013. Earth website on MNDM website http://www.mndm.gov.on.ca /en/mines-and-minerals/applications/ogsearth

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.

PGW (Paterson, Grant and Watson Limited), 2014. Phase 1 Geoscientific Desktop Preliminary Assessment, Processing and Interpretation of Geophysical Data, City of Elliot Lake, Town of Blind River, the Township of The North Shore, Town of Spanish, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0093.

Paillet, F. L., and A. E. Hess, 1986. Geophysical Well-Log Analysis of Fractured Crystalline Rocks at East Bull Lake, Ontario, Canada. USGS Water-Resources Investigations Report 86-4052.

Parks Canada, 2012a. Directory of Federal Heritage Designations. (Retrieved from http://www.pc.gc.ca/apps/dfhd/default_eng.aspx). Accessed April 2013.

Parks Canada, 2012b. National Historic Sites of Canada System Plan. (Retrieved from http://www.pc.gc.ca/docs/r/system-reseau/sec6/sites-lieux68.aspx). Accessed April 2013.

Parks Canada, 2012c. Canada's Historic Places. (Retrieved from http://www.historicplaces.ca/en/home-accueil.aspx). Accessed April 2013.

Parmenter, A.C., C. B. Lee, and M. Coniglio, 2002. "Sudbury Breccia" at Whitefish Falls, Ontario: evidence for an impact origin. Can. J. Earth Sci. **39**, p. 971-982.

Palmer, H.C., R.E. Ernst and K.L. Buchan, 2007. Magnetic fabric studies of the Nipissing sill province and Senneterre dykes, Canadian Shield, and implications for emplacement, Can. J. Earth Sci. **44**, p. 507-528.

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

Peck, D.C. and R.S. James, 1991. Geology and Platinum Group Element Sulphide Mineralization, East Bull Lake. Ontario Geological Survey, Open File Report 5813, 65 p.

Peck, D.C., R.S. James ,P.C. Chubb, S.A. Prevec and R.R. Keays, 1995. Geology, metallogeny and petrogenesis of the East Bull Lake intrusion, Ontario; Ontario Geological Survey, Open File Report 5923, 124 p.

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

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. Can. J. Earth Sci. **43**, p. 1085-1117.

Percival, J.A. and West, G.F. 1994. The Kapuskasing Uplift: A geological and geophysical synthesis. Canadian Journal of Earth Sciences, v.31, p.1256-1286.

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**, p. 237-253.

Phinney, W.C. and H.C. Halls, 2001. Petrogenesis of the Early Proterozoic Matachewan dyke swarm, Canada and implications for magma emplacement and subsequent deformation. Can. J. Earth Sci. **11**, p. 1541-1563.

Piercey, P., D.A. Schneider and D.K. Holm, 2003. Petrotectonic evolution of Paleoproterozoic rocks across the 1.8 Ga Central Penokean orogen, northern MI & WI. Geological Society of America, Abstracts **35**, 554 p.

Piercey, P., 2006. Proterozoic Metamorphic Geochronology of the Deformed Southern Province, Northern Lake Huron Region, Canada: unpublished M.Sc. Thesis, Ohio University, 67 p.

POSIVA, 2007a. Drill Hole Logging Device TERO76 for Determination of Rock Thermal Properties: prepared by Kukkonen, I., A. Suppala, T. Korpisalo, T. Koskinen, 2007. Posiva Oy, February 2007.

POSIVA, 2007b Olkiluoto Site Description 2006: prepared by Andersson, J., H. Ahokas, J.A. Hudson, L. Koskinen, A. Luukkonen, J. Löfman, V. Keto, P. Pitkänen, J. Mattila, A.T.K. Ikonen and, M. Ylä-Mella, 2007-03.

POSIVA, 2011. Thermal Properties of Rocks in Olkiluoto: Results of Laboratory Measurements 1994-2011. Prepared by Kukkonen, I., L. Kivekäs, S. Vuoriainen, M. Kääriä, 2011. Working Report 2011 - 17. 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 **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 **32**, p. 768-786.

Prevec, S.A., 1993. An Isotopic, Geochemical and Petrographic Investigation of the Genesis of Early Proterozoic Mafic Intrusions and Associated Volcanism near Sudbury Ontario, Ph.D. Thesis, University of Alberta, Edmonton, Alberta.

Pritchard, C.J. and D.G.F. Hedley, 1993. Progressive pillar failure and rockbursting at Denison Mine.

Quirke, T.T. 1917. Espanola District. Geological Survey of Canada, Memoir 102, 92 p.

Raharimahefa, T., D.K. Tinkham and B. Lafrance, 2011. New U-Pb Geochronological Constraints on the Structural Evolution of the Southern Province, Sudbury, Canada. Paper No. 101-10. 2011 GSA Annual Meeting in Minneapolis. 9-12 October 2011.

Rainbird R.H., L.M. Heaman, W.J. Davis and A. Simonetti, 2006. Coupled Hf and U–Pb isotope analysis of detrital zircons from the Paleoproterozoic Huronian Supergroup, Geological Society of America Abstracts with Programs **38**, 410 p.

Raven K. G., J.A Smedley, R.A. Sweezey and K.S Novakowski, 1984. Investigations at the East Bull Lake Research area. Summary of 1983 activities: Pinawa, Manitoba, Atomic Energy Canada Ltd, 91 p.

Raven, K.G. and J.E. Gale, 1986. A Study of the Surface and Subsurface Structural and Groundwater Conditions at Selected Underground Mines and Excavations. Atomic Energy of Canada Ltd, Pinawa, TR-177, 81p.

Raven, K.G., D.J. Bottomley, R.A Sweezey, J.A. Smedley and T.J. Ruttan, 1987. 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, 77 p.

Reid, J.L., 2003. Regional modern alluvium sampling survey of the Sault Ste. Marie-Espanola Corridor, Northeastern Ontario: Operation Treasure Hunt. Ontario Geological Survey, Open File Report 6117, 147 p.

Riller, U., W.M Schwerdtner, H.C Halls, and K.D Card, 1999. Transpressive tectonism in the eastern Penokean orogen, Canada: Consequences for Proterozoic crustal kinematics and continental fragmentation. Precambrian Research **93**, p. 51–70.

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

Robertson, J.A. 1961. Geology of townships 143 and 144, District of Algoma. Ontario Department of Mines, Geological Report 4, 65 p.

Robertson, J.A. 1962. Geology of townships 137 and 138, District of Algoma. Ontario Department of Mines, Geological Report 10, 94 p.

Robertson, J.A. 1963a. Geology of townships 155, 156, 161, 162, and parts of 167 and 168, District of Algoma. Ontario Department of Mines, Geological Report 13, 88 p.

Robertson, J.A. 1963b. Geology of the Iron Bridge area, District of Algoma. Ontario Department of Mines, Geological Report 17, 69 p.

Robertson, J.A. 1964. Geology of Scarfe, Mack, Cobden and Striker townships, District of Algoma. Ontario Department of Mines, Geological Report 20, 89 p.

Robertson, J.A., 1965a. Ontario Department of Mines Preliminary Geology Map No P318, Shedden Township Part IR No 7.

Robertson, J.A., 1965b. Ontario Department of Mines Preliminary Geology Map No P319, IR No 7 East and Offshore, District of Algoma.

Robertson, J.A., 1965c. Ontario Department of Mines Preliminary Geology Map No P320, IR No 5 West and Offshore Islands, District of Algoma.

Robertson, J.A., 1967. Recent Geological Investigations in the Elliot Lake – Blind River Uranium Area, Ontario. Ontario Department of Mines, Miscellaneous Paper 9, 58 p.

Robertson, J.A. 1968. Geology of Township 149 and Township 150, District of Algoma. Ontario Department of Mines, Geological Report 57, 162 p.

Robertson, J.A., 1970. Geology of the Spragge area, District of Algoma. Ontario Department of Mines, Geological Report Number 76, 109 p.

Robertson, J.A. 1977a. Geology of the Cutler area, District of Algoma. Ontario Division of Mines, Geological Report 147, 73 p.

Robertson, J.A. 1977b. Geology of Poulin and Sagard townships, District of Algoma. Ontario Division of Mines, Map 2346, scale 1:31,680.

Robertson, J.A., 1983. Huronian Geology and the Blind River Uranium Deposits. Ontario Geological Survey, Open File Report 5430, 159 p.

Robertson, J.A., and J.M. Johnson, 1965. Ontario Department of Mines Preliminary Geology Map No P317, Deagle Township, District of Algoma.

Roed, M.A. and D.R. Hallett,. 1979a. Northern Ontario Engineering Geology Terrain Study, data base map, Biscotasing, NTS 41O/SE. Ontario Geological Survey, Map M5017, scale 1:100,000.

Roed, M.A. and D.R. Hallett, 1979b. Northern Ontario Engineering Geology Terrain Study, data base map, Wenebegon Lake, NTS 41O/SW. Ontario Geological Survey, Map M5016, scale 1:100,000.

Roed, M.A. and D.R. Hallett, 1979c. Northern Ontario Engineering Geology Terrain Study, data base map, Westree, NTS 41P/SW. Ontario Geological Survey, Map M5022, scale 1:100,000.

Roed, M.A. and D.R. Hallett, 1979d. Westree Area (NTS 41P/SW), Districts of Sudbury and Timiskaming. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 88, 12 p.

Roed, M.A. and D.R. Hallett, 1980a. Biscotasing Area (NTS 41O/SE), Districts of Algoma and Sudbury. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 87, 15 p.

Roed, M.A. and D.R. Hallett, 1980b. Wenebegon Lake Area (NTS 41P/SW), Districts of Algoma and Sudbury. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 86, 12 p.

Rogers, M.C., 1992. Geology of the Whiskey Lake Area, East Half. Ontario Geological Survey, Open File Report 5834, 109 p.

Rogers, M.C. 1993. Geology of the Ompa Lake area, District of Sault Ste. Marie. Ontario Geological Survey, Open File Report 5864, 105 p.

Roscoe, D.M., 1969. Huronian rocks and uraniferous conglomerates. Geological Survey of Canada, Paper 68-40, 205 p.

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

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

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

Sage, R.P., 1991. Alkalic rock, carbonatite and kimberlite complexes of Ontario, Superior Province, In: Thurston, P.C., Williams, H.R., Sutcliffe, R.H., Stott GM (eds.) Geology of Ontario, Part 1, Ontario Geological Survey, Special Volume, Part 1, pp. 683-709.

Sage, R.P., 1988. Geology of Carbonatite Alkalic Rock Complexes in Ontario: Seabrook Lake Carbonatite Complex, District of Algoma. Ontario Geological Survey, Study 31, 45 p.

Schneider D.A. and D.K. Holm, 2005. Tectonic switching as a Proterozoic crustal growth mechanism during the assembly of Laurentia, Great Lakes Region, North America. Geophysical Research Abstracts, **7**, 04350.

Schulz K.J., and W. F. Cannon, 2007. The Penokean orogeny in the Lake Superior region. U.S. Geological Survey. Precambrian Research **157**, p. 4–25.

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. Geophysical Research Letters **34**, L02306, doi:10.1029/2006GL027081.

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**, p. 251-261.

Siemiatkowska, K.M., 1977. Geology of the Wakomata Lake area. Ontario Division of Mines, Geological Report 151, 57p. Accompanied by map 2350, scale 1 inch to 1/2 mile (1:31,680).

Siemiatkowska, K.M., 1981. Geology of the Kirkpatrick Lake area, District of Algoma. Ontario Geological Survey, Open File Report 5352, 77 p.

Sims, P.K., W.R. van Schmus, K.J. Schulz and Z.E. Peterman, 1989. Tectono-stratigraphic evolution of the Early Proterozoic Wisconsin magmatic terranes of the Penokean Orogen. Can. J. Earth Sci. **26**, p. 2145-2158.

Singer, S.N. and C.K. Cheng, 2002. An assessment of the groundwater resources of Northern Ontario, Hydrogeology of Ontario Series (Report 2). Ministry of the Environment: Environmental Monitoring and Reporting Branch, 255 p.

Skulski T., H. Sandeman, M. Sanborn-Barrie, T. MacHattie, D. Hyde, S. Johnstone, D. Panagapko and D. Byrne, 2002. Contrasting Crustal Domians in the Committee Bay Belt, Walker Lake-Arrowsmith River Area, Central Nunavut, GSC, Current Research 2002-C11, 11 p.

Stanleigh Mine drawing No. 557 annotated by L.C. Harper.

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

Stone, D., 1984. Sub-surface fracture maps predicted from borehole data: an example from the Eye–Dashwa pluton, Atikokan, Canada. International Journal of Rock Mechanics and Mining Science **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. Can. J. Earth Sci. **26**, p. 387-403.

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

Thompson, L. M., and J. G. Spray, 1996. Pseudotachylyte petrogenesis: constraints from the Sudbury impact structure: Contributions to Mineral Petrology **125**, p. 359–374.

Thurston, P.C., 1991. Geology of Ontario: Introduction; ; *in* Geology of Ontario, Special Volume No. 4, Part 1, p. 3-26.

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.2858, scale 1:50,000.

van Breemen, O., K.B. Heather, and J.A. Ayer, 2006. U-Pb geochronology of the Neoarchean Swayze sector of the southern Abitibi greenstone belt. Current Research 2006 F1, Geological Survey of Canada.

VanDine, D.F., 1979a. Northern Ontario Engineering Geology Terrain Study, database map, Bark Lake, NTS 41J/NE. Ontario Geological Survey, Map 5006, scale 1:100,000.

VanDine, D.F., 1979b. Northern Ontario Engineering Geology Terrain Study, database map, Blind River, NTS 41J/SE. Ontario Geological Survey, Map 5008, scale 1:100,000.

VanDine, D.F., 1979c. Northern Ontario Engineering Geology Terrain Study, database map, Thessalon, NTS 41J/SW. Ontario Geological Survey, Map 5007, scale 1:100,000.

VanDine, D.F., 1979d. Northern Ontario Engineering Geology Terrain Study, database map, Wakomata Lake, NTS 41J/NW. Ontario Geological Survey, Map 5005, scale 1:100,000.

VanDine, D.F., 1980a. Bark Lake Area (NTS 41J/NE), Districts of Algoma and Sudbury. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 93, 12 p.

VanDine, D.F., 1980b. Blind River Area (NTS 41J/SE), Districts of Algoma, Manitoulin, and Sudbury. Ontario Geological Survey, Northern Ontario Terrain Study 98, 14 p.

VanDine, D.F., 1980c. Thessalon Area (NTS 41J/SW), District of Algoma. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 97, 16 p.

VanDine, D.F., 1980d. Wakomata Lake Area (NTS 41J/NW), District of Algoma. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 92, 13 p.

Van Schmus, W.R., 1992. Tectonic setting of the Midcontinent Rift system. Tectonophysics **213**, p. 1-15.

Vogel D.C., R.S. James and R.R. Keays, 1998. The early tectono-magmatic evolution of the Southern Province: implications from the Agnew Intrusion, central Ontario, Canada. Can. J. Earth Sci. **35**, p. 854-870.

von Bitter, R., 2013. Personal Communication on April 26, 2013 re: Archaeological Sites Database. Ministry of Tourism, Culture, and Sport.

Vos, M.A. 1978: Silica in Ontario, Industrial Minerals Supplement. Ontario Geological Survey Miscellaneous Paper 85, 36 p.

West, G.F. and R.E. Ernst, 1991. Evidence from aeromagnetics on the configuration of Matachewan dykes and the tectonic evolution of the Kapuskasing Structural Zone, Ontario, Canada; Canadian Journal of Earth Sciences, Vol. 28, p.1797-1811.

Wetherill, G.W., G.L. Davis and G.R. Tilton, 1960. Age measurements from the Cutler Batholith, Cutler, Ontario. Journal of Geophysical Research **65**, p. 2461-2466.

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

Williams, H., P.F. Hoffman, J.F. Lewry., J.W.H. Monger and T. Rivers, 1991. Anatomy of North America: thematic portrayals of the continent. Tectonophysics **187**, p. 117–134.

Wood, J. 1975. Geology of Rawhide Lake area, District of Algoma. Ontario Division of Mines, Geological Report 129, 67 p.

Young, G.M., D.G.F. Long, C.M. Fedo and H.W. Nesbitt, 2001. Paleoproterozoic Huronian basin: product of a Wilson cycle punctuated by glaciations and a meteorite impact. Sedimentary Geology **141-142**, p. 233-254.

Young, G.M., 1983. Tectono-sedimentary history of early Proterozoic rocks of the northern Great Lakes region; *in* Early Proterozoic Geology of the Great Lakes Region. Geological Society America Memoir 160, p. 15–32.

Zolnai, A.I., R.A. Price and H. Helmstaedt, 1984. Regional cross section of the Southern Province adjacent to Lake Huron, Ontario: implications for the tectonic significance of the Murray Fault Zone. Can. J. Earth Sci. **21**, p. 447-456.

REPORT SIGNATURE PAGE

GOLDER ASSOCIATES LTD.

Phyllis McCrindle

George Schneider

Phyllis McCrindle, M.Sc., P.Geo.
Senior Geoscientist, Associate

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

PMMC/CWM/GWS

c:\gws-work\1 - active\12-1152-0245 1000 elnos\29 final oct 2014\main\12-1152-0245 (1000)_noh_mainrpt_final_31oct2014c.docx

FIGURES

LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Transmission Line
- Watercourse
- Waterbody
- Forest Reserve
- Conservation Reserve
- Provincial Park

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
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 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP
PRELIMINARY ASSESSMENT

TITLE
Communities of Elliot Lake, Blind River,
The North Shore, Spanish and Surrounding Area

Golder Associates
Mississauga, Ontario

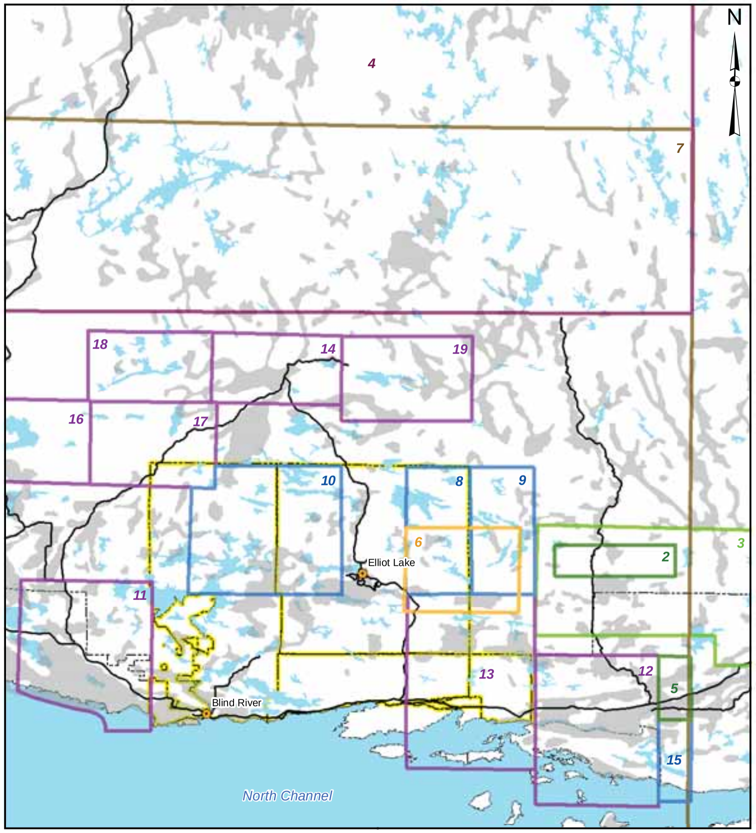
PROJECT NO. 12-1152-0245		
DESIGN	PRM	13 Mar. 2013
GIS	PM/JB	26 Jun. 2014
CHECK	PMcC	26 Jun. 2014
REVIEW	GWS	26 Jun. 2014

SCALE AS SHOWN REV. 0.0

FIGURE: 1.1

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

Geology Mapping Coverage



LEGEND

- Community
- Main Road
- Waterbody
- Municipal Boundary
- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Overburden Cover

Detailed Geology Extent

Map Scale
- 1:10,000
- 1:15,000
- 1:15,840
- 1:20,000
- 1:31,680
- 1:50,000
- 1:126,720
- 1:250,000

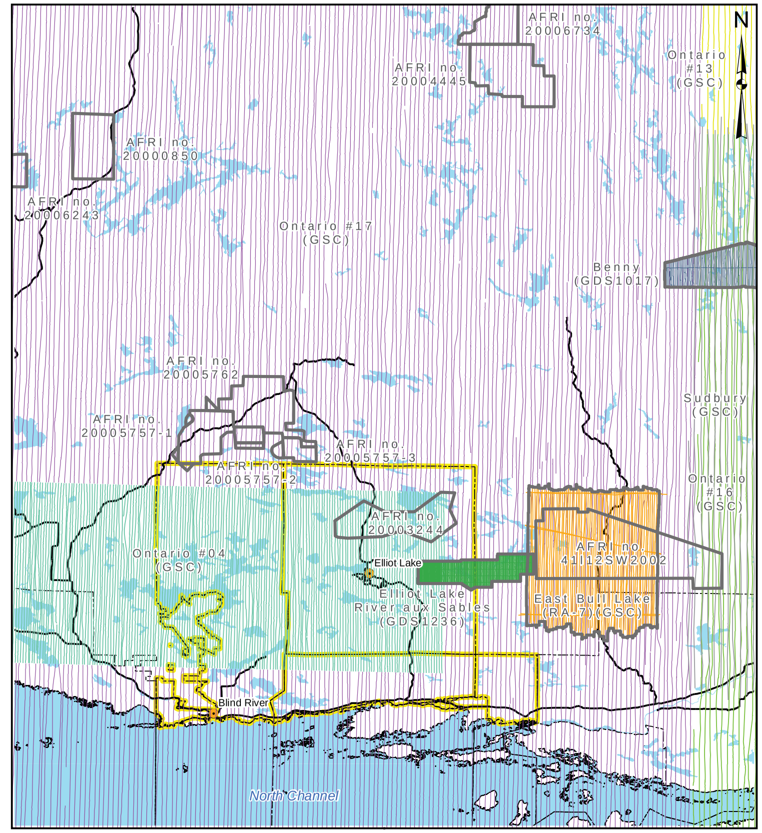
1 - Chandler (1976)
2 - Chubb et al. (1994)
3 - Easton et al. (2011)
4 - Giblin et al. (1977)
5 - Jackson (1994)
6 - Jensen (1994)
7 - Johns et al. (2003)
8 - Robertson (1961)
9 - Robertson (1962)
10 - Robertson (1963)
11 - Robertson (1963)
12 - Robertson (1976)
13 - Robertson (1977)
14 - Robertson (1976)
15 - Robertson et al. (1972)
16 - Siemiatkowska (1977)
17 - Siemiatkowska (1978)
18 - Siemiatkowska et al. (1981)
19 - Wood (1975)

