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

TOWNSHIP OF SCHREIBER, ONTARIO

APM-REP-06144-0035

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Township of Schreiber, Ontario

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Executive Summary

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

The preliminary assessment is a multi-component study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated preliminary assessment report (NWMO, 2013).

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

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

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, 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 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 desktop geoscientific preliminary assessment showed that the Schreiber area contains at least two general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. Both areas, located within the Crossman Lake batholith, have the potential to satisfy NWMO's geoscientific site evaluation factors. Given the geographic extent of the Schreiber area, there may be additional areas that are also potentially suitable for hosting a deep geological repository.

The Crossman Lake batholith hosting the two identified potentially suitable areas appears to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. The batholith appears to have sufficient depth, lateral extent and lithological homogeneity. The two potentially suitable areas have low potential for natural resources, good bedrock exposure and are generally accessible.

While the general potentially suitable areas appear to have favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. Main uncertainties relate to the influence of regional structural features, the presence of numerous dykes and the impact of rugged topography.

Should the community of Schreiber 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 Schreiber area contains sites that can safely contain and isolate used nuclear fuel. This would include the acquisition and interpretation of higher resolution airborne geophysical surveys, detailed geological mapping and the drilling of deep boreholes.

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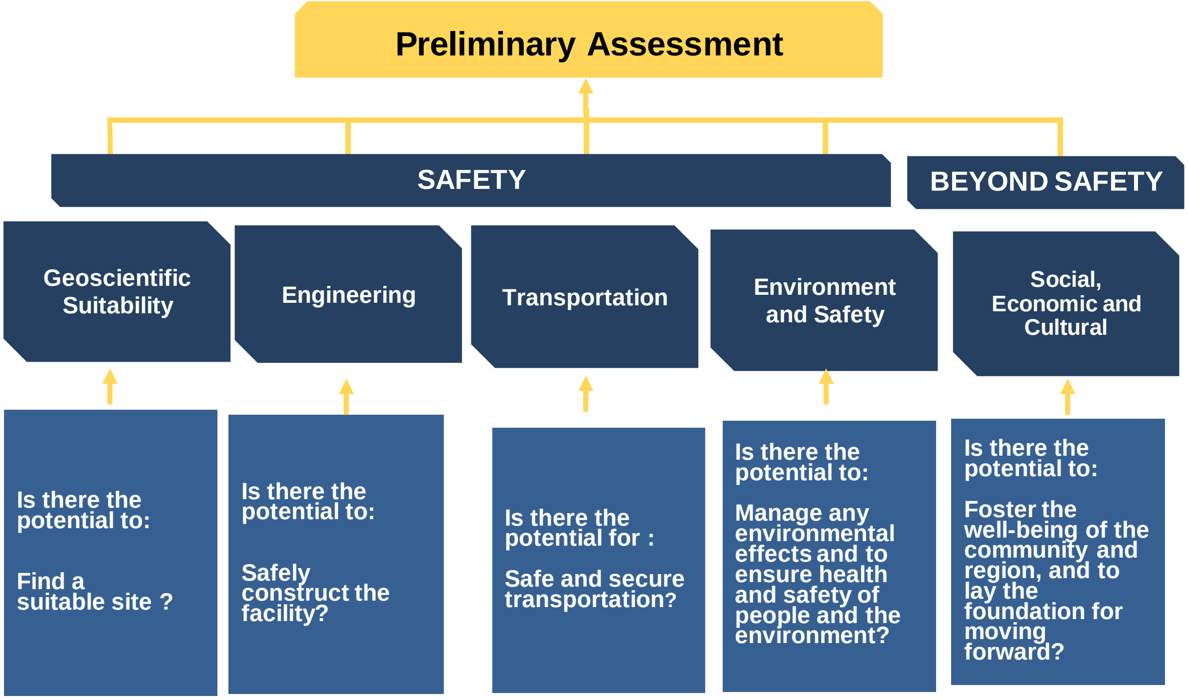
1 INTRODUCTION

1.1 Background

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

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



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

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

- ***Phase 2 - Preliminary Field Investigations****.* For a subset of communities selected by the NWMO, to further assess potential suitability. This phase will involve a site investigation 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.

1.2 Desktop Geoscientific Preliminary Assessment Approach

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

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

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, 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 the characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification of general potentially suitable areas based on key geoscientific characterizations 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 (AECOM, 2013), Geophysical Interpretation (Mira, 2013), and Lineament Interpretation (SRK, 2013). Key findings from these studies are summarized in this report.

1.3 Geoscientific Site Evaluation Factors

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

- ***Safe containment and isolation of used nuclear fuel****:* Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances caused by human activities and natural events?

- ***Long-term resilience to future geological processes and climate change****:* Is the rock formation at the siting area geologically stable and likely to remain stable over the very long term in a manner that will ensure the repository will not be substantially affected by geological and climate change process such as earthquakes and glacial cycles?

- ***Safe construction, operation and closure of the repository****:* Are conditions at the site suitable for the safe construction, operation and closure of the repository?

- ***Isolation of used fuel from future human activities:*** Is human intrusion at the site unlikely, for instance through future exploration or mining?

- ***Amenable to site characterization and data interpretation activities:*** Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

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

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

1.4 Available Geoscientific Information

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

1.4.1 Airborne Geophysics, Digital Elevation Model, Satellite Imagery and Aerial Photography

For the Schreiber area, geophysical data were obtained from available public-domain sources, particularly the OGS and the GSC (Table 1.1, Table B.1). Low-resolution geophysical data, notably the magnetic, gravity, VLF-EM and radiometric data, cover most of the Schreiber area, with the exception of some small areas covered by Lake Superior in the south of the Schreiber area. An OGS magnetic/electromagnetic survey (Ontario Geological Survey, 2003), referred to as the Schreiber “Supergrid” provides higher resolution coverage over approximately 75% of the Schreiber area, with the exception of a north-south trending band along the western boundary and an east-west trending band south of the Lake Superior shoreline along the southern boundary of the Schreiber area. VLF total field and quadrature data, as well as the radiometric data were measured during three GSC surveys: Coldwell-Hemlo-Schreiber, Georgia Lake and Schreiber. Figure 1.2 shows the outline of the available airborne geophysical surveys for the Schreiber area.

A ground gravity dataset is available from the Canadian Gravity Anomaly Data Base maintained by NRCan. The data are of good quality, in terms of accuracy and precision. However, the low density of field measurements allows the data to be used only for regional interpretations. Due to the low number gravity stations in the Schreiber area the data cannot be reliably gridded below a 2 km by 2 km horizontal resolution and, as such, only large scale geologic features can be discerned.

The location and details of several airborne and ground geophysical surveys conducted in the Schreiber area as part of mineral exploration programs are held in the Ministry of Northern Development and Mines' (MNDM) Assessment File Research Inventory (AFRI) database (MNDM, 2012a). With few exceptions, these surveys were mainly conducted over greenstone belt rocks and covered only small portions of the surrounding felsic intrusive rocks. Airborne survey types described in the AFRI data include: electromagnetic (EM); magnetic; and very low frequency-electromagnetic (VLF-EM). Ground surveys described are: electromagnetic; magnetic; VLF-EM; and induced polarization. Most of these geophysical surveys were conducted prior to 2000 with the largest percentage completed in the early to mid-1980s. The reliability of these surveys was therefore evaluated on a case-by-case basis.

Datasets containing remote sensing data were available for use in the Schreiber Phase 1 Desktop Geoscientific Preliminary Assessment. The digital elevation model (DEM) data for the Schreiber area, referred to as the Canadian Digital Elevation Data (CDED), consists of a 1:50,000 scale, 20 m resolution elevation model (Table 1.1; GeoBase, 2011a). SPOT multispectral/panchromatic orthoimagery (20 m resolution) and Landsat 7 orthoimages (15 m resolution) were also available for the Schreiber area (Table 1.1; GeoBase, 2011b).

Complete aerial photographic coverage of the Schreiber area from 1983, at a scale of 1:50,000, was available in the form of high resolution (600 dpi) scans from the Archives of Ontario. The 47 images, part of the MNR's Ontario Base Mapping collection, were captured during seasons with limited vegetation cover thus permitting the identification of topographic features.

Each of the remotely sensed datasets covers the entire Schreiber area and all have a good level of resolution in relation to the scope of the project allowing the interpretation surficial geology. In addition, meaningful and accurate bedrock structural information could be gained from each of the datasets for the majority of the area. The only area were this was not the case was a belt of thick Quaternary sediments in the southeastern corner of the Schreiber area between Terrace Bay and the Township of Schreiber.

Table 1.1: Summary of Satellite, Airborne and Geophysical Source Data Information for the Schreiber Area

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	8-23 m (0.75 arc seconds) depending on latitude	Entire Schreiber area	1995 (published in 2003)	Hillshade and slope rasters used for mapping
Aerial Photography	47 scanned images	OBM	600 dpi	Entire Schreiber area	2000	
Satellite Imagery	Spot 5; Orthoimage, multispectral/ panchromatic	Geobase	20 m (multispectral)	Entire Schreiber area	2009	
	LandSAT 7 orthorectified imagery	Geobase	30 m (multispectral)	Entire Schreiber area	2000	
	LandSAT 7 orthoimages of Canada	Geogratis	15 m (multispectral)	Entire Schreiber area	2006 (west) 2007 (east)	
Geophysics	Coldwell, Hemlo, Schreiber Fixed Wing - Magnetic, EM VLF-EM, Radiometric data	GSC (GSC 2516)	1000 m Line Spacing 120 m Sensor Height	Eastern third of Schreiber area without reaching south or north boundaries	1990	Quality control and initial processing applied by GSC
	Georgia Lake Fixed Wing - Magnetic, EM VLF-EM, Radiometric data	GSC	1000 m Line Spacing 120 m Sensor Height	One survey line covers the northwest corner of Schreiber area	1989	Quality control and initial processing applied by GSC
	North Shore Lake Superior, section 2 (West) Fixed Wing – Radiometric data	GSC	5000 m Line Spacing 120 m Sensor Height	The entire Schreiber area excluding Lake Superior	1982	Quality control and initial processing applied by GSC
	Schreiber Fixed Wing - Magnetic, EM VLF-EM, Radiometric data	GSC (GSC 2514)	1000 m Line Spacing 120 m Sensor Height	Entire Schreiber area but stops at Lake Superior. Denser survey lines in north central half of Schreiber area	1990-1991	Covers entire Schreiber area but stops at Great Lake shoreline in the south. Denser survey lines in north central half of Schreiber area
	Lake Superior Fixed Wing – Magnetic data	GSC	1900 m Line Spacing 300 m Sensor Height	Southern third of Schreiber area	1987	Flown at a higher elevation and with a low spatial resolution

Table 1.1: Summary of Satellite, Airborne and Geophysical Source Data Information for the Schreiber Area

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
	Airborne Magnetic Compilation Fixed Wing Magnetic data (Ontario #8)	GSC/OGS (CABD27)	805m Line Spacing 305m Sensor Height	Entire Schreiber area	1962	Reduced and levelled to common datum magnetic data. Data reprocessed in 1999
	Ground Gravity Measurements	GSC (CGDB, SEP 2010)	5-15 km Station Spacing	Thirteen stations sparsely located over entire Schreiber Area	1944- 1962	Despite a good data quality at stations the sparse coverage of the Schreiber area makes the 2 km grid of low quality
	Schreiber Supergrid Heliborne - Magnetic, FDEM	OGS (GDS 1104)	200 m Line Spacing 30 m Sensor Height	Central, north central, east central and northeast corner of Schreiber area	1999	Quality control applied by OGS. This recent high resolution survey flown at low altitude makes it the most reliable dataset for this assessment

1.4.2 Geology

Precambrian geology mapping in the Schreiber area and surrounding region has been conducted over the last century (Table B.2). A number of early reconnaissance and township-scale mapping initiatives (Hopkins, 1922; Bartley, 1939, 1942; Harcourt, 1939; Pye, 1961, 1964) led to the creation of regional-scale compilation maps (1:250,000) for the area in the 1960s and 1970s. In the 1980s detailed mapping of the Terrace Bay-Schreiber area, at a scale of 1:15,840 (Carter, 1981a-d, 1982a, 1982b, 1988) took place, which has been incorporated into updated regional and provincial compilations, at scales of 1:250,000 (Santaguida, 2002; Johns *et al.*, 2003; Ontario Geological Survey, 2011) and 1:1,000,000 (Ontario Geological Survey, 1991a, 1991b, 1997), respectively. A provincial-scale tectonic assemblage has also been generated from an interpretation of this latest generation of mapping (Ontario Geological Survey, 1992a, 1992b).

Largely completed by the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC), the more recent mapping of the area is considered to be of high quality although the level of detail is dependent on scale (e.g., Williams, 1989; Card, 1990; Williams *et al.*, 1991). The focus of most of the bedrock mapping in the area was on defining the lithologies, structural controls and mineral potential of the Schreiber-Hemlo greenstone belt. The mapping has resulted in the definition of assemblages within the Schreiber-Hemlo greenstone belt and the recognition of their stratigraphic relationships (Muir, 2003). However, the mapping and study of the batholiths and plutons in the area are notably less comprehensive and detailed.

Geological mapping coverage is good and generally current throughout most of the Schreiber area, with the majority of the area having been mapped at a scale of 1:15,840. Parts of the northwest corner of the area, underlain by the Crossman Lake batholith and the metasedimentary rocks of the Quetico Subprovince, are mapped at a scale of 1:250,000. Figure 1.2 shows a summary of available recent bedrock geological map coverage Schreiber area.

Bedrock maps covering the Schreiber area identified the position and orientation of a number of large scale faults and lineaments. The density of the structural data is greatest within the greenstone belt, corresponding to its complex tectonic history. The eastern portion of the Schreiber-Hemlo greenstone belt, notably the area surrounding the Hemlo gold mines, has been studied in detail (e.g., Lin, 2001; Muir, 2003). Limited information is available on the structural history of the Schreiber area. As such, it is inferred that events recognized in the Hemlo area also occurred to the west. Additional field studies would be required to confirm the nature and timing of major events affecting the structural history of the Schreiber area.

Several geochronological investigations have been completed that assist in determining the age of bedrock units within and surrounding the Schreiber area (Corfu and Muir, 1989). This research has principally focused on defining the age of greenstone belt rocks and the alteration halos surrounding mineral deposits (e.g., Hamilton *et al.*, 2002; Davis and Lin, 2003). Dates of the granitoid rocks surrounding the greenstone belt are far fewer and show greater variability in ages. In general, the quality of geochronological data are high, especially dates generated within the past few decades. A database of geochronological dates is maintained by the GSC.

Information on the geochemical analysis of bedrock samples collected from the 1970s to the early 1990s is contained in the OGS lithogeochemistry (formerly Petroch) database (MNDM, 2012a). The majority of the results in this database are of supracrustal greenstone belt rocks with far fewer analyses of felsic intrusive rocks. In general, the quality of the analytical results is dependent on when the analyses were conducted, since modern analytical equipment tends to have better detection levels. Furthermore, the location information recorded for samples taken prior to modern GPS technology may be less reliable in some cases.

A provincial compilation of Quaternary geology at the 1:1,000,000 scale includes the Schreiber Area (Barnett *et al.*, 1991). This is complemented by detailed mapping (1:100,000) of the surficial sediments from airphoto interpretation with limited ground-checking, completed during the Northern Ontario Engineering Geology Terrain Study (NOEGTS; Gartner 1979a, 1979b; OGS *et al.*, 2005). The mapping is of sufficient quality to illustrate the distribution of glacial materials and to determine that they are generally thin over the majority of the Schreiber area. Exceptions include some bedrock-controlled valleys and areas near the Lake Superior coast. Data on overburden thickness are also available from well records in the Ontario Ministry of Environment Water Well Information Systems database (Ontario Ministry of Environment, 2012) and from the OGS drill hole database (MNDM, 2012a) discussed in Section 1.5.4.

The glacial history for the area is reasonably well-understood having been constructed on the basis of detailed mapping in surrounding areas and regional studies assessing glaciation events (e.g., Barnett, 1992; Morris, 2000). Research on glacial lake levels in the Superior Basin has allowed an understanding of isostatic recovery rates in the area (Farrand and Drexler, 1985; Barnett, 1992; Lee and Southam, 1994; Mainville and Craymer, 2005).

Several databases contain records of publications with information on the Schreiber area's bedrock geology, history, structural evolution and economic potential (Table B.3). The most relevant databases to the Desktop Preliminary Assessment are referenced and/or available through GEOSCAN and Geology Ontario (OGS publications).

National seismicity data sources were used to provide an indication of seismicity in the Schreiber area (Hajnal *et al*., 1983; Hayek *et al*., 2011; Natural Resources Canada, 2012).

1.4.3 Hydrogeology and Hydrogeochemistry

The Land Information Ontario (LIO) data warehouse, held by the Ontario Ministry of Natural Resources, contains a database of quaternary level watersheds and subwatersheds (LIO, 2012) including flow direction of all waterways, and lakes. Limited stream/river flow data are available for the Schreiber area (Environment Canada, 2012).

Data on the hydrogeology of the Schreiber area are largely lacking. The reliance on surface water sources and the very limited number of water wells recorded in the Ministry of Environment's Water Well Information Systems (Ontario Ministry of Environment, 2012) results in only a basic understanding of surficial and shallow bedrock flow systems. The completeness of the information in the few water well records for the Schreiber area is uneven.

Groundwater flow regimes and the positions of recharge and discharges areas is inferred from other bedrock dominated areas and the type and distribution of surficial materials. The absence of information in the area on deep aquifers or groundwater geochemistry necessitates inferring conditions from similar geologic settings elsewhere in the Canadian Shield. Specific reports/studies include: Gascoyne, 1994, 2000, 2004; Gascoyne *et al*., 1996; Everitt *et al.,* 1996; Everitt, 1999; Ophori *et al.,*1996.

1.4.4 Natural Resources – Economic Geology

The Schreiber area has had an extensive history of mineral exploration and development, mainly focused on precious and base metals, extending over 150 years. The mineral potential of the Schreiber-Hemlo greenstone belt has resulted in bedrock geological mapping being concentrated on these rocks and the majority of geologic maps and reports noted in Section 1.5.1 containing information relevant to assessing the mineral potential of the area. The various types of precious and base metal deposits in the Schreiber area are described in Marmont (1984), Patterson *et al.* (1986), Carter (1988) and Smyk and Schnieders (1995). The mineral resource potential for other commodities is described by Springer (1978), Sage (1982), Hinz *et al*. (1994), Hinz and Landry (1994), Jagger Hims Limited *et al.* (2001), Morris (2001, 2002) and Campbell *et al.* (2012).

Several databases resulting from mineral exploration and/or mining activities in the Schreiber area are held by the MNDM/OGS and contain information useful to understanding the area's resource potential. The largest of these is the Assessment File Research Imaging (AFRI) database which consists of technical results of exploration programs on Crown Land (MNDM, 2012a). The AFRI database outlines the type of geoscience investigations completed and a summary of findings. The quality and usefulness of the files is highly variable; information varies from site-specific to regional and the level and/or amount of information from low to very high.

The OGS drillhole database is a collection of surface and underground drilling data compiled from some of the AFRI records (MNDM, 2012a). The database includes several fields including: drillhole location; drillhole orientation and depth; overburden depth; and the presence of assay results, if available.

The Mineral Deposits Inventory (MDI) database contains a record of base, precious and industrial mineral deposits, occurrences and showings in the Schreiber area and beyond (MNDM, 2012a). The level of information in each MDI record is highly variable, notably for small occurrences. In general, information is available on geological structure, lithology, minerals and mineral alteration, in addition to production and reserve data. Information quality is variable as the data are compiled from a range of sources and may not always be verified.

The Abandoned Mines Information System (AMIS) contains the location of past-producing mines sites in the area and augments mineral potential evaluations (MNDM, 2012a). The database has records on mining-related features including mining hazards and abandoned mines and is generally considered to be accurate.

Regional-scale geochemical sampling of glacial materials, lake sediments and lake waters has been conducted by the OGS and GSC and reported on for the Schreiber area (Friske *et al.*, 1991; Dyer, 1997a, 1997b). The sampling, primarily conducted to identify mineral exploration targets, is useful in defining mineral potential and can play a role in establishing environmental baseline conditions. The geochemical data from these surveys is of high quality.

1.4.5 Geomechanical Properties

Available geotechnical studies in the area are restricted to near-surface investigations involving surficial materials and the upper few metres of bedrock. The Ontario Ministry of Transportation GeoCres database contains only four records for the area. The geotechnical investigations in the area, especially the more recent ones, are of high quality but add little to the understanding of conditions at depth.

While a large amount of mineral exploration drilling has been completed in the area, some to considerable depths, the bulk of the boreholes are within the metavolcanic units associated with the Schreiber-Hemlo greenstone belt. While numerous boreholes have high quality information on lithology variations, and some geophysical logs, geotechnical testing on core is largely absent.

As geotechnical information on the felsic intrusive bodies at repository depth is lacking, it must be inferred from studies completed on other locations. As such, inferences have been made from geomechanical information derived from similar sites elsewhere in the Canadian Shield, the majority of which was completed under the auspices of Atomic Energy of Canada Limited (AECL) in the 1980s and 1990s as part of the Canadian Nuclear Fuel Waste Management Program. Information on the geomechanical properties of granitic rocks with conditions ranging from intact rock to highly fractured fault zones is available from AECL’s Underground Research Laboratory (URL) near Pinawa, Manitoba, and the Atikokan research area in Ontario (Brown *et al*., 1989; Stone *et al.*, 1989).

2 PHYSICAL GEOGRAPHY

2.1 Location

The Township of Schreiber, located along the north shore of Lake Superior approximately 150 km east of Thunder Bay (~200 km by road), encompasses roughly 40 km^2 and is bounded to the east by the Township of Terrace Bay. The Township of Schreiber and its periphery, referred to as the “Schreiber area”, is approximately 1100 km^2 in size (Figure 1.1). The village of Rossport is located immediately beyond the western boundary of the Schreiber area. A satellite image of the Schreiber area is presented as Figure 2.1, which is a colour composite of Landsat imagery. The composite image was created by assigning a primary colour (red, green and blue) to three of the Landsat multispectral bands. Different materials reflect and absorb solar radiation differently at different wavelengths and therefore have varying intensities within each of the Landsat bands. When combined into a single image, the chosen colour scheme approaches a “natural” representation, where, for example, vegetation appears in shades of green. Exposed soil or rock can appear in shades of pink.

Access to the area is via Ontario King’s Highway 17 (the Trans-Canada Highway) and rail line operated by Canadian Pacific Railways. The routing of both systems generally follows the Lake Superior coastline. Primary access to the interior of the Schreiber area is provided by two north-trending roads; one connecting with the main highway in Terrace Bay and the second approximately 8 km west of Schreiber. A network of forestry roads and trails provides limited access to other parts of the area.

2.2 Topography and Landforms

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

The Schreiber area is located within the Abitibi Upland physiographic region (Thurston, 1991), a subdivision of the extensive James physiographic region (Bostock, 1970). The region is generally characterized by abundant bedrock outcrop with shallow drift cover and a rugged topography.

The topography of the Schreiber area is presented on Figure 2.2. Bedrock-controlled terrain dominates the majority of the area and results in a significant difference in elevation over short distances (Figure 2.3); the maximum relief difference within the Schreiber area is approximately 402 m. The highest land within the area occurs just north of the Township of Schreiber (585 masl), and the lowest point equals the elevation of Lake Superior (~183 masl). Localized variations in elevation caused by bedrock knobs and ridges are prevalent throughout the majority of the Schreiber area.

Across the Schreiber area the elevation of hills and ridges is commonly between 300 and 500 m. There is, however, a general southward decrease in the elevation of hill tops from the 400 to 500 m range in the north to 300 to 400 m range in the south. A distinct area of consistently high elevation is located in the north-central portion of the Schreiber area, with elevations reaching over 580 masl. This higher elevation area becomes fragmented towards the south and the west, with valleys and local areas of lower elevation separating blocks of higher topography.

The central portion of the Schreiber area, underlain by the Crossman Lake batholith, contains a broad area of moderate elevation (Figure 2.2). South of this, the area underlain by the southern arm of the Schreiber-Hemlo greenstone belt contains local blocks of higher topography.

A broad, low-elevation surface, corresponding to a large area of glaciofluvial outwash and glaciolacustrine deposits, occurs in the southeast corner of the Schreiber area. This area, largely underlain by the Terrace Bay batholith, is morphologically distinct from the bedrock controlled terrain in terms of surface roughness; surface elevations for the area are in the 200 to 300 m range.

Distinct bedrock-controlled valleys, corresponding to the Pays Plat River in the west and the Aguasabon River in the east, border the area of high elevation that dominates the north-central portion of the Schreiber area. Other significant valleys occur along the trends of the mapped bedrock faults. The principal orientations of these bedrock-controlled valleys are northwest and north-northeast.

The Schreiber area is characterized by moderate to high relief (greater than 80 m), frequently over distances of less than 250 m, and very rugged topography consisting of knobby bedrock hills and steep escarpments. This is particularly noticeable in the southern two-thirds of the Schreiber area (excluding the southeastern corner). More moderate relief is present along the northern boundary of the Schreiber area where it is generally less than 80 m.

Glaciofluvial deposits generally represent areas of local low relief and near-level topography, although some deposits are characterized by protruding bedrock knobs. The glaciofluvial and glaciolacustrine deposits in the southwestern corner of the Schreiber area also display low relief (in the range of 20 to 40 m) over the majority of their surface area. Increased relief is present on these deposits in the Terrace Bay area due to the development of beach terraces by glacial lakes.

Due to the predominantly high relief and knobby topography, slopes within Schreiber area are steep and complex. The topography can be described as rugged due to the widespread distribution of bedrock knobs and ridges, and the numerous steep-sided, incised river valleys. Near-vertical escarpments are located across the Schreiber area, including along the Lake Superior coast south and west of the Township of Schreiber. In general, the orientation of escarpments align with the trend of several mapped faults that transect the area. The steep slopes in the area are an indicator of areas of minimal overburden cover. Areas with lower slopes, between the bedrock knobs, may represent pockets of locally thicker drift cover.

An area of low to moderate slopes occurs in the southeastern portion of the Schreiber area around Terrace Bay and the mouth of the Aguasabon River. Slopes on the glaciolacustrine and outwash plains only become steeper where bedrock knobs protrude or the deposits have been terraced by proglacial lakes.

2.3 Watersheds and Surface Water Features

The Schreiber area covers four quaternary watersheds, which drain into Lake Superior, and onward to the Atlantic Ocean through the Great Lakes and the St. Lawrence River system (Figure 2.4) (LIO, 2012). The Pays Plat River is the principal drainage course in the westernmost watershed in the Schreiber area. This watershed occupies the northwestern corner of the Schreiber area and drains into Lake Superior through the Pays Plat First Nation Reserve 51, located 6 km west of Rossport. The Whitesand River watershed is located immediately to the east and drains into Lake Superior through the 1.5 km long Hewitson River. This watershed extends as far inland as North Whitesand Lake and extends south to Selim, approximately 8 km west of Schreiber. The areas north and east of Rossport, and north, west and south of Schreiber are considered within this watershed. However, drainage from these areas flows directly into Lake Superior via a number of relatively short waterways.

The central portion of the Schreiber area is drained by the Big Duck Creek watershed, which extends from Charlotte Lake in the north to Schreiber where water discharges into Hays Lake. From this point water enters the Aguasabon River watershed which drains the eastern portion of the Schreiber area. Discharging into Lake Superior near Terrace Bay, the Aguasabon River watershed extends some distance to the north of the Schreiber area. The natural catchment area of this watershed has been enhanced by a diversion of a portion of the Kenogami River watershed north of Long Lac.

The orientation of the drainage network within the Schreiber area is largely controlled by bedrock valleys and the irregular surface topography. Due to this control, the majority of waterways, including lakes, have a north, northwestward or northeastward orientation. While the overall drainage in the area is southward, the catchment areas of individual lakes within the watersheds can result in short segments of northward flow.

The larger rivers draining the watersheds noted above are fed by numerous smaller creeks and rivers that effectively drain the vast majority of the Schreiber area. Creeks are lacking only in the region underlain by a notable thicknesses of glaciolacustrine and glaciofluvial deposits in the area surrounding Terrace Bay where drainage is through groundwater recharge. Typically, segments of the area’s waterways are short, on the order of less than 2 km, as they flow into and out of lakes occurring along the drainage paths.

The numerous lakes within the Schreiber area occupy approximately 7.6% of the land surface (i.e., excluding Lake Superior) and occur with an even distribution, excluding the area near Terrace Bay. The lakes, many of which are elongate in shape, reflect the pattern of bedrock valleys in the Schreiber area.

The larger water bodies in the Schreiber area are listed in Table 2.1. In general, the lakes are of a modest size with the majority having a surface area of less than 1.0 km^2. Bathymetric surveys have been conducted by the Ministry of Natural Resources (MNR) for 20 lakes in the Schreiber area. In addition to these detailed surveys, a lake sediment sampling survey conducted by the OGS recorded lake depths at approximately 630 locations in the Schreiber area

(Dyer, 1997a, 1997b). In this survey, a limited number of the larger lakes in the area had multiple sampling sites. While it was the intent of this survey to sample the deepest part of the lakes, this cannot be confirmed. The lake sediment survey data does, however, provide a general picture of lake depth.

Table 2.1: Size of lakes equal to or larger than 1.5 km^2 in the Schreiber area.