Full Geology Coverage
OGS Quaternary Geology of Ontario (Data Set 14)
OGS Bedrock Geology of Ontario 2011 (MRD 126)

Full Geophysics Coverage
GSC Gravity 1946-1974
GSC Radiometric 1975, 1979, 1996

REFERENCE
Base Data - MNR LIO, obtained 2009-2013
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 17N

Geophysics Mapping Coverage



LEGEND

- Community
- Main Road
- Waterbody
- Municipal Boundary
- Communities of Elliot Lake, Blind River, The North Shore and Spanish

Geophysical Survey Flight Paths
- Flightpath OGS GDS 1017 Benny
- Flightpath OGS GDS 1236 Elliot Lake – River aux Sables
- Flightpath GSC East Bull Lake (RA-7)
- Flightpath GSC Ontario #04
- Flightpath GSC Ontario #13
- Flightpath GSC Ontario #16
- Flightpath GSC Ontario #17
- Flightpath GSC Sudbury

10 5 0 10 20 30 40 50
SCALE 1:750,000 KILOMETRES

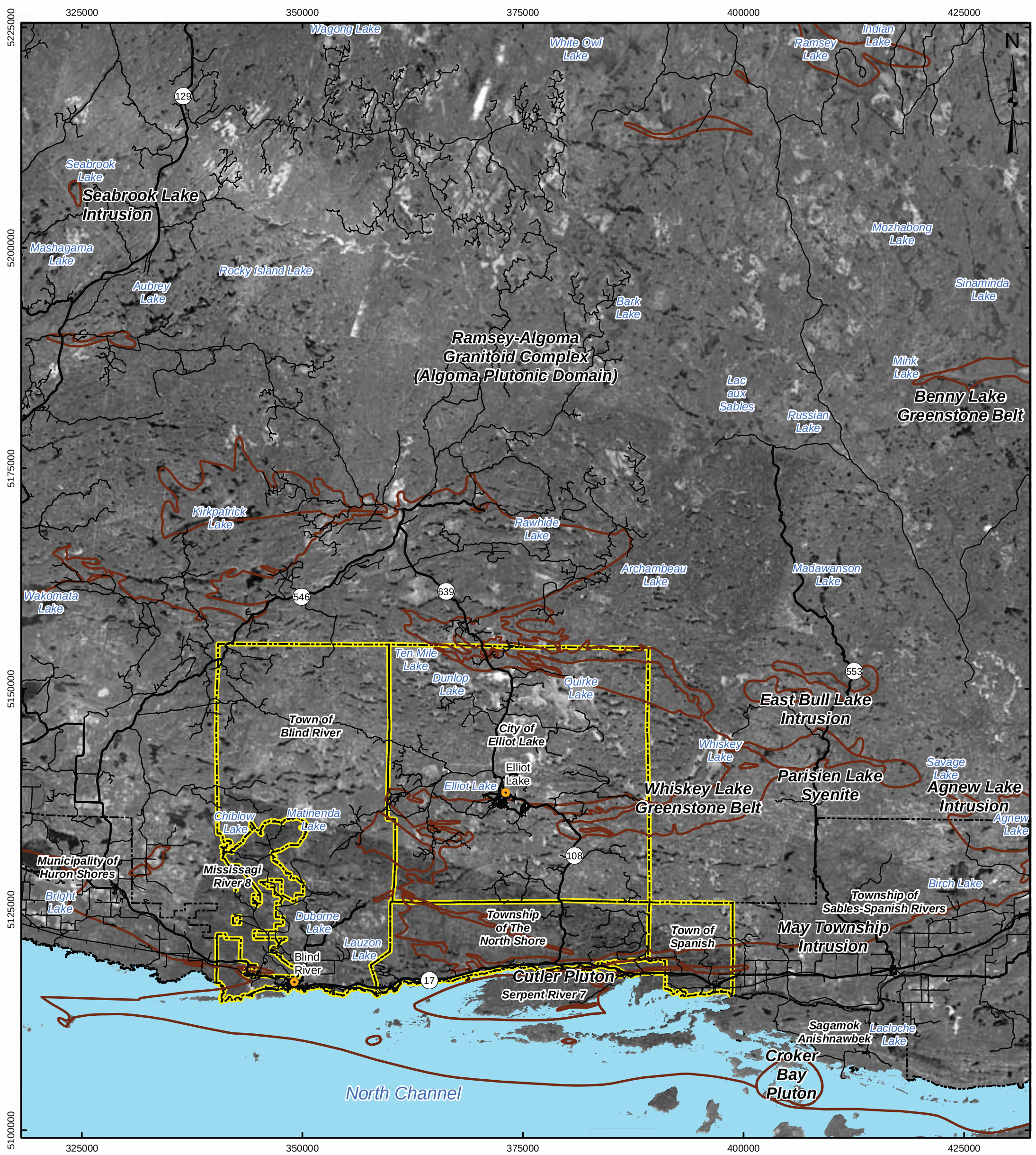
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Geoscience Mapping and Geophysical Coverage of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	19 Oct. 2012	FIGURE: 1.2	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Major Geological Contact

INDEX MAP

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geological Contact - Modified 1:250 000 Scale MRD126-Bedrock Geology
Imagery - SPOT 5, Obtained from Geobase (2006, 10 m resolution)
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 17N

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

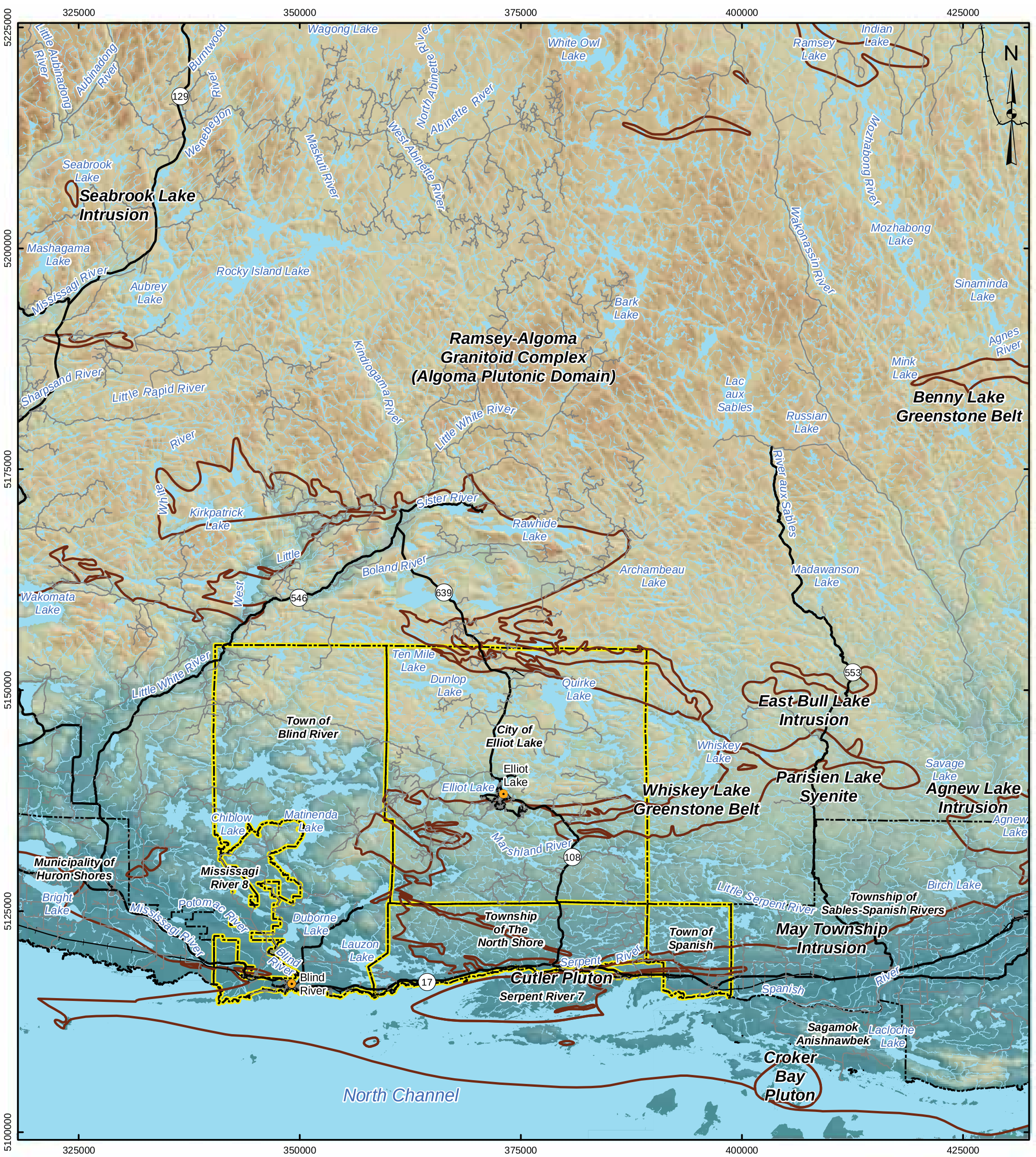
TITLE

Satellite Imagery of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 2.1	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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

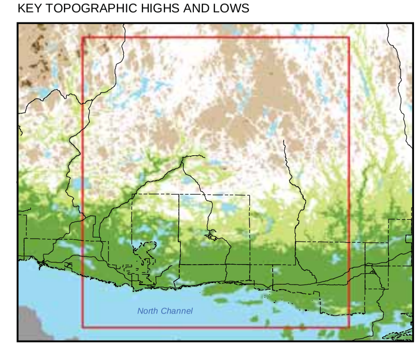


LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Major Geological Contact

Elevation (masl)
High : 612
Low : 176

KEY TOPOGRAPHIC HIGHS AND LOWS



Elevation (m)
176 - 320 | 321 - 395 | 396 - 460 | 461 - 550 | 551 - 654

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geological Contact - Modified 1:250 000 Scale MRD126-Bedrock Geology
Digital Elevation Model - CDED slope raster: Geobase.ca (1:50,000)
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

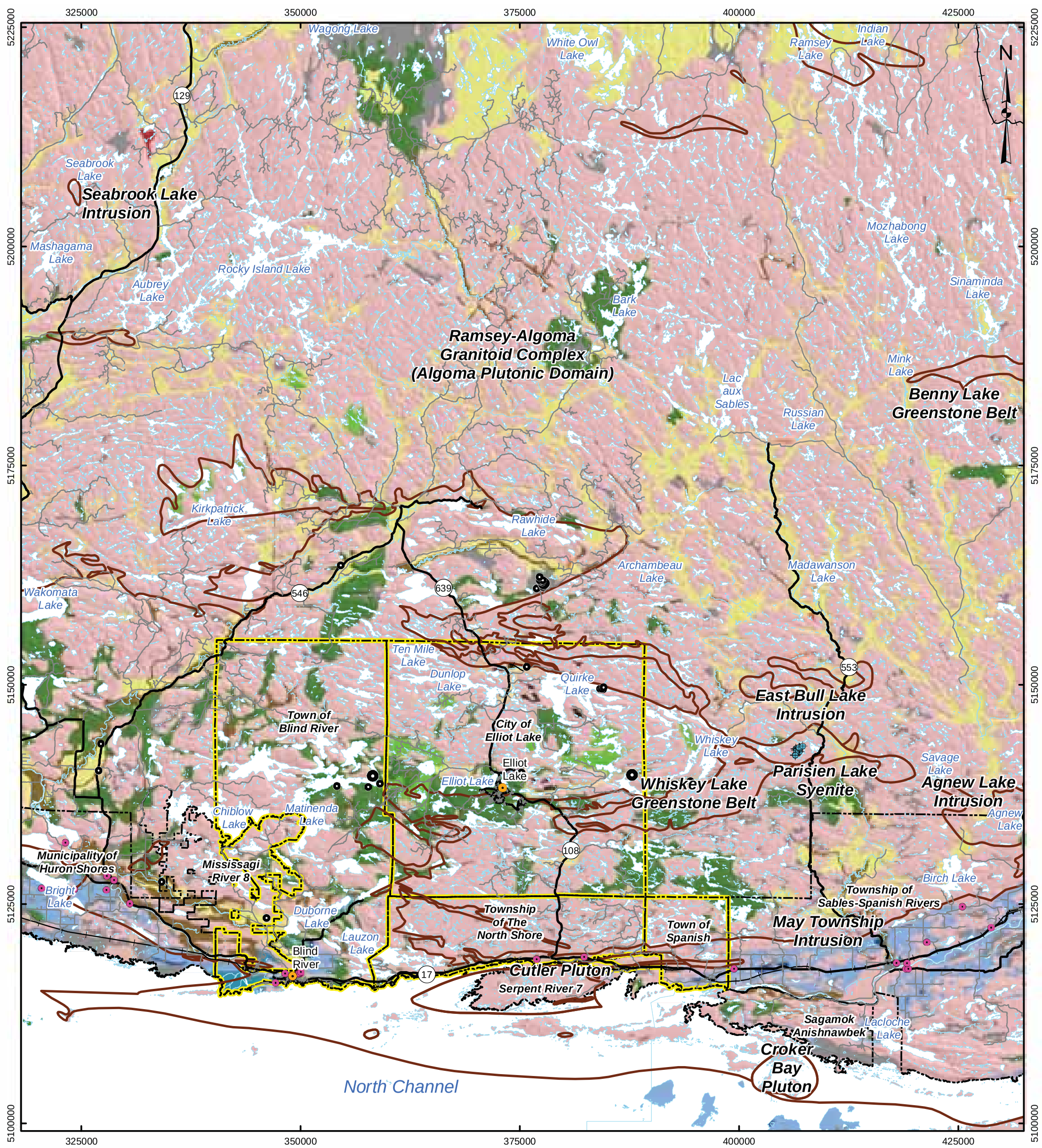
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Elevation and Major Topographic Features of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013		
GIS	PM/JB	26 Jun. 2014	FIGURE: 2.2	
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community

Drillhole

- 40 - 80 m
- > 80 m
- East Bull Lake Drill Hole

Water well

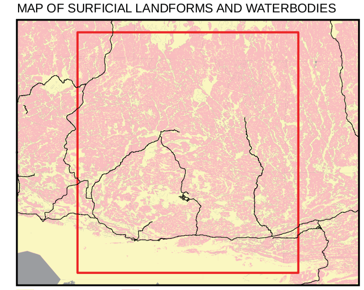
Depth to bedrock

- > 30 m
- Main Road
- Local Road
- Railway
- Waterbody
- Major Geological Contact

Landform

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

MAP OF SURFICIAL LANDFORMS AND WATERBODIES



- Surficial/water
- Bedrock terrain

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Landform- OGS, MND Mines, and Northeast Science and Information Section, MNR 2005
Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160.
Geological Contact - MRD126-Bedrock Geology of Ontario, 2011
East Bull Lake Drill Holes - Raven et al. 1987, Hydrogeological Characterization of the East Bull Lake Research Area.
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 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

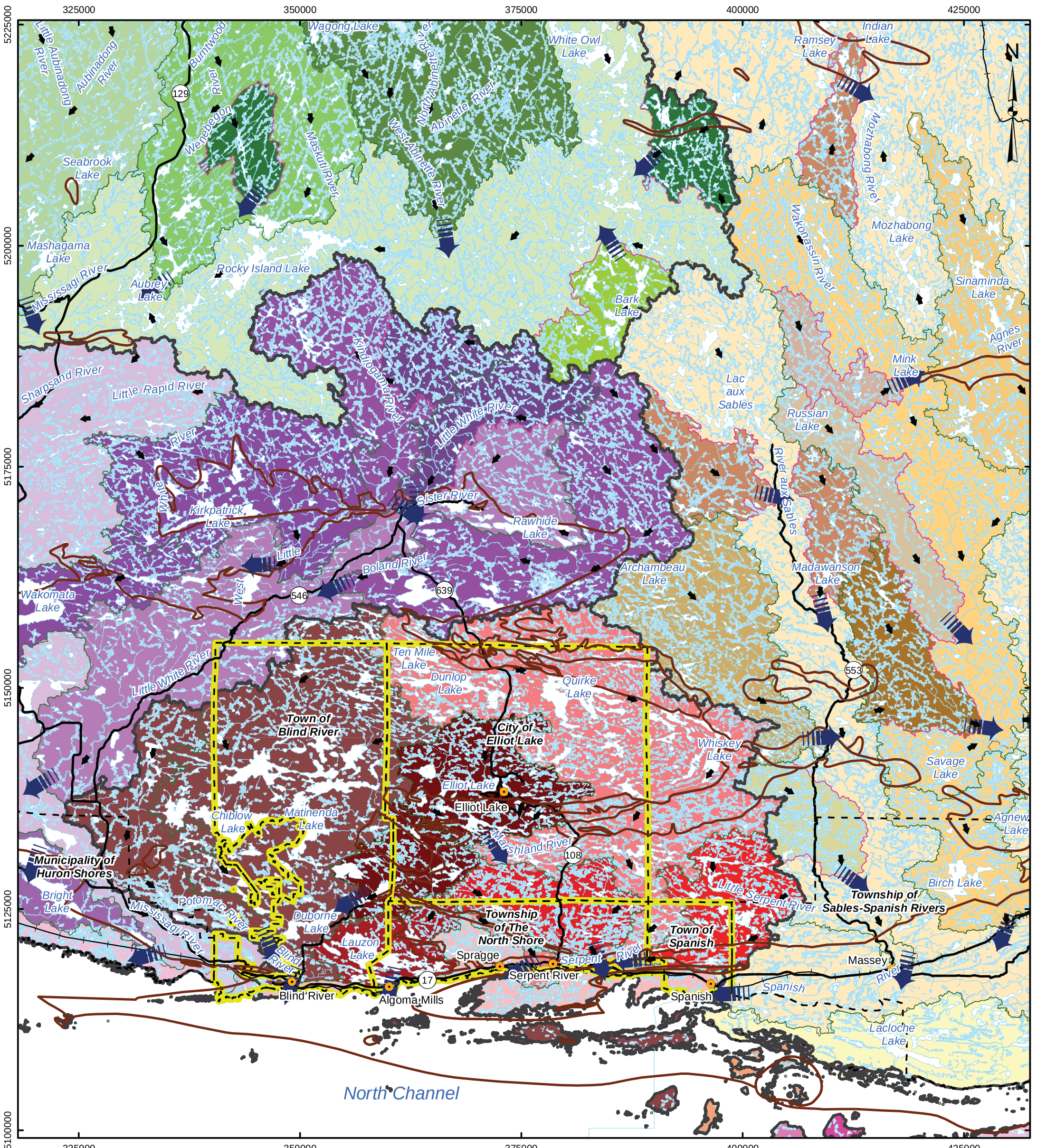
TITLE

Terrain Features of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 2.3	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



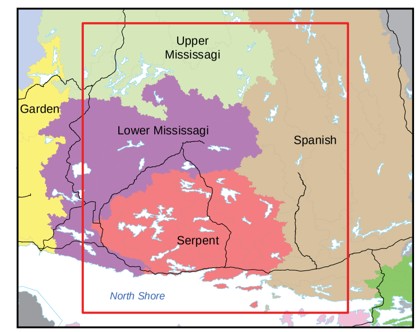
LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Railway
- Major Geological Contact
- Surface Water Flow Direction
- Watershed Outflow Point

Drainage Divide

- Delineated by JDMA
- Delineated by MNR
- Tertiary Watershed
- Watercourse
- Waterbody
- Wetland

TERTIARY WATERSHEDS



REFERENCE

Base Data - MNR LIO, obtained 2009-2013

Drainage Divides - Terrain and remote sensing study - City of Elliot Lake, the Town of Blind River, the Town of Spanish and the Township of North Shore, Ontario (JDMA, 2013)

Geological Contact - Modified 1:250 000 Scale MRD126-Bedrock Geology

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 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

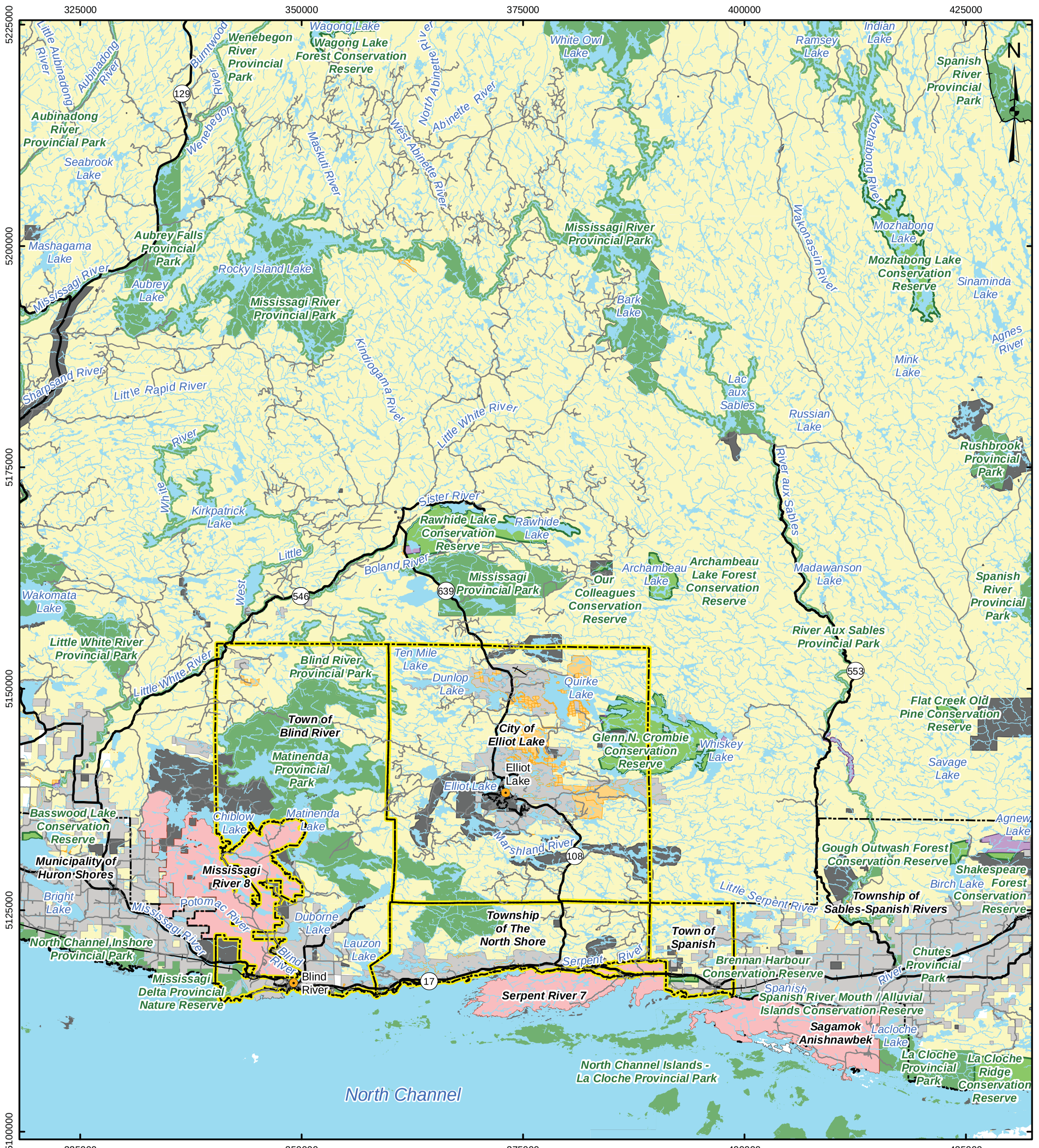
TITLE

Drainage Features of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.0
DESIGN	PRM	29 Mar. 2012	FIGURE: 2.4	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Forest Reserve
- Conservation Reserve
- Provincial Park
- Crown Leased Land
- Crown Land - Non-Freehold Dispositions Public
- Crown Land - Unpatented Public Land
- Crown Reserves
- Private Land
- Federal Land - Indian Reserve

INDEX MAP

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Crown Reserves - Ministry of Northern Mines and Development (April 4, 2013)
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 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Land Disposition and Ownership within the Communities of Elliot Lake, Blind River, The North Shore and Spanish Area

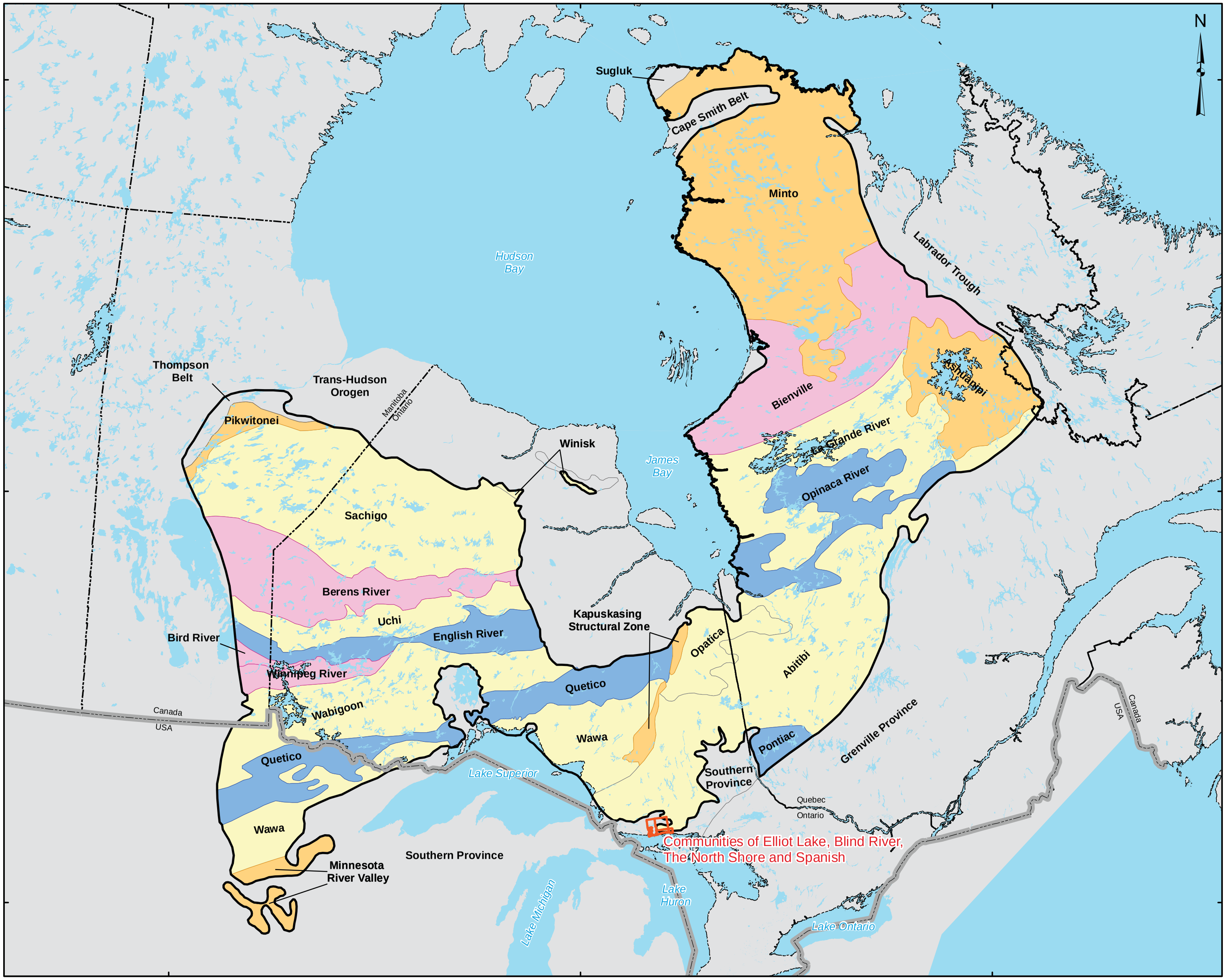
Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245		
DESIGN	PRM	13 Mar. 2013
GIS	PM/JB	26 Jun. 2014
CHECK	PMcC	26 Jun. 2014
REVIEW	GWS	26 Jun. 2014

SCALE AS SHOWN | REV. 0.0

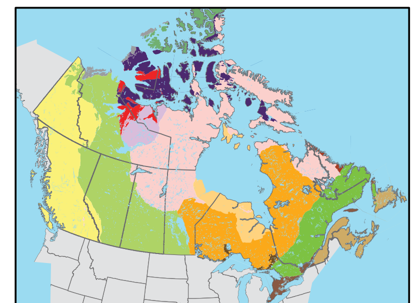
FIGURE: 2.5

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Provincial Boundary
- International Boundary
- Limit of Exposed Archean Rock
- Sub-Province Gneissic - Plutonic
- Sub-Province Plutonic
- Sub-Province Metasedimentary
- Sub-Province Volcanic-Plutonic



Geological Regions of Canada

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

REFERENCE

Base Data - MNR LIO, obtained 2009-2012, CANMAP v2006.4
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 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 15

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

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP
PRELIMINARY ASSESSMENT

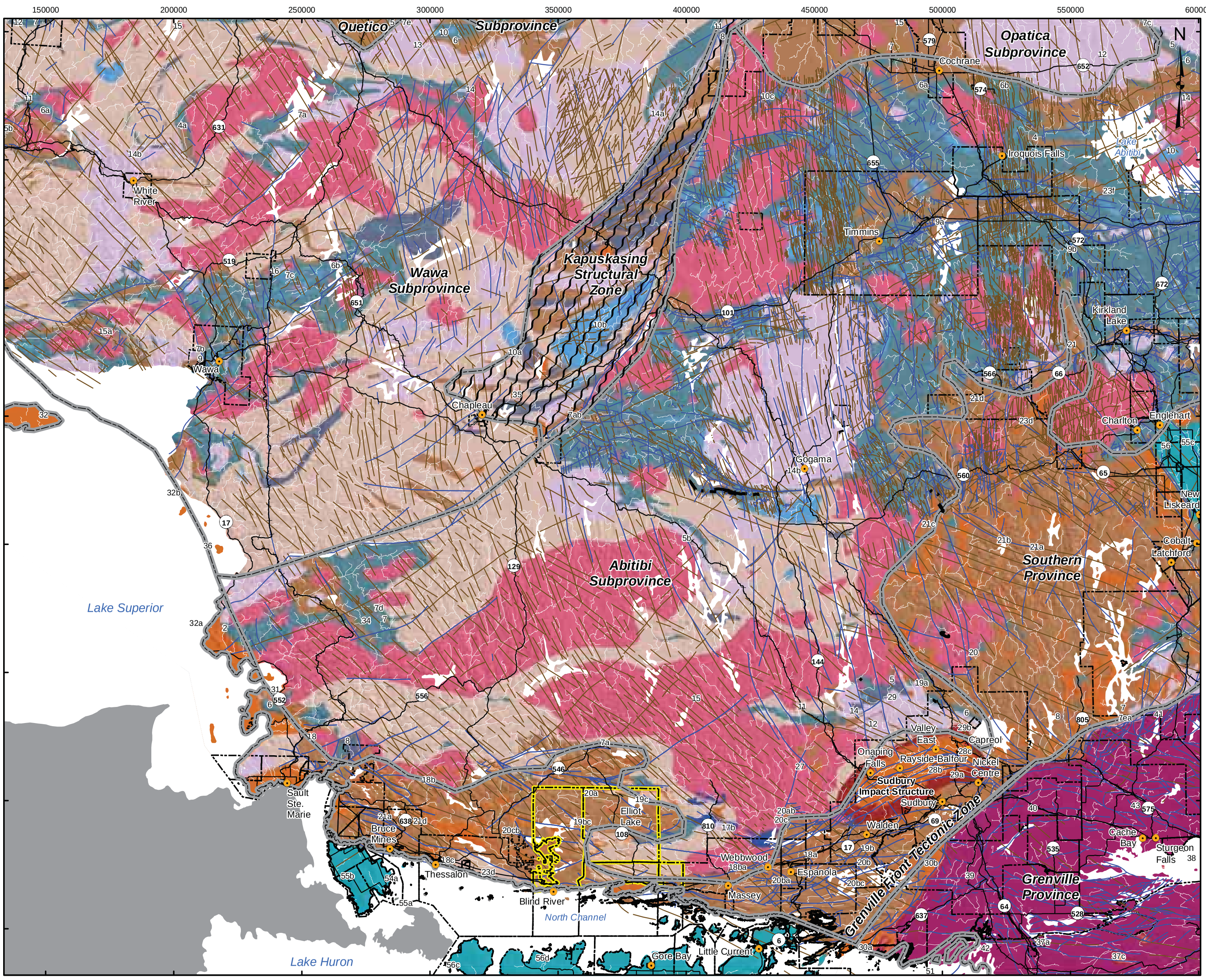
TITLE

Subdivision of the Superior Province of the Canadian Shield

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 1.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.1	
GIS	PM/JB	3 Jul. 2014		
CHECK	CM	3 Jul. 2014		
REVIEW	GWS	3 Jul. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Railway
- Waterbody/Watercourse
- Mapped Fault
- Mapped Dyke
- Kapuskasing Structural Zone
- Iron Formation
- Subprovince Boundary

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (56, 55, 54)

Proterozoic

- Various rock units of the Grenville Province (51, 43, 42, 41, 40, 39)

Southern Province

- Various rock units of the Southern Province (38, 37, 36, 35, 34, 32, 31, 30, 28, 27, 23, 22)
- Sudbury Igneous Complex (29)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Archean granitoid suites (16, 14, 13, 12)
- Massive granodiorite to granite (15)
- Gneissic tonalite suite (11)
- Mafic and ultramafic rocks (10)
- Metasedimentary rocks (9, 7)
- Migmatized supracrustal rocks (8)
- Metavolcanic rocks (6, 5, 4, 2)

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster; Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

25 12.5 0 25 50 75
SCALE 1:1,500,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

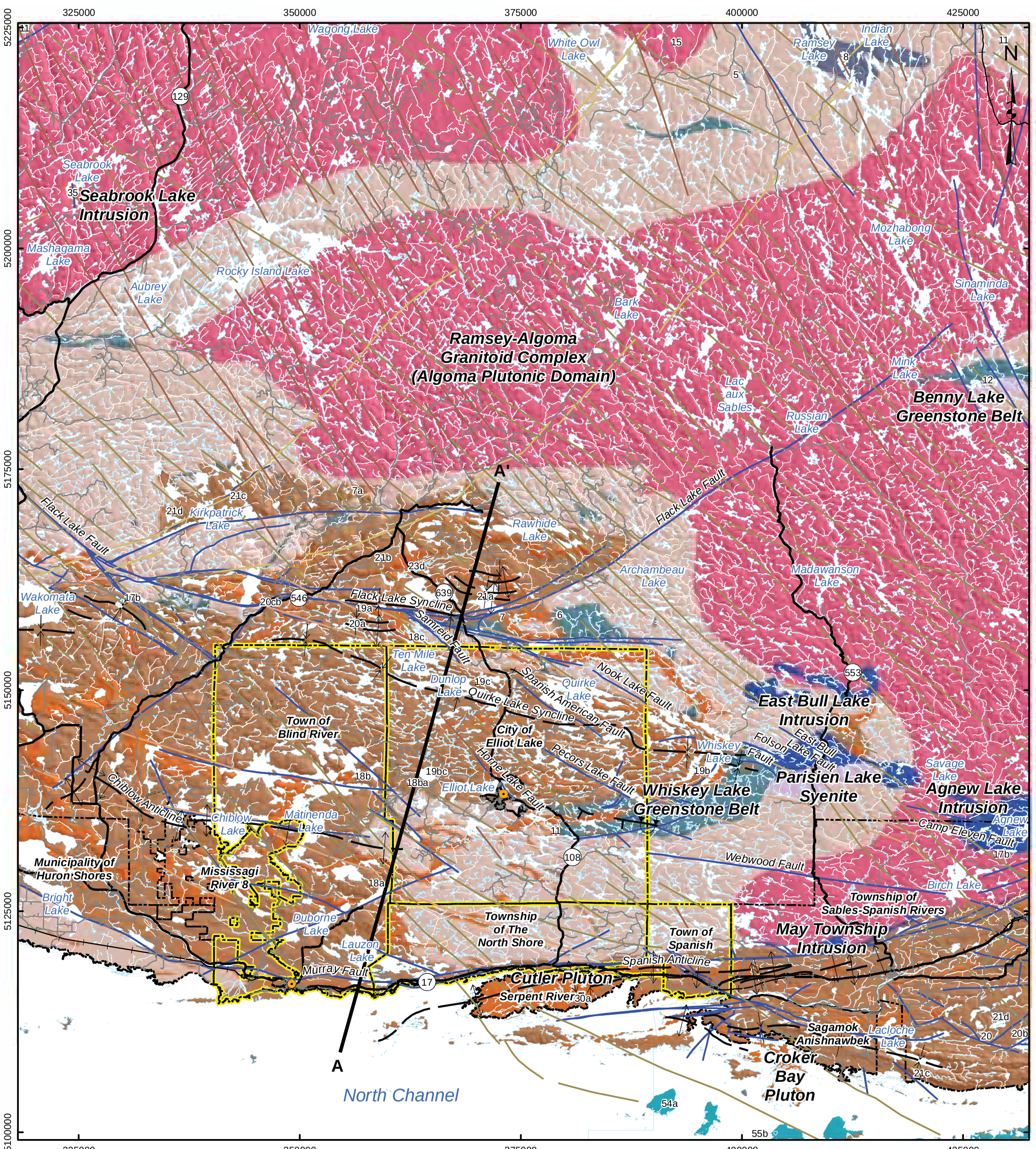
Regional Geology of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245		SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	
GIS	PM/JB	26 Jun. 2014	
CHECK	PMcC	26 Jun. 2014	
REVIEW	GWS	26 Jun. 2014	

FIGURE: 3.2

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse
- Major Fold (syncline)
- Major Fold (anticline)
- Synform with inclined axial plane
- Mapped Fault
- Regional Cross Section of the Southern Province

Mapped Dyke

- Biscotasing Mafic Dyke
- Matachewan Mafic Dyke
- North Channel Mafic Dyke
- Sudbury Mafic Dyke
- Unsubdivided Mafic Dyke

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011, Johns, G.W., et al. 2003.
Precambrian geology compilation map—Sault Ste. Marie–Blind River sheet; OGS, Map 2670.
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 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

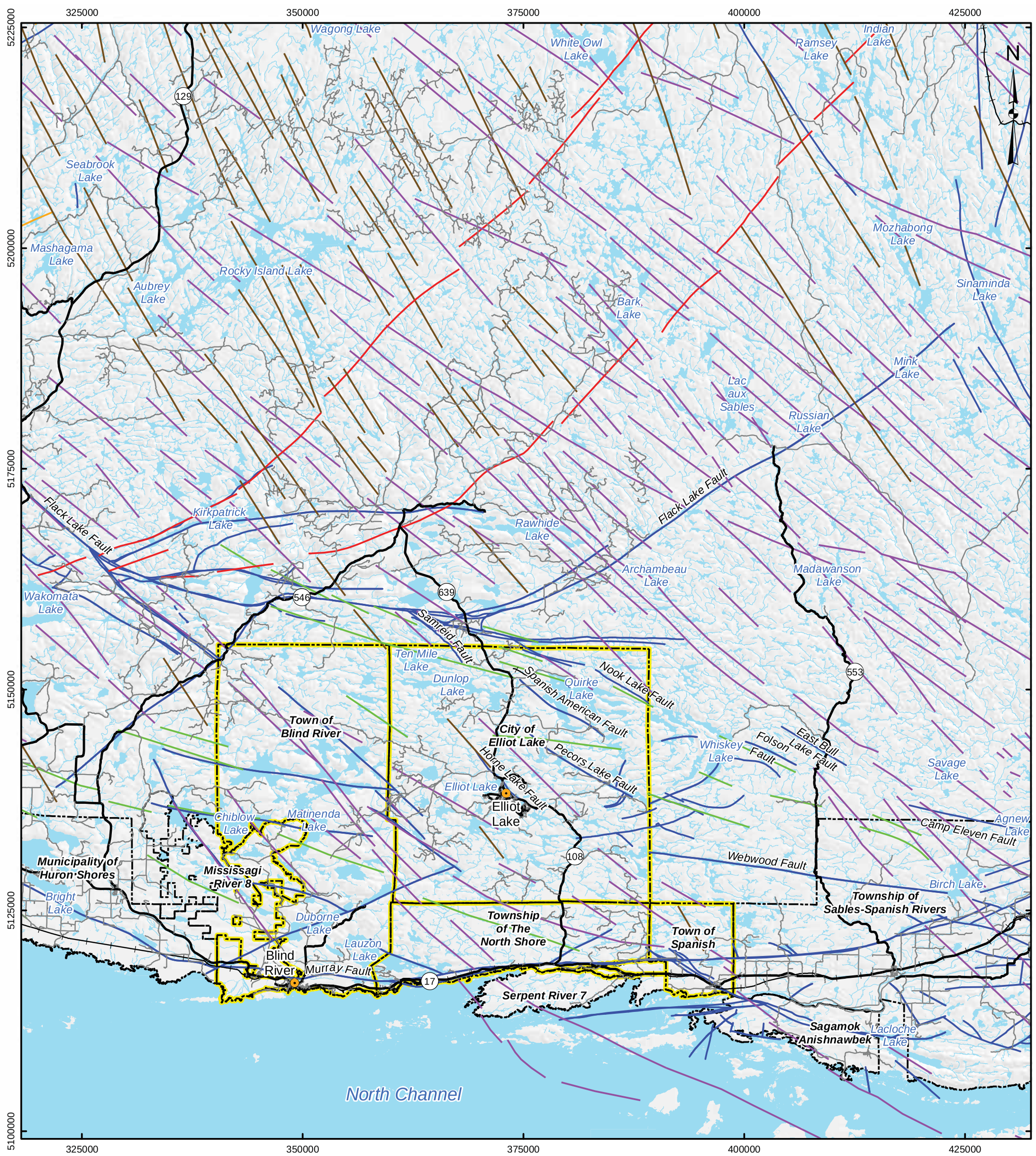
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Local Bedrock Geology of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.3	
GIS	PMJB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault

Mapped Dyke

- Unsubdivided Mafic Dyke
- Sudbury Mafic Dyke
- North Channel Mafic Dyke
- Biscotasing Mafic Dyke
- Matachewan Mafic Dyke

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Digital Elevation Model - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

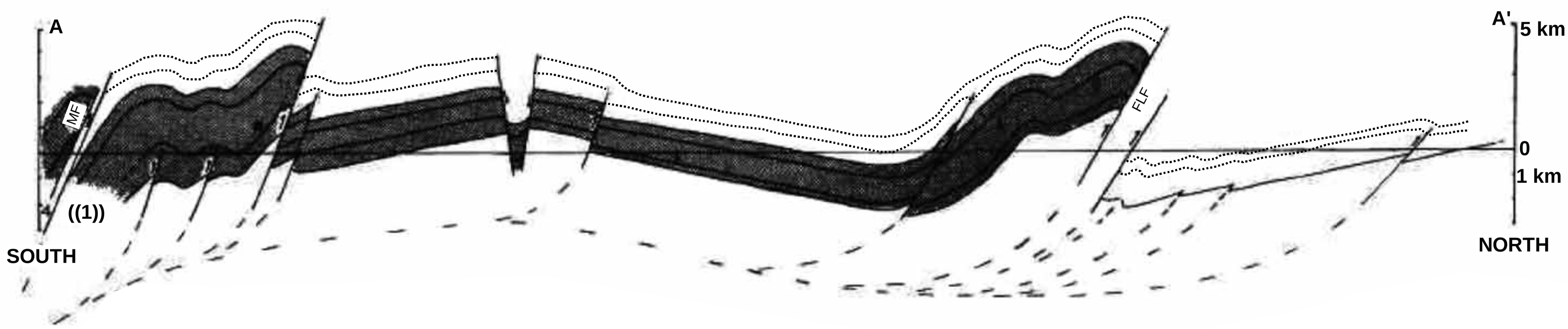
TITLE

Dyke Swarms in the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.4	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

C - Cobalt Group

pC - pre-Cobalt Groups

As - Archean basement (Superior Province)

FLF - Flack Lake Fault

MF - Murray Fault

NOTE

For details on location of Cross-Section A-A' see Figure 3.3.

Scale Approximate

REFERENCE

Regional Cross Section of the Southern Province adjacent to Lake Huron, Ontario: Implications for the tectonic significance of the Murray Fault Zone, Zolnai et al., 1984.

HORIZONTAL SCALE (APPROX.)