Lake	Area (km^2)	Perimeter (km)
Hays Lake	6.3	19.3
Aguasabon River	5.0	42.9
Whitesand Lake	2.8	23.6
Pays Plat Lake	2.5	13.3
Aguasabon Lake	2.3	23.1
Big Duck Lake	2.2	13.9
Lyne Lake	1.7	12.6
Carib Lake	1.5	20.0
Ellis Lake	1.5	12.8
Walker Lake	1.5	20.8

Table 2.2 indicates that approximately 60% of the lake sites measured by Dyer (1997b) have a water depth of less than 5 m. Lakes deeper than 20 m account for only 6.8% of the sites sampled. The deepest lake measurement in the Schreiber area obtained by the OGS survey was 40 m from Big Duck Lake.

Table 2.2: Lake depth data in the Schreiber area (from Dyer, 1997b).

Lake Depth (m)	Number of Lake Sites	Percentage
<5.0	375	59.8
5.1 – 10.0	110	17.5
10.1 – 15.0	75	11.9
15.1 – 20.0	27	4.3
20.1 – 25.0	18	2.9
25.1 – 30.0	11	1.7
>30.1	14	2.2

2.4 Land Use and Protected Areas

Figure 2.5 shows a summary of land disposition and ownership within the Schreiber area, including known protected areas (Golder, 2013).

2.4.1 Land Use

The vast majority of the Schreiber area is undeveloped Crown Land with residences almost exclusively within the Township areas of Terrace Bay and Schreiber or in close proximity to Highway 17, the Trans-Canada Highway. Privately-owned land is concentrated in the Townships of Schreiber and Terrace Bay, with smaller areas related to mineral rights ownership in the vicinity of the past-producing Winston Lake Mine and Big Duck Lake. Infrastructure to support the population, in the form of roads, power and rail lines, etc., is largely concentrated within 5 km of the Lake Superior shore. Two regional roads extend north from Highway 17; one joins the highway at Terrace Bay, and the other meets the highway approximately 8 km west of Schreiber at the south end of Whitesand Lake.

Forestry is a long-standing use of the land and has been an economic mainstay of the area. The area falls within MNR's Kenogami forestry management unit (MNR, 2012a). Timber harvesting, primarily to supply the pulp mill located in Terrace Bay (owned by the Aditya Birla Group), has occurred in several portions of Schreiber area. Current logging activities are focused in the northeastern quadrant.

Mineral exploration is active in the area and numerous active mining claims are held by prospectors and mining companies (Campbell *et al.*, 2012; MNDM, 2012b). The bulk of the claims are located over the two arms of the Schreiber-Hemlo greenstone belt and the immediate surrounding land. A range of exploration work is conducted on the claims to assess the mineral potential including geologic mapping, drilling, and geochemical and geophysical surveys. Several gold and base metal mines have operated in the area; however, none are currently operating. A number of aggregate operations are extracting sand and gravel in the area (MNR, 2012b). The majority of the pits are located close to the Trans-Canada Highway in the vicinity of Terrace Bay and Schreiber. A small number of pits are located near Selim. Natural resources are discussed further in Section 5.

Forestry and mineral sector activities result in the development of an extended road and/or trail network, although some of this access is of a temporary (e.g., open only while logging is on-going) or seasonal nature (e.g., winter roads). Access to the many lakes and remote areas within the Schreiber area allows use of the land for hunting and fishing by the local population and visitors to the region.

2.4.2 Parks and Reserves

Five protected areas are located within the Schreiber area, four near the Lake Superior coast and one along the western boundary (Figure 2.5). Rainbow Falls Provincial Park is located adjacent to Whitesand Lake near Selim, approximately 8 km west of Schreiber. The park has an area of 5.76 km^2 and offers day use and overnight camping (Ontario Parks, 2010). The Superior North Shore Conservation Reserve C2222 consists of an eastern segment bordering the lake southeast of Schreiber and a western segment extending along the coast southwest of Schreiber. The reserve contains landforms (i.e., cliffs and bays) representative of the coastal area within 11.47 km^2.

The Schreiber Channel Nature Reserve, a 0.32 km^2 site with no visitor facilities, is entirely contained within the western segment of the conservation reserve. The bedrock within the reserve contains micro-fossils of Precambrian age (Ontario Parks, 2010).

The Gravel River Conservation Reserve (C2225) occupies less than 2 km^2 of land on the western edge of the Schreiber area in the vicinity of Pays Plat Lake. The bulk of the conservation area's 466.3 km^2 occur to the north and west of the Schreiber area.

A number of islands in Lake Superior are under consideration as conservation reserves that may form part of the Lake Superior National Marine Conservation Area (Parks Canada, 2013; Figure 2.5).

2.4.3 Heritage Sites

Information on archaeological sites in Ontario is provided by the Ontario Ministry of Tourism and Culture, through their Archaeological Sites Database (Ontario Ministry of Tourism and Culture, 2012). Within the Schreiber area there are 13 known archaeological sites (Golder, 2011; Ontario Ministry of Tourism and Culture, 2012) all of which are along the Lake Superior coastline or in the lake. Five of the sites are in the Township of Terrace Bay, two are in the Township of Schreiber along the Lake Superior shoreline and four are along the coastline west of the Township of Schreiber. In addition, one site is located on Copper Island and a submerged shipwreck is present on the lake bottom south of Selim. There are no National Historic Sites in the Schreiber area.

The closest First Nation Reserve is Pays Plat which is located 23 km west of Schreiber. Additional First Nation-related archaeological and/or sacred sites may exist within the Schreiber area, notably along the Lake Superior coast. The presence, location and extent of local heritage sites would need to be further confirmed in discussion with the community and Aboriginal peoples in the area, if the community is selected by the NWMO, and remains interested in continuing in the site selection process.

3 GEOLOGY

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

The Schreiber area is mostly underlain by 3.0 to 2.6 billion-year-old (Ga) bedrock of the Superior Province of the Canadian Shield – a stable craton created from a collage of ancient plates and accreted juvenile arc terranes that were progressively amalgamated over a period of more than 2 billion years (Figure 3.1). The Canadian Shield forms the stable core of the North American continent.

The Superior Province covers an area of approximately 1,500,000 km^2 stretching from the Ungava region of northern Québec through the northern part of Ontario and the eastern portion of Manitoba, and extending south to Minnesota and the northeastern part of South Dakota. The Superior Province is divided into subprovinces, medium- to large-scale regions that are each characterized by their similar rock types, structural style, isotopic age, metamorphic grade and mineral deposits (Figure 3.1). The Schreiber area is primarily within the Wawa Subprovince, which is a volcano-sedimentary-plutonic terrane bounded to the east by the Kapuskasing structural zone and to the north by the metasedimentary-dominated Quetico Subprovince (Figures 3.1 and 3.2). The western end of the Wawa Subprovince is covered to the west by Proterozoic rocks of the Southern Province.

The Wawa Subprovince is composed of well-defined greenstone belts of metamorphosed komatiite, basalt, dacite and rhyolite and associated metasedimentary rocks, separated by granitoid plutons and batholiths. The metasedimentary rocks include turbiditic wacke, minor conglomerate and iron formation. Stratigraphic and structural relationships between these units of volcanic and sedimentary rocks are usually unclear and commonly masked by later shearing (Williams *et al*., 1991). The granitoids that separate the greenstone belts, and comprise 20 to 30 percent of the landmass, consist of massive, foliated and gneissic tonalite-granodiorite, which are cut by massive to foliated granodiorite and granite. The majority of the granitoids were intruded during or after the deposition of the greenstone belts with which they are associated (Williams *et al.,* 1991).

The Quetico Subprovince, occurring in the northern portion of the area, consists primarily of clastic metasedimentary rocks that have undergone amphibolite-facies metamorphism. Granitic intrusions are widely present while mafic to ultramafic intrusions occur sporadically (Williams, 1989; Sutcliffe, 1991). Proterozoic bedrock of the Southern Province, age 1.9 to 1.1 Ga, occurs to the south of the area with a small volume present in the southwest corner of the Schreiber area (Figure 3.3 and 3.4). These metasedimentary and metavolcanic rocks unconformably overlie and/or intrude the Archean rocks of the Superior Province.

In more recent years, a subdivision of the Superior Province into lithotectonic terranes and domains has been developed (Percival and Easton, 2007; Stott, 2010; Stott *et al*., 2010). Terranes are defined as regions with tectonic boundaries with distinct characteristics, while domains refer to lithologically distinct portions within a terrane (Stott, 2010; Stott *et al.,* 2010). The Schreiber area is located in the Wawa-Abitibi terrane, a region composed of a series of plutonic and gneissic rocks interspersed with greenstone belts (Figure 3.2). This terrane has a length of approximately 2200 km, stretching westward from central Québec, across the width of Ontario and into northern Minnesota. Within Ontario, the terrane is juxtaposed to the north by the Quetico Basins terrane and to the south by overlying Proterozoic Basins (e.g., the rocks of the Southern Province).

Within the Wawa Subprovince are two semi-linear zones of greenstone belts, the northern of which includes the Shebandowan, Schreiber-Hemlo, Manitouwadge-Hornepayne, White River, Dayohessarah and Kabinakigami greenstone belts. The southern zone contains the Michipicoten, Mishibishu and Gamitagama greenstone belts which are located west of the Kapuskasing structural zone, well southeast of the Schreiber area (Figure 3.2) The Schreiber area is situated in the western portion of the Schreiber-Hemlo greenstone belt (sometimes referred to as the Terrace Bay-Schreiber greenstone belt). This greenstone belt is divided into a western and eastern portion by the Proterozoic Coldwell alkalic intrusion (Figure 3.2).

The Schreiber-Hemlo greenstone belt consists of a number of narrow, arcuate segments of supracrustal rocks that are bounded and enclosed by granitoid bodies, including the Crossman Lake and Whitesand Lake batholiths (Figure 3.3). The Schreiber-Hemlo greenstone belt is divided into three lithotectonic assemblages by Williams *et al.* (1991); the Schreiber, Hemlo-Black River, and Heron Bay assemblages. The Schreiber and Hemlo-Black River assemblages are separated by the Proterozoic Coldwell alkalic complex (north of the town of Marathon). The Hemlo-Black River and Heron Bay assemblages are located to the north and south of the Lake Superior-Hemlo fault zone (to the east and outside of the Schreiber area), respectively.

Published bedrock geological maps of the region surrounding Schreiber indicate a number of faults that range in length from a few kilometres to several tens of kilometres (Figure 3.3). Faulting occurred over a protracted time period as it began during the formation of the greenstone belts and continued to be active until after the coalescence of the Wawa and the Quetico Subprovinces (i.e., ~2.770 to 2.675 Ga; Williams *et al.*, 1991). It is possible that fault reactivation may have occurred during Proterozoic and Phanerozoic events. All faults shown on the published geological maps of the area are late faults that cross-cut the greenstone belts.

Large regional features close to the Schreiber area include the Midcontinent rift system (Sutcliffe, 1991; Thurston, 1991; Easton et al., 2007) and the Gravel River fault which are located approximately 5 km to the south and 40 km to the northwest, respectively, from the boundary of the Town of Schreiber (Figure 3.3).

3.1.2 Geological History

The development of the early Wawa-Abitibi terrane took place during the period between ca. 3.0 to 2.77 Ga through progressive accretion of rock assemblages produced in several geological environments. Volcanic and sedimentary rock assemblages from several of these environments, including oceanic shelves, volcanic island arc and trench settings, were amalgamated to form an emerging land mass. Progressive aggregation of the assemblages into linear belts took place and these belts were subsequently intruded by calc-alkalic volcanic centres and major batholithic complexes. Several stages of aggregation and calc-alkalic magmatism are recorded in the Wawa Subprovince (Williams *et al.*, 1992).

The development of the portion of the Wawa-Abitibi terrane that comprises the Schreiber-Hemlo greenstone belt began ca. 2.770 Ga and continued to as late as ca. 2.678 Ga (Williams *et al.*, 1991; Muir, 2003). U-Pb geochronology of igneous zircon from rhyolitic host rocks to the Archean Winston Lake massive sulfide deposit, shows that volcanism, which accompanied mineralization, occurred at 2723 ±2 Ma (Davis *et al.*, 1994). Volcanism was dominant in the early stages of the greenstone belt's development, with sedimentary and igneous activity becoming significant after ca. 2.693 Ga (Muir, 2003). Several periods of ductile-brittle deformation are recorded during the formation of the greenstone belt.

The latter stages of development of the greenstone belt coincided with the coalescence of the Wawa and Quetico Subprovinces during the period of ca. 2.690 to ca. 2.680 Ga (Stott, pers comm. 2013). The intrusion of large batholiths, including the Crossman Lake, Whitesand Lake and Terrace Bay, is interpreted to have occurred around this time (Santaguida, 2002), but the timing is poorly constrained. Regional metamorphism in the Schreiber area occurred during the final stage of subprovince amalgamation and continued to approximately 2.675 Ga.

The geological history of the Schreiber area during the Proterozoic (i.e., post-Archean) is enigmatic as the rock record is not well-preserved. During the early development of the Southern Province, 2.5 to 2.2 Ga, deposition of sedimentary rocks of the Paleoproterozoic Huronian Supergroup occurred in basins to the south of the Schreiber area (Young *et al*., 2001). There is no evidence to indicate the former existence of Huronian rocks in the Schreiber area. However, the occurrence of tillites in the Huronian package elsewhere in Ontario may suggest periods of glaciation may have affected the Schreiber area. If this were the case, any deposits related to glacial events have been removed by subsequent erosion.

Clastic sedimentary rocks of the Paleoproterozoic Animikie Group unconformably overlie the Archean rocks along the southernmost portion of the Schreiber area and the area to the west (i.e., in the Thunder Bay area; Figure 3.2). Assuming that the surface distribution of the Animikie Group has been reduced by erosion, it is possible that these rocks may have extended further across the Schreiber area. The Animikie Group is interpreted to have been deposited prior to, and during, the Penokean Orogeny (~2.1 to 1.86 Ga; Sutcliffe, 1991) with Fralick *et al.* (2002) assigning an age of 1.878 Ga. There is no evidence that the bedrock in the Schreiber area was notably deformed by the Penokean Orogeny.

Deposition of Mesoproterozoic clastic and chemical sedimentary rocks (Sibley Group) in the Schreiber area after ca.1.4 Ga (Rogala *et al.,* 2007) may have been controlled by the sagging of the lithosphere during pre-Grenville extension (Sutcliffe, 1991). These sedimentary rocks unconformably overlie Archean and Animikie Group rocks. While their current distribution is largely restricted to a half-graben trending northward from Lake Superior to Lake Nipigon, a wider historic coverage is likely, inferring the possibility of deposition and subsequent erosion in the Schreiber area.

A significant tectonic event, known as the Midcontinent Rift, occurred at ca. 1.11 to 1.09 Ga years in present-day northwestern Ontario region. The event involved voluminous deposition of volcanic rocks and minor deposition of sedimentary units. These rocks, deposited in grabens bound by normal faults that formed during the formation of the Midcontinent Rift (Sutcliffe, 1991), are dominantly located to the west of the Schreiber area although they form some of the islands in the southern part of the Schreiber area. Keweenawan dykes associated with this tectonic event are generally narrow east-striking features that bend to link with more northeast- to north-striking features to the south and west of the Schreiber area (Osmani, 1991). No tectonic activity is evident in the Schreiber area following the intrusion of these dykes.

Little is known of the geological conditions during the late Mesoproterozoic and the Neoproterozoic due to a lack of rock record. It may be inferred that one or more periods of non-deposition and/or erosion affected the Schreiber area and large parts of the Canadian Shield during this period. No evidence of tectonic activity exists for this period in the Canadian Shield.

At the start of the Paleozoic (ca. 540 Ma), a large portion of Ontario was covered by seas in which carbonate and clastic sedimentary units were deposited. Whilst it can be inferred that Cambrian to Devonian sedimentary rocks once covered large portions of the Canadian Shield between Hudson Bay and Lake Ontario (Johnson *et al.*, 1992), these rocks are not preserved in the Schreiber area. There is no indication that the tectonic events that controlled the deposition of these sedimentary rocks affected the Schreiber area.

During the early Paleozoic, a meteor impact occurred southeast of the Schreiber area, approximately 10 km south of Terrace Bay. The Slate Islands impact structure is the eroded remnant of a 30 to 32 km wide feature (Figure 3.3). It can be speculated that the islands are a result of uplift associated with and immediately following meteorite impact. However, no studies have been undertaken to determine whether the present height of the islands are the result of uplift, collapse or erosion, or a combination of these factors. The impacted rocks are Archean and Proterozoic supracrustal (greenstone) and intrusive rocks. The $^{40}Ar/^{39}Ar$ release spectra from two pseudotachylite samples suggest an age of ca. 436 Ma for the Slate Islands impact (Dressler *et al.*, 1999). Whether the impact could have reactivated Precambrian faults in the Schreiber area is an open question.

Erosion is believed to be the dominant geological process affecting the Schreiber area from the Late Paleozoic until at least the Late Mesozoic (Johnson *et al.*, 1992). Sedimentary deposits resulting from this erosional event have not been documented in the Schreiber area. Marine and terrestrial deposits of Cretaceous age are found in the Moose River Basin, James Bay Lowland area, ~400 km to the northeast of Schreiber. Rocks of similar age have not been documented in the Schreiber area.

Erosion is also thought to have been the dominant process affecting the Schreiber area during the Paleocene to Neogene (ca. 67 to 2.5 Ma; Johnson *et al.*, 1992) and no sedimentary deposits of this age have been recorded in the Schreiber Area. During the Quaternary (2.6 Ma years to present), large parts of North America were covered by continental ice sheets. In the Schreiber area, glacial and interglacial deposits, associated with the most recent ice advance during the Late Wisconsinan (ca. 30 Ka), have been recorded.

Table 3.1 outlines the major events in the geological history of the Schreiber area.

Table 3.1: Summary of the Geological and Structural History of the Schreiber area

Approximate Time period (years before present)	Geological Event
3.000 to 2.770 Ga	Progressive growth of the Wawa-Abitibi terrane by accretion of oceanic plateau sequences; volcanic island arc sequences; and arc-derived, syn-kinematic siliciclastic trench turbidites as collages along a SSE-facing convergent plate margin through compressional and transpressional collisions (Polat *et al.*, 1998; Polat, 2009).
2.770 – 2.678 Ga	An extended period of volcanism and sedimentation associated with the formation of the Schreiber-Hemlo greenstone belt. - ca. 2.770 Ga: Formation of the Hemlo-Black River Assemblage (Williams *et al*., 1991) - ca. 2.700 Ga: Formation of the Heron Bay Assemblage (Williams *et al.*, 1991) - ca. 2.697 to 2.688 Ga: Mafic, calc-alkalic and felsic volcanism (Corfu and Muir, 1989; Muir, 2003) - ca. 2.693 to 2.685 Ga: Deposition of clastic and chemical sedimentary rocks (Muir, 2003) - ca. 2.690-2.680 Ga: Inferred emplacement of granitoid intrusions in the Schreiber area (Corfu and Muir, 1989; Smyk and Schnieders, 1995). During the formation of the greenstone belt, four periods of ductile-brittle deformation (D_1-D_4) are recognized as occurring between ca. 2.719 and 2.679 Ga (Muir, 2003).
2.690 to 2.684 Ga	Coalescence of the Wawa and Quetico Subprovinces (Corfu and Stott, 1996).
2.688 to 2.675 Ga	Regional metamorphism (Muir, 2003).
2.688 to 2.675 Ga	Emplacement of granitoid intrusions including the Terrace Bay, Crossman Lake and Whitesand Lake batholiths, and the Mount Gwynne pluton.
2.473 Ga	Emplacement of northwest-trending Matachewan swarm of dykes (Buchan and Ernst, 2004).
2.400 to 2.200 Ga	Development of the Southern Province; possible deposition and subsequent erosion of sedimentary rocks in the Schreiber area.
2.167 Ga	Possible emplacement of the northeast-trending Biscotasing dyke swarm (Hamilton *et al*., 2002). These dykes cannot be separated with confidence from the Marathon dykes.
2.121 Ga	Emplacement of north-trending Marathon dyke swarm (Buchan *et al*., 1996; Hamilton *et al.*, 2002).
2.100 to 1.860 Ga	Penokean Orogen. Deposition of the Animikie Group sedimentary rocks to the west. Possible deposition and subsequent erosion in the Schreiber area.
1.400 Ga	Possible deposition and subsequent erosion of Mesoproterozoic Sibley Group clastic sedimentary rocks (Rogala *et al.*, 2007).
1.150 to 1.090 Ga	Formation of the Midcontinent Rift that resulted in the voluminous deposition of volcanic rocks and minor deposition of sedimentary units. Emplacement of west–trending Keweenawan swarm of dykes related to mid-continental rifting that was centred on proto-Lake Superior (Sutcliffe, 1991; Thurston, 1991; Easton *et al.,* 2007).
1.100 to 1.086 Ga	Deposition of the Osler Group (Sutcliffe, 1991).

Table 3.1: Summary of the Geological and Structural History of the Schreiber area

Approximate Time period (years before present)	Geological Event
540 to 355 Ma	Possible coverage of the area by marine seas and deposition of carbonate and clastic rocks subsequently removed by erosion. Slate Islands meteor impact ca. 436 Ma (Dressler *et al.*, 1999).
145 to 65 Ma	Possible deposition of marine and terrestrial sediments of Cretaceous age, subsequently removed by erosion.
2.6 to 0.01 Ma	Periods of glaciation and deposition of glacial sediments.

3.1.3 Regional Structural History

Direct information on the geological and structural history of the Schreiber area is limited and is mostly based on insights from structural investigations on the Hemlo gold deposit and surrounding region (i.e., the eastern portion of the Schreiber-Hemlo greenstone belt, shown in Figure 3.3). These studies revealed that the region has undergone complicated polyphase deformation but do not clarify the inter-relationship between various structures and their significance for the regional tectonic evolution (Polat *et al*., 1998). Since the various structural studies were carried out on various scales and from different perspectives, disparate structural models and associated terminologies have been developed for the Schreiber-Hemlo greenstone belt. In addition, because more than one generation of structures may develop in a single episode of progressive deformation, correlating the different structural studies is a challenge. It is understood that there are potential problems in applying a regional deformation numbering (D_x) system into a local geological history. This summary represents an initial preliminary interpretation for the Schreiber area, which would need to be reviewed through detailed site-specific field studies.

The most comprehensive structural study in the Schreiber-Hemlo greenstone belt was conducted by Muir (2003) on the eastern portion of the greenstone belt in the vicinity of the Hemlo gold mines, approximately 100 km to the east. Since no previous detailed structural studies have been undertaken in the Schreiber area, Muir's (2003) findings on the structural history are included in the summary below, and may be used as a "best-fit" for the structural history of the Schreiber area. The summary below integrates findings from Muir (2003) with information based on Carter (1988), Polat *et al.* (1998), Jackson (1998), Polat and Kerrich (1999), and Davis and Lin (2003).

Polat *et al.* (1998) and Polat (2009) interpreted the Schreiber-Hemlo and surrounding greenstone belts to represent collages of oceanic plateaus, oceanic arcs, and subduction-accretion complexes amalgamated through subsequent episodes of compressional and transpressional collision. On the basis of overprinting relationships between different structures, Polat *et al.* (1998) suggested that the Schreiber-Hemlo greenstone belt underwent at least two main episodes of deformation. This can be correlated with observations from Muir (2003), who reported at least six generations of structural elements. Two of these generations of structures account for most of the ductile strain, and although others can be distinguished on the basis of crosscutting relationships, they are likely the products of progressive strain events. The main characteristics of these deformation phases are described below.

The earliest deformation phase (D_1) is associated with the development of slaty cleavage (S_1) and asymmetric boudins in metasedimentary rocks. In metavolcanic rocks, D_1 is associated with asymmetric boudins, mesoscopic closed to isoclinal (overturned) folds (F_1) and associated D_1 thrust faults. Muir (2003) included the development of

S_1 compositional layering as part of this deformation event. Despite the orientation of F_1 folds being modified during subsequent deformation, the regionally consistent asymmetry of the F_1 overturned folds, combined with S-C fabrics along ductile D_1 thrust faults, suggests a south-southeast tectonic vergence. Muir (2003) suggested that D_1 likely occurred from ca. 2.719 Ga to 2.691 Ga.

D_2 deformation structures (D_1 in Jackson, 1998) are ubiquitous in the Schreiber-Hemlo greenstone belt and include dominantly east-northeast trending overturned tight to isoclinal F_2 folds, D_2 thrust faults, and northeast- to east-trending D_2 strike-slip faults (collectively forming D_2 fold and thrust duplexes) that overprint or fold D_1 structural elements. During D_2 deformation, the predominantly steep northward-dipping S_2 foliation was developed. The S_2 foliation is characterized by a preferred alignment of phyllosilicate and mafic minerals and flattening and (or) elongation of clasts (Davis and Lin, 2003; Muir, 2003). Several kilometre-scale F_2 folds, with dominant S-shaped asymmetry, developed during D_2 deformation (Muir, 2003). Whereas Polat *et al.* (1998) interpreted that D_2 developed during dextral transpression, Lin (2001) interpreted D_2 deformation as an episode of sinistral transpression based on local observations from the Hemlo shear zone. Muir (2003) suggested that D_2 likely initiated at ca. 2.691 Ga and continued until ca. 2.683 Ga.

Lin (2001) further distinguished open to tight folds with a well-developed axial planar cleavage associated with north-south compression and a dextral strike-slip component. It is not clear whether these structures represent a separate deformation event. If D_2 deformation represents a stage of dextral transpression, as interpreted by Polat *et al*. (1998), these structures can be interpreted to result from the prolongation of D_2 deformation. However, if D_2 represents a stage of sinistral transpression, it follows that these structures must be related to a separate D_3 deformation phase.

Based on observations in the vicinity of the Hemlo gold deposit, Muir (2003) distinguished a variably developed S_3 mineral and (or) crenulation foliation and F_3 folds, which overprint D_2 structural elements. Muir (2003) noted that these features are particularly well-developed within schistose units. Local D_3 S-C shear fabrics and extensional shear bands record a dextral sense of shear, which conforms to their development during dextral transpression as interpreted by Lin (2001). Muir (2003) interpreted that a period of near peak metamorphic temperatures bridged the D_2-D_3 transition from ca. 2.688 Ga to ca. 2.675 Ga.

Again, founded on observations in the vicinity of the Hemlo gold deposit, Lin (2001) and Muir (2003) recognized D_4 structural elements, including F_4 kink folds and various sets of D_4 fractures and small-scale faults. Muir (2003) interpreted that the orientation of conjugate sets of D_4 contractional kink bands is consistent with their development during northwest- to west-northwest–directed shortening. Northwest-directed D_3-D_4 shortening is estimated to have occurred from ca. 2.682 Ga to 2.679 Ga (Muir, 2003).

Based on this summary, it may be surmised that a prolonged period of brittle-ductile deformation spanning D_1 to $D_{4,}$ comprising both compression and transpression, occurred between ca. 2.719 Ga and 2.679 Ga. It should be noted that this age range partly overlaps with the inferred ages for granitoid intrusions (ca. 2.690 to 2.680 Ga), which suggests that these intrusions may have been affected by D_2-D_4 deformation.

A later stage of deformation (D_5) is present in greenstone and granitic rocks in the Schreiber area. This event is only described in literature as “post-D_4 brittle structures subparallel to S_2 foliation in the Hemlo greenstone belt” (Lin, 2001). This event, interpreted to form brittle lineaments, occurred after emplacement of granites and Proterozoic dykes (post ca. 2.121 Ga). However, absolute age constraints are not available for this phase of deformation. Lineaments interpreted to be associated with this event trend northwest (SRK, 2013).

A D_6 deformation event in the Schreiber area is also inferred in the greenstone and granitic rocks by north-northwest-trending brittle features (SRK, 2013). They are only described in the literature as “post-D_4 southeasterly-trending dextral strike-slip faults in the Hemlo greenstone belt” (Lin, 2001). Other than that these faults post-date the intrusion of Proterozoic diabase dykes and there are no published estimates for the timing of this post-D_4 brittle deformation.

3.1.4 Mapped Regional Structure

The east-west-trending Wawa-Quetico subprovince boundary occurs along the northern edge of the Schreiber area (Figure 3.3 and 3.4). The boundary is a northward-dipping zone of highly sheared rocks that locally displays high grades of metamorphism. Kinematic indicators show a general north over south displacement (Williams *et al.*, 1991).

In the Schreiber area, several faults that are likely related to the post-D_4 faults (i.e., D_5 and D_6 events) are indicated on public domain geological maps (Carter, 1981a-d, 1982a, 1982b; OGS, 2011). These include the major northwest- and north-northwest-trending faults, namely from west to east, the Sox Creek fault, the Ross Lake fault and the Cook Lake fault (Figure 3.4). In addition, a number of other unnamed faults with a similar orientation have been recognized in the area.

A number of northeast-trending faults are also indicated on the geological maps of the Schreiber-Terrace Bay area (Carter, 1981a-d, 1982a, 1982b; OGS, 2011). The largest of these that have been named are, from west to east: the Schreiber Point fault and it extension; the Syenite Lake fault; the Worthington Bay fault; and the Ellis Lake fault (Figure 3.4). A small number of other faults with the same orientation, all of limited length, have been identified in the Schreiber area. The timing and kinematics of these faults are not described in literature, but may potentially be interpreted as a conjugate set to the northwest-trending faults.

Carter (1988) conducted a field mapping program and developed geological maps for the Schreiber area, primarily on the basis of 1:15,840 scale aerial photographs and north-south-trending traverse mapping at roughly quarter mile intervals. As a result of this mapping program, Carter (1988) attempted an interpretation of the fault movement along some of the faults shown on public domain geological maps. No supporting structural information was included in Carter (1988), so it is assumed that the fault movement interpretation was derived from aerial photographs. Carter’s (1988) interpretation is included here for historical reference. Carter (1988) interpreted the Sox Lake fault and the Schreiber Point fault as dextral strike-slip faults; the Cook Lake fault and Syenite Lake fault as dip-slip faults; and the Worthington Bay fault as a sinistral strike-slip fault.