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

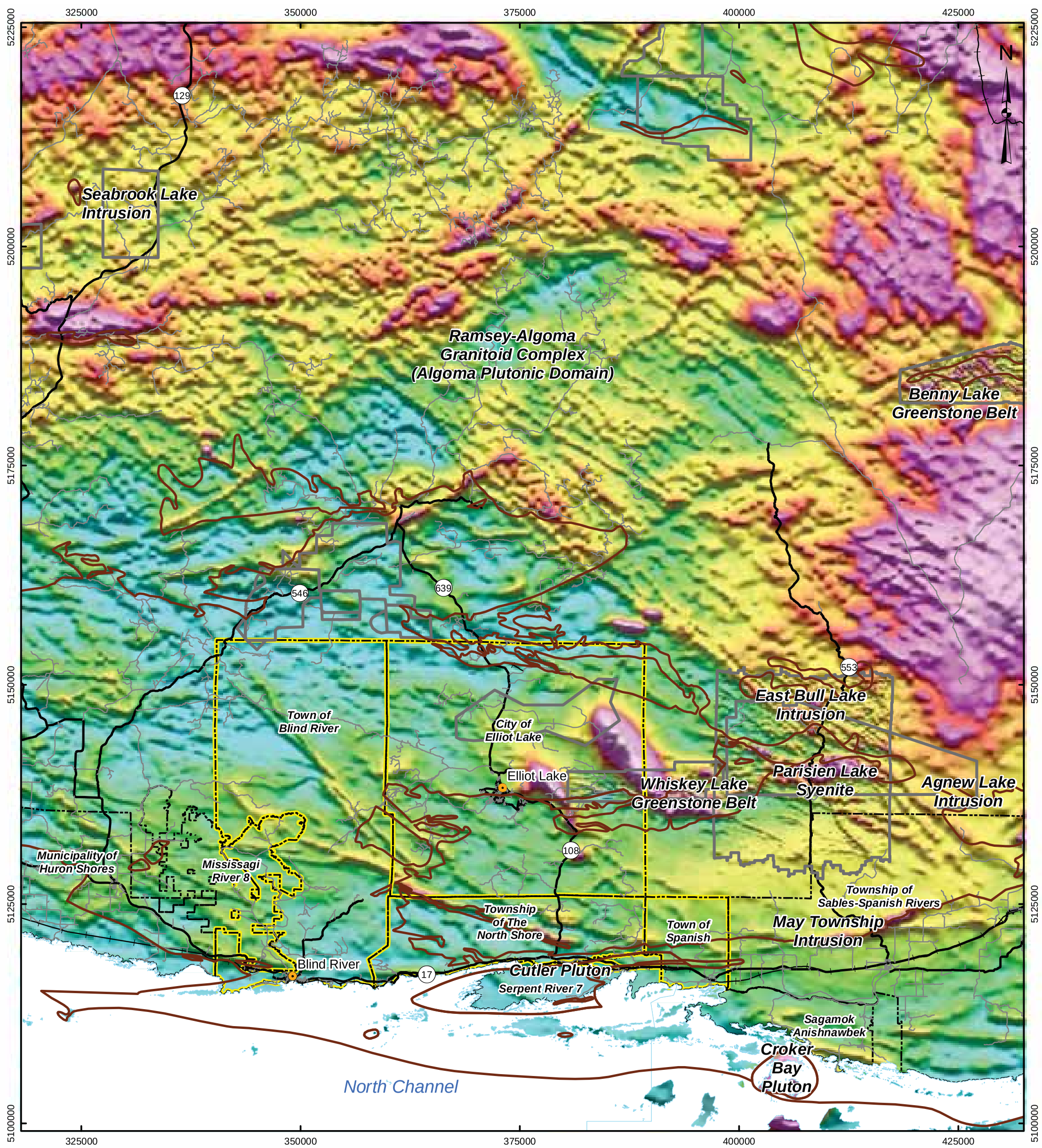
Regional Cross Section of the Southern Province adjacent to Lake Huron

Golder Associates

Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	27 Jun. 2013	FIGURE: 3.5	
GIS	PMJB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Major Geological Contact
- Higher Resolution Geophysical Surveys

Total Magnetic Field (Reduced to Pole) (nT)

3009, 550, 370, 280, 230, 180, 160, 140, 120, 110, 90, 80, 60, 40, 30, 10, 0, -20, -40, -60, -70, -90, -110, -130, -150, -180, -230, -300, -522

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys: Ontario #4, #13, #16, #17, East Bull Lake (RA-7) (2013)
Ontario Geological Survey - Geophysical Surveys: GDS1017 (2003), GDS1236 (2011)
Geological Contact - 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 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

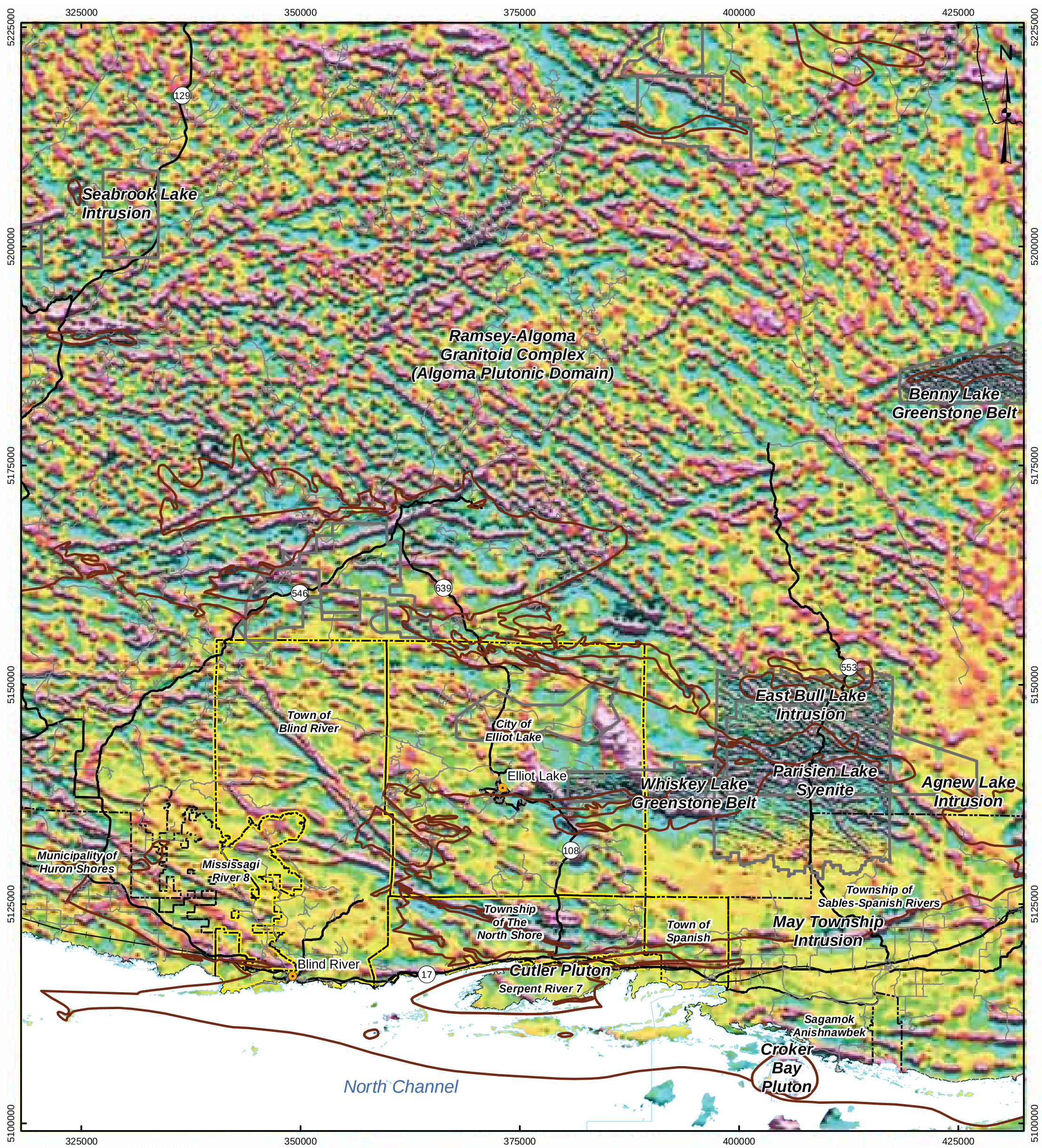
TITLE

Total Magnetic Field (Reduced to Pole) of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.6	
GIS	PM/JB	26 Jun. 2014		
CHECK	CM	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Major Geological Contact
- Higher Resolution Geophysical Surveys

1st Vertical Derivative of the Magnetic Field (Reduced to Pole) (nT/m)

20.483
0.220
0.145
0.105
0.080
0.065
0.050
0.040
0.030
0.020
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.050
-0.055
-0.065
-0.075
-0.090
-0.105
-0.130
-0.180
-7.102

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada - Aeromagnetic Surveys: Ontario #4, #13, #16, #17, East Bull Lake (RA-7) (2013)
Ontario Geological Survey - Geophysical Surveys: GDS1017 (2003), GDS1236 (2011)
Geological Contact - 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 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

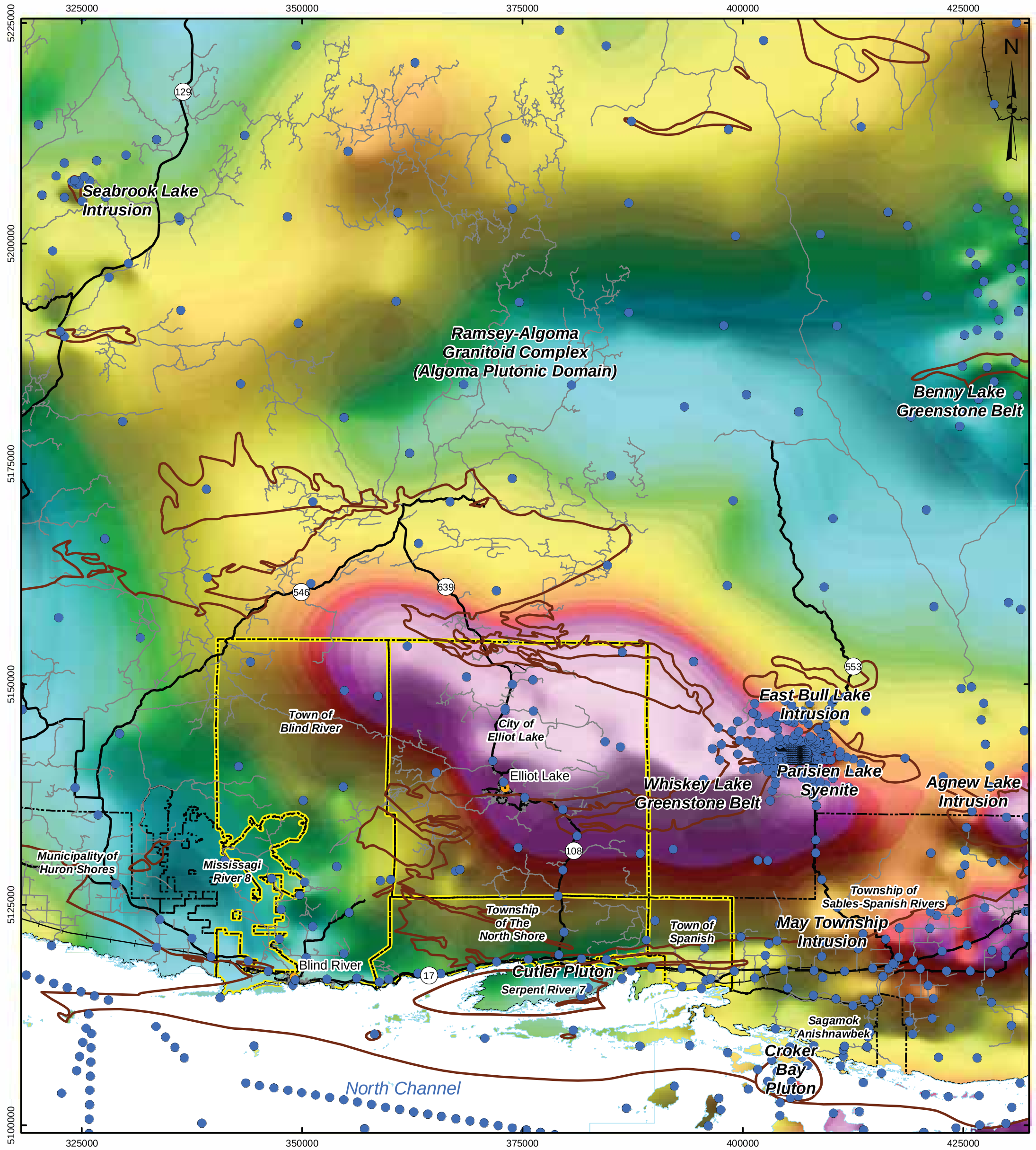
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
First Vertical Derivative of the Magnetic Field (Reduced to Pole) of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.7	
GIS	PM/JB	26 Jun. 2014		
CHECK	CM	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\ELNOS\Draft_Integrated_Report\1stVerticalDerivativeMagneticFieldELNOS.mxd



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody
- Gravity Station
- Major Geological Contact

Bouguer Gravity (mGal)

-16.8
-30.5
-34.0
-36.0
-37.5
-39.0
-40.5
-41.5
-43.0
-44.0
-45.0
-46.0
-47.0
-48.0
-49.0
-50.0
-50.5
-51.5
-52.5
-53.5
-54.0
-55.0
-56.0
-57.0
-58.5
-59.5
-61.0
-62.5
-65.5
-75.9

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geophysics - Geological Survey of Canada Nationwide Gravity Compilation (2013)
Geological Contact - 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 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

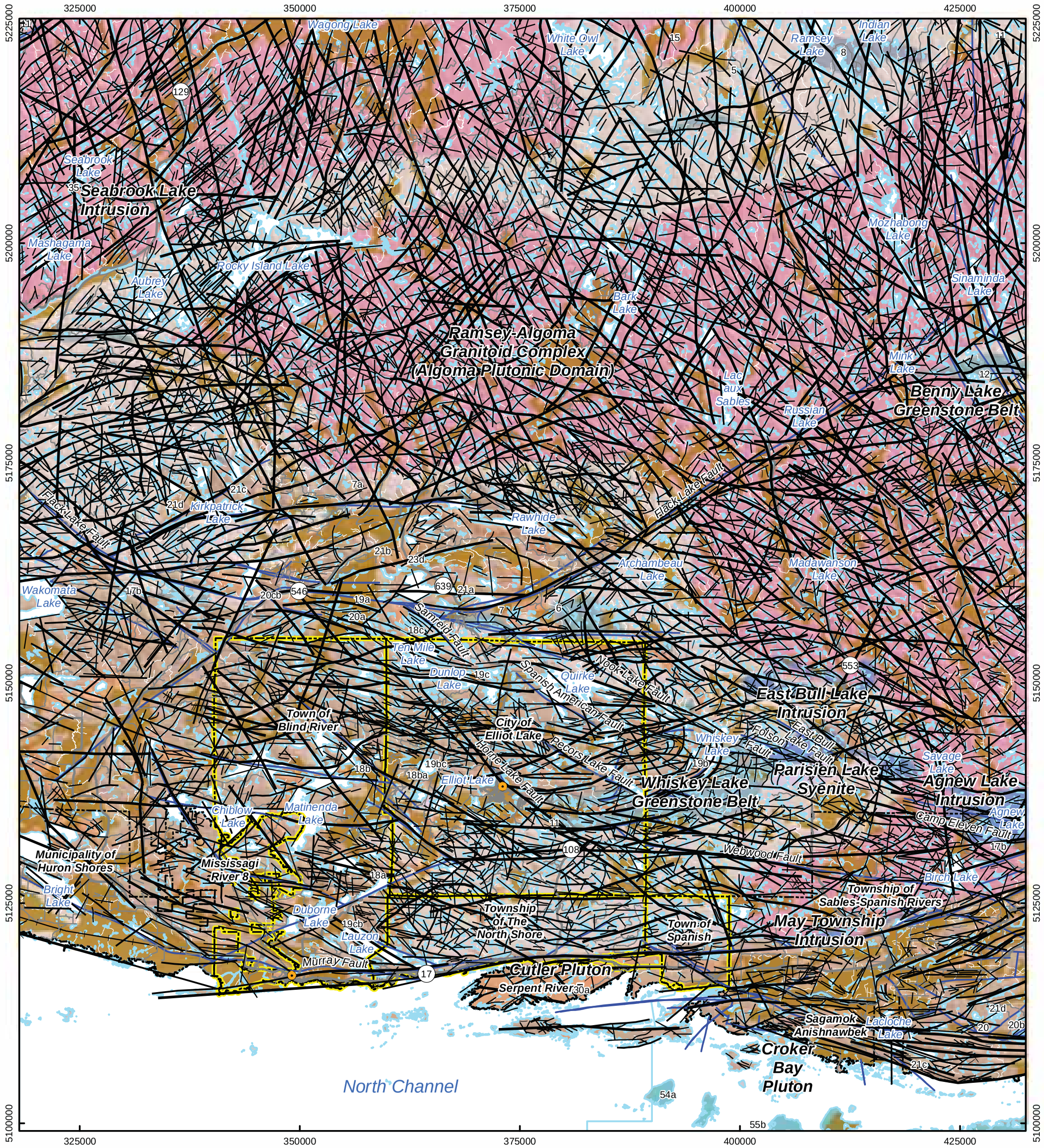
TITLE

Bouguer Gravity of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.8	
GIS	PM/JB	26 Jun. 2014		
CHECK	CM	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse
- Mapped Fault
- Overburden Cover

Surficial Lineament (SPOT and CDED)

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

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

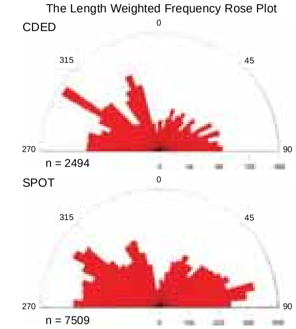
- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

The Length Weighted Frequency Rose Plot



REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Lineaments - Lineament interpretation - City of Elliot Lake, The Town of Blind River, The Town of Spanish and the Township of North Shore (JDMA, 2013)
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR 2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

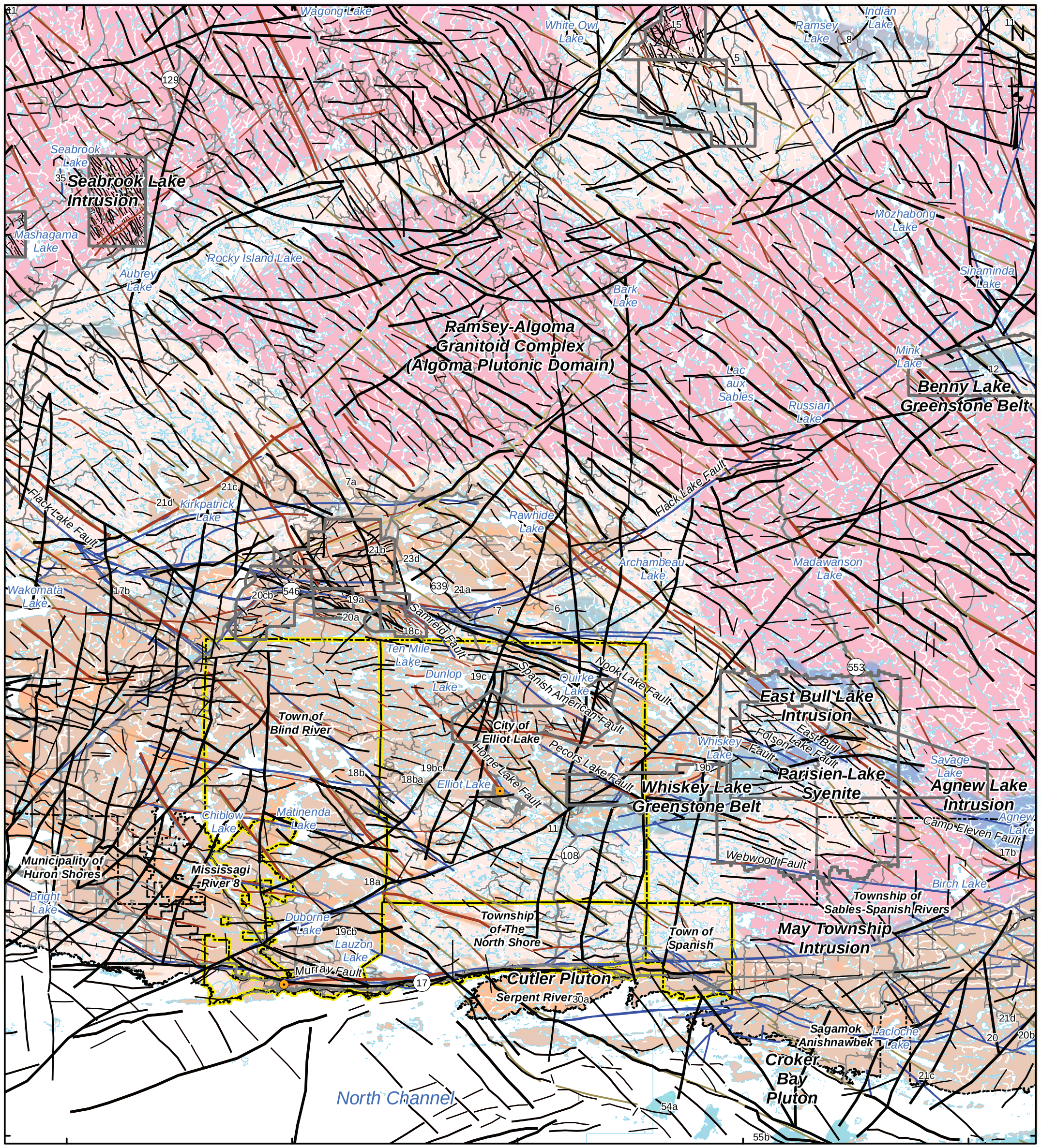
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Surficial Lineaments of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.9	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse
- Mapped Fault

Brittle Lineament

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

Dyke Lineament

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

Mapped Dyke

- Biscotasing Mafic Dyke
- Matachewan Mafic Dyke
- North Channel Mafic Dyke
- Sudbury Mafic Dyke
- Unsubdivided Mafic Dyke
- Higher Resolution Geophysical Surveys

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

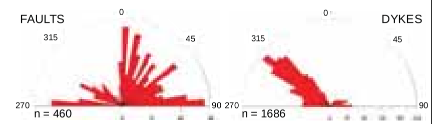
- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

The Length Weighted Frequency Rose Plot



REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Lineaments - Lineament interpretation - City of Elliot Lake, The Town of Blind River, The Town of Spanish and the Township of North Shore (JDMA, 2013)
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 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Geophysical Lineaments of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

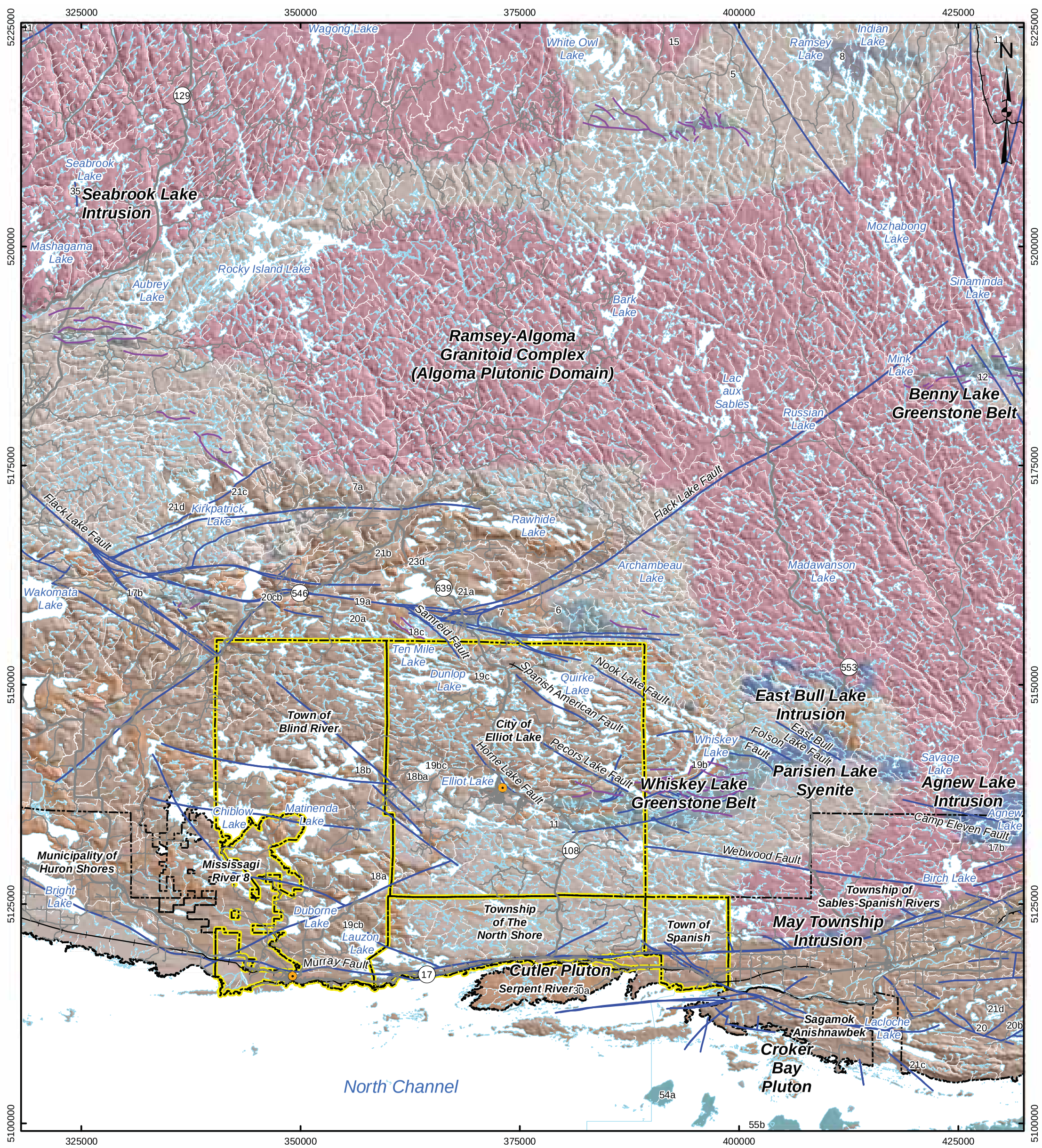
Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245		
DESIGN	PRM	13 Mar. 2013
GIS	PM/JB	26 Jun. 2014
CHECK	PMcC	26 Jun. 2014
REVIEW	GWS	26 Jun. 2014

SCALE AS SHOWN | REV. 0.0

FIGURE: 3.10

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse
- Mapped Fault
- Ductile Lineament

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Ductile Lineaments - Processing and Interpretation of Geophysical Data - Communities of Elliot Lake, Blind River, North Shore and Spanish and Surrounding Area (PGW, 2013)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Ductile Lineaments of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

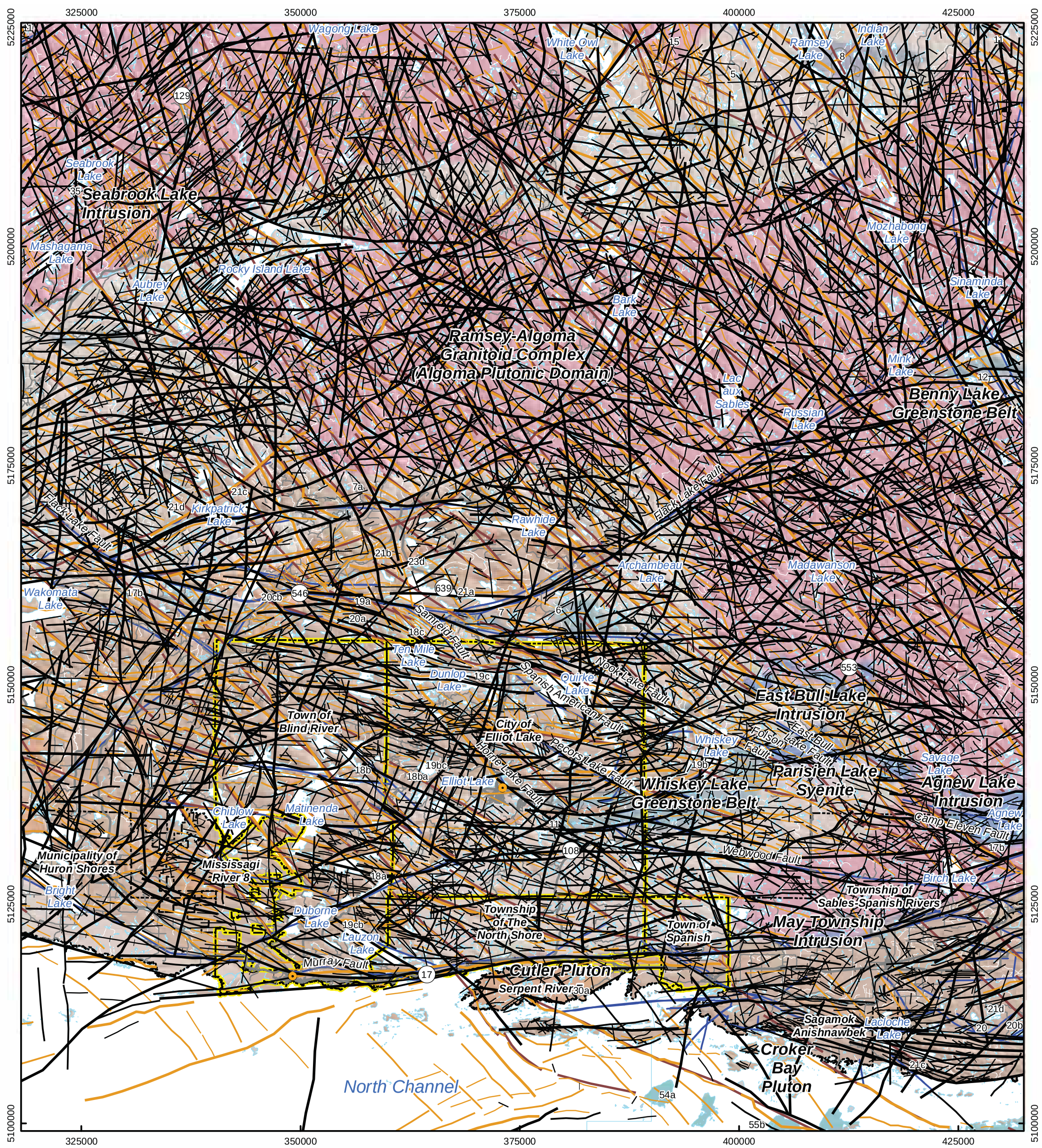
Golder Associates
Mississauga, Ontario

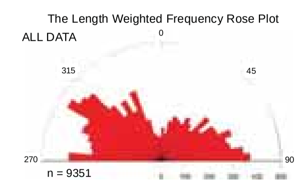
PROJECT NO. 12-1152-0245		
DESIGN	PRM	13 Mar. 2013
GIS	PM/JB	26 Jun. 2014
CHECK	PMcC	26 Jun. 2014
REVIEW	GWS	26 Jun. 2014

SCALE AS SHOWN REV. 0.0

FIGURE: 3.11

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





LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse
- Mapped Fault
- Mapped Dyke

Brittle Lineaments (Surficial and Geophysical)

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

Interpreted Dykes

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

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Lineaments - Lineament interpretation - City of Elliot Lake, The Town of Blind River, The Town of Spanish and the Township of North Shore (JDMA, 2013)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

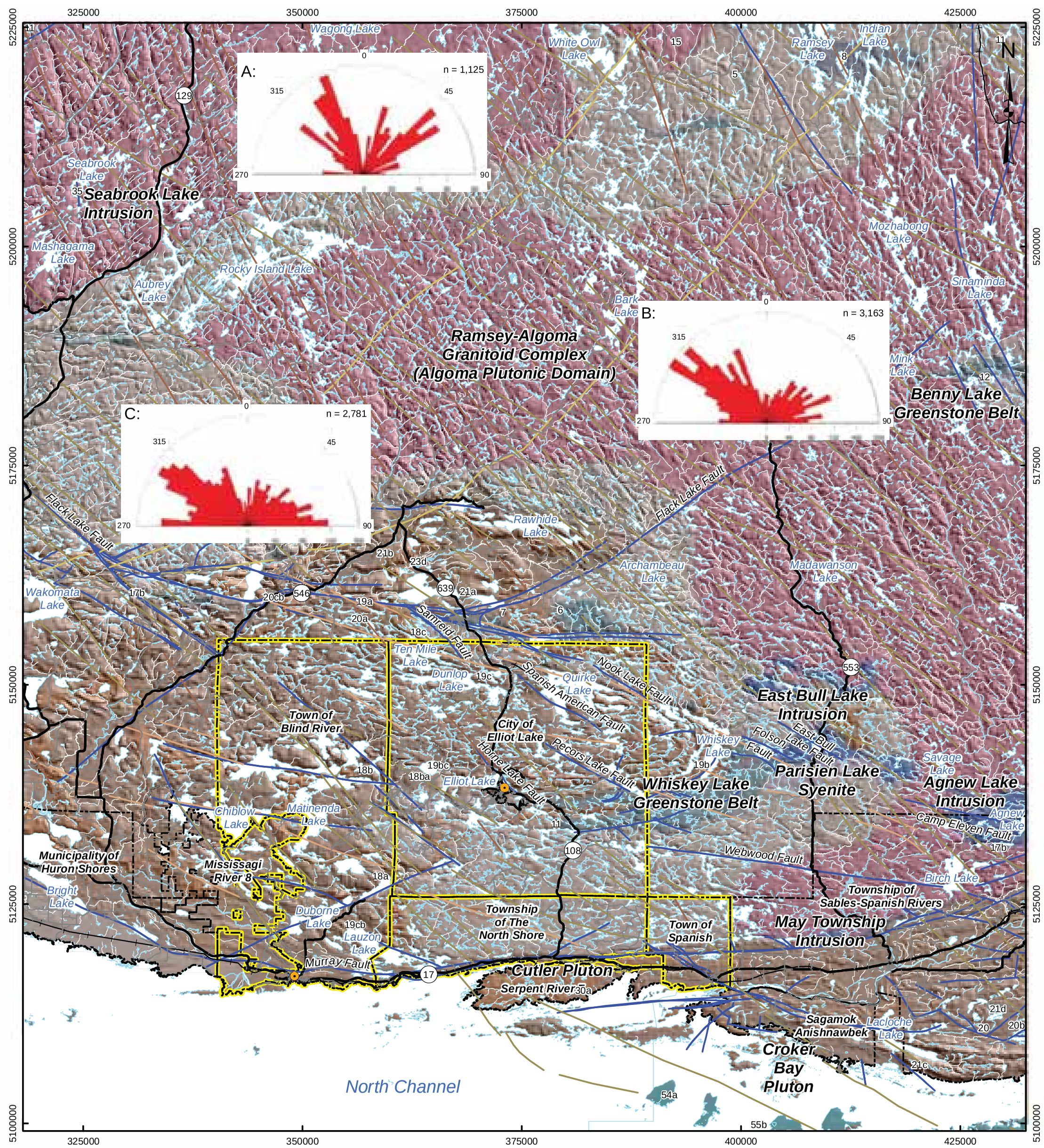
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Merged Lineaments of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.12	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse
- Mapped Fault

Mapped Dyke

- Biscotasing Mafic Dyke
- Matachewan Mafic Dyke
- North Channel Mafic Dyke
- Sudbury Mafic Dyke
- Unsubdivided Mafic Dyke

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster; Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Produced by Golder Associates Ltd under licence from
Ontario Ministry of Natural Resources, © Queens Printer 2012
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

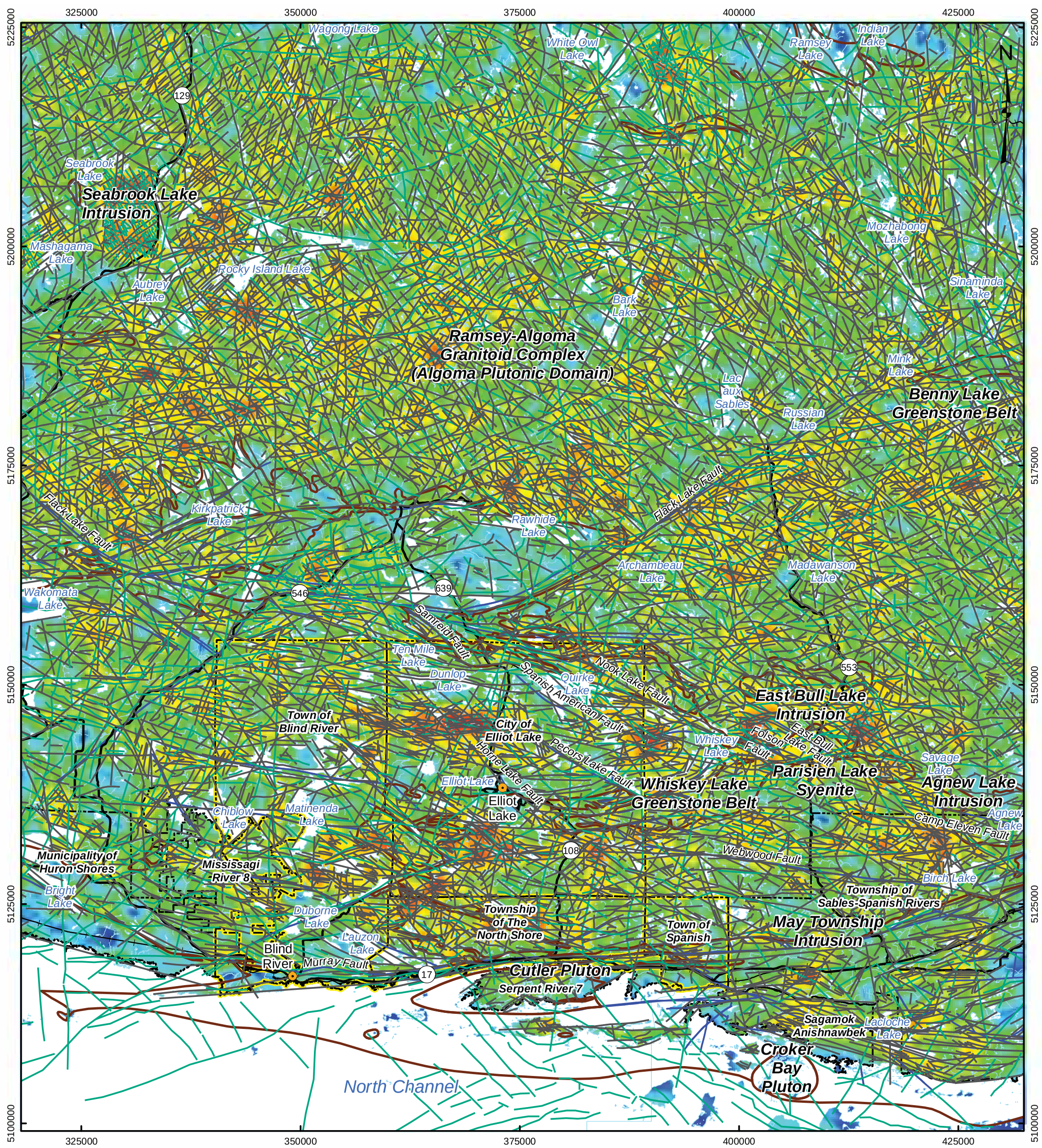
TITLE
Lineament Orientations of Principal Geological Units of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates, Mississauga, Ontario

PROJECT NO. 12-1152-0245		
DESIGN	PRM	13 Mar. 2013
GIS	PM/JB	26 Jun. 2014
CHECK	PMcC	26 Jun. 2014
REVIEW	GWS	26 Jun. 2014

SCALE AS SHOWN REV. 0.0

FIGURE: 3.13



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Surficial Lineament
- Geophysical Lineament
- Major Geological Contact

Lineament Density (km/km²)
High : 6.5
Low : 0

INDEX MAP

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geological Contact - MRD126-Bedrock Geology of Ontario, 2011
Lineaments - Lineament interpretation - City of Elliot Lake, The Town of Blind River, The Town of Spanish and the Township of North Shore (JDMA, 2013)
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 17N

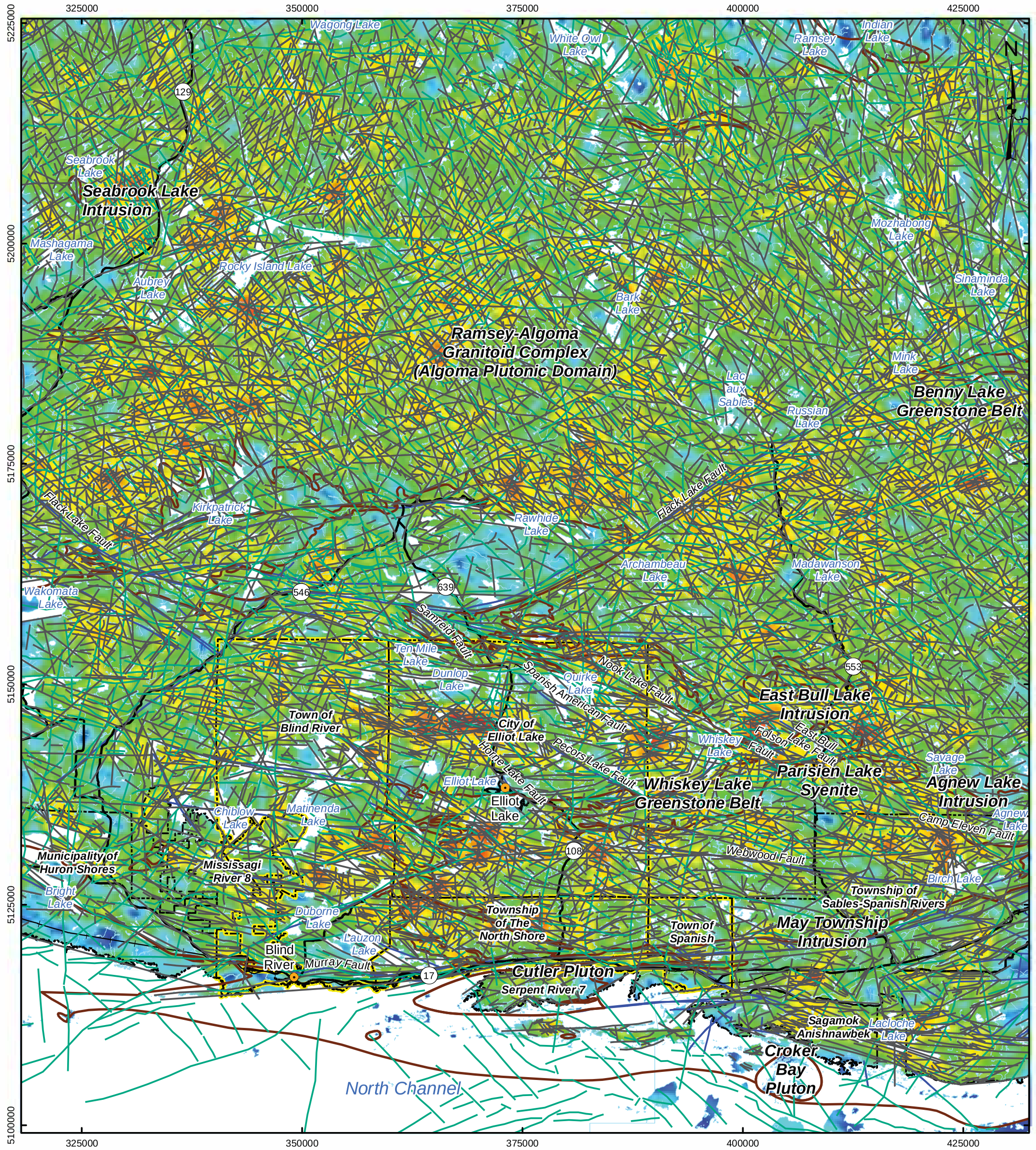
10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Brittle Lineament Density Calculated for Lineaments in the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.14	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Surficial Lineament (> 1km)
- Geophysical Lineament (> 1km)
- Major Geological Contact

Lineament Density (km/km^2)

High : 6.5

Low : 0

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geological Contact - MRD126-Bedrock Geology of Ontario, 2011
Lineaments - Lineament interpretation - City of Elliot Lake, The Town of Blind River, The Town of Spanish and the Township of North Shore (JDMA, 2013)
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 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