3.1.5 Metamorphism

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in a few publications since the 1970s (e.g., Fraser and Heywood 1978; Kraus and Menard, 1997; Menard and Gordon, 1997; Berman *et al.*, 2000; Easton, 2000a and Easton, 2000b; and Berman *et al*., 2005) and the thermochronological record for large parts of the Canadian Shield is documented in a number of studies (Berman *et al*., 2005; Bleeker and Hall, 2007; Corrigan *et al*., 2007; and Pease *et al*., 2008).

The Superior Province of the Canadian Shield largely preserves low pressure – high temperature Neoarchean (ca. 2.710-2.640 Ga) metamorphic rocks. The relative timing and grade of regional metamorphism in the Superior Province corresponds to the lithological composition of the subprovinces (Easton, 2000a; Percival *et al*., 2006). Subprovinces comprising volcano-sedimentary assemblages and synvolcanic to syntectonic plutons (i.e., granite-greenstone terranes) are affected by relatively early lower greenschist to amphibolite facies metamorphism.

Subprovinces comprising both metasedimentary- and migmatite-dominated lithologies, such as the English River and Quetico, and dominantly plutonic and orthogneissic domains, such as the Winnipeg River, are affected by relatively late 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). Most late orogenic shear zones in the Superior Province and Trans-Hudson Orogen experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through Ar/Ar dating to ca. 2500 Ma the value of which remains unclear (Powell *et al.* 1995).

A widespread Paleoproterozoic tectonothermal event, the Trans-Hudson Orogeny, involved volcanism, sedimentation, plutonism and deformation that affected the Churchill Province through northernmost Ontario, western Manitoba, northern Saskatchewan and Nunavut (e.g., Skulski *et al.*, 2002; Berman *et al.,* 2005). This event was associated with ca. 1.84 to 1.8 Ga collisional convergence of the Archean Hearne domain and Superior Province (Kraus and Menard, 1997; Menard and Gordon, 1997; Corrigan *et al*., 2007). Associated metamorphism at moderate to high temperatures and low to moderate pressures resulted in amphibolite facies metamorphism that overprinted Archean metamorphic signatures in Archean rocks of the Churchill Province, and a complex brittle overprint in Archean rocks of the Superior Province (e.g., Kamineni *et al*., 1990).

Along the eastern flank of the Canadian Shield, the Grenville Province records a complex history of episodic deformation and subgreenschist to amphibolite and granulite facies metamorphism, from ca. 1.300 Ga to 950 Ma (Easton, 2000b; Tollo *et al*., 2004 and references therein). Lower greenschist metamorphism was documented along faults in the vicinity of Lake Nipigon and Lake Superior and is inferred to be the result of ca. 1 Ga far-field reactivation during the Grenville Orogeny (Manson and Halls, 1994).

In northwestern Ontario, the concurrent post-Archean effects, including the Trans-Hudson Orogen, are limited to poorly documented reactivation along faulted Archean terrane boundaries (e.g., Kamineni *et al*., 1990 and references therein). Most late orogenic shear zones in the Superior Province and Trans-Hudson Orogen experienced lower to middle greenschist retrograde metamorphism (e.g., Kamineni *et al*., 1990 and references therein).

Overall, most of the Canadian Shield preserves a complex episodic history of Neoarchean metamorphism overprinted by Paleoproterozoic tectonothermal events culminating at the end of the Grenville orogeny ca. 950 Ma. The distribution of contrasting metamorphic domains in the Canadian Shield is a consequence of relative uplift, block rotation and erosion resulting from Neoarchean orogenesis, subsequent local Proterozoic orogenic events and broader epeirogeny during later Proterozoic and Phanerozoic eons.

In the Schreiber area, the metamorphic grade of exposed Archean rocks is upper greenschist facies (Williams *et al*., 1991). Locally, higher metamorphic grades, up to upper amphibolite facies, are recorded in rocks along the margins of plutons. No records exist that suggest rocks in the Schreiber area may have been affected by thermotectonic overprints related to post-Archean events.

3.1.6 Erosion

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

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

3.2 Local Bedrock and Quaternary Geology

3.2.1 Bedrock Geology

The bedrock geology of the Schreiber area is shown on Figures 3.3, 3.4 and 3.5. The reduced to pole residual magnetic field and its first vertical derivative over the Schreiber area are shown in Figures 3.6 and 3.7, respectively and regional Bouguer gravity data are shown on Figure 3.8. A detailed interpretation of geophysical data was carried out as part of this preliminary assessment (Mira, 2013) and summarized in this section.

The main geological units in the Schreiber area include several granitoid batholiths (Terrace Bay, Crossman Lake and Whitesand Lake), a granitoid pluton (Mount Gwynne), the supracrustal rocks of the Schreiber assemblage of the Schreiber-Hemlo greenstone belt, and several suites or swarms of mafic diabase dykes. Each of these sets of rock units is discussed in more detail below.

A schematic cross section of the bedrock in the Schreiber area, reproduced from Santaguida (2002), is presented in Figure 3.5. The figure illustrates the spatial relationship of the Schreiber-Hemlo greenstone belt and some of the batholiths in the area. The batholiths are interpreted to underlie the supracrustal rocks, to an undetermined depth, and may be cut by deep faults. While Santaguida (2002) interpreted that the units within the greenstone belt have a shallow dip, Carter (1982b) noted that foliation, and parallel-bedding and pillow structures, dip steeply in parts of the area. Given that the latter is based on factual observation, Santaguida's representation may be considered as highly simplified for illustrative purposes. The location of mineral deposits in Figure 3.5 is schematic and not geographic.

3.2.1.1 Granitoid Intrusive Rocks

Within the Schreiber area, massive granite to granodiorite intrusions are present within and adjacent to the Schreiber-Hemlo greenstone belt (Figure 3.4). These intrusions are typically composite, ovoid intrusions that vary in size up to 25 km in diameter. These intrusions range from dominantly granite and granodiorite to quartz diorite, syenite and quartz monzonite (and their gneissic equivalents) and also include some aplite and pegmatite dykes. These intrusions likely formed by partial melting of mafic to ultramafic sources (e.g., Polat, 1998).

Granitoid intrusions in the Hemlo assemblage of the Schreiber-Hemlo greenstone belt, approximately 100 km to the east, returned ages between ca. 2.688 and 2.678 Ga (Corfu and Muir, 1989). Due to the similar character and emplacement style of granitoid intrusions in the Schreiber assemblage of the Schreiber-Hemlo greenstone belt, these are also considered to be emplaced during this time period (i.e., concurrent with or postdating regional penetrative deformation; Corfu and Muir, 1989; Smyk and Schnieders, 1995). In addition, U-Pb age dates from the

GSC's geochronology database for the Marathon-Hemlo area provides dates of 2.681 and 2.690 Ga for the granitoids.

The prominent granitoid intrusions in the Schreiber area include the Terrace Bay, Crossman Lake and Whitesand Lake batholiths, and the Mount Gwynne pluton (Figure 3.4). In total, these intrusions cover approximately 495 km^2 within the Schreiber area. The emplacement of these batholiths followed regional metamorphism and resulted in the development of contact aureoles increasing the metamorphic grade of the adjacent greenstone belt rocks to amphibolite grade (Marmont, 1984). The thickness of the granitoid bodies is not known. However, given the timing of their emplacement and their size, with the exception of the Mount Gwynne pluton, it is expected that they extend well below the depth at which a repository would be developed.

Terrace Bay Batholith

The Terrace Bay batholith is located in the southeastern part of the Schreiber area (Figure 3.4) and trends northeast, at an angle to the strike of the generally easterly trending greenstone belt rocks. The Terrace Bay batholith covers 67 km^2 within the Schreiber area. The predominant rock type is massive, homogeneous, equigranular and medium-grained biotite-hornblende granodiorite to biotite alkali-feldspar granite, with common variations in texture, grain size and colour from minor hornblende-biotite quartz diorite to hornblende-biotite quartz monzonite (Marmont, 1984; Carter, 1988). Alkali-feldspar granite occurs along the northern boundary of the batholith, which is medium-grained and massive to slightly foliated. Locally, foliation appears to represent small-scale faults characterized by a cataclastic texture. Quartz monzonite and quartz monzodiorite are massive and medium-grained. Minor phases in the batholith occur as dykes and irregular intrusive bodies at the contact with the metavolcanic rocks, or as independent dykes intruding metasedimentary and metavolcanic rocks of the greenstone belt (discussed in Section 2.2.2) within 1.5 km of the contact. Compositionally the dykes comprise aphyric and porphyritic rocks.

The magnetic response observed over the batholith is characterized generally by a negative expression (Mira, 2013). Processed magnetic images reveal the magnetic texture of the Terrace Bay batholith to be relatively flat. However, the southwestern edge of the batholith exhibits a higher magnetic response. Much of the Terrace Bay batholith is transected by several uniformly-spaced, east-west-trending linear magnetic perturbations, representing Keweenawan dykes (Mira, 2013), which extend through the entire batholith into adjacent greenstone units to the west and northwest, and continue well outside of the Schreiber area to the east (SRK, 2013).

The northern contact of the Terrace Bay batholith locally appears as a sharp magnetic contact with the adjacent greenstone belt rocks, which exhibit an increased magnetic response and magnetic intensity. This contact follows a well-defined east-northeast trend that is generally coincident with the mapped bedrock geology. However, on the basis of the magnetic response, it could be interpreted that the geological contact occurs ca. 1 km further north of where it is interpreted on the mapped bedrock geology (Mira, 2013). It has to be taken into account that the magnetic data predominantly reflect the subsurface response, which may not match the mapped surface bedrock contact, and that the difference in interpretation of the geological contact may therefore be the result of dipping geological units.

Radiometric data shows a relatively moderate response in all radioelement concentrations throughout the Terrace Bay batholith, and exhibits a discrete contact between the batholith and the greenstone units to the north. In general, the radiometric response agrees well with the mapped bedrock geology for the batholith (Mira, 2013). The apparent resistivity of the Terrace Bay batholith shows significant variability. Much of this variability, however, is a result of surficial water bodies, and localized overburden deposits that result in resistivity lows.

Crossman Lake Batholith

The Crossman Lake batholith occupies the majority of the northern part of the Schreiber area, covering 300 km^2 (Figure 3.4). According to mapping conducted by Carter (1988), the batholith is predominantly medium-grained, massive, and varies compositionally between monzodiorite, tonalite, granodiorite, granite, and alkali-feldspar granite. Mafic minerals within the batholith comprise hornblende and biotite. The tonalite phase is massive, medium-grained, and of weak foliation. The granodiorite phase is fine- to medium-grained and weakly foliated and the granite phase is massive and medium-grained. The alkali-feldspar granite phase is massive and medium-grained. The rock has been affected by brittle deformation. Gneissosity and porphyritic facies are seen only in the southwestern and southern parts of the batholith beyond the boundaries of the Township of Schreiber. As well, minor phases occur as dykes varying compositionally between microgranitic rocks, quartz porphyries, quartz-feldspar porphyries and aplites, which are mostly found in areas beyond the boundaries of the Township of Schreiber.

The magnetic response observed over the Crossman Lake batholith (Figures 3.6 and 3.7) is characterized by a negative expression (Mira, 2013); however, peak anomaly values may correspond to remnant volcanic units. Processed magnetic images reveal the magnetic texture of the batholith to be relatively flat, although several distinct linear structural trends are coincident with the faults and dykes shown on published maps.

The outline of the Crossman Lake batholith, as reflected in the magnetic data, is consistent with the mapped bedrock geology (Mira, 2013). Contacts between the greenstone units and the batholith are generally sharp in the magnetic and processed magnetic field data. In areas, however, the contact is reflected as a subtle gradational change, particularly along the northern boundary adjacent to the mafic and ultramafic units.

An anomalously high magnetic response within the Crossman Lake batholith, in comparison to the remainder of the intrusion, is present in that part of the granitic body southeast of the Syenite Lake fault which is partially encircled by the Schreiber-Hemlo greenstone belt. Here, the magnetic signature, as well as a radiometric response, is more consistent with that of the Whitesand batholith and may reflect the presence of a different granitic phase internal to the Crossman Lake batholith. However, no supporting mineralogical or lithological evidence has been published to verify this interpretation.

Apparent resistivity of the Crossman Lake batholith is relatively uniform with average values that are consistent with resistivity values for granitic bedrock elsewhere in the Schreiber area. Several linear features observed in the electromagnetic data largely correspond to the locations of faults illustrated on published maps (Mira, 2013; SRK, 2013). The location of these features is similarly reflected in the magnetic data, suggesting a relative depletion in magnetic minerals and an increased presence of conductive minerals.

Radiometric data shows a relatively moderate response in thorium, uranium and potassium concentrations throughout the Crossman Lake batholith. The western portion of the Crossman Lake batholith displays a gradational increase of radioelement concentrations toward the Whitesand batholith, perhaps representing a subtle change in lithologies between the two intrusions.

Whitesand Lake Batholith

The Whitesand Lake batholith occurs in the southwestern portion of the Schreiber area (Figure 3.4). This batholith is elongated in an east-west direction parallel to the structural trend within the surrounding greenstone belt rocks. The batholith consists of mostly massive alkali-feldspar granite with lesser porphyritic granite, monzodiorite, quartz monzonite and rare aplite (Carter, 1988). The Whitesand Lake batholith covers 123 km^2 within the Schreiber area. At the southeastern end of the batholith, at Walker Lake, the main intrusive phases are granite to tonalite, with more localized facies of massive- and medium-grained rocks monzodioritic in composition.

The reduced to pole magnetic field (Figure 3.6) and the processed magnetic data indicate that the overall outline of the Whitesand Lake batholith is consistent with contacts shown on bedrock geology maps. The eastern contact with the greenstone belt is sharp, and expressed as a relatively flat response associated with greenstone units transitioning westward into an elevated response along the edge of the batholith. The northeastern boundary of the Whitesand Lake batholith, adjacent to the greenstone belt, displays a sharp magnetic contact which is coincident with the location of the mapped regional Cook Lake fault.

Much of the Whitesand Lake batholith displays a high magnetic response, though the reduced magnetic field as well as the vertical derivatives, indicate the presence of several obvious magnetic perturbations indicative of heterogeneity within the intrusion. This internal heterogeneity corresponds to linear magnetic lows that have been interpreted as brittle lineaments (SRK, 2013). A number of these are coincident with mapped faults, in particular the Sox Creek fault. Additionally, the noisy magnetic response in that part of the Whitesand Lake batholith covered by the regional high-resolution geophysical survey may reflect the presence of mafic metavolcanic rocks intermixed with the batholith.

To the north of the Sox Creek fault, the magnetic data displays a general decrease in the magnetic intensity, which may indicate a subtle change in bedrock lithology. Although the boundary between the Whitesand Lake and Crossman Lake batholiths is poorly defined, Carter (1988) places the boundary between the two batholiths along narrow septa of east-trending greenstone belt rocks along the western margin of the Schreiber area. The area of change in magnetic intensity corresponds to the inferred boundary between the two batholiths.

Elevated radiometric values for potassium, thorium and uranium are associated with the southern margin of the Whitesand Lake batholith along the Lake Superior coastline in the Schreiber area. The source of these radiometric highs is not known. The radiometric response to the north and west of the Whitesand Lake batholith decreases toward the Crossman Lake batholith. This variation in the radiometric response may represent a change in lithologies between the two batholiths and may correspond to the geological contact between the two intrusions.

The apparent resistivity of the Whitesand batholith shows significant variability. The higher end of the apparent resistivity range is consistent with resistivity values for granitic bedrock elsewhere in the Schreiber area. Several linear features observed in the electromagnetic, as well as the magnetic, data largely correspond to the locations of faults indicated on published maps of the area.

Mount Gwynne Pluton

The Mount Gwynne pluton, located near the southern margin of the central part of the Schreiber area (Figure 3.4), intrudes along the southern boundary of the Schreiber-Hemlo greenstone belt. The Mount Gwynne pluton covers approximately 5 km^2 within the Schreiber area. The pluton is fault-bounded and it intrudes the greenstones on its southern boundary. Rocks of this pluton are massive, medium-grained, varying between alkali-feldspar granite, granodiorite, quartz monzonite, and quartz diorite (Carter, 1988). A minor fine-grained dyke of quartz alkali-feldspar syenite cuts the pluton in its northeastern corner. Carter (1988) suggested this pluton is underlain by granitic rocks similar to those of the Terrace Bay, but thickness of this batholith is not known.

The magnetic response observed over the Mount Gwynne pluton is characterized generally as a high-amplitude, positive anomaly, as observed in the reduced to pole magnetic field data (Figure 3.6). This response could be interpreted to be the result of the presence of underlying and outcropping basic to intermediate metavolcanic rocks.

Typical apparent resistivity values calculated from the low-frequency electromagnetic data for the pluton show a relatively uniform distribution, making it difficult to differentiate from the adjacent metavolcanic units of the Schreiber-

Hemlo greenstone belt. In radiometric data, the northern half of the Mount Gwynne pluton has a slight increase in concentrations of thorium, uranium and potassium.

3.2.1.2 Schreiber-Hemlo Greenstone Belt

Supracrustal rocks in the Schreiber area occur in the western part of the Schreiber-Hemlo greenstone belt (Santaguida, 2002; Johns *et al.*, 2003; OGS, 2011) and are considered to be part of the Schreiber lithotectonic assemblage (Williams *et al*., 1991) (Figure 3.4). Carter (1988) identified three major types of supracrustal rocks in the Schreiber-Hemlo greenstone belt assemblage: 1) tholeiitic, mafic, metavolcanic rocks comprising mainly massive to pillowed basalt, tuff and related breccias; 2) calc-alkalic, mafic to felsic, metavolcanic rocks dominated by pyroclastic units; and 3) clastic and chemical metasedimentary rocks of turbiditic origin interbedded with minor banded iron formations. These three supracrustal rock types in the greenstone belt are described in further detail below.

Tholeiitic, mafic, metavolcanic rocks are massive or schistose and variably metamorphosed ranging from dominantly greenschist facies to amphibolite facies and locally pyroxene hornfels facies. Greenschist facies, mafic, metavolcanic rocks are either massive or foliated and are aphanitic to medium-grained, whereas amphibolite facies mafic, metavolcanic rocks are medium-grained and well-foliated (Carter, 1988). The greenschist facies, tholeiitic rocks comprise aphanitic, fine-grained massive and pillowed flows, as well as porphyritic, amygdaloidal and variolitic flows. Interbedded with these flows are minor autoclastic flow breccias and mafic to intermediate tuff horizons. The tholeiitic rocks include fine- to medium-grained, foliated amphibolite and garnet amphibolite. The minimum age of mafic volcanism is constrained by crosscutting pluton apophyses in the eastern half of the Schreiber-Hemlo greenstone belt at ca. 2.697 Ga (Muir, 2003).

Calc-alkalic, mafic to felsic, metavolcanic rocks are mainly greenschist facies, massive, aphanitic to fine-grained andesite to porphyritic dacite flows. Minor amygdaloidal, felsic interbeds occur with the massive flows. In addition, fine-grained to aphanitic tuff units with rare lapilli tuff and tuff breccia are interlayered with the mafic to felsic flows. Muir (2003) indicated that felsic, calc-alkalic volcanism occurred from ca. 2.698 to 2.692 Ga, and intermediate volcanism occurred around 2.689 Ga in the eastern half of the Schreiber-Hemlo greenstone belt. These ages conform to U-Pb zircon age determinations for calc-alkaline volcanism that are generally within a narrow range between 2.698 and 2.688 Ga (Corfu and Muir, 1989). In the Schreiber area, a date on an igneous zircon from rhyolitic host rocks of the Archean Winston Lake massive sulfide deposit yielded an age of 2.723 Ga (Davis *et al.*, 1994; Figure 3.5).

Metasedimentary rocks are composed of greenschist facies wacke, silicified shale (including graphitic intervals), chert horizons and banded iron formation as well as minor amphibolite facies garnet- and sillimanite-bearing wacke. The wacke comprises foliated, fine- to medium-grained, quartz-plagioclase-biotite rocks with minor epidote, apatite, muscovite and pyrite. Banded iron formations form thinly bedded units interlayered with the metavolcanic rocks comprising magnetite-chert or magnetite-only (oxide-facies) and pyrite-pyrrhotite-chert (sulphide-facies) horizons. Sedimentation of turbiditic, wacke-mudstone in the Schreiber-Hemlo greenstone belt occurred after ca. 2.693 Ga for volcaniclastic deposits and possibly as late as ca. 2.685 Ga for wacke (Muir, 2003).

3.2.1.3 Mafic Dykes

Several swarms of diabase dykes crosscut the Schreiber area (Figure 3.4), including:

- Northwest-trending Matachewan dykes (ca. 2.473 Ga; Buchan and Ernst, 2004);
- North-trending Marathon dykes, which are part of a broadly fan-shaped distribution pattern around the northern, eastern and western flanks of Lake Superior. These dykes vary in orientation from northwest to northeast, and occur as steep to subvertical sheets, typically a few metres to tens of metres thick, but

occasionally up to 75 m thick (Hamilton *et al*., 2002). The Marathon dykes comprise quartz-tholeiite dominated by equigranular to subophitic clinopyroxene and plagioclase. Halls *et al*. (2008) reported U–Pb dating that shows the Marathon swarm ranges in age between ca. 2.126 and 2.101 Ga. Buchan *et al*. (1996) reported a U-Pb age of ca. 2.121 Ga from a Marathon diabase dyke; and

- East-west–trending Keweenawan dykes related to the ca. 1.100 Ga Midcontinent Rift that was centred on proto-Lake Superior (Thurston, 1991). The vertical derivative data sets show the presence of linear magnetic lows extending from the Terrace Bay batholith into the Mount Gwynne pluton (Mira, 2013). These features are interpreted as the western extent of the dyke swarm observed in the Terrace Bay batholith.

Potentially, a western extension of the ca. 2.167 Ga Biscotasing dyke swarm also occurs in the Schreiber area (Hamilton *et al*., 2002). These generally trend northeast and it is uncertain how using only dyke orientation these may be distinguished from northeast-trending Marathon dykes.

3.2.2 Quaternary Geology

The Quaternary sediments, commonly referred to as drift, soil or overburden, are glacial and post-glacial materials that overlie the bedrock in the Schreiber area. Their distribution, thickness and physical characteristics have an important influence on several aspects of the current assessment. Areas of thicker drift can hinder the interpretation of lineaments by masking their presence in satellite imagery or muting the response obtained from geophysical surveys. Coarser-grained surficial sediments typically have a moderate to high transmissivity and can serve as local aquifers as well as being a potential source of mineral aggregates for use in building and road construction.

All glacial landforms and related materials within the Schreiber area are associated with the Wisconsinan glaciation which began approximately 115 Ka (Barnett, 1992). The Quaternary (i.e., surficial) geology of the Schreiber area has been mapped at a regional scale (>1:100,000) by several authors, including Zoltai (1965), Sado and Carswell (1987), and Barnett *et al.* (1991) and at a higher resolution by Gartner (1979a, 1979b) and Morris (2000, 2001). Quaternary deposits and landforms in the area are, however, thought to have been formed in the Late Wisconsinan, which began 30 Ka before present.

Morris (2000) reported bedrock erosional features and landforms in the Schreiber area that indicate a regional ice flow direction of 194 degrees with a range of measured directions, due to local topographic conditions, of between 165 to 238 degrees. For the majority of the Schreiber area, drift thickness over bedrock is limited and the ground surface reflects the bedrock topography. Over the majority of the area bedrock outcrops are common and the terrain is classified for surficial purposes as a bedrock-drift complex, i.e., thin drift cover that only locally achieves thicknesses that mask the bedrock topography.

The remote sensing and terrain evaluation completed as part of the Phase 1 preliminary assessment (AECOM, 2013) provides the most detailed assessment of the type, distribution and thickness of surficial deposits in the Schreiber area (Figure 2.3). The most common glacial deposit in the Schreiber area is a thin, discontinuous till, generally less than a metre thick. Greater accumulations of till are found within bedrock depressions, large scale lineaments and on the down-ice (lee) side of bedrock highs. The till has a silty-sand matrix and contains abundant clasts in the pebble to cobble size range.

Two types of glaciofluvial deposits are present in the Schreiber area. Ice-contact stratified drift deposits (ICSD) are associated with recessional moraines, dead-ice topography, eskers and valley fills (Morris, 2000). The largest ice-contact deposit forms the core of a 9 km long feature situated between Terrace Bay and Schreiber, south of Hays Lake. Ice-contact deposits consist primarily of stratified, well to poorly sorted, sand and gravel that locally can achieve thicknesses of several tens of metres.

Glaciofluvial outwash deposits occur as relatively level areas within some narrow, bedrock controlled valleys (Figure 2.3). While valley-controlled outwash deposits are widespread within the Schreiber area, significant deposits are located along the Aguasabon, Whitesand and Pays Plat rivers, and Big Creek and its tributaries. Thickness of the deposits is likely to be variable, and may be locally substantial. Outwash deposits are generally well-sorted and comprised of stratified sand, gravel and, in some locations, boulders.

Following retreat of the glacial ice approximately 9.5 Ka before present, the Lake Superior basin was occupied by a series of glacial lakes. It is likely, however, that only the later of these lakes, Glacial Lake Minong and younger, affected the Schreiber area (Clayton, 1983; Farrand and Drexler; 1985; Barnett 1992). Lake inundation was limited to the area along the Lake Superior shoreline, to an elevation of ~305 m, and for a short distance inland within bedrock-controlled valleys. Elevations of the various glacial lakes were controlled by the position of the ice mass and isostatic recovery of the land surface following deglaciation.

Fine-grained glaciolacustrine silts and clay deposits associated with the glacial lake have been encountered at depth in boreholes in the Terrace Bay area and other embayments further west along the Lake Superior shoreline (Gartner, 1979a). Stratigraphically above, coarse-grained glaciolacustrine sediments were deposited in a deltaic environment where bedrock valleys that served as drainage channels entered the glacial lake. The largest glaciolacustrine delta is located in the Terrace Bay area where a sediment thickness of 48.3 m has been recorded. Another notable, but smaller, deltaic feature is found at Selim, at the mouth of the Whitesand River (Figure 2.3).

Bogs and organic-rich alluvial deposits are present along water courses in the area and in rock-floored basins. These deposits tend to have a limited thickness and areal extent.

The majority of the Crossman Lake and Whitesand Lake batholiths and the Mount Gwynne pluton have a thin, discontinuous drift cover, consisting mainly of ground moraine (till), with abundant outcrops. Locally the till thickens somewhat (1 to 3 m) but this does not substantially diminish relief or obscure the trends of structural elements. Outwash deposits, believed to range from a few to several metres in thickness, occur in several of the larger fault-controlled valleys that transect the intrusions. In contrast, the majority of the Terrace Bay batholith within the Schreiber area is covered by thick, sand-rich deposits that mask the bedrock. Drift thickness can achieve several tens of metres, but thins where bedrock knobs protrude.

3.2.3 Lineament Investigation

A detailed lineament investigation was conducted for the Schreiber area (SRK, 2013) using publicly available remote sensing data sets, including airborne geophysical (aeromagnetic and electromagnetic) data, digital elevation model data (CDED), and satellite imagery data (SPOT and LandSAT). Lineaments are linear features that can be observed on remote sensing and geophysical data and which may represent geological structures (e.g. fractures). However, at this stage of the assessment, it is uncertain if interpreted lineaments are a reflection of real geological structures, and whether such structures extend to depth. The assessment of these uncertainties would require detailed geological mapping and borehole drilling.

The lineament investigation identified interpreted brittle structures, dykes and ductile lineaments in the Schreiber area, and evaluated their relative timing relationships within the context of the local and regional geological setting. A detailed analysis of interpreted lineaments is provided by SRK (2013) and key aspects of the lineament investigation are summarized in this section.

At this desktop stage of the 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 study.

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

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

For each dataset, brittle lineaments were interpreted by two independent experts using a number of attributes, including certainty and reproducibility (SRK, 2013). The certainty attribute describes the clarity of the lineament within each dataset based on the expert judgement and experience of the interpreter (i.e., with what certainty is a feature 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 within a dataset. Reproducibility assessment RA_2 reflects the coincidence of interpreted lineaments between the four datasets used (magnetic, electromagnetic, satellite imagery, topographic data). Combined surficial and geophysical lineaments are presented in Figure 3.9 and 3.10, respectively. In addition, ductile lineaments (i.e., magnetic form lines) were identified from the geophysical dataset (Figure 3.11). These lineaments are included to provide context to our understanding of the tectonic history of the Schreiber area, but were not included in the merged lineament sets or statistical analyses. A detailed description of the lineament investigation workflow and discussion of the results of the analysis is provided by SRK (2013). The key aspects of the lineament investigation are summarized in this section.

The resolution of each available dataset has a strong impact on the resolution and number of interpreted lineaments. Most of the area is covered by the Schreiber Magnetic Supergrid data (OGS, 2003), which has a high resolution (200 m line spacing) except for a strip along the western side that is covered only by the Single Master Gravity and Aeromagnetic (SMGA) data for Ontario (OGS, 1999) (Figure 1.2). In addition, electromagnetic data (200 m line spacing) was available and used for the lineament analysis.

The Spot 5 satellite and LandSAT 7 satellite images cover the entire area and have resolutions of 20 m and 30 m, respectively (Figure 2.1). The CDED topography data covers the entire Schreiber area with a resolution of 8 to 23 m (Figure 2.2).