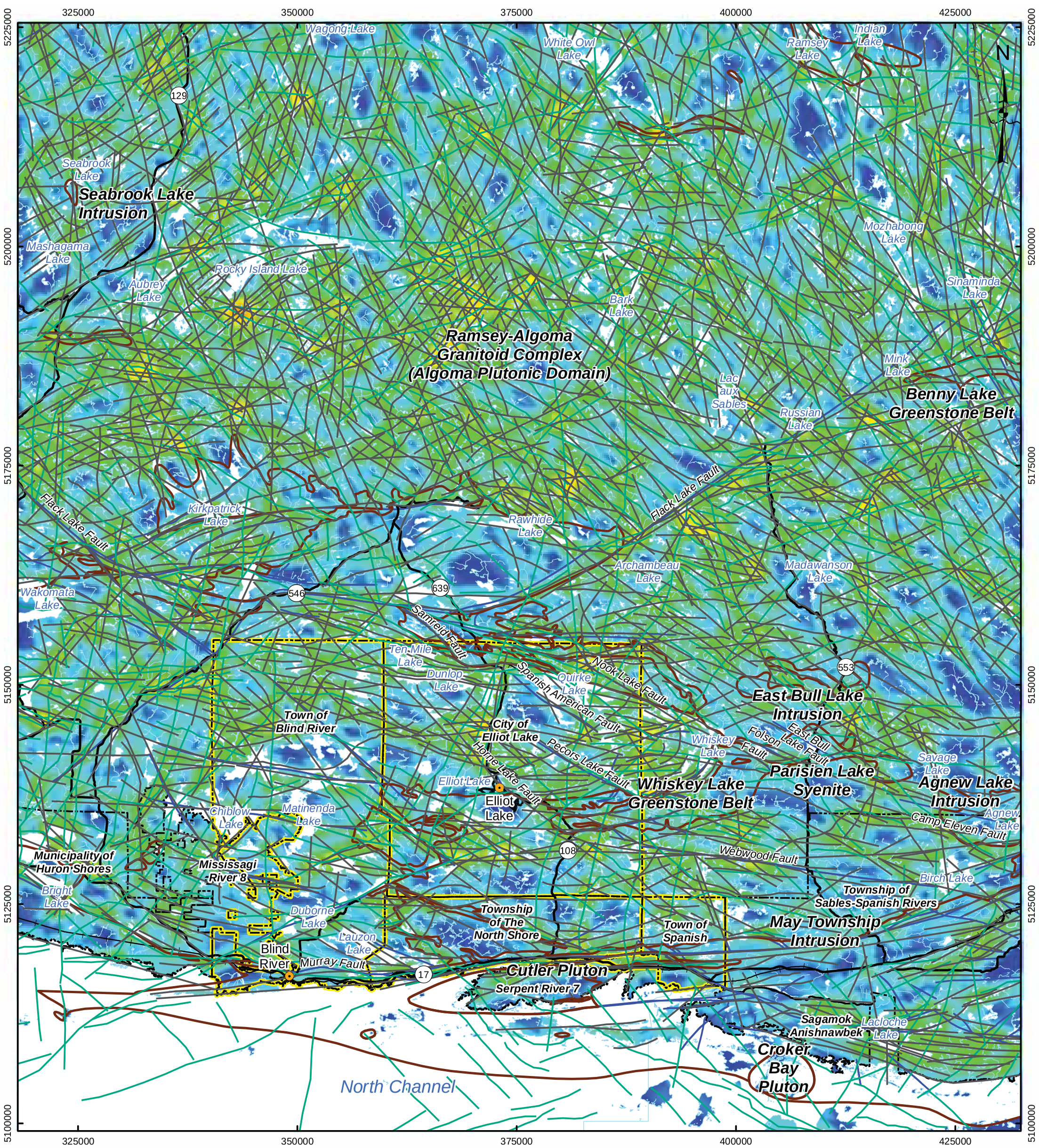
TITLE

Brittle Lineament Density Calculated for Lineaments (>1 km) in the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.15	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\ELNOS\Draft_Integrated_Report\LineamentsDensityGreater1kmELNOSArea.mxd



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Surficial Lineament (> 5 km)
- Geophysical Lineament (> 5 km)
- Major Geological Contact

Lineament Density (km/km²)

High : 6.5

Low : 0

INDEX MAP

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geological Contact - MRD126-Bedrock Geology of Ontario, 2011
Lineaments - Lineament interpretation - City of Elliot Lake, The Town of Blind River, The Town of Spanish and the Township of North Shore (JDMA, 2013)
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 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

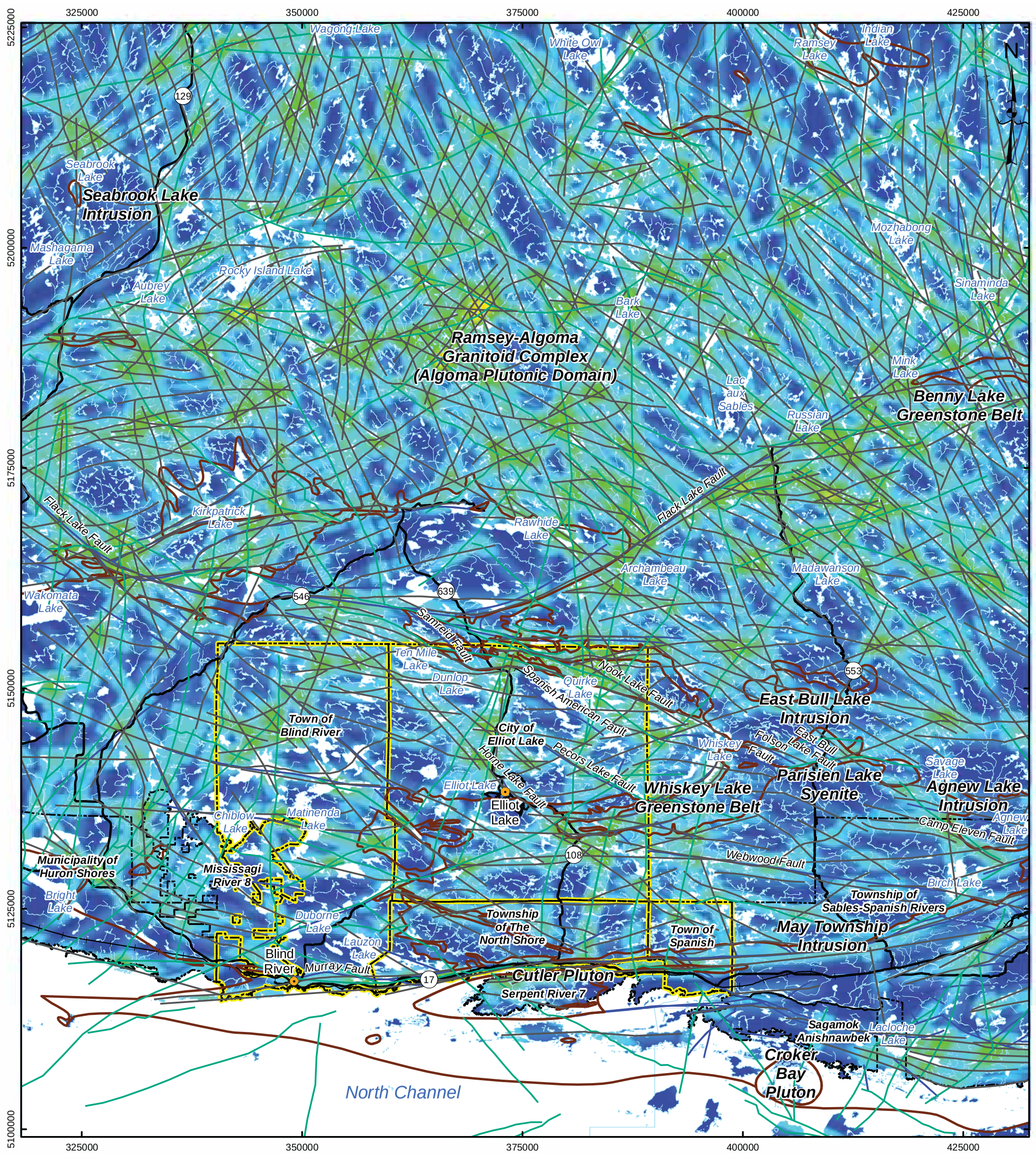
TITLE

Brittle Lineament Density Calculated for Lineaments (>5 km) in the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.16	
GIS	PMJB	25 Jun. 2014		
CHECK	PMcC	25 Jun. 2014		
REVIEW	GWS	25 Jun. 2014		

G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\ELNOS\Draft_Integrated_Report\LineamentsDensityGreater5kmELNOSArea.mxd



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Railway
- Watercourse
- Waterbody
- Mapped Fault
- Surficial Lineament (>10 km)
- Geophysical Lineament (>10 km)
- Major Geological Contact

Lineament Density (km/km²)

High : 6.5

Low : 0

INDEX MAP

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geological Contact - MRD126-Bedrock Geology of Ontario, 2011
Lineaments - Lineament interpretation - City of Elliot Lake, The Town of Blind River, The Town of Spanish and the Township of North Shore (JDMA, 2013)
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 17N

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP
PRELIMINARY ASSESSMENT

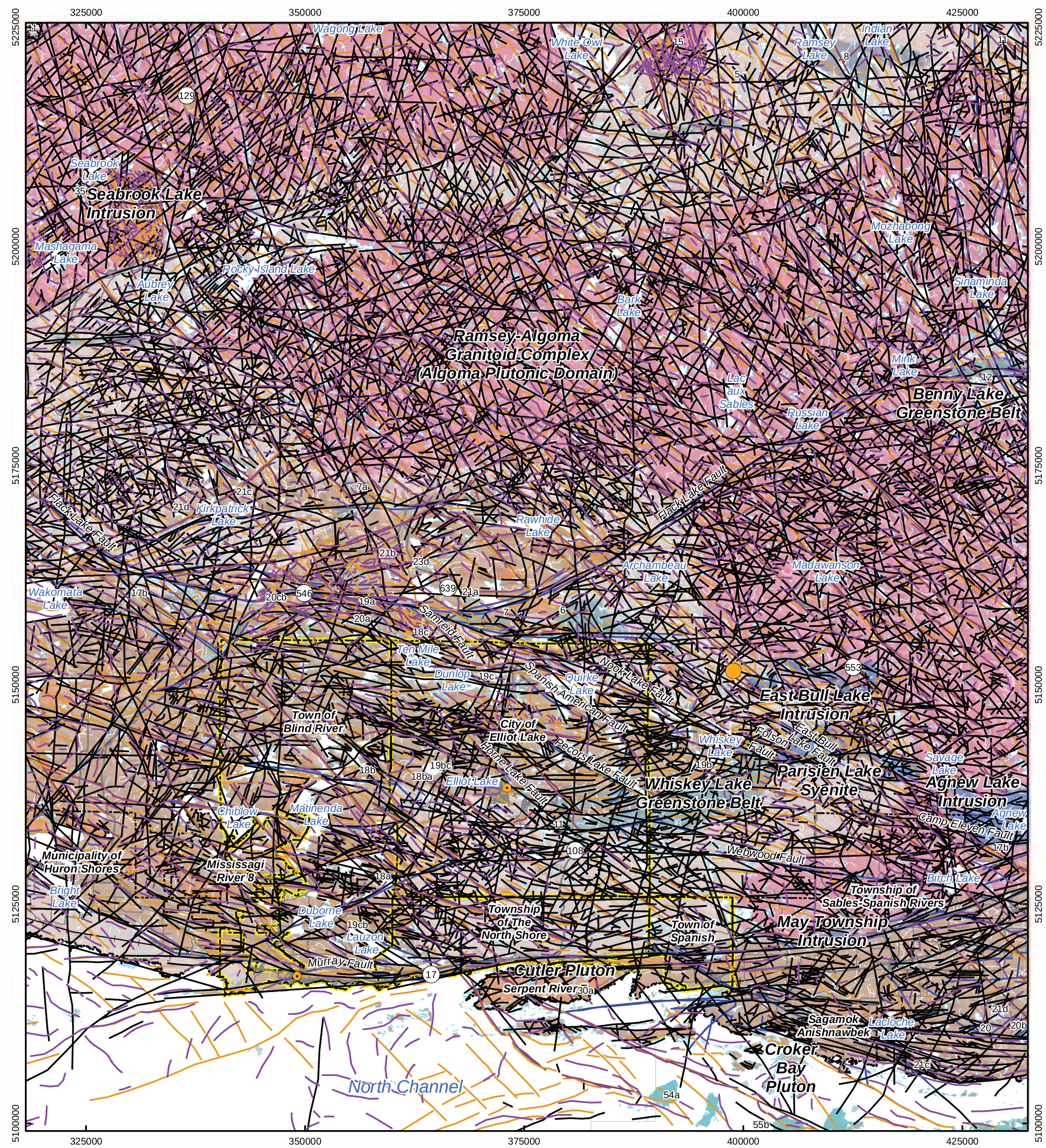
TITLE

Brittle Lineament Density Calculated for Lineaments (>10 km) in the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.17	
GIS	PM/JB	25 Jun. 2014		
CHECK	PMcC	25 Jun. 2014		
REVIEW	GWS	25 Jun. 2014		

G:\Projects\2012\12-1152-0245_NWMO_Phase1_Assessment\GIS\MXDs\Reporting\ELNOS\Draft_Integrated_Report\LineamentsDensityGreater10kmELNOSArea.mxd



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse

Seismic Events (Magnitude)

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

- Mapped Fault
- Mapped Dyke
- Interpreted Ductile Feature
- Interpreted Brittle Lineament
- Interpreted Dykes

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster; Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Lineaments - Lineament interpretation - City of Elliot Lake, The Town of Blind River, The Town of Spanish and the Township of North Shore (JDMA, 2013)
Seismic - Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), April 2013
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 17N

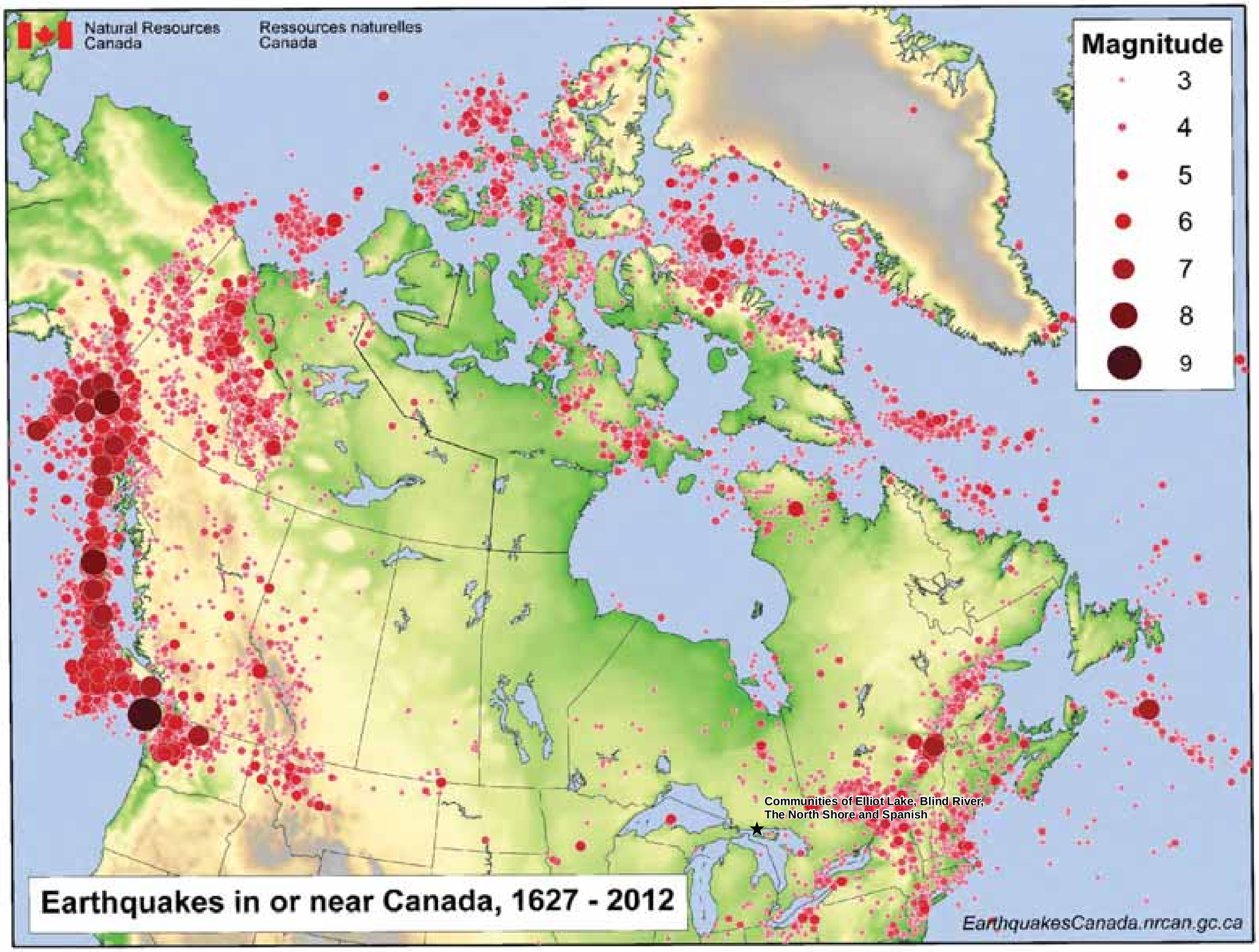
10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

PROJECT	PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT
TITLE	Combined Structural Features of the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN / REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.18
GIS	PM/JB	26 Jun. 2014	
CHECK	PMcC	26 Jun. 2014	
REVIEW	GWS	26 Jun. 2014	

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



LEGEND

★ Communities of Elliot Lake, Blind River, The North Shore and Spanish

REFERENCE

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

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Earthquakes Map of Canada 1627-2012

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245		
DESIGN	PRM	13 Mar. 2013
GIS	JB	26 Jun. 2014
CHECK	PMcC	26 Jun. 2014
REVIEW	GWS	26 Jun. 2014

SCALE AS SHOWN REV. 2.0

FIGURE: 3.19

LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody

Seismic Events (Magnitude)

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

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Faults - MRD126-Bedrock Geology of Ontario, 2011
Seismic - Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), April 2013
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 17N

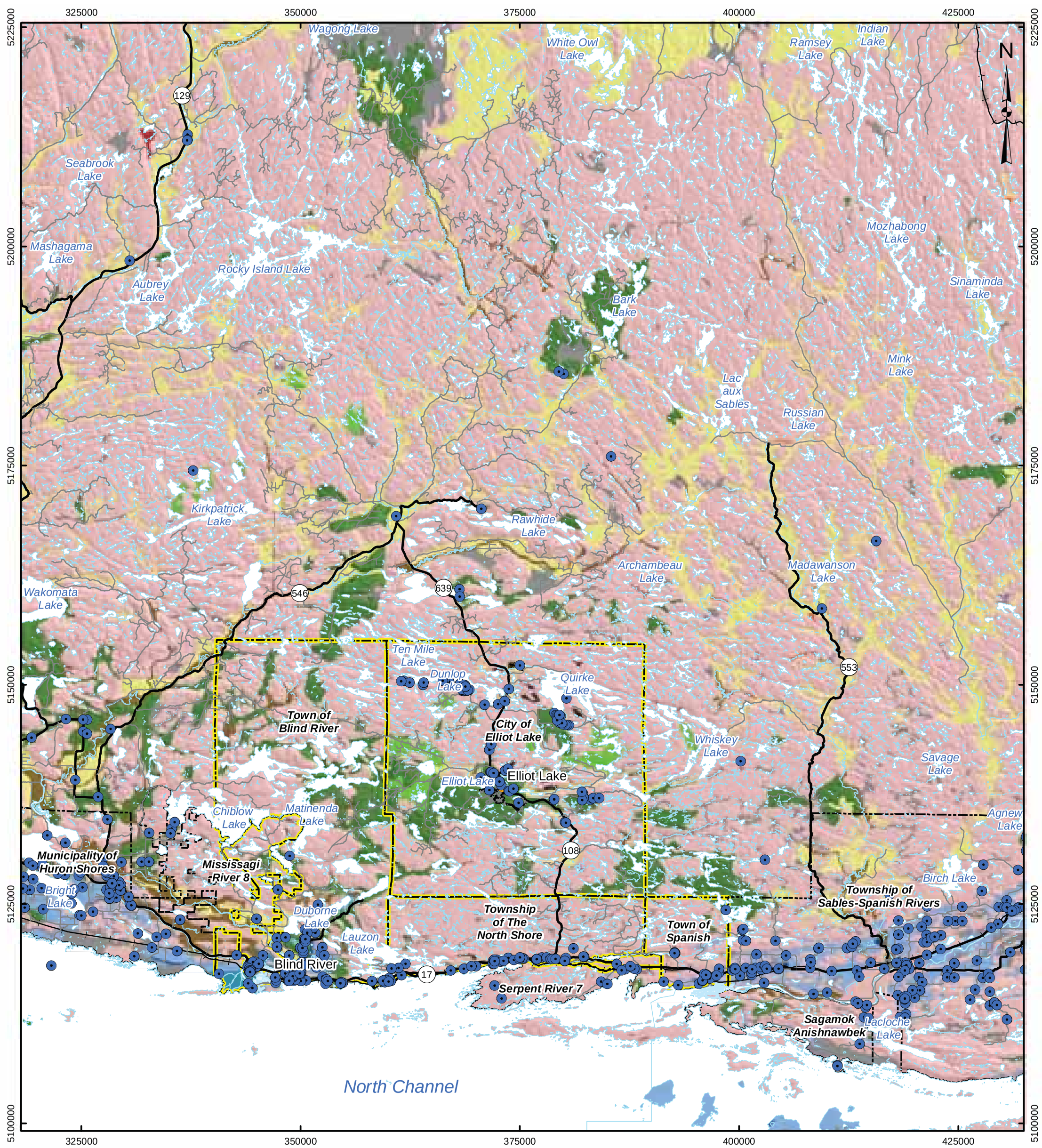
10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP
PRELIMINARY ASSESSMENT

TITLE
Historical Earthquake Records of the
Communities of Elliot Lake, Blind River,
The North Shore and Spanish 1985-2012

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 3.20	
GIS	PMJB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- MOE Well Location
- Main Road
- Local Road
- Railway
- Waterbody
- Provincially Significant Wetland

Landform

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

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Landform - OGS, MNDMines, and Northeast Science and Information Section, MNR 2005.
Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release - Data 160.
Water Wells - Ministry of the Environment, last accessed October 18, 2012.
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 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

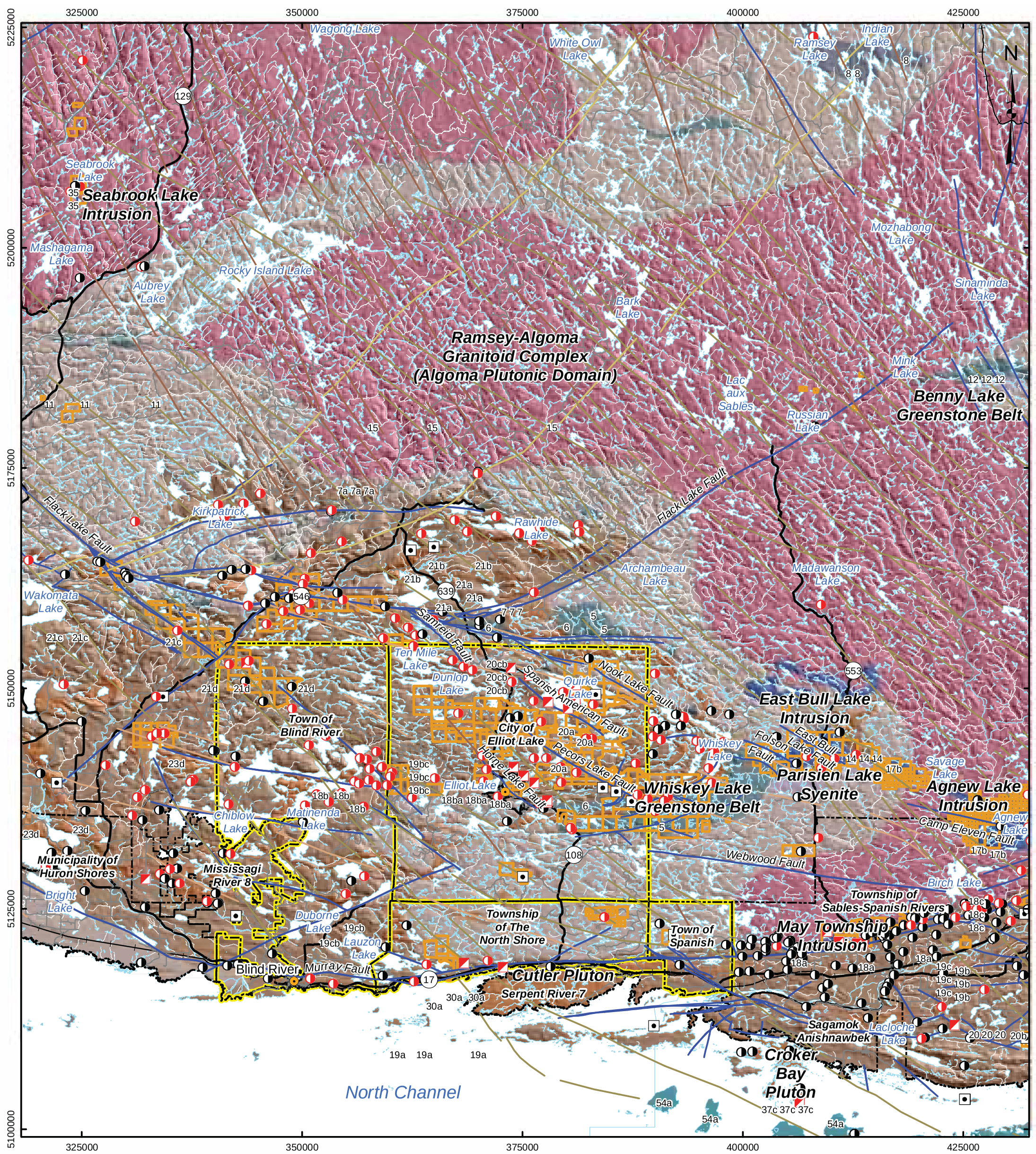
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Groundwater Wells within the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 4.1	
GIS	PMJB	3 Jul. 2014		
CHECK	PMcC	3 Jul. 2014		
REVIEW	GWS	3 Jul. 2014		

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



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Waterbody/Watercourse
- Discretionary Mineral Occurrence
- Mineral Occurrence
- Past Producing Mine
- Prospect
- Mapped Fault

Mapped Dyke

- Biscotasing Mafic Dyke
- Matachewan Mafic Dyke
- North Channel Mafic Dyke
- Sudbury Mafic Dyke
- Unsubdivided Mafic Dyke

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development September 20, 2013
Mineral Inventory - Mineral Deposit Inventory—2013; Ontario Geological Survey 2013.
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 17N

10 5 0 10 20 30
SCALE 1:525,000 KILOMETRES

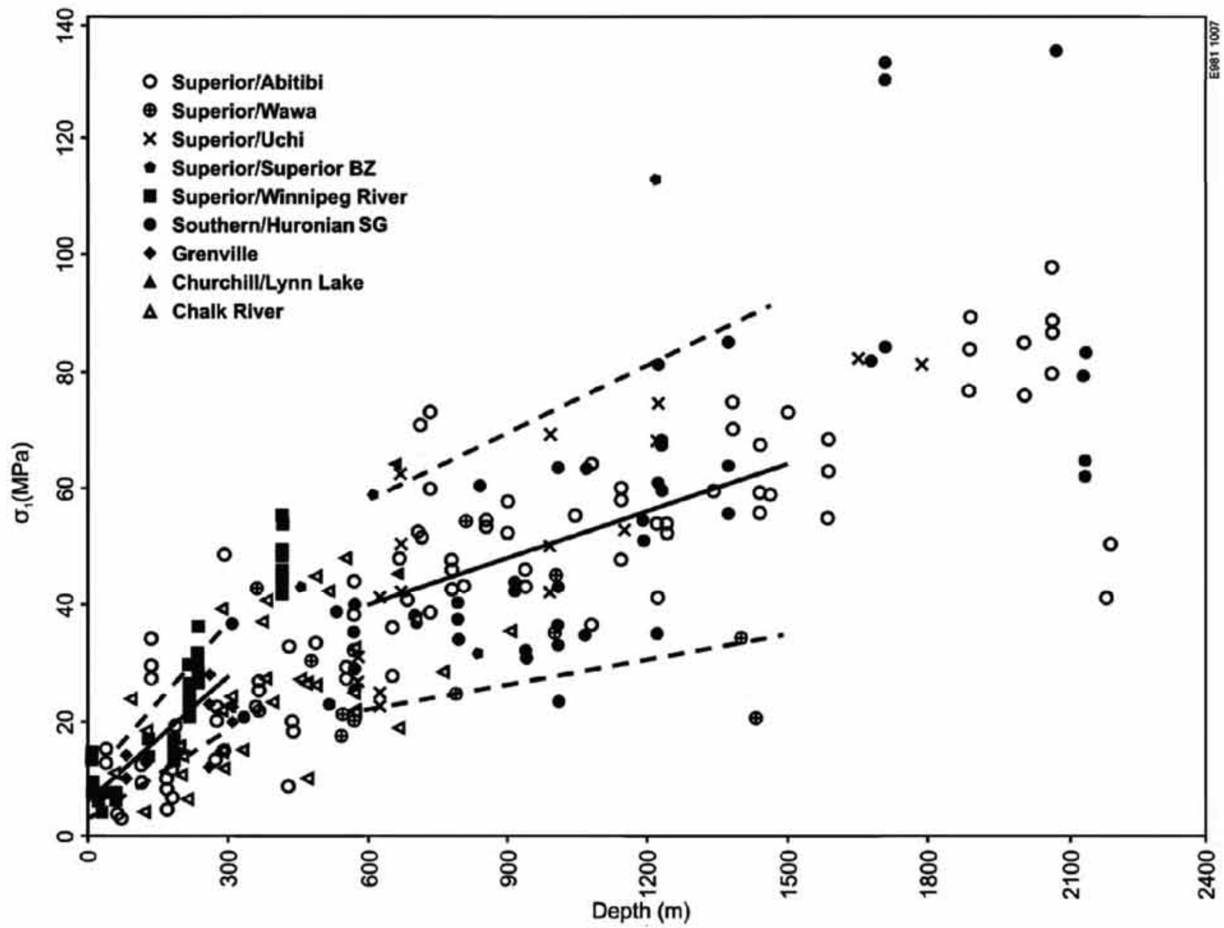
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE
Mineral Showings and Dispositions in the Communities of Elliot Lake, Blind River, The North Shore and Spanish

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 5.1	
GIS	PM/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



REFERENCE

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

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP
PRELIMINARY ASSESSMENT

TITLE

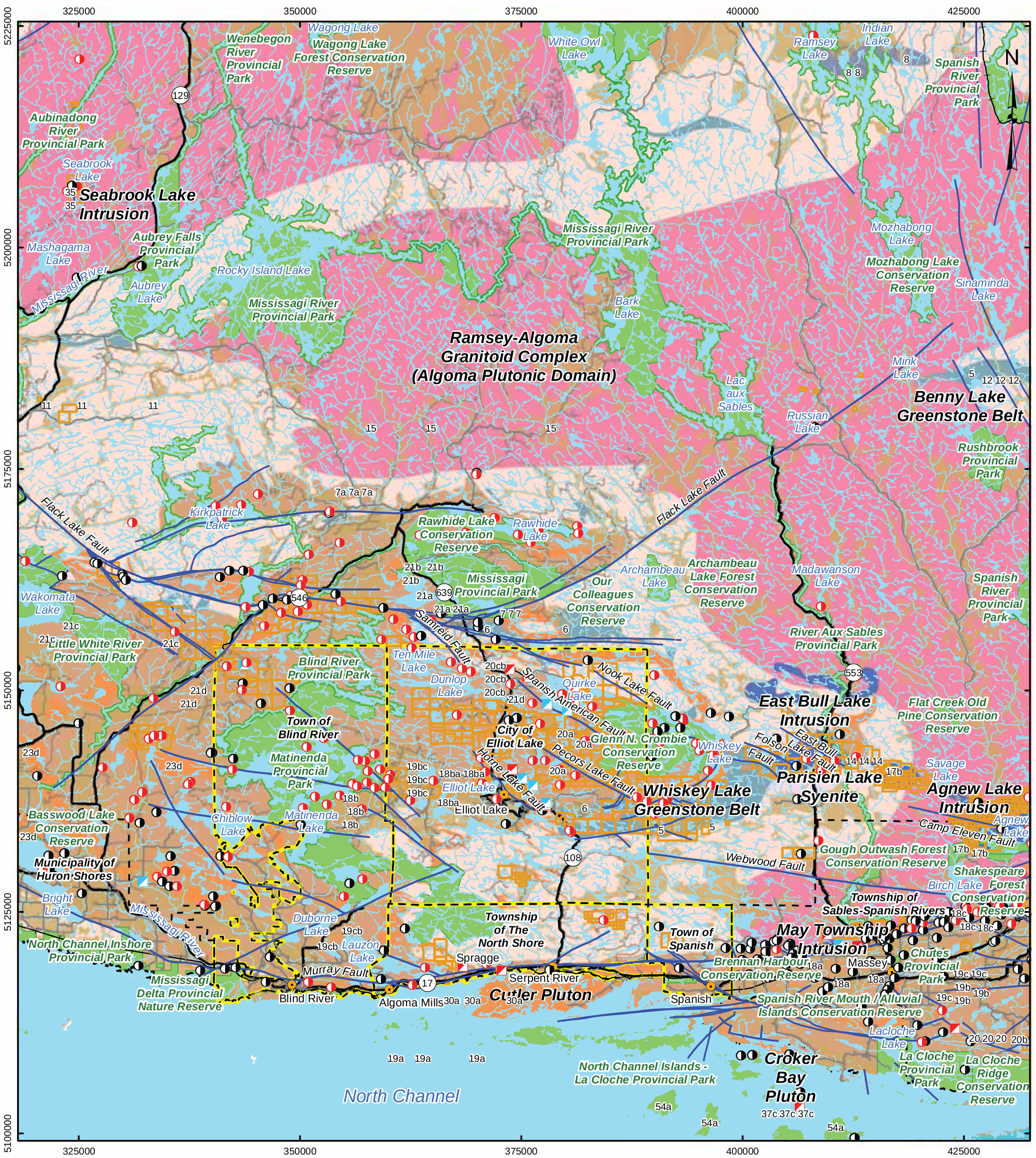
Maximum Horizontal In Situ Stresses Typically Encountered in Crystalline Rock of the Canadian Shield

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245		
DESIGN	PRM	6 Nov. 2012
GIS	PM/JB	26 Jun. 2014
CHECK	CM	26 Jun. 2014
REVIEW	GWS	26 Jun. 2014

SCALE AS SHOWN | REV. 0.0

FIGURE: 6.1



LEGEND

- Communities of Elliot Lake, Blind River, The North Shore and Spanish
- Municipal Boundary
- Community
- Main Road
- Local Road
- Railway
- Watercourse
- Waterbody
- Discretionary Mineral Occurrence
- Mineral Occurrence
- Past Producing Mine With Reserves
- Past Producing Mine Without Reserves
- Mapped Fault
- Active Mining Claims
- Protected Area
- Overburden Cover

Bedrock Geology

Phanerozoic

- Various Paleozoic sedimentary rock units (55, 54)

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)
- Mafic and ultramafic intrusive rocks and mafic dikes (17)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Migmatized supracrustal rocks (8)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

REFERENCE

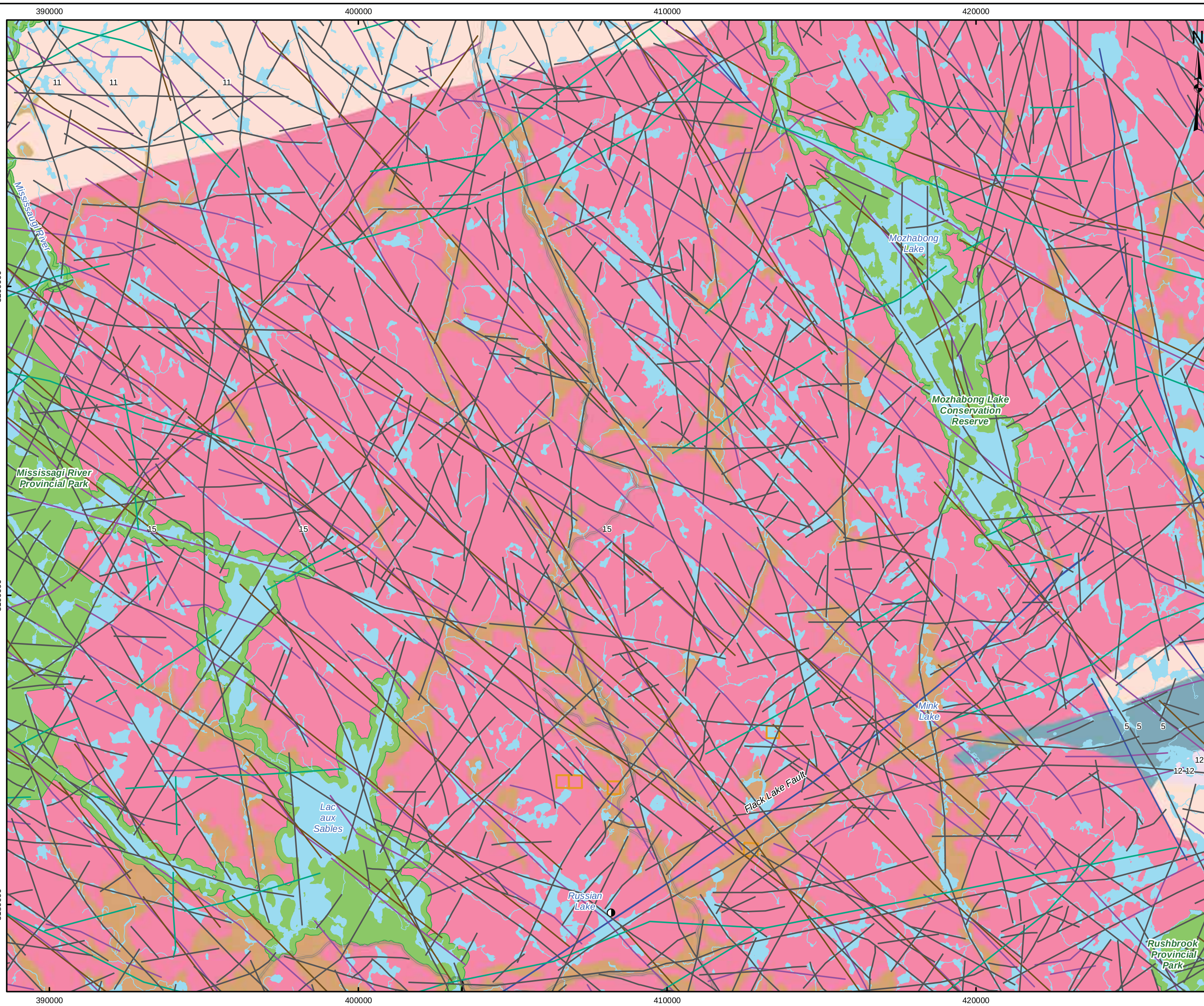
Base Data - MNR LIO, obtained 2009-2013
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development September 20, 2013
Mineral Inventory - Mineral Deposit Inventory—2013; Ontario Geological Survey 2013.
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR
2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

PROJECT	
	PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT
TITLE	Key Geoscientific Characteristics of the Communities of Elliot Lake, Blind River, The North Shore and Spanish and Surrounding Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	13 Mar. 2013	FIGURE: 7.1	
GIS	PMJB	3 Jul. 2014		
CHECK	PMcC	3 Jul. 2014		
REVIEW	GWS	3 Jul. 2014		

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



LEGEND

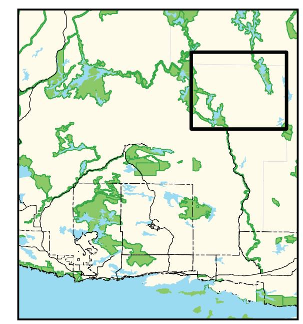
- Main Road
- Local Road
- Watercourse
- Waterbody
- Discretionary Mineral Occurrence
- Mapped Fault
- Mapped Dyke
- Interpreted Dyke
- Surficial Lineament
- Geophysical Lineament
- Active Mining Claims
- Protected Area
- Overburden Cover

Bedrock Geology

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Archean granitoid suites (14, 12)
- Gneissic tonalite suite (11)
- Metavolcanic rocks (6, 5)



Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development September 20, 2013
Mineral Inventory - Mineral Deposit Inventory—2013; Ontario Geological Survey 2013.
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR
2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

2 1 0 2 4 6

SCALE 1:125,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Key Geoscientific Characteristics of the Ramsey-Algoma Granitoid Complex (North East)

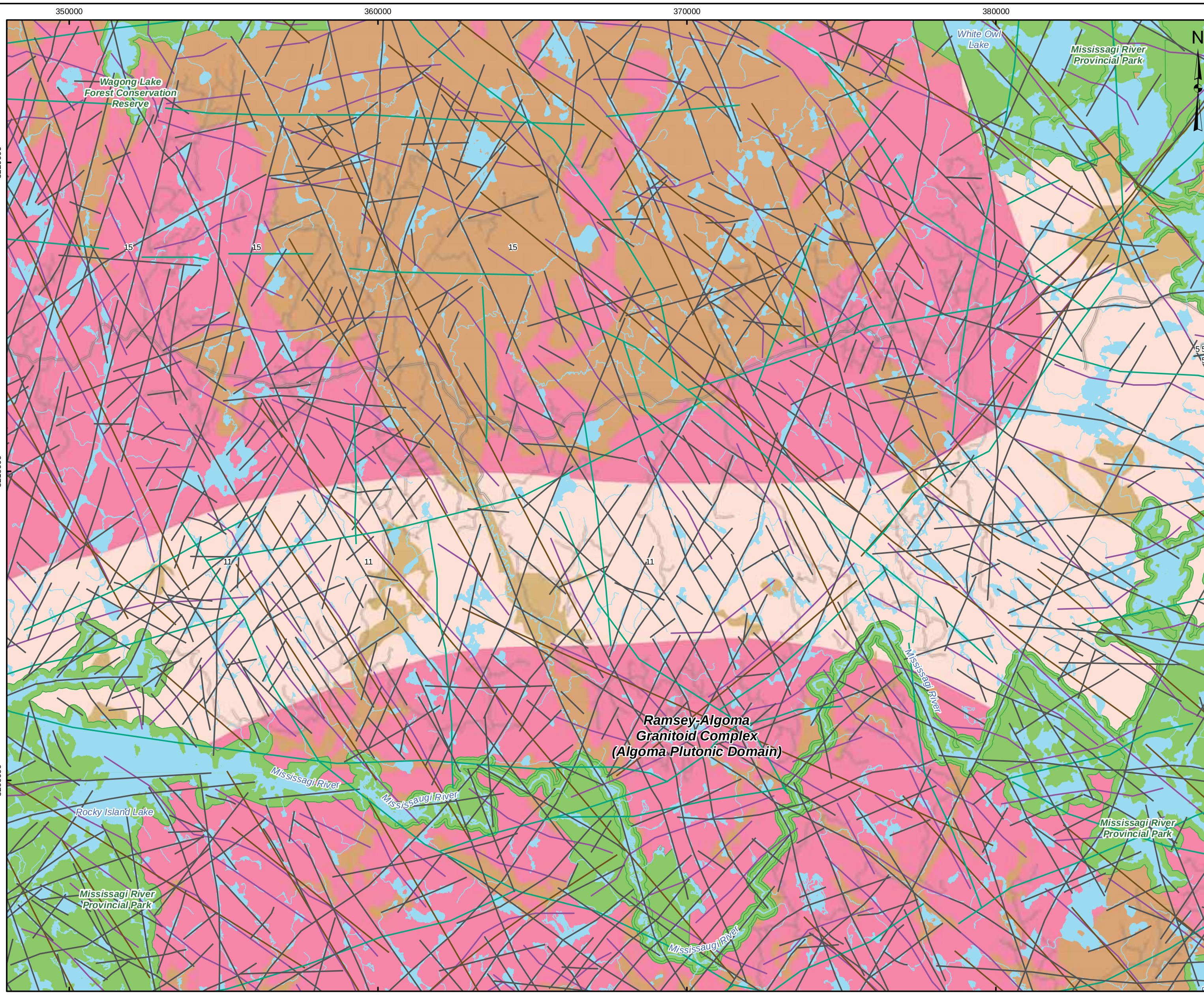
Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245		
DESIGN	JB	13 Mar. 2013
GIS	JC/JB	26 Jun. 2014
CHECK	PMcC	26 Jun. 2014
REVIEW	GWS	26 Jun. 2014