The higher resolution of the topography and satellite imagery data sets helped identify a greater density of smaller scale faults that were not evident in the lower resolution SMGA data. The general absence of thick or extensive overburden cover in the Schreiber area facilitates the practical interpretation of lineaments from surficial imagery. The only significant area of thick drift is in the southeast portion near Terrace Bay, where large deposits of glaciolacustrine/glaciofluvial sediments exist (Figure 2.3). In this area, bedrock structural information available from the satellite imagery and topography data was limited. However, high resolution Schreiber Supergrid magnetic and electromagnetic data are available for this area, thus providing the required information to complete a suitable structural lineament interpretation.

A total of 783 lineaments were observed in both the CDED topography data and the satellite images (i.e. 100% coincidence) and were reported as surficial lineaments, as shown in Figure 3.9 distinguished on the basis of length (SRK, 2013). The CDED lineaments range in length from 110 m to 38.1 km, with a geometric mean length of 1.65 km and a median length of 1.47 km (Figure 3.9). The interpreted surficial lineaments from the satellite images range in length from 280 m to 48.7 km, with a geometric mean length of 1.96 km and a median length of 1.83 km. Surficial lineament orientations display a strong west-northwest-trend, a prominent northwest trend and a minor trend to the east-northeast is also present (Figure 3.9 inset).

Combined interpretation of magnetic and electromagnetic datasets yielded 477 lineaments, which were reported as geophysical lineaments, as shown in Figure 3.10 distinguished on the basis of length (Figure 3.10). A total of 419 lineaments were identified from the magnetic data and 147 lineaments identified from the EM data, but form the latter only 58 lineaments constitute lineaments not yet observed in the magnetic data. A portion of these lineaments were interpreted as dykes (shown in brown on Figure 3.10). Dominant lineament orientations are to the west-northwest and northwest with a subordinate trend to the east-northeast (Figure 3.10 inset).

Interpretation of the geophysical magnetic data resulted in a dataset containing 419 geophysical lineaments. Of the 419 lineaments, 243 are interpreted as brittle lineaments, while 176 are interpreted as dyke lineaments (SRK, 2013). The length of the magnetic lineaments ranges from 160 m to 48.7 km, with a geometric mean length of 2.5 km and a median length of 2.2 km. Azimuth data, weighted by length, for the magnetic lineaments interpreted as brittle lineaments exhibit a dominant orientation to the west-northwest. Other prominent orientations include a northwest-trend and minor east-northeast trend. The 176 dyke lineaments identified from the magnetic data include dominant northwest-, northeast- and east-trending dyke sets that belong to several different swarms (SRK, 2013).

The lineament dataset from the electromagnetic data contains a total of 147 geophysical lineaments. Of the 147 lineaments, 125 are interpreted as brittle lineaments, while 22 are interpreted as dyke lineaments (SRK, 2013). The length of the electromagnetic lineaments ranges from 260 m to 48.7 km, with a geometric mean length of 5.0 km and a median length of 5.8 km. Azimuth data, weighted by length, for the electromagnetic lineaments interpreted as brittle lineaments exhibit a dominant orientation to the west-northwest. Other prominent orientations include a northwest-trend and minor east-northeast-trend. The dykes identified from the electromagnetic data include dominant northeast- and east-trending sets that are interpreted to belong to several different swarms.

The final merged dataset (Figure 3.12) containing both surficial and geophysical lineaments contained 949 lineaments, 772 of these were interpreted as brittle lineaments, while 177 were interpreted as dyke lineaments. This figure contains all lineaments, regardless of how their reproducibility was attributed.

The orientation data for the brittle and dyke lineaments (Figure 3.12 inset, Figure 3.13) exhibit the same dominant trends described above, namely dominant west-northwest trending and northwest-trending lineaments with a minor east-northeast-trending lineament set. It should be noted that the rose diagrams for the brittle and dyke lineaments (Figure 3.12 inset and Figure 3.13) are weighted by lineament length, and thus, these orientations are influenced by longer lineaments. Lineaments longer than 10 km, and lineaments from 5 to 10 km in length, represent 9.6% and 8.6% of the merged lineaments, respectively, while lineaments from 1 to 5 km long and less than 1 km long represent 59.2% and 22.6% of the merged lineaments, respectively. SRK (2013) noted the following trends in the final merged lineament dataset:

- Longer lineaments generally have a higher certainty and reproducibility.
- There is similar coincidence between surficial lineaments identified in both CDED and SPOT datasets (100% coincidence between CDED and SPOT) and between geophysical brittle lineaments and surficial lineaments (100% of the geophysical brittle lineaments were observed in the surficial datasets; 166 geophysical dyke lineaments were not observed in the surficial dataset).

The 177 dyke lineaments were divided into several groups (SRK, 2013):

- Fifty-one dyke lineaments are interpreted to belong to the northwest-trending Matachewan dyke swarm (ca. 2.473 Ga; Buchan and Ernst, 2004);
- Twenty-one dyke lineaments are interpreted to belong to the north-northwest- to northeast-trending Marathon dyke swarm (ca. 2.121 Ga; Buchan *et al.*, 1996); and
- Forty-three dyke lineaments are interpreted to belong to the east-west-trending, reversely polarized Keweenawan dyke swarm (ca. 1.100 Ga; Thurston, 1991).

Hamilton *et al.* (2002) described northeast-trending Biscotasing dykes (ca. 2.167 Ga) in the Schreiber area. However, these could not be distinguished from northeast-trending Marathon dykes, and therefore, 61 northeast-trending dyke lineaments are attributed as “Marathon/Biscotasing”. All other north-northwest- to north-trending interpreted 21 dykes were only attributed as “Marathon” (as above). Also, given its distinct character in the magnetic data (a non-linear magnetic low), a single interpreted dyke lineament in the southeast of the Schreiber area was interpreted to be associated with the Coldwell alkalic complex.

One aspect of uncertainty 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 ca. 20 m, but also describes minor dykelets as narrow as several cm 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. In addition, 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). The presence of smaller dykes and the potential for damage to the host rock between dykes would need to be evaluated at later stages of the assessment, through the collection of site-specific information, provided the community is selected by the NWMO, and remains interested in continuing with the site selection process.

The drawing of ductile lineaments (i.e., stratigraphic and structural form lines) was completed using first vertical-derivative magnetic data. These lineaments are shown in Figure 3.11 and were not used in lineament statistics (e.g., rose diagrams, density plots). The form lines trace the geometry of magnetic high lineaments and represent the geometry of stratigraphy within metavolcanic and metasedimentary rocks or the internal fabric (foliation) within granitoid batholiths and gneissic rocks. This process highlighted discontinuities between form lines, particularly in

stratigraphic form lines (e.g., intersecting form lines) that represent structural lineaments (e.g., faults, folds, unconformities, or intrusive contacts). The form lines were drawn using the Schreiber Magnetic Supergrid first-vertical derivative and the tilt-derivative data. Where the Schreiber area was not covered by the Schreiber Magnetic Supergrid, no form lines were drawn since the lower resolution of the data hindered the interpretation.
The percentage of all geophysical lineaments (magnetic and electromagnetic) coincident with surficial lineaments is 33% (311/949). Aside from the higher number of lineaments observed in surficial data, this relatively poor correlation between surficial and geophysical lineaments may be the result of various factors, such as: deeper structures identified in geophysics may not have a surface expression; surficial features may not extend to great depth; and, structural features may not possess a magnetic susceptibility contrast with the host rock. However, the better resolution of the surficial datasets may best explain why a larger number of lineaments are identified from these data compared to the geophysical datasets. Importantly, all 301 brittle lineaments observed from geophysical datasets were observed in surficial datasets. Of the 177 dykes interpreted from all datasets only 11 dykes (6%) were observed in the surficial datasets.

The total density of brittle lineaments in the Schreiber area (surficial and geophysical) is presented as Figure 3.14. This figure was constructed using all lineaments regardless of how their reproducibility was attributed. In general, lineament density is higher in the Schreiber-Hemlo greenstone belt. In addition, within the Crossman Lake batholith a northeast-trending area of increased density is present between Upper Ross Lake and Charlotte Lake.

As a means of evaluating the influence of lineament length on lineament density across the Schreiber area, the results of progressive “filtering” by lineament length are shown in Figures 3.15 to 3.17. These figures illustrate only lineaments >1 km, >5 km and >10 km, respectively. This process allows longer brittle lineaments to be viewed more easily. Limited change in the density pattern exists with the exclusion of the <1 km lineaments (Figure 3.15). However, notable decreases in lineament density occurs when only those lineaments of >5 and >10 km in length are considered (Figures 3.16 and 3.17, respectively). This is likely because most of the surficial lineaments are excluded from the plotted dataset when only lineaments >5 km are plotted (Figure 3.16). When just lineaments >10 km are plotted, only two surficial lineaments remain, both in the western edge of the area, where only low resolution geophysical coverage exists. The remaining lineaments are from the geophysical datasets.

Although the brittle lineaments density in the Schreiber area is high, areas with a relatively low density of brittle lineaments can be identified. In addition, as the progressive filtering by lineament length is applied, the position of these low density areas remains the same.

Figure 3.18 shows the combined datasets (i.e., mapped regional faults, brittle lineaments, dykes and ductile lineaments) which helps provide a structural understanding of the Schreiber area. Virtually all of the mapped faults were coincident with surficial lineaments, and the vast majority were also coincident with geophysical lineaments. A small number of short, northward trending mapped faults were not recognized in the geophysical data, likely due to the fact the flight lines of the aerial geophysical surveys were parallel to that north-trending fault orientation.

The orientation of the dense network of lineaments in the Schreiber area provides a framework to interpret the geological history of the area by linking the lineaments with the structural history of the Schreiber area. This was accomplished by defining the age relationships of the interpreted lineaments on the basis of crosscutting relationships between different generations of brittle lineaments.

3.2.3.1 Relative Age Relationships of Lineaments

The structural history of the Schreiber area, outlined in Section 3.1.3, provides a framework that may aid in constraining the relative age relationships of the interpreted bedrock lineaments. In brief summary, six regionally distinguishable deformation episodes (D_1 – D_6) are inferred to have overprinted the bedrock geological units of the Schreiber area.

D_1 developed a compositional layering and isoclinal folds between ca. 2.719 and ca. 2.691 Ga. D_2-D_4 produced the dominant brittle-ductile structures observed within the greenstone belts, including steeply dipping foliations, isoclinal folds, and thrust faults prior to ca. 2.680 Ga. D_5 was a brittle deformation event that involved the activation and possible re-activation of major regional faults sub-parallel to S_2 between ca. 2.680 and ca. 1.100 Ga. D_6 represents another regional brittle deformation event that occurred between 2.680 and 1.100 Ga. The youngest major event of brittle fault displacement is constrained by the ca. 1.100 Ga Keweenawan dykes that transect the Schreiber area with no apparent fault offset. This suggests that only limited displacement could have occurred along the interpreted fault network since the intrusion of the Keweenawan dykes.

The 772 brittle lineaments identified in the Schreiber area are interpreted to represent successive stages of brittle-ductile and brittle deformation (SRK, 2013). These lineaments can therefore be classified into three main stages based on relative age and in accord with the structural history described above: 217 D_2-D_4 lineaments, 240 D_5 lineaments, and 315 D_6 lineaments. D_2-D_4 brittle lineaments are interpreted as Archean brittle-ductile faults characterized as zones of pervasive foliation and phyllonite development, potentially with hydrothermal veining. D_5 and D_6 brittle lineaments are interpreted as brittle faults characterized as zones of pseudotachylite, gouge and (or) breccia. Limited information exists on the character of each interpreted fault set. At the desktop stage of preliminary assessment, it is still uncertain whether or not each interpreted lineament is in fact an actual brittle-ductile or brittle geological feature with a significant expression at depth.

No information is available on the depth of fault penetration in the Schreiber area. However, brittle lineament strike length may be a proxy for the depth extent. In general, D_5 and D_6 faults have longer strike lengths than D_2-D_4 faults and may have a greater depth extent.

3.2.3.2 Lineament distribution in batholiths and plutons

As described in Section 3.2.1, the bedrock geology of the Schreiber area is dominated by large granitic intrusive bodies that intrude older metavolcanic and metasedimentary rocks associated with greenstone belts. Lineament orientation trends for the individual intrusive bodies in the Schreiber area (i.e., the Crossman Lake, Whitesand Lake and Terrace Bay batholiths and the Mount Gwynne pluton) are presented in Figure 3.13 and discussed below.

Crossman Lake batholith

The Crossman Lake batholith covers a large part (~300 km^2) of the northern half of the Schreiber area and is crosscut by 386 interpreted brittle lineaments (Figure 3.13 and 3.18; SRK, 2013). Fifty-six brittle lineaments are interpreted as D_2-D_4 faults. This is consistent with overlap between the inferred age of the Crossman Lake batholith and the timing of D_2-D_4 deformation. Alternatively, these faults may represent conjugate segments of D_5 faults. One hundred and eight of the interpreted brittle lineaments are D_5 faults, with the remaining 151 brittle lineaments interpreted as D_6 faults. The D_5 and D_6 faults that intersect the Crossman Lake batholith range in strike length from 0.4 to 37 km and from 0.5 to 49 km, respectively. D_5 faults are largely oriented west-northwest and D_6 faults are largely oriented northwest with subordinate south- and northeast-trends. A total of 20 Matachewan, one Keweenawan, 10 Marathon, and 40 Marathon/Biscotasing dyke segments are interpreted to crosscut the Crossman Lake batholith.

Whitesand Lake batholith

There were 133 interpreted brittle lineaments identified as crosscutting the Whitesand Lake batholith (Figure 3.13 and 3.18; SRK, 2013) which occupies most of the southwestern quadrant in the Schreiber area (approximately 123 km^2). Of these, 46 brittle lineaments are interpreted as D_5 faults, 75 as D_6 faults and one as a D_2- D_4 fault. The interpreted D_5 and D_6 faults that intersect the Whitesand Lake batholith range in strike length from 0.3 to 35 km and from 1 to 31 km, respectively. D_5 faults largely trend west-northwest and D_6 faults largely trend northwest within the Whitesand Lake batholith. Four dyke lineaments interpreted to be related to the Marathon Suite, four dyke lineaments related to the Matachewan Suite and three dyke lineaments interpreted to be related to the Keweenawan Suite also crosscut the Whitesand Lake batholith.

Terrace Bay batholith

The segment of the Terrace Bay batholith that occurs in the southeastern portion of the Schreiber area covers an area of approximately 67 km^2 and is crosscut by 65 interpreted brittle lineaments (Figure 3.13 and 3.18; SRK, 2013). Five of these are D_2-D_4 faults that overlap in age with the inferred age for emplacement of this batholith. Eleven of the remaining brittle lineaments are interpreted to be D_5 faults, and the remaining 14 as D_6 faults. D_5 and D_6 faults that intersect the Terrace Bay batholith range in strike length from 1 to 34 km and from 3.5 to 49 km, respectively. D_5 faults are largely oriented west-northwest and D_6 faults are largely oriented northwest within the Terrace Bay batholith. Twenty-seven Keweenawan, one Marathon and six Marathon/Biscotasing and one suspected Coldwell dyke segments are interpreted to crosscut the Terrace Bay batholith.

Mount Gwynne pluton

The Mount Gwynne pluton, which covers approximately 5 km^2 along the southern margin of the Schreiber area, is crosscut by 19 interpreted brittle lineaments (Figure 3.13 and 3.18; SRK, 2013). One of these brittle lineaments are considered extensions of D_2-D_4 faults, six are interpreted as D_5 faults and the remaining five lineaments as D_6 faults. The D_5 and D_6 faults that intersect the Mount Gwynne pluton range in strike length from 1 to 24 km and from 0.8 to 24 km, respectively. D_5 faults are largely oriented west-northwest and D_6 faults are largely oriented northwest or northeast within the Mount Gwynne pluton. Six dykes of the Keweenawan swarm and one dyke of the Marathon/Biscotasing swarm are interpreted to crosscut the Mount Gwynne pluton.

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

The Schreiber area lies within the Superior Province of the Canadian Shield where large parts have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). Figure 3.19 illustrates the location of earthquakes with a magnitude 3 or greater that are known to have occurred in Canada and the northern United States from 1627 until 2010 (Earthquakes Canada, 2012). The Canadian Shield is considered the least seismically active portion of the North American continent (Maloney *et al.*, 2006). Although Hayek *et al.* (2011) indicated that the general western Superior Province has experienced a number of low magnitude, shallow seismic events, all recorded earthquakes in the region of the Schreiber area are of a magnitude less than 3 (Figure 3.20) (Earthquakes Canada, 2012). The closest earthquake to the Schreiber area with a magnitude greater than 3, was a magnitude 5.6 event that occurred in 1905 about 180 km to the south, in the geological Southern Province. Smaller events, of magnitudes between 1 and 2, have taken place as close as 30 km to the west of the Schreiber area (Figure 3.20).

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

3.3.2 Neotectonic Activity

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

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

The geology of the Schreiber area is typical of many areas of the Canadian Shield, which has been subjected to numerous glacial cycles during the last million years, resulting in post-glacial isostatic rebound in the northern portion of the North America plate. During the maximum extent of the Wisconsinan glaciation, approximately 21,000 years ago (Barnett, 1992), the Earth's crust was depressed by more than 340 m in the Minnesota/North Dakota area (Brevic and Reid, 1999), due to the weight of glacial ice. The amount of crustal depression in the Schreiber area would be of a somewhat greater magnitude, due to its closer proximity to the main centre of glaciation located over Hudson's Bay.

Post-glacial isostatic rebound began with the waning of the continental ice sheets and is still occurring across most of Ontario. Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella *et al*., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1-2 mm/yr) south of the Great Lakes. The ‘‘hinge line’’ separating uplift from subsidence is consistent with data from water level gauges along the Great Lakes, showing uplift along the northern shores and subsidence along the southern ones (Mainville and Craymer, 2005). Current rates of isostatic uplift in the Schreiber area are not precisely known, although Lee and Southam (1994) estimated that the land is rising at a rate of 2.9 mm/yr at Michipicoten, Ontario, some 180 km to the southeast.

As a result of the glacial unloading, acting along with tectonic stresses, principal stress magnitudes and orientations are changed. Seismic events could be associated with these post-glacial stress changes as a result of reactivation of existing fracture zones. In addition, natural stress release features can include elongated compressional ridges or pop-ups such as those described by McFall and Allam (1990), McFall (1993) and Karrow and White (2002).

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

Under the appropriate conditions, glacial deposits may preserve neotectonic features indicative of paleo-seismic activity. Existence of such features can be used to extend the seismic record for a region well into the past. In the Schreiber area should any pop-up features be present, they may be recognized by their narrow, linear shape which could extend for hundreds of metres (White *et al.,* 1973). Such features would likely only be found in areas of bedrock outcrop or thin overburden cover (<1 to 2 m). It is possible that tree cover, typical of that found in the boreal forest, would assist in making their identification difficult when interpreting air photo or other remotely sensed imagery. Faults resulting from neotectonic activity may be equally challenging to discern from ancient features. Recent faults (i.e., post-glacial faults) may show evidence of displacement, fresh brecciation or an unhealed character suggestive of recent formation.

4 HYDROGEOLOGY

4.1 Groundwater Use

The Township of Schreiber obtains its municipal water supply from Cook Lake located 2 km north of the township boundary. The town's water treatment plant filters and chlorinates the water prior to distribution. The Township of Terrace Bay's main source of water is Lake Superior. However, the system is designed to draw from Hays Lake if required. The system uses a slow sand filtration with in-pipe ultra-violet and sodium hypo-chlorite disinfection, and has treated water storage.

There is limited information on groundwater resources in the Schreiber area. The Ontario Ministry of Environment Water Well Database (2012) contains records for 30 wells in the Schreiber area. The location of known water wells is shown on Figure 4.1, except for one well in a remote location which was deemed to have erroneous co-ordinates. Several of the water well records in the MOE database are incomplete in terms of contained information. Fifteen of the well records provided useful information regarding aquifer type, yield and other parameters noted in Table 4.1.

Table 4.1: Water Well Record Summary for the Schreiber Area

Water Well Type	Number of Wells	Total Well Depth (m)	Median Well Depth (m)	Static Water Level (mbgs)	Tested Well Yield (L/min)	Depth to Top of Bedrock (m)
Overburden	7	4.3 to 47.2	25.8	2.1 to 3.0	0 to 23	NR
Bedrock	8	31.1 to 94.5	62.8	0 to 22.5	0 to 455	0 to 38.7

NR = Bedrock not reached

4.2 Overburden Aquifers

There are seven water well records in the Schreiber area that can be confidently assigned to the overburden aquifer. Wells confirmed to be in overburden are restricted to glaciolacustrine/glaciofluvial deposits in the southern part of the area, with one exception. Wells are located in the town sites of Terrace Bay and Schreiber (one each), at the south end of Whitesand Lake (one well) and at the south end of Walker Lake (3 wells). The remaining water well was drilled at the site of the Winston Lake Mine. The overburden wells have depths of between 4.3 and 47.2 metres below ground surface (mbgs), and generally have low pumping rates (MOE, 2012) although little data on yields are contained in the water well database. These well yields reflect the purpose of the wells (private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from the overburden aquifers. The limited number of well records limits the interpretation of available information regarding the extent and characteristics of overburden aquifers in the Schreiber area.

4.3 Bedrock Aquifers

No information was found on deep bedrock groundwater conditions in the Schreiber area at a typical repository depth of approximately 500 m. Within the Schreiber area, there are eight water wells that can confidently be assigned to being developed in bedrock (MOE, 2012). These wells encountered bedrock at depths ranging from 0 to 38.7 mbgs and have maximum depths between 31.1 and 94.5 mbgs. Reported yields range from 0 to 455 L/min with static water levels ranging from 0.9 to 9.1 mbgs. Two additional wells located south of Terrace Bay, in close proximity to the Lake Superior shoreline, have recorded pumping rates of approximately 716 and 719 L/min from depths of 20.7 and 22.9 m, respectively. The depth of the wells suggests that they may be completed in bedrock, however, this is not confirmed. The high pumping rates may indicate that recharge to the wells is, at least in part, from Lake Superior either through one or both of bedrock fractures or coarse-grained glacial sediments.

The reported well yields reflect the purpose of the wells (i.e., private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from the shallow bedrock aquifers. Long-term groundwater yield in fractured bedrock will depend on the number and size of fractures, their connectivity, transmissivity, storage and on the recharge properties of the fracture network in the wider aquifer.

The MOE water well records indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Schreiber area or anywhere else in Northern Ontario.

4.4 Regional Groundwater Flow

In many shallow groundwater flow systems the water table is generally a subdued replica of the topography (AECOM, 2013). The variation of the water table elevation across an area reflects the changes in hydraulic head, the driving force within the flow system. However, the pattern of groundwater flow will also be influenced by horizontal and vertical variations in the hydraulic properties of the medium, for example associated with inter-bedding of sand and clay layers in overburden sediments and the presence of fracture networks in bedrock. As a general concept, shallow groundwater flow in Canadian Shield terrain will tend to be directed from areas of higher hydraulic head, such as highlands, towards areas of lower hydraulic head such as adjacent or nearby valleys and depressions. The extent of these localized flow systems are defined by local, topography-controlled, drainage divides across which flow will not readily occur. However, the geometry of shallow flow systems can be more complex in the presence of permeable fracture zones and more complex topography.

Within the Schreiber area it is believed that groundwater flow divides mimic the boundaries of surface watersheds (Figure 2.4) due to the fact that large areas are characterized by the presence of bedrock at or near the surface. Groundwater recharge in these areas is through an interconnected fracture network present in the bedrock. Recharge can be rapid but is largely restricted to a near surface zone. Groundwater flow is directed towards flanking valleys and depressions where the bulk of the groundwater discharges either directly to waterways or into surficial deposits occupying the lower ground. Surficial deposits on the highland bedrock areas, most commonly till, are usually thin and relatively coarse-grained, allowing downward infiltration to the bedrock surface. These high relief areas can have higher hydraulic gradients that may impact the depth extent of shallow flow systems. Site specific, subsurface characteristics such as hydraulic conductivity and groundwater density variations, will also influence flow system geometry. No information was found in the available literature regarding groundwater recharge rates and temporal patterns in the Schreiber area. However, it is expected to be typical for the shield region with elevated recharge in spring and fall, reduced recharge in late summer, and essentially no recharge during frozen winter conditions.

Coarse-grained outwash deposits found along the major bedrock valleys in the Schreiber area (Figure 2.3) are recharged by overland and subsurface storm flow from the bedrock highlands and direct precipitation (rain and snow). Groundwater discharge from these deposits is as baseflow to streams and rivers which transect them. The presence of a shallow water table in many of the valley outwash deposits is suggested by the fact that the elevation of the dissecting waterway is often close to that of the surrounding ground surface.

The large elevated sand- and gravel- rich deposits located between Terrace Bay and Schreiber are also an area of significant groundwater recharge (Figure 2.3). Creeks and streams are generally lacking over the distribution of these glaciolacustrine/glaciofluvial sediments indicating that groundwater discharge is both southward to Lake Superior, and northward to Hays Lake and the Aguasabon River system.

Deeper into the bedrock, fracture frequency in a mass of rock will tend to decline, and eventually, the movement of ions will be diffusion dominated. However, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion limited conditions. As such, in the Schreiber area, it can be expected that features such as long regional faults will be important in the deep groundwater flow system.

There is little known about the hydrogeologic properties of the deep bedrock in the Schreiber area, as no deep boreholes have been advanced for this purpose. Experience from other areas in the Canadian Shield with similar rock types, has shown that active groundwater flow in bedrock is generally confined to shallow fractured localized systems, and is dependent on the secondary permeability associated with the fracture networks (Singer and Cheng, 2002). For example, in Manitoba's Lac du Bonnet batholith, groundwater movement is largely controlled by a fractured zone down to about 200 m depth (Everitt *et al*., 1996).

The low topographic relief of the Canadian Shield tends to result in low hydraulic gradients for groundwater movement in the shallow active region (McMurry *et al.*, 2003). In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson *et al*., 1996; McMurry *et al*., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson *et al*., 1996; McMurry *et al*., 2003). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell and Atikokan research areas range from approximately 10^{-10} to 10^{-15} m/s (Ophori and Chan, 1996; Stevenson *et al*., 1996). Another example is data reported by Raven *et al.* (1985) which shows that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400 to 500 m.

There is no site-specific information on the hydraulic characteristics of the dykes interpreted for the Schreiber area. Information from mines in the Canadian Shield (Raven and Gale, 1986) and other geological settings shows that dykes may act as either pathways or barriers for groundwater flow in a host rock. Their hydraulic characteristics depend on a wide range of factors that include their frequency and location within the host rock, their orientation with respect to the direction of groundwater flow, their mineralogical composition, degree of alteration and their potential association with brittle deformation structures (e.g., Ryan *et al.*, 2007; Svensson and Rhén, 2010; Gupta *et al*., 2012; Holland, 2012), including both pre-existing structures and those developed as a result of dyke emplacement. The orientation of fracture networks relative to the orientation of the maximum horizontal compressive stress may also influence permeability. A lower effective hydraulic conductivity would be predicted for fractures oriented at a high angle to the maximum compressive stress axis compared to otherwise identical low angle fractures. Horizontal stress measurements from various locations in the Canadian Shield (Kaiser and Maloney, 2005; Maloney *et al.*, 2006) indicate that the axis of maximum horizontal stress is oriented predominantly in the east-northeast-trending direction.

However, due to lack of data in the Schreiber area, caution is warranted in extrapolating the west-southwest stress orientations without site-specific data. The exact nature of deep groundwater flow systems in the Schreiber area will need to be evaluated at later stages of the site evaluation process, through the collection of site-specific information.

4.5 Hydrogeochemistry

A lake sediment and water geochemical survey of the Schreiber area and surrounding region, which collected samples at a density of 1 per 2 km^2, was completed by the Ontario Geological Survey (Dyer, 1997a, 1997b). This survey provided a greater degree of detail than an earlier regional survey, reported on by Friske *et al.* (1991), which collected samples at a much lower average density.

The OGS survey collected lake water samples from 1,222 lakes within the Schreiber area. Lakes in the area had an average pH and conductivity of 6.7 and 31.6 µS/cm, respectively. Generally, pH was consistently near neutral, particularly over the area of the Crossman Lake and Whitesand Lake batholiths (Dyer, 1979a). Somewhat more alkaline conditions and higher electrical conductivity occur near the contact between the Terrace Bay batholith and surrounding metavolcanic rocks. Dyer (1979a) attributed this to the relative abundance of carbonate in the metavolcanic bedrock resulting from it being strongly faulted and sheared, and having undergone pervasive hydrothermal alteration. The results of the Schreiber lake water survey indicate that due to the thin overburden cover in the area, the water geochemistry reflects the underlying bedrock geology. The lake water geochemistry is influenced by shallow groundwater and surface water inputs.

There is a lack of information or studies on groundwater hydrogeochemistry for the Schreiber area. Existing literature, however, has shown that groundwater within the Canadian Shield can be subdivided into two main hydrogeochemical regimes: a shallow, generally fresh water flow system, and a deep, typically saline water flow system (Singer and Cheng, 2002).

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

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

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

5 NATURAL RESOURCES – ECONOMIC GEOLOGY

Mining in the Schreiber area has historically focused on metals, especially gold, within the Schreiber-Hemlo greenstone belt and the contact aureoles surrounding granitoid batholiths. This is clearly illustrated by the distribution of active mining claims in the area, the bulk of which are located over the two arms of the Schreiber-Hemlo greenstone belt and the immediate surrounding land (Figure 5.1). The greenstone belt hosts the majority of mineral occurrences, historic mining operations (Figure 5.1) and exploration diamond drilling activity. Approximately 100 km east of the settlement area of Schreiber, mining occurs at Barrick Gold's Williams and David Bell gold mines in the Hemlo area.

There are currently no producing metallic mineral mines in the Schreiber area. The potential for economically exploitable base and precious metal mineralization remains high, however, and mineral exploration is active (Campbell *et al.*, 2012). Exploration emphasis is on:

- Gold and volcanogenic massive sulphide (VMS) base-metal deposits within the Schreiber-Hemlo greenstone belt;
- Copper-nickel deposits within a gabbroic intrusion that borders the Crossman Lake Batholith; and
- Copper-molybdenum deposits near the contact between the granitic batholiths and the metavolcanic rocks in the greenstone belt.

Metallic mineral deposits and occurrences in the Schreiber area include: gold, silver, and base metal occurrences as well as some singular metal occurrences. A description of the various types of precious and base metal deposits in the Schreiber area, mainly based on Patterson *et al.* (1986), Carter (1988), and Smyk and Schnieders (1995), is outlined below.

5.1 Petroleum Resources

The Archean suites of felsic intrusive and metavolcanic rocks found in the Schreiber area are unfavourable host rocks for petroleum generation and/or containment. For this reason there is negligible potential for hydrocarbon reserves in the area and no records exist of exploration for oil or gas.

5.2 Metallic Mineral Resources

Gold

Gold exploration in the Schreiber area dates to 1851, recognized when Terrace Bay became the site of the first molybdenum discovery in Canada (Smyk and Schnieders, 1995). Some of the earliest claim staking took place south of Schreiber in 1872, prior to the construction of the Canadian Pacific Railway. In the Schreiber area, early gold discoveries occurred between 1895 and 1920 (Hopkins, 1922). This exploration ultimately led to surface and underground development on a number of small properties, resulting in a modest, collective gold production of approximately 3000 ounces.

Gold, in places accompanied by silver, occurs in four associations:

- Auriferous quartz-veins and quartz-stringers in shear zones and faults in mafic metavolcanic rocks;
- Quartz veins in shear zones in mafic metavolcanic rocks within 400 m or close to the contact aureole of the Terrace Bay Batholith, such as the past Harkness-Hays, Gold Range, and Derraugh Mines, with the former two and the latter located some 4 km and 8 km east of the settlement area of Schreiber, respectively;

- Veins either inside or in the border zone of the granitic rocks, such as the past North Shores Mine (mix host of metavolcanic and granitic rocks) in the Mount Gwynne pluton, and Gale and Worthington Bay No.1 occurrences in the Terrace Bay Batholith; and
- In some interflow iron formation units inter-layered within the metavolcanic rocks; for example, gold at the abandoned Otisse Mine, adjacent to the western shore of Hays Lake, occurs in several veins, associated with strongly sheared basalts inter-layered with graphitic and ferruginous metasedimentary rocks (Marmont, 1984).

Marmont (1984) described known gold showings along the contact zone of the Terrace Bay batholith as sets of sub-parallel, en echelon, lensoidal quartz veins that occur within metavolcanic rocks and commonly are oriented parallel to the margin of the batholith. Some examples of this type of gold showings include the Empress Mine, and the Hays Lake, Gold Range, and Harkness-Hays prospects.

Several gold occurrences are also spatially associated with the Big Duck Lake porphyry (Smyk and Schnieders, 1995), which is located in the north-central part of the Schreiber area, east of the Winston Lake Mine. The location of past-producing gold mines in the area is shown by Santaguida (2002).

Silver

Silver deposits, associated with gold and copper, occur as vein-type deposits in two settings:

- With massive argentiferous sphalerite and galena and chalcopyrite in quartz and carbonate veins in fractures and argentiferous shears in calc-alkalic rocks in the lower volcanic sequence southeast of the settlement of Schreiber; and
- As native silver with massive pyrite and chalcopyrite in diabase dykes.

The silver occurrences are all located in the eastern half of the Schreiber Peninsula in fractures in calc-alkalic andesite and dacite (Carter, 1988). Two occurrences of silver occur in diabase dykes. One is the Longworth Vein located in the eastern half of the Schreiber Peninsula about 3 km south-southeast of the settlement of Schreiber. The other is Worthington Bay No. 2 Occurrence located in the shore about 1.5 km northwest of the Les Petits Ecrits Islands (Carter, 1988).

Base metals

Patterson *et al.* (1986) classified base metal mineralization in the Schreiber-Terrace Bay area as follows:

- *Volcanogenic Massive Sulphide (VMS) Deposits*
  Characterized by base metals (Cu-Zn) in calc-alkalic felsic volcanic rocks;
- *Zinc-Lead-Silver Veins*
  Characterized by zinc, lead, and silver mineralization concentrated within narrow carbonate and quartz veins within shear zones, faults, and fractures associated with metavolcanic and metasedimentary rocks;
- *Lead-Zinc-Barite Veins*
  Characterized by lead-zinc-barite veins within Proterozoic rocks spatially associated with the unconformity between Proterozoic and Archean rocks;
- *Copper-Molybdenum Veins*
  Characterized by copper-molybdenum with minor silver and gold mineralization in quartz veins, quartz-feldspar veins and aplite or pegmatite dykes.

Carter (1988) and Smyk and Schnieders (1995) added oxide- and sulphide-facies banded iron formation copper-lead-zinc mineralization to this classification. This type of mineralization is described as occurring in narrow bands interlayered with chert, silicified argillite, carbonatized wacke and graphitic schist within the mafic metavolcanic sequence of the Schreiber-Hemlo greenstone belt. Examples of these occurrences occur about 1 km south-southwest of Big Bear Lake, approximately 4 km northeast of the settlement of Schreiber (Carter, 1988) and at the Morley pyrite deposit, 3 km south of Schreiber (Smyk and Schnieders, 1995). Carter (1988) also noted exploration for nickel sulphide mineralization was conducted in sulphide facies iron formation and in metagabbro.

Copper, as chalcopyrite, is frequently associated with gold and occurs in veins, stringers and disseminations in shears in basalt and rhyolite, an example of which is the Ansell Lake occurrence, adjacent to the north boundary of the Township of Schreiber. This type of copper mineralization is related to mineralized quartz veins and quartz stringers in shear zones and is not of the VMS type, but considered a by-product of gold mineralization (Carter, 1988).

Base metals are also reported from the Winston Lake Zn-Ag-Cu mine (closed in 1998), approximately 19 km northwest of Schreiber, near the boundary between the Wawa and Quetico subprovinces. Exploration and mining activity in this area dates back to discovery and initial development of the Zenith Mine in 1879, when mining of sphalerite-rich massive sulphide started (Smyk and Schnieders, 1995).

Occurrences of molybdenum-copper vein-type deposits are spatially related to the granitic rocks of the Crossman Lake, Whitesand Lake and Terrace Bay batholiths. They occur at the margins of the Crossman Lake and Whitesand Lake batholiths, and at the margins of, and within the main mass of the granitic rocks in the Terrace Bay batholith (Marmont, 1984). An example of a molybdenum-copper-bearing vein in the Terrace Bay batholith is the Pitkanen showing (Marmont, 1984).

In the case of the Crossman Lake and Whitesand Lake batholiths, the large volumes toward the centre of the intrusions seem devoid of metallic mineralization, as no such mineralization has been reported. Quartz veins that carry chalcopyrite and molybdenum with traces of gold occur throughout the Terrace Bay batholith, but seem to be more concentrated in the western portion of the intrusion (Marmont, 1984). Molybdenite occurs as disseminated blebs, flakes and rosettes, and copper as disseminated grains and stringers impregnating quartz veins, aplite, pegmatite and feldspar-porphyry (Carter, 1988). Molybdenite occurrences are also reported in quartz veins and disseminations in granitic rocks and gneiss in the Sox Lake area.

Nickel-copper mineralization occurs as nickel sulphide deposits comprising nickel-bearing pyrrhotite, pentlandite and chalcopyrite. Nickel-copper mineralization is associated with magnetite, ilmenite and pyrite in metagabbro and granitic rocks, an example being the Nicopor occurrence, located 1.5 km northwest of Schreiber Township (Carter, 1988).

Rare Earth Elements

Rare earth elements (REE) mineralization has not been identified in the Schreiber area. The chemical composition of the main granitic intrusions (Terrace Bay, Whitesand Lake, and Crossman Lake batholiths) suggests a low potential for REE-bearing pegmatites in the area (Carter, 1988).

Dyer (1997a) noted that REEs were enriched in some lake sediment samples collected over greenstone terrain, particularly near granite-greenstone contacts. He interpreted this as a possible indication of pervasive hydrothermal alteration as elevated calcium concentrations in both water and lake sediment displayed a close spatial relationship with areas known to have pervasive hydrothermal alteration.

Platinum Group Elements

No occurrences of platinum group element (PGE) mineralization have been identified within the Schreiber area. The possibility for such mineralization does exist, mainly in the ultramafic volcanic and mafic-ultramafic intrusive rocks, however, the potential for an economic PGEs deposit is considered low.

Uranium

No uranium mineralization has been identified within the Schreiber area. The closest known uranium mineralization occurs approximately 20 km to the east of Terrace Bay.

5.3 Non-metallic Mineral Resources

Sand and Gravel

A number of active sand and gravel operations existing along the route of Highway 17. The majority of the pits are located approximately 4 km east of Schreiber where ice-contact material, reworked by post-glacial lake beach and near-shore processes, is extracted. Additional pits are located in the vicinity of Terrace Bay where pits are developed in sand-rich deltaic deposits (Figure 2.3). The Ontario Ministry of Natural Resources (MNR, 2012b) and Ontario Ministry of Transportation records indicate there are approximately 20 permitted aggregate operations in the area.

A number of small, unpermitted pits have been developed along forestry roads and trails. These pits are largely developed in glaciofluvial material and are temporary or utilized on an as-needed basis to meet local demand in remote areas.

Aggregate – Crushed Stone

The Ontario Ministry of Natural Resources (MNR, 2012b) records indicate no active quarry permits for the Schreiber area. Highway construction in the area has, however, used the “cut and fill” method, whereby excavated rock along the right-or-way has been used as fill in lower areas.

Jagger Hims Limited *et al.* (2001) completed a study of the potential of the Terrace Bay and Whitesand Lake batholiths and the Gwynne Mountain pluton to supply high-quality crushed stone. The inland boundary of the study was limited to approximately 5 km from the Lake Superior shoreline as the investigation was focused on determining the possibility of a large quarry that exported production by marine transport. Aggregate testing of the Terrace Bay batholith confirmed that the rock is hard and durable, is capable of producing large volumes of high-quality aggregates. No testing was completed on the Mount Gwynne pluton although, based on visual examination of outcrops, it was believed to have potential for hosting a quarry. Areas of the Whitesand Lake batholith were found to have the potential to supply high specification aggregate. However, composition of the batholith was variable and quarrying would have to avoid strongly foliated to schistose zones. Development of lake-side quarry in the Schreiber area would require the construction of docking facilities suitable for large self-unloading ships outside of the coastline areas designated as conservation land.

Building Stone

The potential for a building stone extraction in the Schreiber area has been recognized and regional investigations to investigate the bedrock have been conducted and reported on by the Ontario Geological Survey (Hinz *et al.*, 1994). The investigation focussed on a suite of felsic lithologies which are all considered “granite” in construction terminology. While the potential for a building stone quarry in the Schreiber area exists, past exploration and development activity has been limited.

Regionally, in the Marathon area to the east, a number of quarries have seen extractive activity; however, none are now operating. Some of these quarries appear to have been developed to supply stone for the construction of the CPR railway. All quarries were developed in iron-rich syenite with the rock being described as black granite (Hinz *et al.*, 1994).

Diamonds (kimberlite)

To date no reports of kimberlite intrusions, with which diamonds are associated, have been reported in the Schreiber area. Sage (1982), however, described a diatreme breccia occurring at the margin of a body of biotite-rich lamprophyre approximately 4.5 km east of Schreiber. While indicating that more such bodies may be found in the area, Sage suggested a north-trending corridor between Marathon and Terrace Bay is more prospective for diamond exploration.

Kimberlite indicator minerals recovered from a regional overburden sampling program have been reported to the east of the Schreiber area, northeast of Terrace Bay. The indicator minerals were found in the vicinity of the contact of the Terrace Bay batholith and the Schreiber-Hemlo greenstone belt northwest of Jackfish Lake (Morris, 2001; Morris, 2002; Morris *et al.* 2002).

Peat

No records of peat extraction exist for the Schreiber area. Organic deposits in the Schreiber area are generally small and appear to hold limited potential for development (Monenco Ontario Limited, 1981). A regional evaluation of peat deposits to the north of Schreiber area was conducted by Dendron Resource Surveys Limited (1986). Their findings indicated that large peat deposits develop on poorly drained glaciolacustrine and till substrates; extensive deposits of these materials do not exist in the Schreiber area.

Other Industrial Minerals

The felsic intrusive bodies within and surrounding the Schreiber area are recognized as having three primary settings with potential for non-metallic/metallic mineralization (Springer, 1978). These are:

- Vein infillings - amethyst, barite and fluorite mineralization;
- Migmatite contact zones – uranium, thorium mineralization;
- Pegmatitic zones - lithium, beryllium, cesium, molybdenum and rare earth elements.

In the Schreiber area several fluorite occurrences associated with the Crossman Lake, Terrace Bay and Whitesand Lake batholiths have been identified. The fluorite is found as veins within the granitic bodies and, in instances, other mineralization is also present (e.g., barite). At this time all deposits are uneconomic.

Within the Crossman Lake batholith to the west and northwest of the Schreiber area three undeveloped, industrial mineral occurrences have been identified (Hinz and Landry, 1994). A large quartz vein occurrence, of unknown purity, is located on Dickison Lake, 39 km north-northwest of Schreiber. A narrow calcite vein occurrence has been found on the west bank of the Gravel River 38 km northwest of Schreiber. An amethyst-barite occurrence, consisting of a series of veins and breccia zones, is located in south-central Yesno Township approximately 28 km west of Schreiber.

6 GEOMECHANICAL AND THERMAL PROPERTIES

Geomechanical information including intact rock properties, rock mass properties and *in situ* stresses are needed to design stable underground openings, predict the subsequent behaviour of the rock mass around these openings and predict the response of the groundwater flow system. As such, geomechanical information associated with a potential host rock can be used when addressing several geoscientific, safety-related factors defined in the site selection process document (NWMO, 2010). There is limited geomechanical information on the granitic intrusions in the Schreiber area. Table 6.1 summarizes all available geomechanical information from the granitic intrusions elsewhere in the Canadian Shield with rock types similar to those of interest in the Schreiber area. These sites are the Lac du Bonnet granite at AECL's Underground Research Laboratory (URL) in Manitoba and the Eye-Dashwa granite near Atikokan, Ontario. The majority of the geomechanical characterization work for the URL in Pinawa, Manitoba, was conducted on these rocks as part of AECL's Nuclear Fuel Waste Management Program in the 1990s.

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[b]
Split Tension Strength (Brazilian) (MPa)	4 to 9[c]	NA
Porosity (%)	0.35[a]	0.33[b]
P-wave velocity (km/s)	3220 (±100) - 4885 (±190)[d]	NA
S-wave velocity (km/s)	2160 (±55) - 3030 (±115)[d]	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}/^{0}C)	6.6[a]	15[a]

NA = Not Available; [a]Stone *et al*., 1989; [b]Szewcyk and West, 1976; [c]Annor *et al.*, 1979; [d]Eberhardt *et al.*, 1999

6.1 Intact Rock Properties

Intact rock properties tabulated in Table 6.1 are based on laboratory testing of rock core specimens from boreholes. The table includes basic rock properties such as density, porosity, uniaxial compressive strength and tensile strength for use in engineering design and structural analyses. These parameters feed into the rock mass classification schemes, and *in situ* stress determination.

There is a general paucity of information on the geomechanical properties of the granitic intrusive bodies in the Schreiber area. A limited amount of construction and development has taken place in the area that required near surface investigation of the batholiths' engineering properties and no deep subsurface investigations have been conducted. No specific information is available for the Crossman Lake, Whitesand Lake and Terrace Bay batholiths and the Mount Gwynne pluton within the Schreiber area.

At this stage of the site evaluation process, it is reasonable to assume that the geomechanical properties of intact rock in the Schreiber area may resemble those of the similar rock types elsewhere in the northwestern Superior Province. The rock property values presented in Table 6.1 are consistent with the values selected for numerical modeling studies conducted to evaluate the performance of hypothetical repository designs in a similar crystalline rock environment (SNC-Lavalin Nuclear Inc., 2011; Golder Associates, 2012a, 2012b). Site-specific geotechnical assessment would need to be conducted during later stages of the site evaluation process.

6.2 Rock Mass Properties

Rock mass properties address the behaviour of a body of rock, including its fracture or joint network. The presence of fractures changes the strength and hydraulic behaviour of a rock mass compared to what would be measured on small intact samples of the rock. For example, the strength of a rock mass containing a network of joints will be lower than the uniaxial compressive strength of a core sample measured in a laboratory. One would also expect the permeability of a rock mass to be greater than what would be measured on an intact core sample.

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. There is no information available on rock mass properties of the granitic intrusions in the Schreiber area. However, it is known that crystalline rock of the Canadian Shield can have a spectrum of fracture conditions at a given site. In general, there will be a downward decreasing fracture density from highly fractured rocks in shallow horizons (ca. <300 m below ground surface) to sparsely fractured intact rock at greater depths as experienced at other shield sites (e.g., Everitt, 2002). Fractures observed on surface bedrock exposures may occur as well-defined sets of geological discontinuities, or as randomly oriented and variably-dipping features. Based on observations from other shield sites (e.g., Everitt, 2002) and stress measurement data (e.g., Maloney *et al*. 2006), one could infer that a shallowly-dipping to sub-horizontal fracture set may exist as a result of either strain releasing during the rebound from the last glacial cycle or the presence of pre-existing fabric anisotropy (e.g., bedding, tectonic foliation) in the rock structure. Rock mass properties for the Schreiber area would need to be determined at later stages of the assessment.

6.3 In situ stresses

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

No site-specific information is available regarding the *in situ* stress conditions within the Schreiber area; however, in eastern North America the current stress orientation is approximately east-northeast (Heidbach *et al*., 2008). Horizontal stress conditions are 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.

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 (Maloney *et al*., 2006). The data presented by Maloney *et al.* (2006) indicate an average southwest orientation for the maximum horizontal stress, which is consistent with the World Stress Map, although anomalous stress orientations have been identified in northwest Ontario including a 90° change in azimuth of the maximum compressive stress axis which was identified in the near surface of the Whiteshell area of Manitoba (Brown *et al.*, 1995). In addition, a roughly north-south orientation of maximum horizontal compressive stress was found for the Sioux Falls Quartzite in South Dakota (Haimson, 1990).

Local stress-relief features such as faults and shear zones can be expected to locally affect stress regime. For example, thrust faults at AECL's URL were shown to be boundaries between significant changes in the magnitude and orientation of the principal stresses. Above a major thrust fault, located at depth of 270 m (referred to as Fracture Zone 2, or FZ2 at the site), the magnitude was close to the average value for the Canadian Shield and the orientation of the maximum horizontal stress was consistent with the average predicted by the World Stress Map (i.e., southwest) (Zoback, 1992). Below the same thrust fault, the stress magnitudes are much higher than the average data for the Canadian Shield, and the maximum principal stress rotates approximately 90° to a southeast orientation (Martino et al., 1997). The principal maximum horizontal stress magnitude below the Fracture Zone 2 thrust fault remains relatively constant around 55-60 MPa, which is more typical of the values found at greater depths. The southeast orientation of the maximum principal horizontal stress is consistent with the data.

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

6.4 Thermal Conductivity

Thermal conductivity values for potential host rocks provide information on how effectively the rock will transfer heat from the repository and dissipate it into the surrounding rock. The thermal conductivity of a rock is in part dependent on its mineral composition, with rocks comprised of higher quartz content generally having higher thermal conductivities. The thermal conductivity of quartz (7.7 W/(m˚K)) is greater than those 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 Schreiber area. Available information indicates that the dominant compositions of these batholiths are: granite and tonalite in the Whitesand batholith; monzodiorite, tonalite, granodiorite and granite in the Crossman Lake batholith; and granite, granodiorite and quartz monzonite in the Terrace Bay batholith. The dominant composition of the Mount Gwynne pluton is granite and granodiorite. The quartz mineral content of granite and granodiorite rock types can range from approximately 20% to 60% by volume (Streckeisen, 1976). The range of measured thermal conductivity values for granite, granodiorite and tonalite found in the literature are presented in Table 6.2; data for monzonite was not found.

At this desktop stage of the investigation, there is additional uncertainty as to whether the existence of dykes will have a positive or negative impact on the thermal conductivity of the surrounding host rocks. The potential heterogeneity in thermal conductivity associated with the presence and nature of dykes is difficult to quantify at the desktop stage of the investigation and will need to be studied in further.

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]Kukkonen *et al*., 2011; [c]Stone *et al*., 1989; [d]Back *et al*., 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]Kukkonen *et al*., 2007.

Although no thermal conductivity values are available for the Schreiber area, some useful comparisons are provided by Stone *et al.* (1989) in their summary of thermal conductivity values for two late Archean granitic intrusions of the Superior Province of the Canadian Shield, the Lac du Bonnet Batholith and the Eye-Dashwa Pluton (Table 6.1). Both intrusions were described as having similar mineralogical compositions. 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 general comparison purposes as part of this preliminary assessment. However, actual values will need to be determined at later stages of the assessment.

7 POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE SCHREIBER AREA

7.1 Approach

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

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

The geoscientific assessment of suitability was carried out in two steps. The first step (Section 7.2) was to identify general potentially suitable areas using the key geoscientific characteristics described below. The second step (Section 7.3) was to verify that identified general areas have the potential to meet all NWMO's geoscientific site evaluation factors (NWMO 2010). The potential for finding general 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 (Golder, 2011) were not considered. This included the north and south arms of the Schreiber-Hemlo greenstone belt and detached fragments of greenstone located in the southwest quadrant of the area (Figure 3.4). These geological units were considered not suitable due to their heterogeneity, structural complexity and potential for mineral resources. The Mount Gwynne pluton was also not considered due to its small size which would limit its ability to host a repository. Rock bodies considered potentially suitable for hosting the repository were the large, relatively homogenous and massive granitic batholiths: Crossman Lake, Whitesand Lake and Terrace Bay batholiths. Within these batholiths, the geophysical data was examined (Mira, 2013), such that areas with "quiet" aeromagnetic signatures were favoured. These three intrusions were further evaluated on the basis of the subsequent considerations.
- ***Structural Geology*****:** The spatial distribution, character and presence of local and regional scale faults in the Schreiber area were considered. Areas in the vicinity of the Wawa-Quetico subprovince boundary were not considered because there is highly sheared rock in some areas (Williams et al., 1991). The thicknesses of the batholiths in the Schreiber area are unknown and were therefore not a differentiating feature.
- ***Lineament Analysis:*** In the search for potentially suitable areas, there is a preference to select areas that have a relatively low density of lineaments, particularly a low density of longer lineaments as they are more likely to extend to greater depth than shorter lineaments (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.
- ***Overburden:*** The distribution and thickness of overburden cover is an important site characteristic to consider when assessing amenability to site characterization of an area. For practical reasons, it is considered that areas covered by more than 2 metres of overburden deposits would not be amenable 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., Andersson et al., 2007). At this stage of the assessment, preference was given to areas with greater bedrock exposures (Figure 2.3). Areas of extensive overburden are present in the northeast and northwest corners of the Schreiber area. Notable glaciofluvial deposits occupy some of the larger bedrock valleys in the Schreiber area. The only region of thick, extensive overburden cover is in the southeastern corner of the Schreiber area, between the towns of Schreiber and Terrace Bay (Figure 2.3). This area, overlying a large portion of the Terrace Bay batholith, was not considered.
- ***Protected Areas:*** Provincial parks and conservation reserves were excluded from consideration. The five protected areas, four of which are located along the Lake Superior coast and one on the western boundary, occupy a combined total of approximately 22.1 km^2. Several of these protected areas fall within the batholiths of interest (Crossman Lake, Whitesand Lake and Terrace Bay batholiths). The eastern part of the Superior North Shore Conservation Reserve occurs within the Terrace Bay batholith in an area of bedrock-dominated terrain where outcrop is abundant. The western portion of this reserve occupies a minor area along the Lake Superior coast underlain by the Whitesand Lake batholith. Rainbow Falls Provincial Park also overlies a relatively small area of the Whitesand Lake batholith. These areas were eliminated from further consideration.
- ***Natural Resources:*** The potential for natural resources in the Schreiber area is shown on Figure 5.1. As noted above, the Schreiber-Hemlo greenstone belt has known potential for exploitable natural resources and was not considered due to its unfavourable geology. In contrast, the Terrace Bay, Crossman Lake and Whitesand Lake batholiths are generally considered to have a low mineral potential despite the presence of

a number of occurrences and active claims (Figure 5.1). 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:*** The Schreiber area is generally rugged with significant local relief, with the exception of the region surrounding and west of the town of Terrace Bay (Figure 2.2). Rapid changes in relief are common as is illustrated by the numerous steep slopes which, in some instances, form near vertical cliffs. The distribution of lakes and wetlands is relatively uniform across the Schreiber area; only in a few areas of limited extent would the concentration or size of water bodies affect the placement of potential general siting areas. For the identification of potentially suitable areas, the principle factors considered were topography and the size and location of water bodies and wetlands. The similar nature of conditions, especially over the larger batholiths, resulted in no areas being directly excluded from further consideration.

7.2 Potential for Finding General Potentially Suitable Areas

Areas closer to the Township of Terrace Bay (i.e., the Terrace Bay batholith), the islands in Lake Superior, and the area north of the Wawa-Quetico subprovince boundary were not investigated for their potential, but rather were included to improve the understanding of the geology of the Schreiber area. The consideration of the above key geoscientific evaluation factors revealed that the Schreiber area contains two general areas where there is a potential to find suitable sites for hosting a deep geological repository. These two areas are located within the Crossman Lake batholith. Figure 7.1 shows features illustrating some of the key characteristics and constraints used to identify general potentially suitable areas, including: bedrock geology; protected areas; areas of thick overburden cover; surficial and geophysical lineaments, existing road network, the potential for natural resources and mining claims. The legend 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 Crossman Lake batholith is a ca. 2.690 to 2.680 billion year old grantitic intrusion occupying the majority of the northern part of the Schreiber area, covering 300 km^2. The depth of the batholith in the Schreiber area is not known, although it is believed to extend well below the planned repository depth of approximately 500 m based on the interpretation of regional gravity data (Mira, 2013), the regional geological model for the area (Santaguida, 2002; Muir, 2003) and the areal extent of the batholith.

The vast majority of the Crossman Lake batholith has a high percentage of outcrop and/or thin overburden cover, no protected areas and a low potential for natural resources (Figure 7.1). Therefore the primary constraints used to identify general potentially suitable areas within the Crossman Lake batholith were structural geology and lineament density. The topography of the Crossman Lake batholith in the Schreiber area is rugged due to the widespread distribution of bedrock knobs and ridges and the numerous steep-sided, incised river valleys (Figure 2.2).

The first general potentially suitable area is in the western portion of the Crossman Lake batholith to the west of Ross Lake fault and north of the Sox Creek and Cook Lake faults (Figure 3.4 and 7.1). The second area is in the eastern portion of the Crossman Lake batholith to the north of the Syenite Lake fault, and to the east of the north-trending unnamed fault that parallels Deep Lake (Figure 3.4 and 7.1).

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

7.2.1 Crossman Lake Batholith - West

As is the case for the vast majority of the Crossman Lake batholith, the area to the west of Ross Lake fault and north of the Sox Creek and Cook Lake faults (Figure 3.4) has a high percentage of outcrop and/or thin overburden cover, no protected areas and a low potential for natural resources (Figure 7.1). The exceptions are morainal deposits (till) in the northwest corner that provide more extensive but relatively thin overburden cover and a narrow belt of glaciofluvial deposits, of uncertain depth, present along the course of the Pays Plat River in the northwest corner (Figure 2.3).

In the vicinity west of the Ross Lake fault, mapping of the Crossman Lake batholith by Carter (1981) has shown it to be primarily a massive, hornblende, biotite granite. Carter also described occasional outcrops in this part of the batholith as hornblende, biotite syenite, quartz syenite. The Wawa-Quetico subprovince boundary is approximately 1 km to the north. Nearby regional features include the Midcontinent Rift (about 20 km to the south) and the Gravel River fault (about 18 km to the northwest). There are no published faults to the west of the Ross Lake fault and to the north of the Cook-Lake and Sox Creek faults in the Schreiber area (Figure 3.4 and 7.1). The Ross Lake fault approaches the area from the southeast and may truncate the western end of the Schreiber-Hemlo greenstone belt. The northwest tending Cook Lake fault is shown as ending to the south of the area. However, more detailed mapping could see it extended, in which case it would cut across the southwestern corner of the area for a short distance.

Additional insight into the potential suitability of the area is provided by the analysis of interpreted lineaments (Figure 3.12), which is described in detail in SRK (2013). The lack of substantial overburden cover in the area and the high resolution geophysics enables a detailed assessment of the bedrock structure of the Crossman Lake batholith. A high resolution magnetic-electromagnetic survey covers most of the Crossman Lake batholith west of the Ross Lake fault, with the western edge having less detailed coverage. The magnetic geophysical signature of the area is relatively flat, suggesting lithologic homogeneity (Mira, 2013). Analysis of lineaments suggested that the area to the west of Ross Lake fault and north of the Sox Creek and Cook Lake faults has a low lineament density. The spacing between geophysical lineaments in the area ranges between 0.4 and 3.1 km (SRK, 2013). Geophysical lineament density is affected by the distribution of high-resolution magnetic-electromagnetic survey coverage, such that a modest increase in magnetic lineament density occurs in the area of high-resolution data. The dominant orientation of longer geophysical lineaments within the area is west-northwest and northwest. Lineaments of all orientations appear to have a near vertical dip, based on the observations of Carter (1988) and the steepness of cliff faces across the Schreiber area.