SCALE AS SHOWN REV. 0.0

FIGURE: 7.2

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



LEGEND

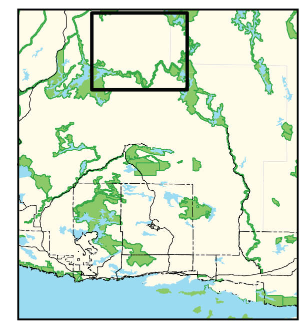
- Local Road
- Watercourse
- Waterbody
- Mapped Dyke
- Interpreted Dyke
- Surficial Lineament
- Geophysical Lineament
- Protected Area
- Overburden Cover

Bedrock Geology

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Gneissic tonalite suite (11)
- Metavolcanic rocks (6, 5)



Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development September 20, 2013
Mineral Inventory - Mineral Deposit Inventory—2013; Ontario Geological Survey 2013.
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR
2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

2 1 0 2 4 6

SCALE 1:125,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

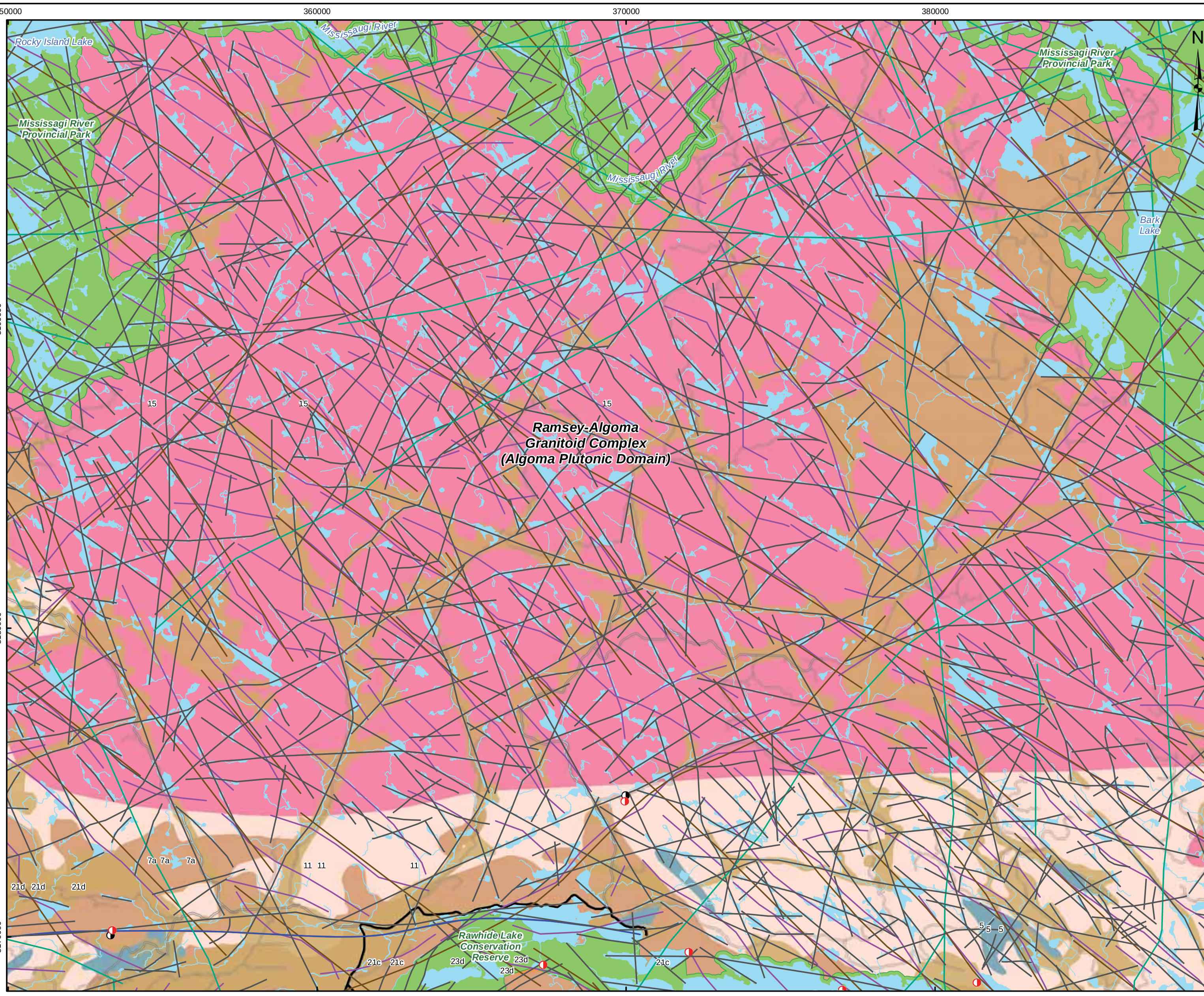
TITLE

Key Geoscientific Characteristics of the Ramsey-Algoma Granitoid Complex (North Central)

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	JB	13 Mar. 2013	FIGURE: 7.3	
GIS	JC/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Main Road
- Local Road
- Watercourse
- Waterbody
- Discretionary Mineral Occurrence
- Mineral Occurrence
- Mapped Fault
- Mapped Dyke
- Interpreted Dyke
- Surficial Lineament
- Geophysical Lineament
- Protected Area
- Overburden Cover

Bedrock Geology

Proterozoic

Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)
- Huronian Supergroup (21, 20, 19, 18)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Gneissic tonalite suite (11)
- Metasedimentary rocks (7)
- Metavolcanic rocks (6, 5)

Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development September 20, 2013
Mineral Inventory - Mineral Deposit Inventory—2013; Ontario Geological Survey 2013.
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR
2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

2 1 0 2 4 6

SCALE 1:125,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

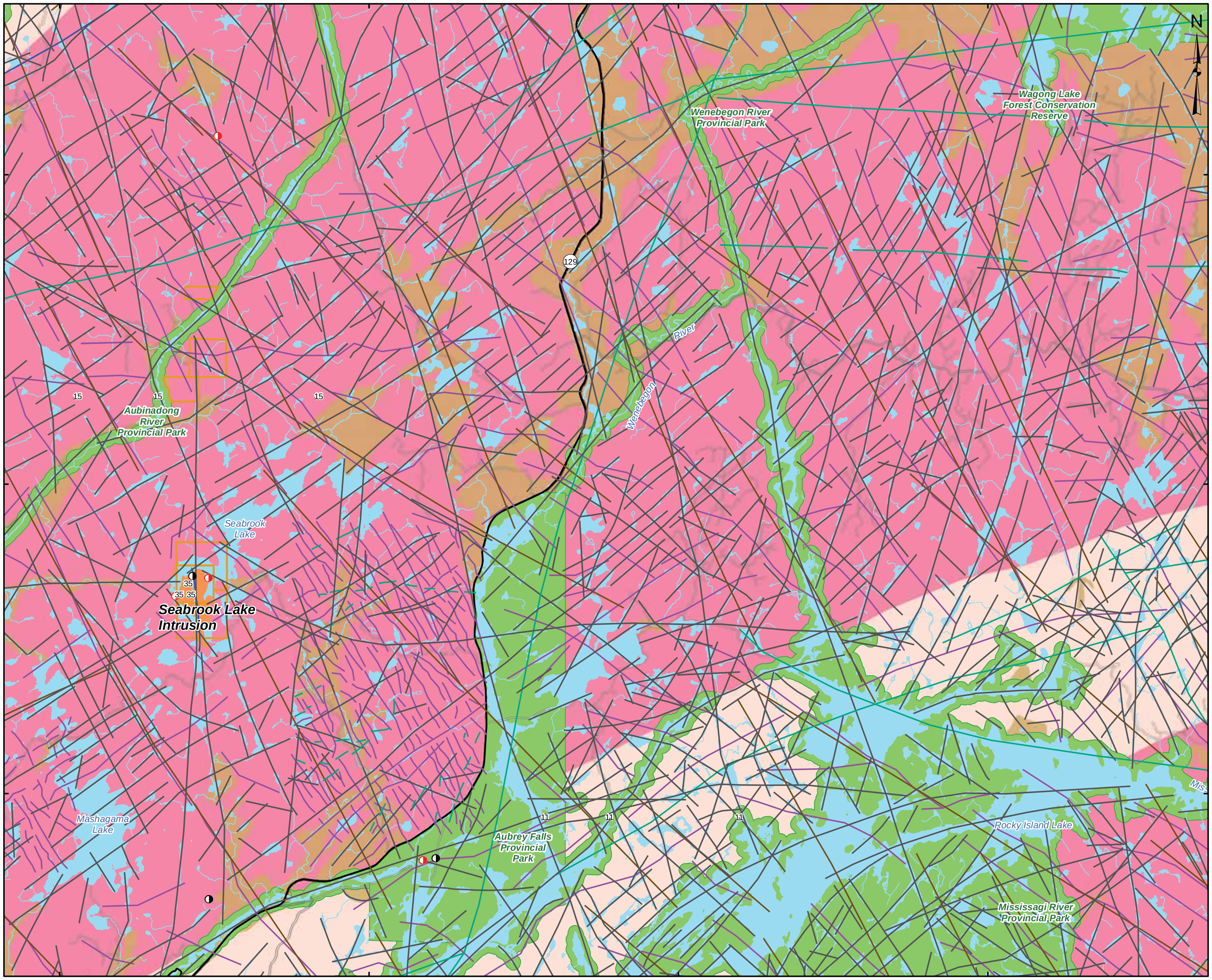
TITLE

Key Geoscientific Characteristics of the Ramsey-Algoma Granitoid Complex (South Central)

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245			SCALE AS SHOWN	REV. 0.0
DESIGN	JB	13 Mar. 2013	FIGURE: 7.4	
GIS	JC/JB	26 Jun. 2014		
CHECK	PMcC	26 Jun. 2014		
REVIEW	GWS	26 Jun. 2014		

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



LEGEND

- Main Road
- Local Road
- Watercourse
- Waterbody
- Discretionary Mineral Occurrence
- Mineral Occurrence
- Mapped Fault
- Mapped Dyke
- Interpreted Dyke
- Surficial Lineament
- Geophysical Lineament
- Active Mining Claims
- Protected Area
- Overburden Cover

Bedrock Geology

Proterozoic

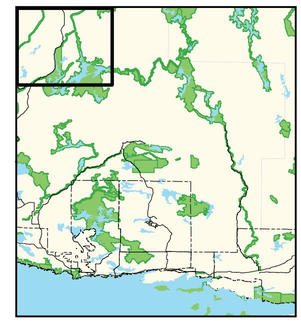
Southern Province

- Various rock units of the Southern Province (37, 35, 30, 23)

Archean

Superior Province (Abitibi Subprovince)

- Massive granodiorite to granite (15)
- Gneissic tonalite suite (11)



Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Base Data - MNR LIO, obtained 2009-2013
Geology - MRD126-Bedrock Geology of Ontario, 2011
Claims - Ministry of Northern Mines and Development September 20, 2013
Mineral Inventory - Mineral Deposit Inventory—2013; Ontario Geological Survey 2013.
Overburden - OGS, MND Mines, and Northeast Science and Information Section, MNR
2005 Digital NOEGTS - Ontario Geological Survey, Miscellaneous Release-Data 160
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2013
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17N

2 1 0 2 4 6

SCALE 1:125,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT

TITLE

Key Geoscientific Characteristics of the Ramsey-Algoma Granitoid Complex (North West)

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0245		
DESIGN	JB	13 Mar. 2013
GIS	JC/JB	26 Jun. 2014
CHECK	PMcC	26 Jun. 2014
REVIEW	GWS	26 Jun. 2014

SCALE AS SHOWN | REV. 0.0

FIGURE: 7.5

APPENDIX A

Geoscientific Factors

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

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

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

APPENDIX B

Geoscientific Data Sources

Table B-1: Summary of Geological Mapping Sources for the Communities of Elliot Lake, Blind River, The North Shore, Spanish and Surrounding Area

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
Map 2555	Quaternary geology of Ontario, east-central sheet	Barnett, P.J., A.P. Henry and D. Babuin	1:1,000,000	4 miles to the inch	1991	complete	Part of the "Geology of Ontario" compilation
S465	Surficial geology, Algoma, Sudbury, Timiskaming and Nipissing	Boissonneau, A.N	ODLF	1: 253,440	1965	partial	
P.3274	Precambrian geology, East Bull Lake Gabbro-Anorthosite Intrusion;	Chubb, P.T., K.K. Hannila and D.C. Peck	OGS	1:20 000	1994	partial	Detailed mapping of the East Bull Lake Gabbro-Anorthosite Intrusion
P.3596	Geological compilation, East Bull Lake and Agnew intrusions	Easton, R.M., S.D. Josey, E.I. Murphy and R.S. James	OGS	1:50 000	2011	partial	
P0237	Geological compilation series, Rocky Island Lake-Biscotasing sheet, districts of Algoma and Sudbury	Giblin, P.E., E.J. Leahy, P.C. Thurston, G.M. Siragusa and R.P. Sage	OGS	1:126,720	1977	partial	
P0674	Geological series, Operation Chapleau, Chapleau sheet, districts of Algoma and Sudbury	Thurston, P.C., G.M. Siragusa and R.P. Sage	OGS	1:126 720	1971	partial	
P0675	Geological series, Operation Chapleau, Opeepeesway-Rocky Island lakes sheet, districts of Algoma and Sudbury	Thurston, P.C., G.M. Siragusa and R.P. Sage	OGS	1:126,720	1971	partial	
P.793	Geology of Harrow and adjacent islands, districts of Sudbury, Manitoulin and Algoma; Ontario	Robertson, J.A., Siemiatkowska, K.M. and Cape, D.F.		1:15 840.	1972.	partial	P.793
P0753	Geological compilation series, subsurface stratigraphy contours on Archean surface and distribution of volcanic members of Elliot Lake Group, Blind River-Elliot Lake sheet, District of Algoma	Rupert, R.J., E.J. Leahy and S. Mirza	OGS	1:126 720	1972	partial	
P0317	Deagle Township, District of Algoma	Robertson, J.A. and J.M. Johnson	OGS	1:15 840	1965	partial	
P3186	Whiskey Lake Greenstone Belt (West Half), District of Algoma	L.S. Jensen		1:15 000	1994	partial	

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
M2314	Proctor and Deagle townships, Algoma District	Robertson, J.A.	OGS	1:31 680	1976	partial	
P0130	Esten Township, District of Algoma	Robertson, J.A.	OGS	1:15 840	1961		
M2185	McGiverin and Esten townships, Algoma District	Abraham, E.M. and J.A. Robertson	OGS	1:31 680	1970		
M2032	Blind River-Elliot Lake area, Algoma District	Robertson, J.A.	OGS	1:126 720	1963		
M2012	Iron Bridge area, District of Algoma, Ontario	Robertson, J.A.	OGS	1:31 680	1962		
M2028	Scarfe, Mack, Cobden, and Striker townships, Algoma District	Abraham, E.M. and J.A. Robertson	OGS	1:31 680	1963		
M2186	Long and Spragge townships and part of Indian Reserve No. 7, Algoma District	Abraham, E.M. and J.A. Robertson	OGS	1:31 680	1970		
M2315	Lewis and Shedden townships and parts of Indian Reserves No. 5 and No. 7, Algoma District	Robertson, J.A.	OGS	1:31,680	1977	partial	
M2308	Victoria and Salter townships, Sudbury District	Robertson, J.A.	OGS	1:31,680	1975	partial	
M2309	Part of Indian Reserve No. 5 and offshore islands, Algoma and Manitoulin districts	Robertson, J.A. and W. McCrindle	OGS	1:31,680	1975	partial	
OFM0233	Precambrian Geology, May Township	Jackson, S.L., J.A. Robertson, I.G. Henderson and K.M. Siemiatkowska	OGS	1:20 000	1994	partial	
M2316	Bay of Islands, north channel of Lake Huron, Sudbury and Manitoulin districts	Card, K.D.	OGS	1:31 680	1975	partial	
P0090	Biscotasing area, District of Sudbury, Ontario	Rogers, D.P.	OGS	1:63 360	1960	partial	
M2013	Biscotasing area, District of Sudbury, Ontario	Rogers, D.P.	OGS	1:63 360	1962	partial	
M2444	Sayer and LeCaron townships, Algoma District	Siemiatkowska, K. M., A.E. Guthrie and M.R. Gent	OGS	1:31,680	1981	partial	
M2346	Poulin and Sagard townships, Algoma District	Robertson, J.A.	OGS	1:31,680	1976	partial	
M2305	Viel and Piche	Wood, J.	OGS	1:31,680	1974	partial	

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
	townships, Algoma District						
M2399	Endikai Lake, Algoma District	Siemiatkowska, K.M.	OGS	1:31,680	1977	partial	
M2350	Wakomata Lake, Algoma District	Siemiatkowska, K.M.	OGS	1:31,680	1977	partial	
M2331	Saunders Lake, Algoma District	Chandler, F.W.	OGS	1:31 680	1976	partial	
M2027	Township 162 and part of Township 168, District of Algoma, Ontario	Robertson, J.A.	OGS	1:15 840	1963	partial	
M2015	Township 156, District of Algoma, Ontario	Robertson, J.A.	OGS	1:15 840	1962	partial	
M2114	Township 150, Algoma District	Abraham, E.M. and J.A. Robertson	OGS	1:15 840	1967	partial	
M2002	Township 144, District of Algoma, Ontario	Robertson, J.A.	OGS	1:15 840	1961	partial	
M2004	Township 138, District of Algoma, Ontario	Robertson, J.A.	OGS	1:15 840	1961	partial	
ARM52D	East Bull Lake area, District of Algoma, Ontario	Moore, E.S. and H.S. Armstrong	OGS	1:63,360	1943	partial	
M2003	Township 137, District of Algoma, Ontario	Robertson, J.A.	OGS	1:15,840	1961	partial	
M2001	Township 143, District of Algoma, Ontario	Robertson, J.A.	OGS	1:15,840	1961	partial	
M2113	Township 149, Algoma District	Abraham, E.M. and J.A. Robertson	OGS	1:15,840	1967	partial	
M2014	Township 155, District of Algoma, Ontario	Robertson, J.A.	OGS	1:15,840	1961	partial	
M2026	Township 161 and part of Township 167, District of Algoma, Ontario	Robertson, J.A.	OGS	1:15,840	1963	partial	
M2670	Bedrock geology compilation map, Sault Ste. Marie-Blind River map sheet. Ontario Geological Survey	Johns, G. W., S. McIlraith, and T.L. Muir	OGS	1:250,000	2003	partial	

Table B-2: Summary of Geophysical Mapping Sources for the Communities of Elliot Lake, Blind River, The North Shore, Spanish and Surrounding Area

Product	Source	Type	Line Spacing/ Sensor Height	Line Direction	Location	Date	Additional Comments
East Bull Lake (RA-7)	GSC	Fixed wing vertical gradiometer magnetic, VLF	300 m/150 m	0°	East central over the East Bull Lake and nearby intrusions	1981	Higher resolution over intrusions
Ontario #4	GSC	Fixed wing magnetic	402 m/305 m	0°	West central	1956	Moderate resolution dataset
Ontario #13	GSC	Fixed wing magnetic	805 m/305 m	0°	Northeast	1960	Lowest resolution dataset
Ontario #16	GSC	Fixed wing magnetic	805 m/305 m	0°	East	1959	Lowest resolution dataset
Ontario #17	GSC	Fixed wing magnetic	805 m/305 m	0°	Most of area of the four communities	1963	Lowest resolution dataset
GDS1017 Benny (OGS, 2003)	OGS	Helicopter magnetic, FDEM, VLF	200 m/30 m	0°	East central over Benny greenstone belt	1990	4-frequency Aerodat system, radar navigation, higher resolution over Benny greenstone belt
GDS1236 Elliot Lake-River aux Sables (OGS, 2011b)	OGS	Helicopter magnetic, TDEM	100 m (east), 50 m (west)/ 67 m (mag), 47 m (TDEM)	0°	South central over Whiskey Lake greenstone belt	2008	VTEM system, higher resolution over Whiskey Lake greenstone belt
Sudbury	GSC	Fixed wing magnetic, radiometric, VLF	1000 m/120 m	0°	East	1989	Utilized for its radiometric and VLF coverage only
Elliot Lake	GSC	Fixed wing radiometric	500 m/124 m	0°	South central over Huronian Supergroup	1970	Higher resolution over Huronian Supergroup
Elliot Lake (detail)	GSC	Fixed wing radiometric	123 m/115 m	0°	South central over Huronian Supergroup	1977	Higher resolution over Huronian Supergroup
GSC Gravity Coverage	GSC	Ground gravity measurements	5-15 km, 25 m to 1 km locally		Entire study area of the four communities	1945-1989	Station spacing somewhat variable, focus on overall with more detailed data over the East Bull Lake (RA-7).and Seabrook Lake intrusions

Table B-3: Summary of the characteristics for the airborne geophysical assessment file reports in the Communities of Elliot Lake, Blind River, The North Shore, Spanish and Surrounding Area

AFRI No.	Source	Type	Line Spacing/ Sensor Height	Line Direction	Location	Date	Additional Comments
20000850	North American Gem	Fixed wing horizontal gradiometer magnetic, radiometric, VLF	100 m/70 m	0°	Northwest	2008	
20003244	Canada Enerco	Fixed wing magnetic, TDEM	200 m/73 m	55°	North of Elliott Lake	2007	MEGATEM system
20004445	Delta Uranium	Fixed wing horizontal gradiometer magnetic, radiometric, VLF	100 m/70 m	0°	North central	2006	
200005757-1 to -3	Carina Energy	Helicopter magnetic, TDEM	100 m/47 m	0°	West central over the Huronian Supergroup	2007	AeroTEM II system
20005762	Carina Energy	Helicopter magnetic, radiometric	150 m/30 m	0°	West central over the Huronian Supergroup	2007	
20006243	North American Gem	Fixed wing horizontal gradiometer magnetic, radiometric, VLF	100 m/70 m	0°	Northwest	2008	
20006734	Hawk Uranium	Helicopter magnetic, radiometric, VLF	100 m/30 m	0°	North central	2007	
41I12SW2002	Mustang Minerals	Helicopter vertical gradiometer magnetic, FDEM	100 m/45 m	0°	Southeast over the East Bull Lake and nearby intrusions	2000	Dighem V system

At Golder Associates we strive to be the most respected global group of companies specializing in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organizational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

Africa	+ 27 11 254 4800
Asia	+ 852 2562 3658
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

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