The assessment of potentially suitable areas within the Crossman Lake batholith also took into consideration interpreted surficial lineaments. Figure 3.12 and 7.1 show the surficial lineament density to be generally moderate to high throughout the Crossman Lake batholith. However, surface lineament density over the area to the west of Ross Lake fault is amongst the lowest in the intrusion. Many of the shorter lineaments (<5 km) were only recognized in surficial datasets, while the majority of lineaments >5 km in length were identified in both geophysical and satellite data. At the desktop stage, it is uncertain if surficial lineaments represent real bedrock structure and how far they extend to depth, particularly in the shorter lineaments.

The distribution of total lineament density as a function of lineament length is shown on Figures 3.15 to 3.17 for lengths greater than 1 km, 5 km and 10 km, respectively. As expected, the figures show that the density of lineaments in the western portion of the Crossman Lake batholith decreases slightly when the <1 km long lineaments are filtered out (Figure 3.15) and decreases again when the lineaments <5 km are removed (Figure 3.16). There in only a modest subsequent change in the lineament density from filtering out the <10 km long features (Figure 3.17). In general, the western portion of the Crossman Lake batholith is identifiable as an area of total lower lineament density prior to and at all stages of the progressive filtering of lineaments by length.

While there are no mapped dykes in the area, the lineament analysis interpreted several dykes in the area, with a higher frequency to the southeast of the area (Figure 3.12). Interpreted dykes were attributed to the Matachewan, Marathon or Keweenawan dyke swarms (SRK, 2013). The assessment revealed that that dykes tend to have well-defined orientations, consistent with the geological history of the area (SRK, 2013). However, there remain some uncertainties regarding the nature and distribution of the dykes. For example, the potential existence of thin dykes, which are too small to be identified with any confidence from the geophysical data cannot be ruled out. Another aspect of uncertainty associated with the presence of dykes relates to understanding the extent of 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).

Active mining claims (as of December 2012) are present adjacent to the greenstone belt (Figure 5.1 and 7.1). These mining claims, staked in early 2012, are not thought to impact the potential suitability of the Crossman Lake batholith, as they are located in a geological environment considered to have a low mineral resource potential. Furthermore, any mineral occurrences in the area are within/adjacent to the greenstone belt.

The western portion of the Crossman Lake batholith is well drained by numerous streams, rivers and lakes, the largest of which is the Pays Plat River. Lakes occupy approximately 7.5% of the Crossman Lake batholith to the west of the Ross Lake fault and the majority of the area is within the Plays Plat watershed, although some areas drain via the Whitesand River (AECOM, 2013). An all-weather road from the Trans Canada Highway, leading to the past-producing Winston Lake Mine, is present to the east of the area (Figure 1.1).

In summary, the general area west of the Ross Lake fault within the Crossman Lake batholith (Figure 3.4) appears to be potentially suitable based on its favourable geology, structural geology and lineament density. It is within a large granitic intrusion; it contains no mapped faults; it has a low interpreted lineament density; and it has low potential for economically exploitable natural resources. The western portion of the Crossman Lake batholith is largely Crown Land without any parks or protected areas and should be easily accessible from a nearby road network. In addition, the area has good bedrock exposure which is amenable for site characterization.

Uncertainties remain in relation to the potential presence of smaller-scale dykes not identifiable in geophysical data and the potential damage of the host rock due to the intrusion of dykes. In addition, the potential effect that nearby regional features, such as the Midcontinent Rift, Gravel River fault and Wawa-Quetico subprovince boundary may have on the structural geology and fracture network would require assessment. Similarly, the impact of the rugged topography on accessibility and constructability would need to be assessed.

7.2.2 Crossman Lake Batholith - East

There is a high percentage of outcrop and/or thin overburden cover, no protected areas and a low potential for natural resources in the eastern portion of the Crossman Lake batholith to the north of the Syenite Lake fault, and to the east of the north-trending unnamed fault that parallels Deep Lake (Figure 3.4 and 7.1).

Mapping of the Crossman Lake batholith in this region by Carter (1982b) has shown it to be primarily a massive granite/tonalite with parts of the intrusion enriched in hornblende and biotite. The area is generally bounded by the Schreiber-Hemlo greenstone belt which arcs around the north, east and south of the area. Nearby regional features include the Wawa-Quetico subprovince boundary (about 5 km to the north), the Midcontinent Rift (about 19 km to the south) and the Gravel River fault (about 30 km to the northwest). Published geological maps covering the eastern portion of the Crossman Lake batholith show two unnamed, northwest-trending faults transecting the area (Figure 3.4).

A high resolution magnetic-electromagnetic survey covers all of the eastern Crossman Lake batholith to north of the Syenite Lake fault and suggests lithologic homogeneity (Mira, 2013). Analysis of lineaments suggested that the area to the east of the north-trending unnamed fault that parallels Deep Lake had a lower lineament density relative to other areas. Virtually all magnetic and electromagnetic geophysical lineaments are greater than 10 km in length. The spacing between geophysical lineaments in the area ranges between 0.2 and 2.3 km (AECOM, 2013). The dominant orientation of longer geophysical lineaments within the area is west-northwest and northwest. Lineaments of all orientations appear to have a near vertical dip, based on the observations of Carter (1988) and the steepness of cliff faces across the Schreiber area.

Figure 3.12 and 7.1 show that the surficial lineament density is generally higher compared to the Crossman Lake batholith area west of Ross Lake fault. Similarly to the western area, many of the shorter lineaments (<5 km) were only recognized in surficial datasets, while the majority of lineaments >5 km in length were identified in both geophysical and satellite data. Again, at the desktop stage, it is uncertain if surficial lineaments represent real bedrock structures and how far they extend to depth, particularly in the shorter lineaments.

The distribution of total lineament density as a function of total lineament length is shown on Figures 3.15 to 3.17 for lengths greater than 1 km, 5 km and 10 km, respectively. The figures illustrate that the lineament density in the eastern portion of the Crossman Lake batholith decreases with the progressive filtering of lineaments of <1 km, <5 km and <10 km in length. Lineaments of <5 km in length occur with a spacing of 1 to 1.5 km. Longer lineaments, those with a length of >5 km, are less frequent in the northern portion of the area where the spacing exceeds 2 km. With the exclusion of <10 km features, lineament density becoming more uniform across the area. In general, the eastern portion of the Crossman Lake batholith is identifiable as an area of lower total lineament density prior to and at all stages of the progressive filtering of lineaments by length.

A single northeast-trending dyke is present in the northernmost tip of the area. However, the lineament analysis (SRK, 2013) interpreted several dykes of fairly uniform distribution throughout the area that were attributed to the Matachewan, Marathon or Keweenawan dyke swarms (Figure 3.12). Dykes are more numerous in the area compared to the eastern portion of the batholith. As described in Section 7.2.1, there remain some uncertainties regarding the nature and distribution of the dykes that would require further assessment.

With the exception of the northernmost area adjacent to the greenstone belt, no mineral claims are present in the area (Figure 5.1). No mineral occurrences are documented (Figure 5.1). The eastern portion of the Crossman Lake batholith is well-drained by several creeks, rivers and lakes, the latter of which occupy approximately 4.7 percent of the area. This portion of the batholith straddles the boundary between the Big Duck Creek and the Aguasabon River watersheds (AECOM, 2013). The former drains the northwest and southwestern portions of eastern Crossman Lake batholith and the latter the remaining land area. A west-trending logging road, which connects to the all-weather road on the eastern side of the Schreiber area, provides access to this area (Figure 1.1). Several trails, most of limited length, also extend into the area.

In summary, the general area east of the unnamed north-trending fault within the Crossman Lake batholith (Figure 3.4) appears to be potentially suitable based on its favourable geology, structural geology and lineament density. It is within a large granitic intrusion; it contains abundant bedrock exposure with a low interpreted lineament density; and it has low potential for economically exploitable natural resources.

The eastern portion of the Crossman Lake batholith is largely Crown Land without any parks or protected areas and an existing logging road and trail network provide access to portions of the area. In addition, the area has good bedrock exposure which is amenable for site characterization.

As for the other potentially suitable area in the Crossman Lake batholith, the same uncertainties apply in relation to the presence and nature of dykes, the potential effect that nearby regional features (Midcontinent Rift, Gravel River fault, and Wawa-Quetico subprovince boundary) may have on the structural geology and fracture network, and the impact of rugged topography on accessibility and constructability. In addition, the characteristics and potential impact of the two mapped faults in the northern portion of the area would require further assessment.

7.2.3 Other Areas

While the western- and eastern-most portions of the Crossman Lake batholith have lower lineament density, the central portion of the Crossman Lake batholith (between the Ross Lake and north-trending unnamed faults), may have potential general siting areas should field investigation of the lineaments and/or mapped faults indicate that they are not a significant concern to the safety of a deep geological repository for used nuclear fuel.

Similarly, it may be possible to identify potential general siting areas in the Whitesand Lake batholith occurring in the southwestern corner of the Schreiber area. This portion of the batholith is within an area of bedrock-dominated terrain (Figure 2.3) and has a lower lineament density relative to other parts of the Schreiber area (Figure 3.14). However, the lineament analysis for this portion of the Whitesand Lake batholith is influenced by the fact that the area is only covered by a low resolution magnetic geophysical survey (Figure 3.6) which hinders lineament analysis using geophysical data. Some parts of the batholiths would also require additional geologic studies to prove their acceptability as a possible repository site; for example, those parts of the Whitesand Lake batholith where geophysical data indicates the possible presence of remnant mafic metavolcanic rocks intermixed with the intrusion.

Given the geographic extent of the Schreiber area, it may be possible to identify additional general potentially suitable areas. However, the two general areas identified in the Crossman Lake batholith are those judged to best meet the preferred geoscientific characteristics outlined in Section 7.1, based on available information.

7.2.4 Summary of Geoscientific Characteristics of the Crossman Lake Batholith

Table 7.1 provides a summary of the key geoscientific descriptive characteristics of the western and eastern portions of the Crossman Lake batholith in the Schreiber area.

Table 7.1: Summary of Geoscientific Characteristics of the Crossman Lake Batholith - Schreiber

Geoscientific Descriptive Characteristic	Crossman Lake Batholith - West	Crossman Lake Batholith - East
Area	Crossman Lake batholith covers 300 km^2 in the Schreiber area	
Mineralogy and composition	Crossman Lake Batholith: predominantly granite	Crossman Lake Batholith: predominantly quartz-monzonite, monzodiorite, granite
Age	ca.2.690-2.680 Ga	ca.2.690-2.680 Ga
Inferred host rock thickness	Unknown	Unknown
Structure: faults, foliation, dykes, joints	High apparent surface lineament density; Low to moderate apparent aeromagnetic lineament density Numerous dykes are present	High apparent surface lineament density; Moderate apparent aeromagnetic lineament density Numerous dykes are present
Aeromagnetic characteristics and resolution	Relative flat with distinct linear trends coincident with faults; high resolution coverage except for western third of area which has low resolution coverage	Relative flat with distinct linear trends coincident with faults; high resolution coverage
Relative proximity to mapped geological features (fault zones, shear zones, geological sub-province boundaries, etc.)	Midcontintent Rift ~20 km Gravel River fault ~18 km Wawa-Quetico subprovince boundary ~1 km	Midcontinent Rift ~ 19 km Gravel River fault ~ 30 km Wawa-Quetico subprovince boundary ~ 5 km
Terrain: topography, vegetation	Moderate to high relief; boreal forest cover	Moderate to high relief; boreal forest cover
Access	All weather road is present in the area. Limited number of trails in area	East-trending forestry access road is present. Limited number of logging roads in northern portion of area
Resources Potential	Low	Low
Bedrock Exposure*	ca. 50%; remainder of area has generally thin drift cover (1-3 m), thicker in Pays Plat River valley	ca.50%; remainder of area has generally thin drift cover (1-3 m)
Drainage	Good; majority of area within Pays Plat River watershed, small percentage in the southeast drains via Whitesand River	Good; Surface water drainage divide within area: eastern and western portions of area drain via Big Duck Creek and Aguasabon River watersheds, respectively

* Estimated percentage of area with outcrop at surface; this is a subset of the Bedrock Terrain area shown on Figure 2.3.

7.3 Evaluation of General Potentially Suitable Areas in the Schreiber Area

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

- ***Safe containment and isolation of used nuclear fuel**:* Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances 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. An evaluation of the two general potentially suitable areas in the Schreiber area in the Crossman Lake batholith is provided in the following subsections.

7.3.1 Safe Containment and Isolation of Used Nuclear Fuel

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

This requires that:

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

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

The thickness of the Crossman Lake batholith is unknown. Given the understanding of the regional geological setting and the nature of the batholiths, it is reasonable to assume it is likely to extend well below typical repository depth (approximately 500 m). Therefore, the thickness of the Crossman Lake batholith would contribute to the isolation of the repository from human activities and natural surface events.

Analysis of interpreted lineament spacing, including dykes, indicate that the two identified general areas in the Schreiber area have a lower density of lineaments and the potential to contain structurally bounded rock volumes of sufficient size to host a deep geological repository. The existence of a high resolution magnetic/electromagnetic geophysical survey covering most of the Schreiber area and lack of thick overburden over most of the Crossman Lake batholith allowed a detailed assessment of lineament distribution. Given the likely lithologic homogeneity of the batholith, zones of lower lineament density were the favoured locations for the identified general areas. Within the two general areas, the spacing between longer lineaments (>10 km) was an additional consideration since these were most likely to appear in multiple datasets and hence most likely to represent real features with a potential to extend to repository depth. In these general areas, longer lineaments occurred with spacing on the order of 2 to 3 km, suggesting there is potential for sufficient volumes of structurally favourable rock at typical repository depth. The western-portion of the Crossman Lake batholith contains no mapped faults, while the eastern-portion is segmented by two unnamed faults. Sufficient land, with the potential to host a siting area, may exist between these faults, but it is recognized that the characteristics of these faults would require further investigation.

The hydrogeological regime at repository depth should exhibit low groundwater velocities and retard the movement of any potentially released radioactive material. There is no information on the hydrogeologic properties of the deep granitic bedrock in the Schreiber area. It is therefore not possible at this stage of the evaluation to predict the nature of the groundwater regime at repository depth in the two areas. The potential for groundwater movement at repository depth is, in part, controlled by the fracture frequency, the degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of mineral infilling. Experience from other areas in the Canadian Shield indicates that ancient faults, similar to those in the Schreiber area, have been subjected to extensive periods of rock-water interaction resulting in the long-term deposition of infilling materials that contribute to sealing and a much reduced potential for groundwater flow at depth. Site-specific conditions that can influence the nature of deep groundwater flow systems in the Schreiber area 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.

As discussed in Section 4.4, available information for other granitic intrusions (plutons and batholiths) within the Canadian Shield, indicates that active groundwater flow within structurally-bounded blocks tends to be generally limited to shallow fracture systems, typically less than 300 m. In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson *et al*., 1996; McMurry *et al*., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson *et al*., 1996; McMurry *et al*., 2003). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan range from approximately 10^{-10} to 10^{-15} m/s (Ophori and Chan, 1996; Stevenson *et al*., 1996). Data reported by Raven *et al.* (1985) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400 to 500 m.

High relief areas can have higher hydraulic gradients that may impact the depth extent of shallow flow systems. Site-specific, subsurface characteristics, such as hydraulic conductivity and groundwater density variations, will also influence flow system geometry. The specifics of flow system geometry will need to be evaluated at later stages of the assessment, via site-specific studies.

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 largely lacking for the Schreiber area. The review of available information from other locations, with similar geological settings, did not reveal any obvious conditions that would suggest unfavourable mineralogical or hydrogeochemical characteristics for the granitic rocks characterizing the two areas identified within the Schreiber area (Sections 4.0 and 7.2). Site-specific mineralogical and hydrogeochemical characteristics, including pH, eH and salinity would need to be assessed during subsequent site evaluation stages. Similarly, it is expected that the geomechanical and thermal characteristics of the granitic intrusions within the Schreiber area may resemble those of other granitic bodies (i.e., the Lac du Bonnet batholith) elsewhere in the Superior Province (Section 6.0) with no obvious unfavourable conditions known at present. These characteristics would need to be assessed during subsequent site evaluation stages.

Dykes associated with Matachewan, Marathon and Keweenawan dyke swarms have been mapped and/or were identified during the lineament analysis of the Schreiber area. At this desktop stage of the investigation, information about the hydraulic and thermal conductivity properties is lacking. These aspects of uncertainty related to the nature of dykes in the Schreiber area is difficult to quantify at the desktop stage of the investigation and will need to be studied in further detail at later stages if the community remains in the site selection process. In addition, the potential existence of thin dykes, which are too small to be identified with any confidence from the geophysical data, or the presence of damage to the host rock (i.e., additional smaller lineaments) associated with dyke emplacement cannot be ruled out at this time and would require confirmation during subsequent studies.

In summary, the review of available geoscientific information, including completion of a lineament analysis and geophysical interpretation of the area, did not reveal any obvious conditions that would cause the rejection of either of the two identified areas on the basis of them not satisfying the containment and isolation requirements demanded of a repository. Potential suitability of these areas would have to be further assessed during subsequent site evaluation stages.

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 two general potentially suitable areas identified in the Schreiber area. The remainder of this section provides a summary of the factors listed above.

The Schreiber area is located in the Superior Province of the Canadian Shield, where large portions of land have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). Although a number of low magnitude seismic events (i.e., less than magnitude 3) have been recorded in the surrounding region, there are no recorded earthquakes within the Schreiber area (Figure 3.20).

Nearby regional features include the Midcontinent Rift (~19-20 km), the Gravel River fault (~18-30 km) and the Wawa-Quetico subprovince boundary, which is within the Schreiber area (Figure 3.3). In addition, numerous mapped faults are present in the Crossman Lake batholith within the Schreiber area. The structural geology of the Schreiber area, and associated fracture network, will require additional assessments and field evaluations, if the community is selected by NWMO, and continues to be interested in the site selection process.

A number of smaller faults are identified on the published bedrock geological maps covering the Schreiber area (Figure 3.4). There is no evidence to suggest these faults have been tectonically active within the past 1.100 billion years. The youngest major event of brittle fault displacement is constrained by the 1.100 billion year old Keweenawan dykes that transect the Schreiber area with no apparent fault offset. This suggests that only limited displacement could have occurred along the interpreted fault network since the intrusion of these dykes.

The geology of the Schreiber area is typical 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 units, particularly plutonic intrusions, have remained largely unaffected by past perturbations such as glaciation (e.g., Laine, 1980, 1982; Bell and Laine 1985). Findings of a comprehensive paleohydrogeological study of the fractured crystalline rock at the Whiteshell Research Area, located within the Manitoba portion of the Canadian Shield (Gascoyne, 2004), indicated that the evolution of the groundwater flow system was characterized by periods of long-term hydrogeological and hydrogeochemical stability. Furthermore, there is evidence that only the upper 300 m shallow groundwater zone has been affected by glaciations within the last million years. McMurry *et al.* (2003) summarized several studies conducted in a number of plutons in the Canadian Shield and in the crystalline basement rocks of western Ontario. These various studies found that fractures below a depth of several hundred metres in the plutonic rock were ancient features. Subsequent geological processes such as plate movement and continental glaciation have typically caused reactivation of existing zones of weakness rather than the formation of large new zones of fractures.

The Schreiber area is still experiencing isostatic rebound following the end of the Wisconsinan glaciations. Current rates of isostatic uplift in the Schreiber area are not precisely known, although Mainville and Craymer (2005) reported a vertical velocity rate of 2.75 mm/yr for a water level gauge at Rossport, just beyond the western limit of the Schreiber area. Lee and Southam (1994) estimated that the land is rising at a rate of 2.9 mm/yr at Michipicoten, Ontario, some 180 km to the southeast.

There is no site-specific information on erosion rates for the Schreiber area. However, as discussed in Section 3.1.6, the erosion rates from wind, water and past glaciations on the Canadian Shield are reported to be low, and are unlikely to affect the integrity of a deep geological repository in the Schreiber area in the long term.

In summary, available information indicates that the identified areas in the Schreiber area have the potential to meet the long-term stability factor. 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, or prevent the identified areas from remaining stable over the long term. The long-term stability factor 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.

The western- and eastern-most areas of the Crossman Lake batholith in the Schreiber area, although characterized by a rugged surface, contain enough land outside protected areas and significant sized water bodies to accommodate the required repository surface facilities. While there are few surface constraints that would prevent the construction of surface facilities in the two areas, the rugged terrain may require extensive site contouring during construction. Significant relief commonly occurs over short distances creating uneven ground and steep slopes.

From a constructability perspective, limited site-specific information is available on the local rock strength characteristics and *in-situ* stresses for the Schreiber area. However, there is abundant information at other locations of the Canadian Shield that could provide insight into what might be expected for the Schreiber area in general. As discussed in Section 6.0, 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 areas within the Crossman Lake batholith are situated in areas having extensive outcrop exposure. The overburden cover in areas between outcrops is generally thin (<3 m thick); however, local thickening is present due to the uneven bedrock surface. The most common surficial sediment in both areas is ground moraine (till) and the western-portion of the Crossman Lake batholith; contains a spatially restricted deposit of glaciofluvial outwash in the Pays Plat River valley.

In summary, the two general potentially suitable areas in the Schreiber area have good potential to meet the safe construction, operation, closure and long term performance factors required of a repository.

7.3.4 Isolation of Used Fuel from Future Human Activities

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.

In the Schreiber area, the Schreiber-Hemlo greenstone belt has the greatest mineral potential, with the Terrace Bay Batholith and the Mount Gwynne pluton having low to moderate potential (Section 5.0). No known or significant economic mineralization has been identified to date in the Crossman Lake and Whitesand Lake batholiths within the Schreiber area. Active mining claims exist in the western portion of the batholith. However, these claims have only recently been staked and there is no history of exploration for the ground or reported mineral occurrences.

The review of available information did not identify any groundwater resources at repository depth for the Schreiber area. As discussed in Section 4.0, water wells in the Schreiber area obtain water from overburden or shallow bedrock sources with well depths ranging from 4.3 to 94.5 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). Records contained in the Ontario Ministry of Environment databases indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Schreiber area or anywhere else in northern Ontario. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits potential yield, even if suitable water quality were to be found.

In summary, the potential for groundwater resources and economically exploitable natural resources at repository depth is considered low in the two identified areas within the Schreiber area although this conclusion will be subject to further confirmation if the community advances in the site selection process.

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. 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.

Detailed bedrock mapping, at a scale of 1:15,840, has been completed for the majority of the land within the identified areas. The Crossman Lake batholith is a dominantly massive granite, with a relatively flat magnetic geophysical signature indicating lithologic homogeneity.

As described 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 resolution of the data used for the mapping. Two factors significantly influenced the lineament interpretation for the Schreiber area: the majority of the area is covered by a high resolution magnetic-electromagnetic geophysical survey, and the bulk of the area has bedrock at or near surface. Together, these allow a detailed assessment of the lineament distribution and length. The fact that the western edge of the Schreiber area has only lower resolution geophysical coverage is compensated, in part, by the thin overburden that enable the recognition of lineaments from satellite imagery and by the topographic data.

The densities of lineaments in the western- and eastern-portions Crossman Lake batholith are not dissimilar. 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.

In the Schreiber area, future mapping of geology and identification of geological structures will be strongly influenced by the extent and thickness of overburden cover. The generally good bedrock exposure is amenable for evaluating the relative lithological homogeneity of the intrusion and for confirming the well defined orientation and existence of lineaments. Extensive deposits of thick overburden in the area are largely restricted to the Terrace Bay batholith and some bedrock-controlled valleys. Information on the thickness of overburden deposits within the Schreiber area is derived from a terrain assessment (AECOM, 2013), data within the MOE's water well records and MNDM's diamond drill hole database. These data indicate that the majority of the Schreiber area has thin, but variable, drift cover. The identified areas are similar with respect to their amount of bedrock outcrop and percent of bedrock-dominated terrain (i.e., bedrock with a thin, discontinuous overburden cover). In the western portion of the Crossman Lake batholith, thicker overburden exists in the northwest corner of the area along the Plays Plat River where outwash deposits are present.

The Winston Mine Road comes close to the western portion of the Crossman Lake batholith, while the eastern portion is accessible by a logging road that connects with an all-weather road 4 km to the east.

The review of available information did not indicate any obvious conditions which would make the rock mass in the two identified areas unusually difficult to characterize. Both areas have a high percentage of outcrop allowing for detailed surface mapping to support site characterization. No conditions were identified that would make site characterization unusually difficult at either of the areas.

8 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

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

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

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, and overburden deposits;

- Interpretation of available geophysical surveys (magnetic, electromagnetic, gravity, radiometric);
- 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 desktop geoscientific preliminary assessment showed that the Schreiber area contains at least two general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. These general areas are located within the Crossman Lake batholith.

The Crossman Lake batholith hosting the two identified potentially suitable areas appears to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. The batholith appears to have sufficient depth, lateral extent and lithological homogeneity. The two potentially suitable areas have low potential for natural resources, good bedrock exposure and are generally accessible.

While the general potentially suitable areas appear to have favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The main uncertainties relate to the influence of regional structural features, the presence of numerous dykes and the impact of rugged topography.

Both identified potentially suitable areas are located away from regional structural features, such as the Midcontinent Rift, Gravel River fault and Wawa-Quetico subprovince boundary. However, the potential impact of these regional features on the suitability of the two areas needs to be further assessed. The Schreiber area contains numerous dykes. While the spacing between mapped and interpreted dykes and lineaments within the two potentially suitable areas appears to be favourable, the potential presence of smaller dykes not identifiable on geophysical data, and potential damage of the host rock due to the intrusion of dykes would need to be assessed. In addition, the impact that the rugged topography may have on constructability and the hydrogeological regime would require additional evaluation.

Should the community of Schreiber 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 Schreiber area contains sites that can safely contain and isolate used nuclear fuel. This would include the acquisition and interpretation of higher resolution airborne geophysical surveys, detailed geological mapping and the drilling of deep boreholes.

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APPENDIX A

Geoscientific Factors

Safety Factors Performance Objectives Evaluation Factors to be Considered

Table 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.

Table 1: Safety Factors, Performance Objectives and Geoscientific Factors

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 1: Summary of Geophysical Mapping Sources for the Schreiber Area

Product	Source	Type	Line spacing / Sensor Height	Coverage	Acquired	Additional comments
Coldwell, Hemlo, Schreiber (GSC 2516)	GSC	Fixed Wing - Magnetic, EM VLF, Radiometric data	1000 m/120 m	Eastern third of Schreiber area without reaching south or north boundaries	1990	Quality control and initial processing applied by GSC.
Georgia Lake	GSC	Fixed Wing - Magnetic, EM VLF, Radiometric data	1000 m/120 m	One survey line covers the northwest corner of Schreiber area	1989	Quality control and initial processing applied by GSC.
North Shore Lake Superior, section 2 (West)	GSC	Fixed Wing – Radiometric data	5000 m/120 m	The entire Schreiber area excluding Lake Superior	1982	Quality control and initial processing applied by GSC.
Schreiber Data Set 2514	GSC	Fixed Wing - Magnetic, EM VLF, Radiometric data	1000 m/120 m	Entire Schreiber area but stops at Lake Superior. Denser survey lines in north central half of Schreiber area.	1990-1991	Covers entire Schreiber area but stops at Great Lake shoreline in the south. Denser survey lines in north central half of Schreiber area.
Lake Superior	GSC	Fixed Wing – Magnetic data	1900 m/300 m	Southern third of Schreiber area	1987	Flown at a higher elevation and with a low spatial resolution
Airborne Magnetic Compilation Ontario #8 (CABD27) (GDS 1036)	GSC/OGS	Fixed Wing - Magnetic data	805m/305m	Entire Schreiber area	1962	Reduced and leveled to common datum magnetic data. Data reprocessed in 1999.
Ground Gravity (CGDB, SEP 2010)	GSC	Ground Gravity Measurements	5-15 km	Thirteen stations sparsely located over entire Schreiber area	1944-Present	Despite a good data quality at stations the sparse coverage of the Schreiber area makes the 2 km grid of low quality
Schreiber Area Geophysical Data Set 1104	OGS	Heliborne - Magnetic, FDEM	200 m/30 m	Central, north central, east central and northeast corner of Schreiber area	1999	Quality control applied by OGS. This recent high resolution survey flown at low altitude makes it the most reliable dataset for the Schreiber area.

Table 2: Summary of Geological Mapping Sources for the Schreiber Area

Map Product	Title	Author	Source	Scale	Date	Coverage	Comments
P.3533	Geology, Tectonometamorphic map of Ontario, Canada and part of the United States of America	Easton, R.M. and Berman, R.G.	Geological Survey of Canada Open File 1810; Ontario Geological Survey	1:500,000	2004	Full	Large scale
Map 2137	Nipigon-Schreiber sheet, Geological Compilation Series, Thunder Bay District	Pye, E.G.	Ontario Department of Mines	1:253,440	1968	Partial	Compilation series
Map 2232	Nipigon- Schreiber Geological Compilation Series	Carter, M.W, Mcilwaine, W. H. and Wisbey, P. A.	Ontario Division of Mines	1:253,440	1973	Full	
Map 2518	Surficial geology of northern Ontario	Sado,E.V. and Carswell, B.F	Ontario Geological Survey	1:1,200,000	1987	Full	Based on compilation of NOEGTS maps
Map 2542	Bedrock geology of Ontario, west-central sheet; Ontario Geological Survey	Ontario Geological Survey	Ontario Geological Survey	1:1,000,000	1991	Partial	Geology of Ontario series
Map 2543	Bedrock geology of Ontario, east-central sheet	Ontario Geological Survey	Ontario Geological Survey	1:1,000,000	1991	Partial	Geology of Ontario series
Map 2554	Quaternary geology of Ontario, west-central sheet	Barnett, P.J.,Henry,A.P. and Babuin,D.	Ontario Geological Survey	1:1 000,000	1991	Full	Based on compilation of NOEGTS maps
Map 2576	Tectonic assemblages of Ontario, west-central sheet	Ontario Geological Survey	Ontario Geological Survey	1:1,000,000	1992	Partial	Geology of Ontario series
Map 2577	Tectonic assemblages of Ontario, east-central sheet	Ontario Geological Survey	Ontario Geological Survey	1:1,000,000	1992	Partial	Geology of Ontario series
Map 2614	Geological Compilation of the Eastern Half of the Schreiber-Hemlo greenstone belt	Muir, T.L.	Ontario Geological Survey	1:50,000	2000	N/A	East of Schreiber Area

Table 2: Summary of Geological Mapping Sources for the Schreiber Area

Map Product	Title	Author	Source	Scale	Date	Coverage	Comments
Map 2665-revised	Precambrian geology compilation series – Schreiber sheet	Santaguida, F.	Ontario Geological Survey	1:250,000	2002	Partial	Detailed geology inset maps of Schreiber area
Map 2667	Precambrian geology compilation series – Longlac sheet	Johns, G.W., McIlrath, S. and Stott, G.M.	Ontario Geological Survey	1:250,000	2003	Partial	North part of Schreiber area
Map 5079	Northern Ontario Engineering Geology Terrain Study, Data Base Map Roslyn Lake	Gartner, J.F.	Ontario Geological Survey	1:100,000	1980	Partial	Map accompanies Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 43
Map 5092	Northern Ontario Engineering Geology Terrain Study, Data Base Map Schreiber	Gartner, J.F.	Ontario Geological Survey	1:100,000	1980	Partial	Map accompanies Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 59
Map 30a	Schreiber- Duck Lake Area	Hopkins, P.E.	Ontario Department of Mines, Vol 30, Part 4	1:125,000	1922	Full	
Map 360	Schreiber sheet, Geological Compilation Series, District of Thunder Bay	Pye, E.G	Ontario Department of Mines	1:125,000	1966	Partial	Black/White, georeferenced against DEM
Map 47j	Schreiber area, District of Thunder Bay, Ontario	Harcourt, G. A. and Bartley,M. W.	Ontario Department of Mines Annual Report Vol. XLVII, Part 9,	1:31,680	1938	Partial	
Map 49m	Geology of the Big Duck-Aguasabon Lakes Area	Bartley, M.W.	Ontario Department of Mines, Volume 49, Part 7, p.1-11	1:125,000	1942	Partial	
Map S265	Surficial geology of the Thunder Bay map area	Zoltai, S. C.	Ontario Department of Lands and Forests	1:506,880	1965	Full	Regional scale surficial map

Table 2: Summary of Geological Mapping Sources for the Schreiber Area

Map Product	Title	Author	Source	Scale	Date	Coverage	Comments
P.1520	Ontario Mineral Potential, Schreiber Sheet, District of Thunder Bay	Springer, Janet	Ontario Geological Survey, Mineral Deposits Ser.	1:250,000	1978	Full	Black/white - some lineaments
P.1805	Uranium reconnaissance program, Schreiber sheet and part of Longlac sheet, sample location map, District of Thunder Bay	Ontario Geological Survey	Ontario Geological Survey	1:250,000	1977	Full	Limited lineaments
P.2390	Precambrian geology of the Schreiber area, west part, Thunder Bay District	Carter, M.W.	Ontario Geological Survey, Geological Series	1:15,840	1981	Partial	Black/White, georeferenced against DEM
P.2391	Precambrian geology of the Schreiber area, east part, Thunder Bay District;	Carter, M.W.	Ontario Geological Survey, Geological Series	1:15,840	1981	Partial	Black/White, georeferenced against DEM
P.2417	Precambrian geology of the Terrace Bay area, west sheet, Thunder Bay District	Carter, M.W.	Ontario Geological Survey, Geological Series	1:15,840	1981	Partial	Black/white - some lineaments
P.2418	Precambrian geology of the Schreiber area, east sheet, Thunder Bay District	Carter, M.W.	Ontario Geological Survey, Geological Series	1:15,840	1981	Partial	Black/white - some lineaments
P.2556	Precambrian Geology of the Terrace Bay Area, Northwest Sheet, Thunder Bay District	Carter, M.W.	Ontario Geological Survey, Geological Series	1:15,840	1982	Partial	Black/white - some lineaments
P.2557	Precambrian Geology of the Terrace Bay Area, Northeast Sheet, Thunder Bay District	Carter, M.W.	Ontario Geological Survey, Geological Series	1:15,840	1982	Partial	Black/white - some lineaments

Table 3: Summary of Geoscientific Databases for the Schreiber Area

Database	Source / Description	Scale (Regional/Local)	Used? (Yes/No)
Abandoned Mines	Ministry of Northern Development and Mines. 2012. Ontario Ministry of Northern Development and Mines, Abandoned Mines Inventory (AMIS), May, 2012.	Regional	Yes
Aggregate Data	Ontario Ministry of Natural Resources, Licence and permit list, 2012	Site	No
Bedrock Geology	Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release–Data 126 - Revision 1.	Site	Yes
Earthquake Data	Earthquakes Canada, 2012. Earthquake Search (On-line Bulletin) 2010. Natural Resources Canada, Geologic Survey of Canada	Regional	Yes
Exploration Data (Assessment Files)	Ministry of Northern Development and Mines. 2012. Assessment Files April 2012.	Site	Yes
Exploration Drill holes	Ministry of Northern Development and Mines. 2012, Diamond Drill Hole Database.	Site	Yes
Geochemical and till pebble lithology data	Morris, T.F. 2001. Ontario Geological Survey, Miscellaneous Release – Data 74.	Regional	Yes
Geochemical lake sediment and water data	Dyer, R.D. 1997. Ontario Geological Survey, Miscellaneous Release-Data 33.	Regional	Yes
Geochemical lake sediment and water data	Friske, P.W.B., Hornbrook, E.H.W., Lynch, J.J., McCurdy, M.W., Gross, H., Galletta, A.C. and Durham, C.C. 1991. National, northwestern Ontario (NTS 42D, 42E South); Geological Survey of Canada, Open File 2360.	Regional	No
Geochron	Geological Survey of Canada 2012. Geochron Database	Site	Yes
Geophysical Data	Natural Resources of Canada, 2012. Aeromagnetic and Electromagnetic data, Canadian Aeromagnetic Data Base, http://gdr.nrcan.gc.ca/aeromag/about_e.php	Regional	Yes

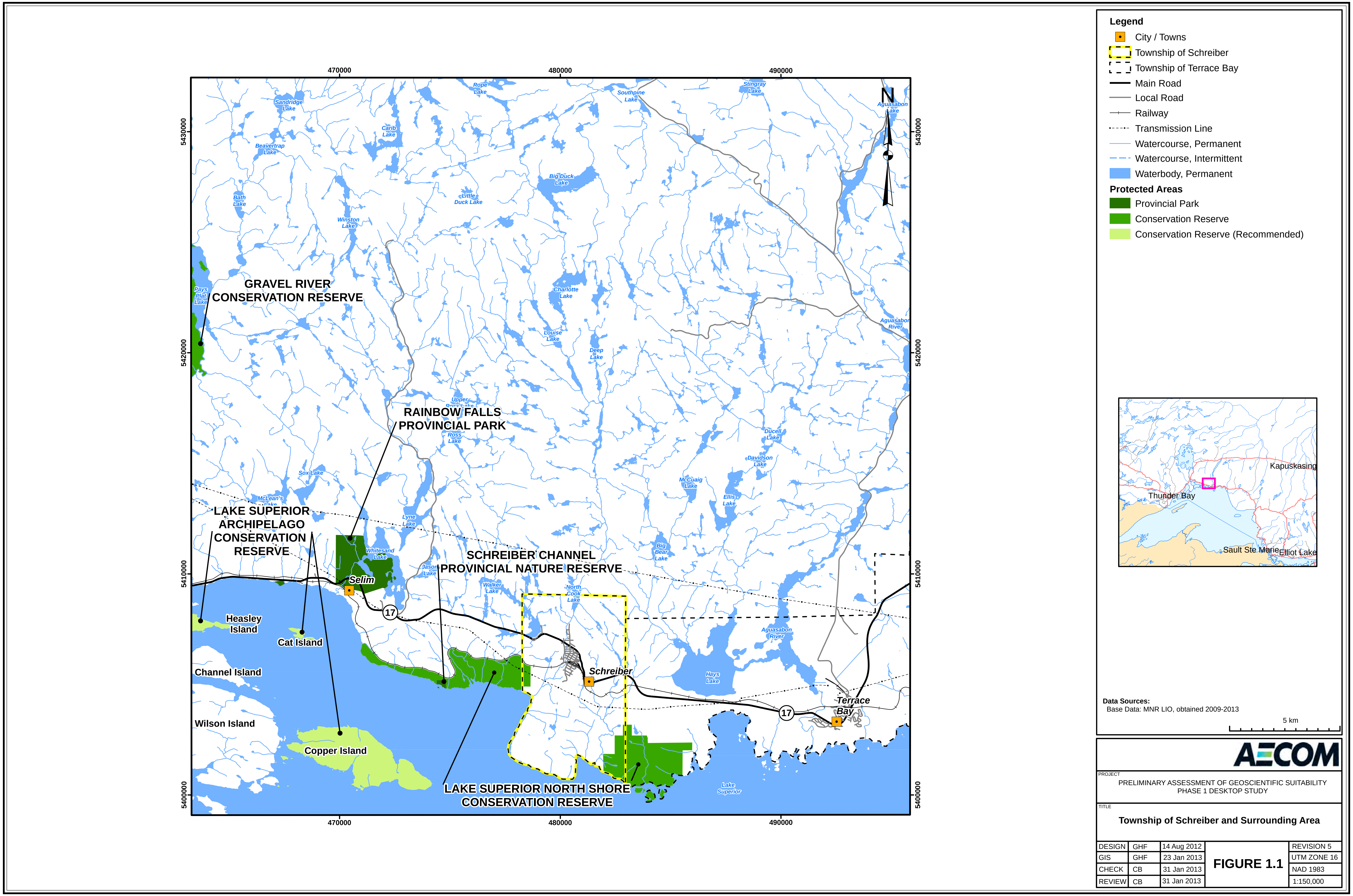
Table 3: Summary of Geoscientific Databases for the Schreiber Area

Database	Source / Description	Scale (Regional/Local)	Used? (Yes/No)
Geophysical Data	Ontario Geological Survey, 2012. Geophysical Atlas of Ontario,	Regional	Yes
Geoscience Data	Natural Resources Canada. 2012. Geoscience Data Repository (GDR),	Regional	Yes
Geotechnical Records	Ontario Ministry of Transportation, 2012. GeoCres Files; Downsview, Ontario	Site	No
In-situ ground stresses	Arjang, B. 2004. CANMET Division Report MMSL 01-029 (TR).	Regional	Yes
Lineament Data	Shirota, J. and Barnett, P.J., 2004. Lineament Extraction from Digital Elevation Model (DEM) for the Province of Ontario; Ontario Geological Survey, Miscellaneous Release - Data 142.	Regional	No
Mineral deposits	Ontario Geological Survey 2011. Mineral Deposit Inventory-2011; Ontario Geological Survey, Mineral Deposit Inventory, December 2011 release.	Site	No
Mining Claims (CLAIMaps)	Ministry of Northern Development and Mines. 2012. Ontario Ministry of Northern Development Mines. Mining Lands Section: Ontario Mining Land Tenure Spatial Data, April 2012.	Regional	Yes
Ontario Base Mapping	Land Information Ontario 2012. Ontario Ministry of Natural Resources	Regional	Yes
Quaternary Geology	Ontario Geological Survey, 1997. Quaternary Geology. Seamless coverage of the Province of Ontario: Ontario Geological Survey, Data Set 14.	Regional	Yes
Rock Geochemistry	Ontario Geological Survey. Miscellaneous Release—Data 250 Data from the PETROCH Lithogeochemical Database by M. Haus and T. Pauk	Site	Yes

Table 3: Summary of Geoscientific Databases for the Schreiber Area

Database	Source / Description	Scale (Regional/Local)	Used? (Yes/No)
Stream Flow Data	Environment Canada. 2012. Water Survey of Canada	Regional	Yes
Terrain Map	Ontario Geological Survey, Ministry of Northern Development and Mines, and Northeast Science and Information Section, Ministry of Natural Resources 2005. Digital Northern Ontario Engineering Geology Terrain Study (NOEGTS); Ontario Geological Survey, Miscellaneous Release Data 160.	Regional	Yes
Topographic Data	Natural Resources Canada. 2009. Canadian Digital Elevation Data, Government of Canada, Natural Resources Canada, Earth Sciences Sector, Centre for Topographic Information: 042D14, 043E03.	Regional	Yes
Water Information, Basemaps	Ministry of Natural Resources 2012. Land Information Ontario Date Warehouse.	Site	Yes
Water Well Data	Ontario Ministry of Environment. 2012. Water Well Information System (WWIS) Database.	Site	Yes

Figures



Legend

- ■ City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- — Local Road
- —+— Railway
- ---- Transmission Line
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- 🟦 Waterbody, Permanent

Protected Areas

- 🟩 Provincial Park
- 🟩 Conservation Reserve
- 🟩 Conservation Reserve (Recommended)

Data Sources:
Base Data: MNR LIO, obtained 2009-2013

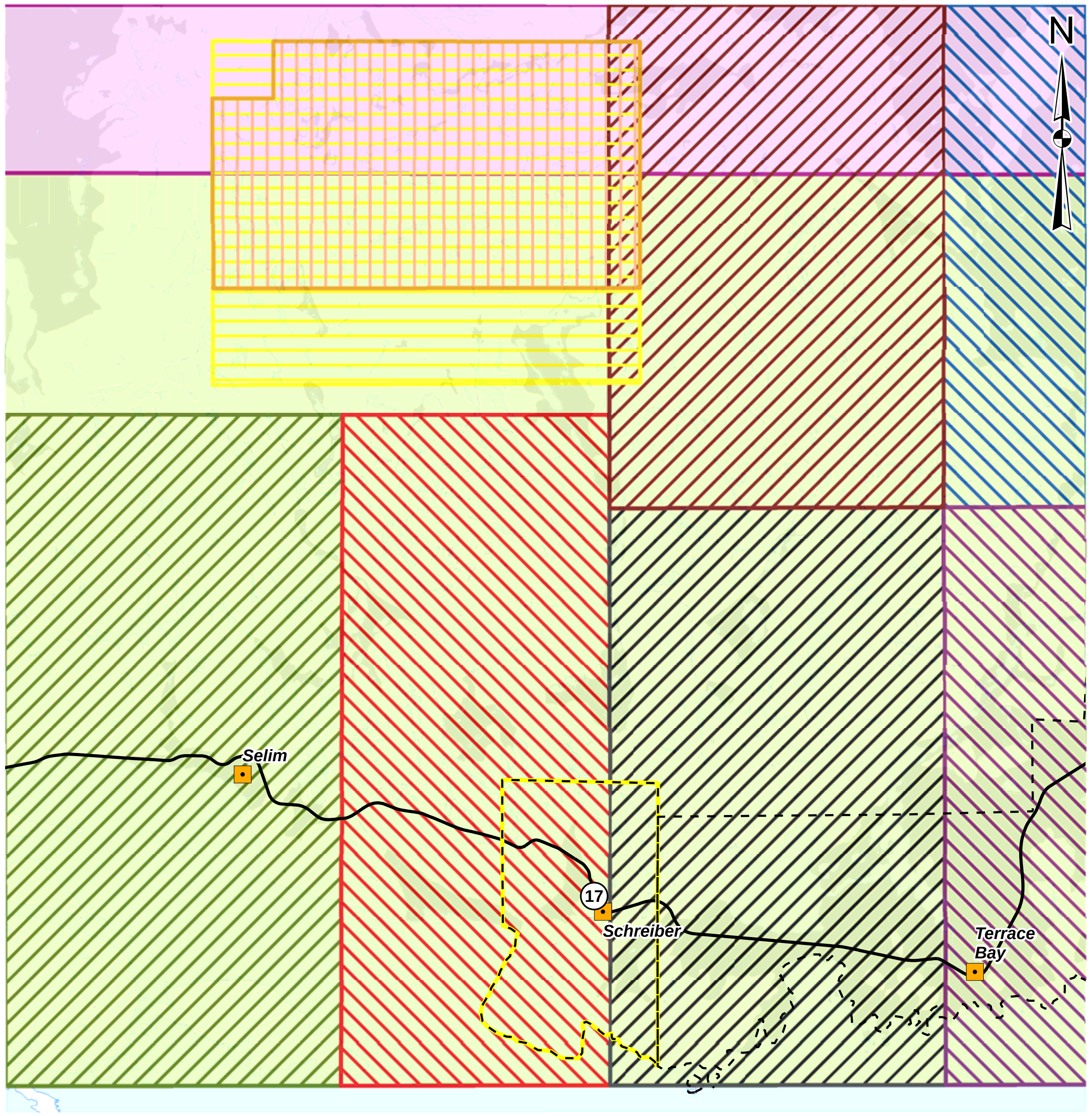
AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

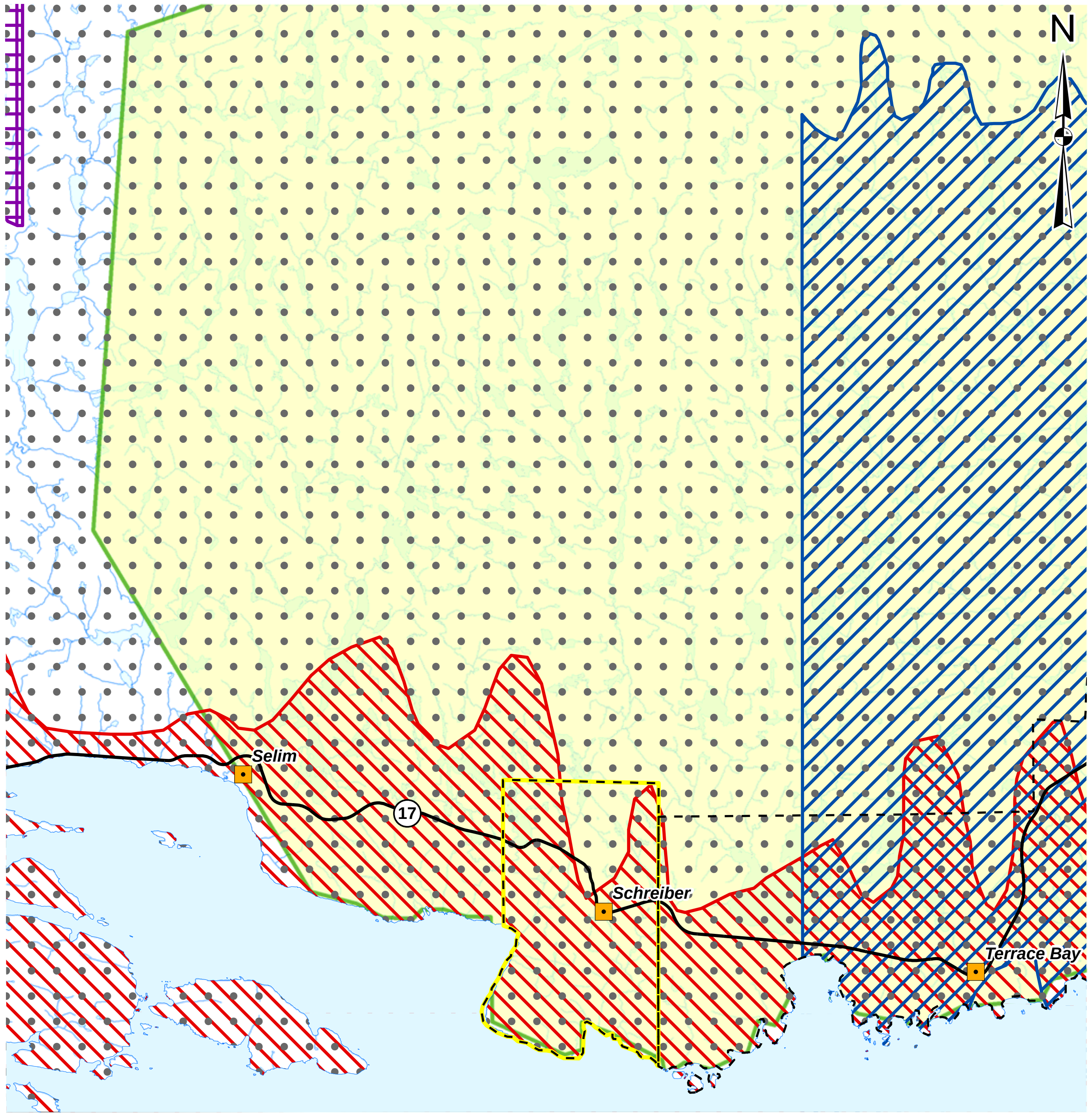
TITLE
Township of Schreiber and Surrounding Area

DESIGN	GHF	14 Aug 2012	FIGURE 1.1	REVISION 5
GIS	GHF	23 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000

Geology Mapping Coverage



Geophysics Mapping Coverage



LEGEND

- ■ City / Towns
- ⬚ Township of Schreiber
- ⬚ Township of Terrace Bay
- — Main Road
- ▭ Waterbody, Permanent

Detailed Geological Extent

- ▨ Carter 1981 (P2390)
- ▨ Carter 1981 (P2391)
- ▨ Carter 1981 (P2417)
- ▨ Carter 1981 (P2418)
- ▨ Carter 1982 (P2556)
- ▧ Carter 1982 (P2557)
- ▭ Johns et al. 2003 (2667)
- ▤ Pye 1961 (P0087)
- ▥ Pye 1964 (2023)
- ▭ Santaguida 2002 (2665-revised)

Full Geology Coverage
OGS Bedrock Geology of Ontario 2011 (MRD 126)
OGS Surficial Geology (MRD-160)

Full Geophysics Coverage
Airborne Magnetic Compilation (GSC CABD27)
Ground Gravity (CBDB, Sep 2010) - GSC
North Shore Lake Superior, Section 2 (West) (GSC)

Data Sources:
Base Data: MNR LIO, obtained 2009-2013

LEGEND

- ■ City / Towns
- ⬚ Township of Schreiber
- ⬚ Township of Terrace Bay
- — Main Road
- ▭ Waterbody, Permanent

Geophysical Survey Extent

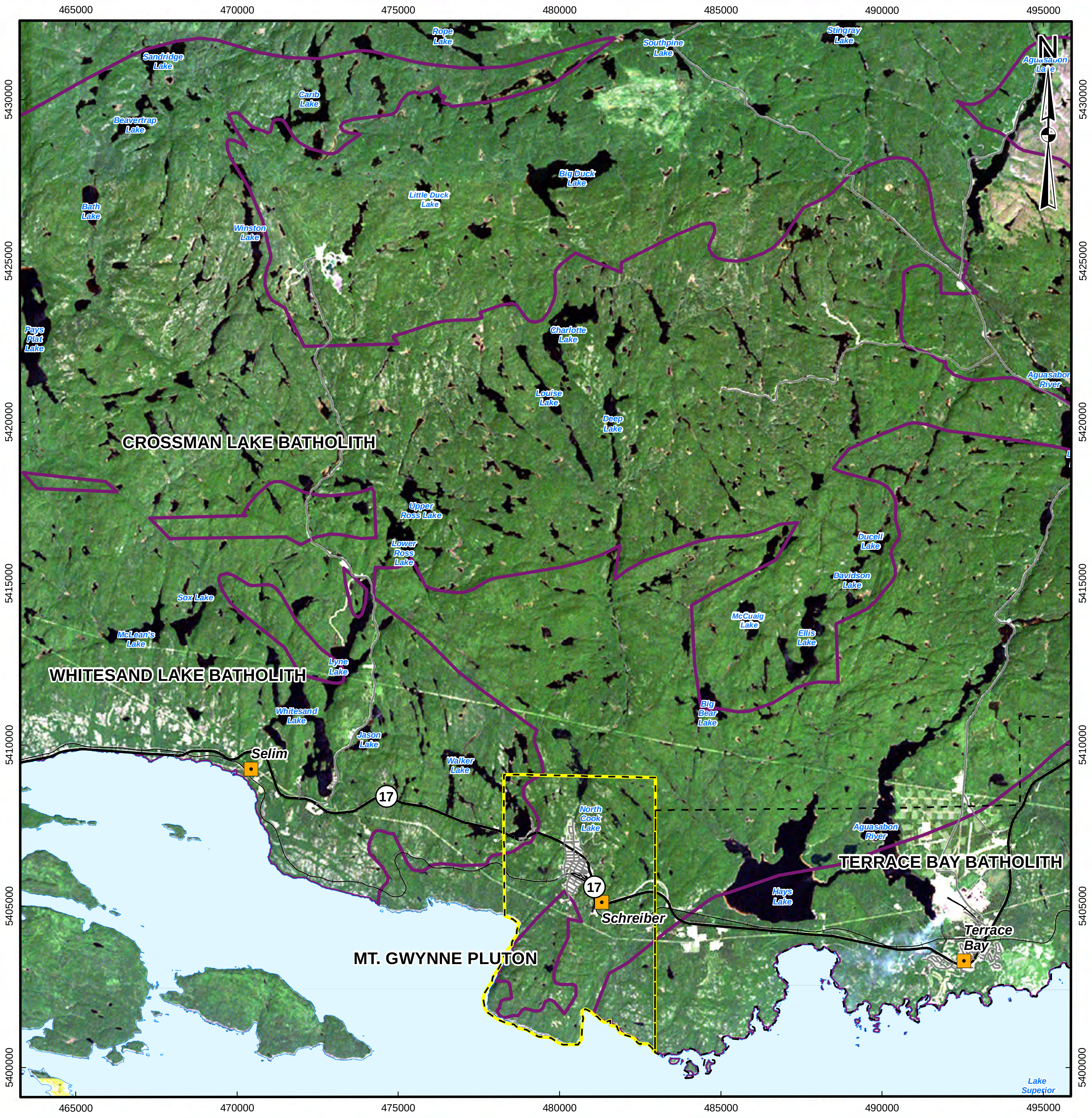
- ▨ Coldwell, Hemlo, Schreiber 1990 (GSC 2516)
- ▦ Georgia Lake 1989 (GSC)
- ▧ Lake Superior Fixed Wing 1987 (GSC)
- ▭ Schreiber Area 1999 (OGS-GDS1104)
- ⁘ Schreiber Fixed Wing (GSC 2514)

5 km

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

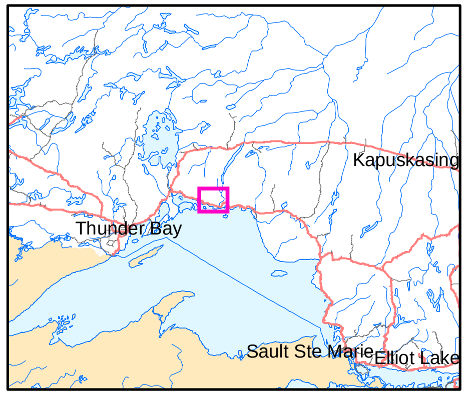
TITLE
Geoscience Mapping and Geophysical Coverage of the Schreiber Area

DESIGN	GHF	14 Aug 2012	FIGURE 1.2	REVISION 4
GIS	GHF	23 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:180,000



LEGEND

- ■ City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- ━ Main Road
- ─ Local Road
- ┼ Railway
- ▭ Outline of batholith/pluton



Data Sources:
Batholith: Generalized from OGS 2006
Imagery: NRCAN CanImage - Landsat 7 Orthoimage, 1:50,000,
True Colour Composite
Base Data: MNR LIO, obtained 2009-2013

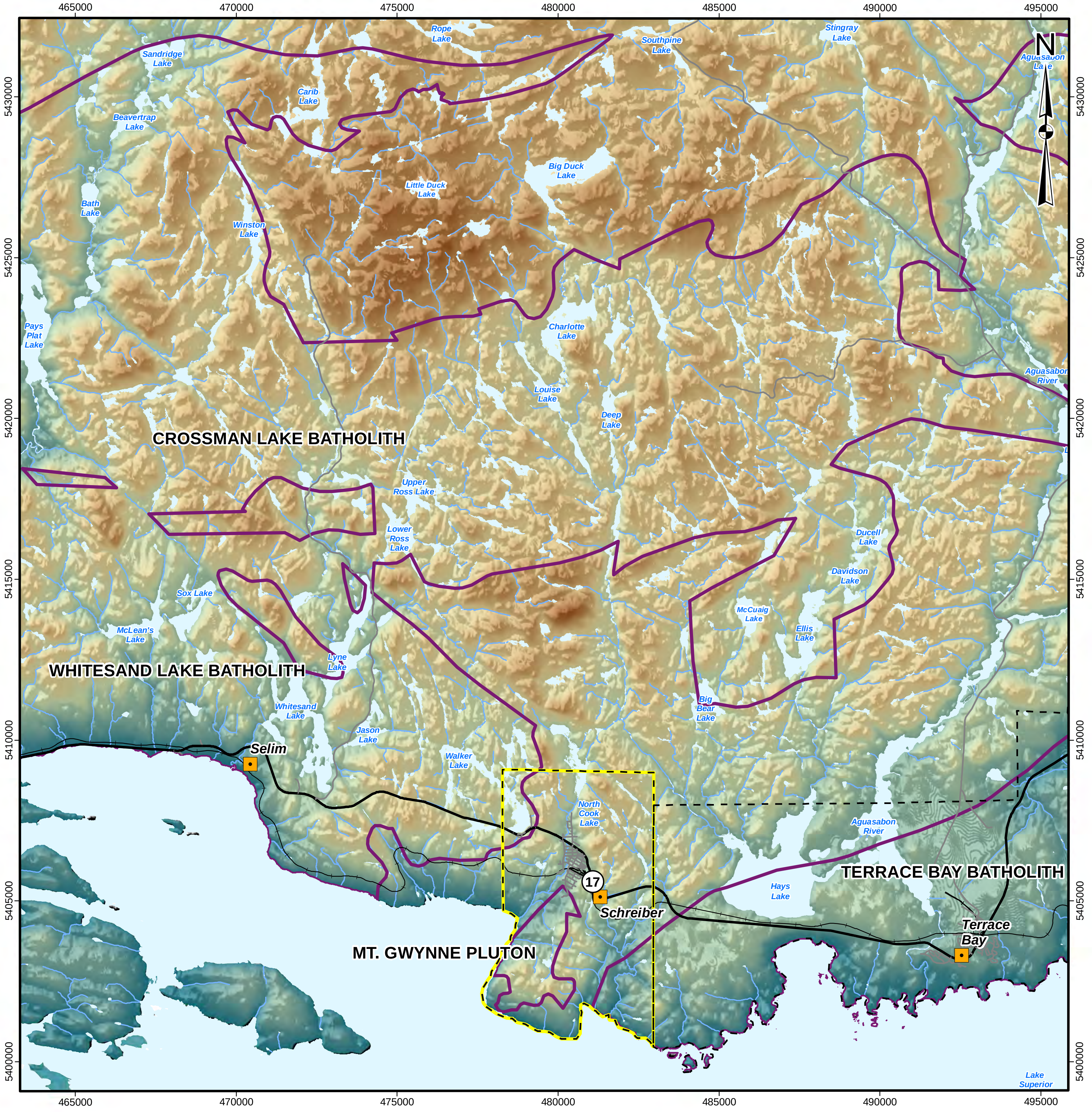
5 km

AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Satellite Imagery of the Schreiber Area

DESIGN	GHF	14 Aug 2012	**FIGURE 2.1**	REVISION 4
GIS	GHF	23 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



LEGEND

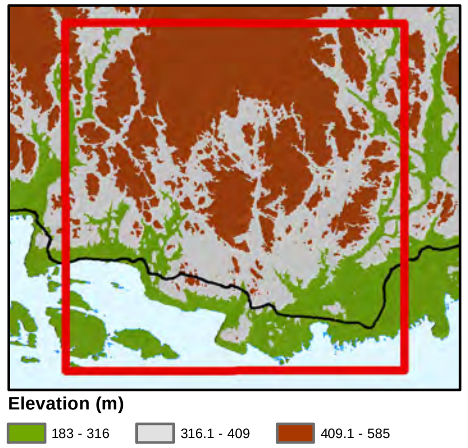
- 🟧 City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- — Local Road
- ┼ Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▭ Waterbody, Permanent
- ▭ Outline of batholith/pluton

Elevation (masl)

585

183

KEY TOPOGRAPHIC HIGHS AND LOWS



Data Sources:
Batholith: Generalized from OGS 2006
DEM - MNR Elevation and Slope
Base Data: MNR LIO, obtained 2009-2013

5 km

AECOM

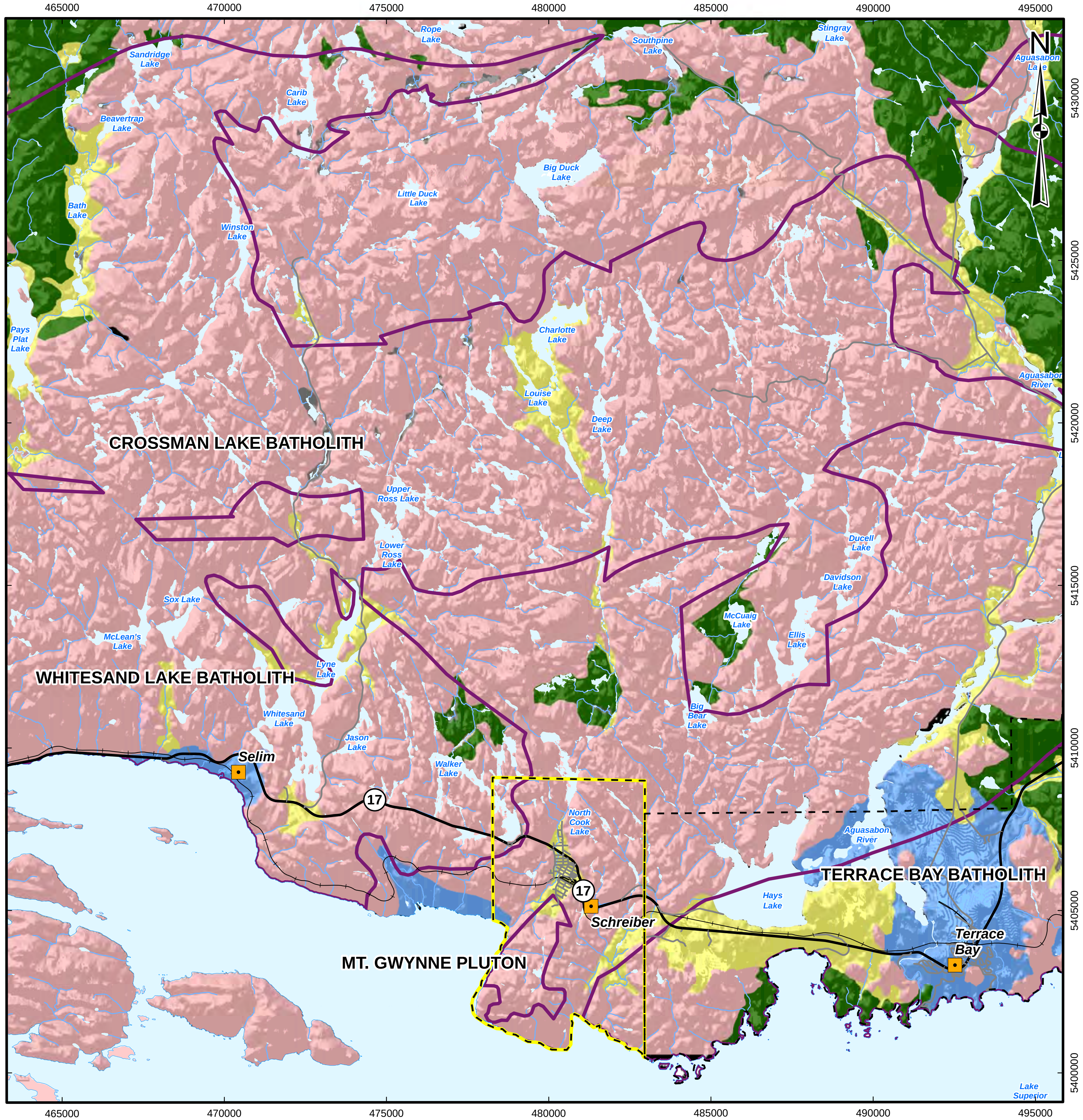
PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Elevation and Major Topographic Features
of the Schreiber Area

DESIGN	GHF	14 Aug 2012	FIGURE 2.2	REVISION 3
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



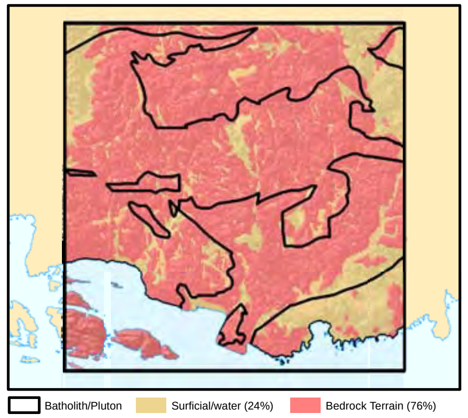
LEGEND

- ▣ City / Towns
- ⬚ Township of Schreiber
- ⬚ Township of Terrace Bay
- — Main Road
- — Local Road
- ┼ Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▭ Waterbody, Permanent
- ▭ Outline of batholith/pluton

Surficial Geology

- 🟩 Morainal Terrain
- 🟨 Glaciofluvial Terrain
- 🟦 Glaciolacustrine Terrain
- ⬛ Organic Terrain
- 🟥 Bedrock Terrain

MAP OF SURFICIAL LANDFORMS AND WATERBODIES



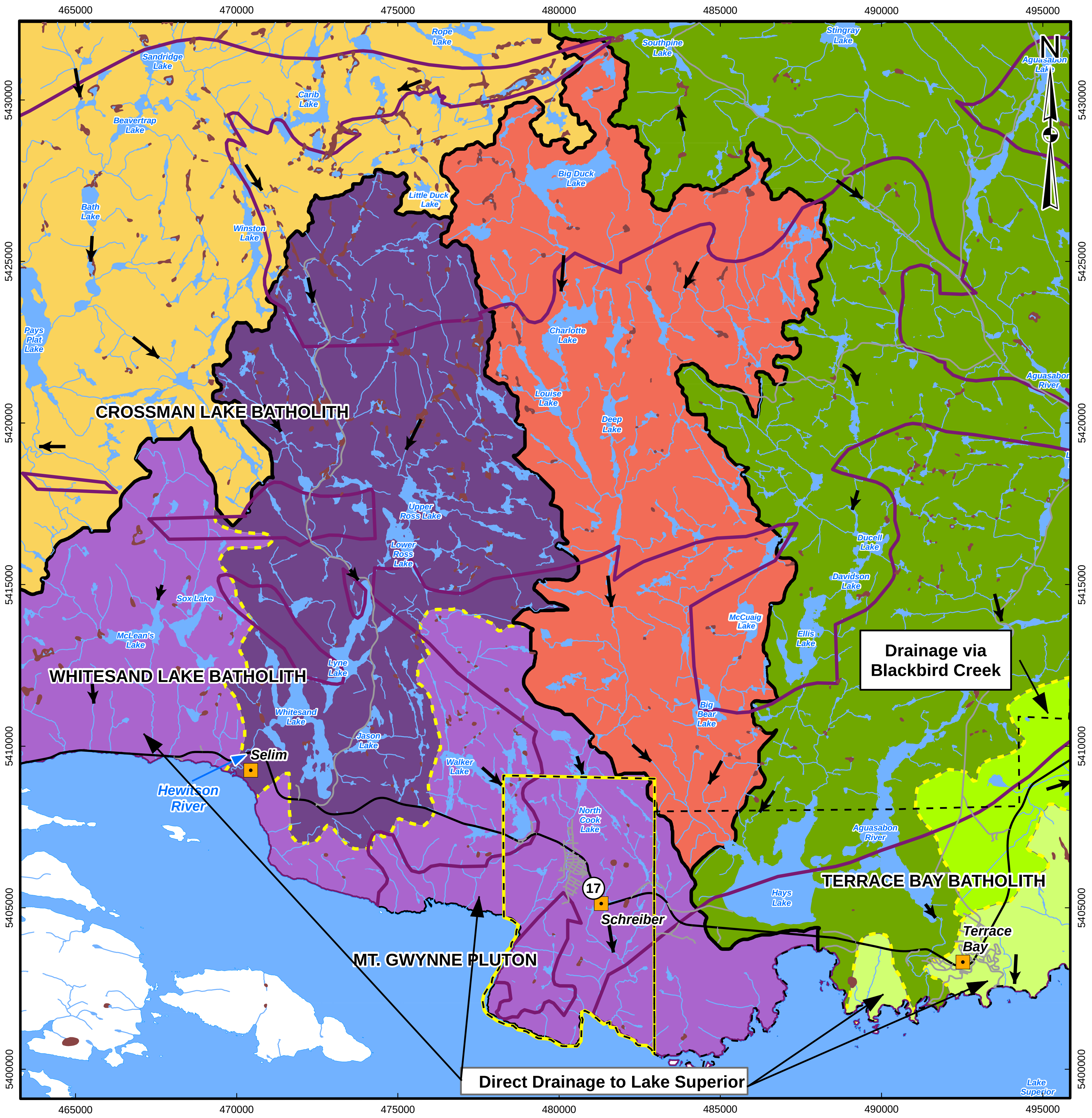
Data Sources:
Batholith: Generalized from OGS 2006
Overburden: OGS MRD-160 (1:100,000), AECOM, 2013
Base Data: MNR LIO, obtained 2009-2012
Underlay: Hillshade DEM, MNR Elevation and slope

5 km

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Terrain Features of the Schreiber Area

DESIGN	GHF	14 Aug 2012	**FIGURE 2.3**	REVISION 3
GIS	GHF	24 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000

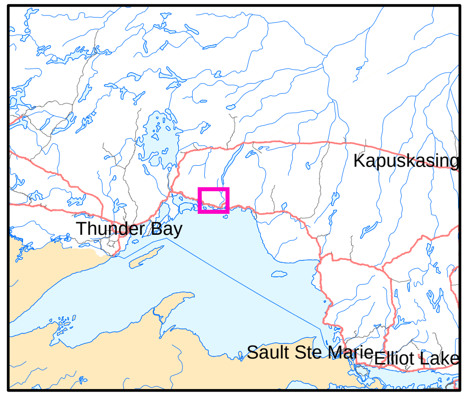


LEGEND

- ■ City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- — Local Road
- → Surface Flow Direction
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ■ Waterbody, Permanent
- ■ Wetlands
- ▭ Outline of batholith/pluton

Quaternary Watersheds

- 🟩 Aguasabon River
  - 🟩 Subwatershed Drainage Via Blackbird Creek
  - 🟩 Subwatershed Direct Drainage to Lake Superior
- 🟥 Big Duck Creek
- 🟨 Pays Plat River
- 🟪 Whitesand River
  - 🟪 Subwatershed Direct Drainage to Lake Superior



Data Sources:
Batholith: Generalized from OGS 2006
Base Map: MNR LIO, obtained 2009-2013
Quaternary Watersheds: LIO Quaternary Watersheds

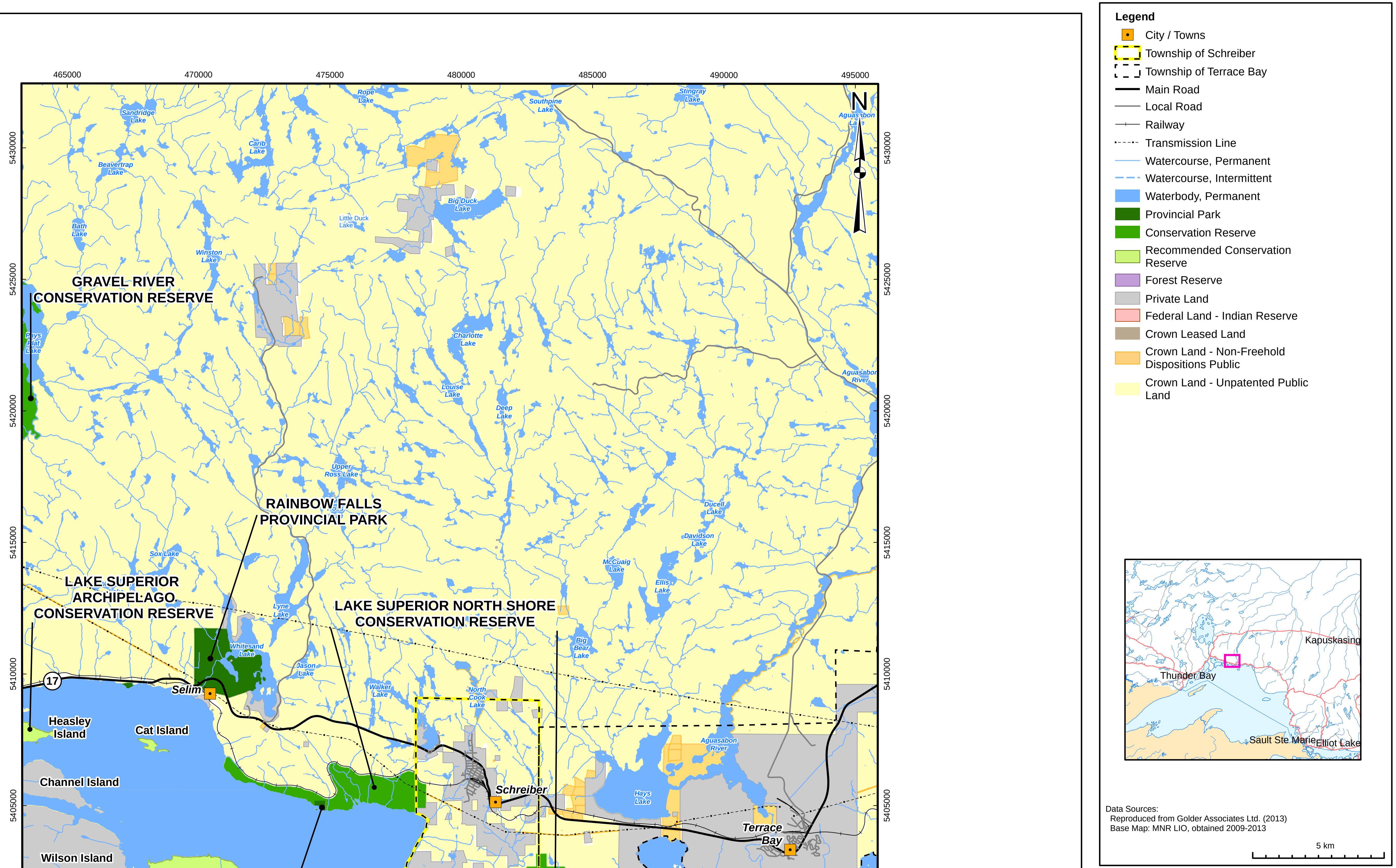
5 km

AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Drainage Features of the Schreiber Area

DESIGN	GHF	14 Aug 2012	FIGURE 2.4	REVISION 4
GIS	GHF	24 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



Legend

- 🟧 City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- — Local Road
- ┼ Railway
- ⋯ Transmission Line
- — Watercourse, Permanent
- ‐ ‐ Watercourse, Intermittent
- 🟦 Waterbody, Permanent
- 🟩 Provincial Park
- 🟩 Conservation Reserve
- 🟩 Recommended Conservation Reserve
- 🟪 Forest Reserve
- ⬜ Private Land
- 🟥 Federal Land - Indian Reserve
- 🟫 Crown Leased Land
- 🟧 Crown Land - Non-Freehold Dispositions Public
- 🟨 Crown Land - Unpatented Public Land

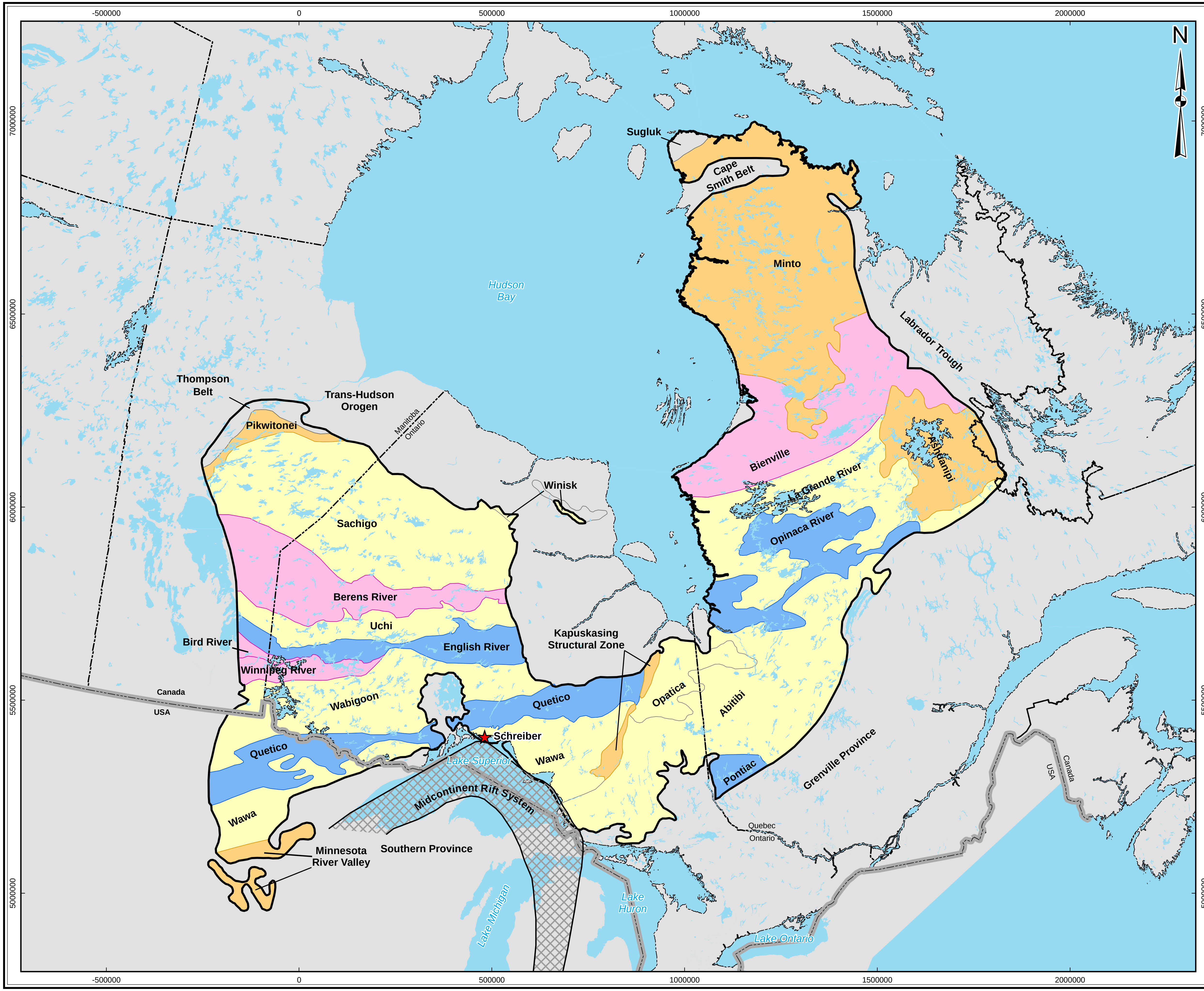
Data Sources:
Reproduced from Golder Associates Ltd. (2013)
Base Map: MNR LIO, obtained 2009-2013

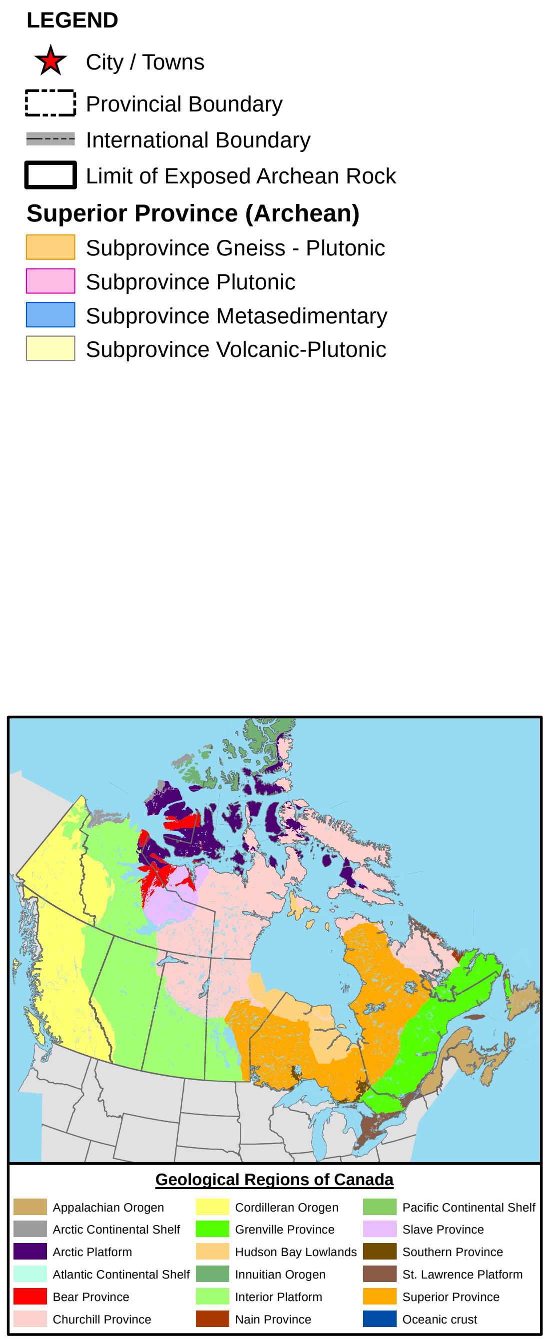
AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Schreiber Area Land Ownership

DESIGN	PRM	02 Apr 2012	FIGURE 2.5	REVISION 3
GIS	GHF	24 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000





Data Sources:
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 16
Base Data - MNR LIO, obtained 2009-2013, CANMAP v2006.4
Subdivisions of Superior Province - Thurston, P. C. 1991 Geology of Ontario:
Introduction in Geology of Ontario, Ontario Geological Survey,
Special Volume 4, Part 1, p.3-25
Geological Regions: Geological Map of Canada 1996, Map D1860A
Midcontinent Rift System: Sage, 1986

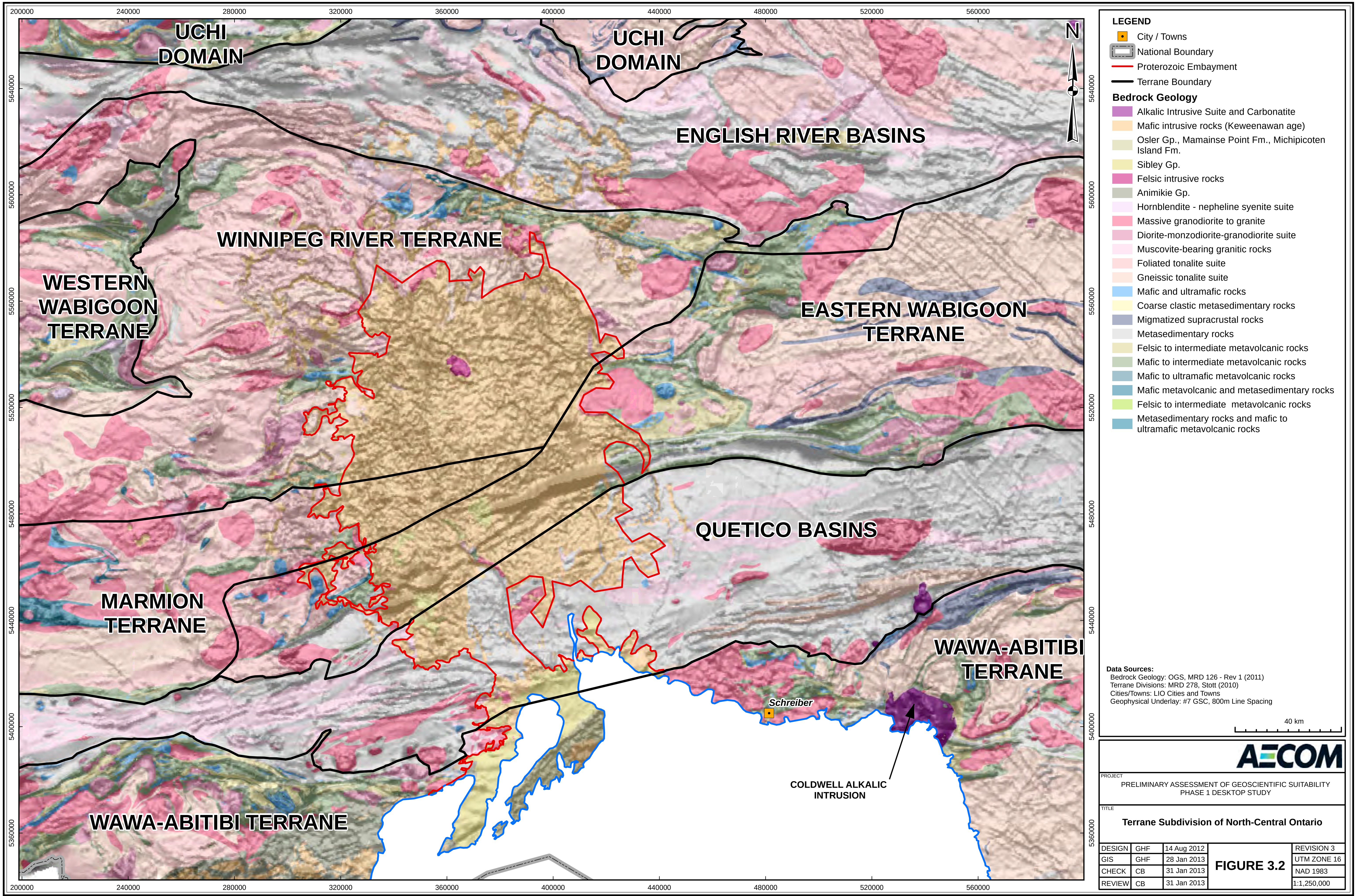
310 km

Golder Associates
AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Subdivision of the Superior Province of the Canadian Shield

DESIGN	PRM	30 Aug 2010	**FIGURE 3.1**	REVISION 3
GIS	GHF	24 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:9,500,000



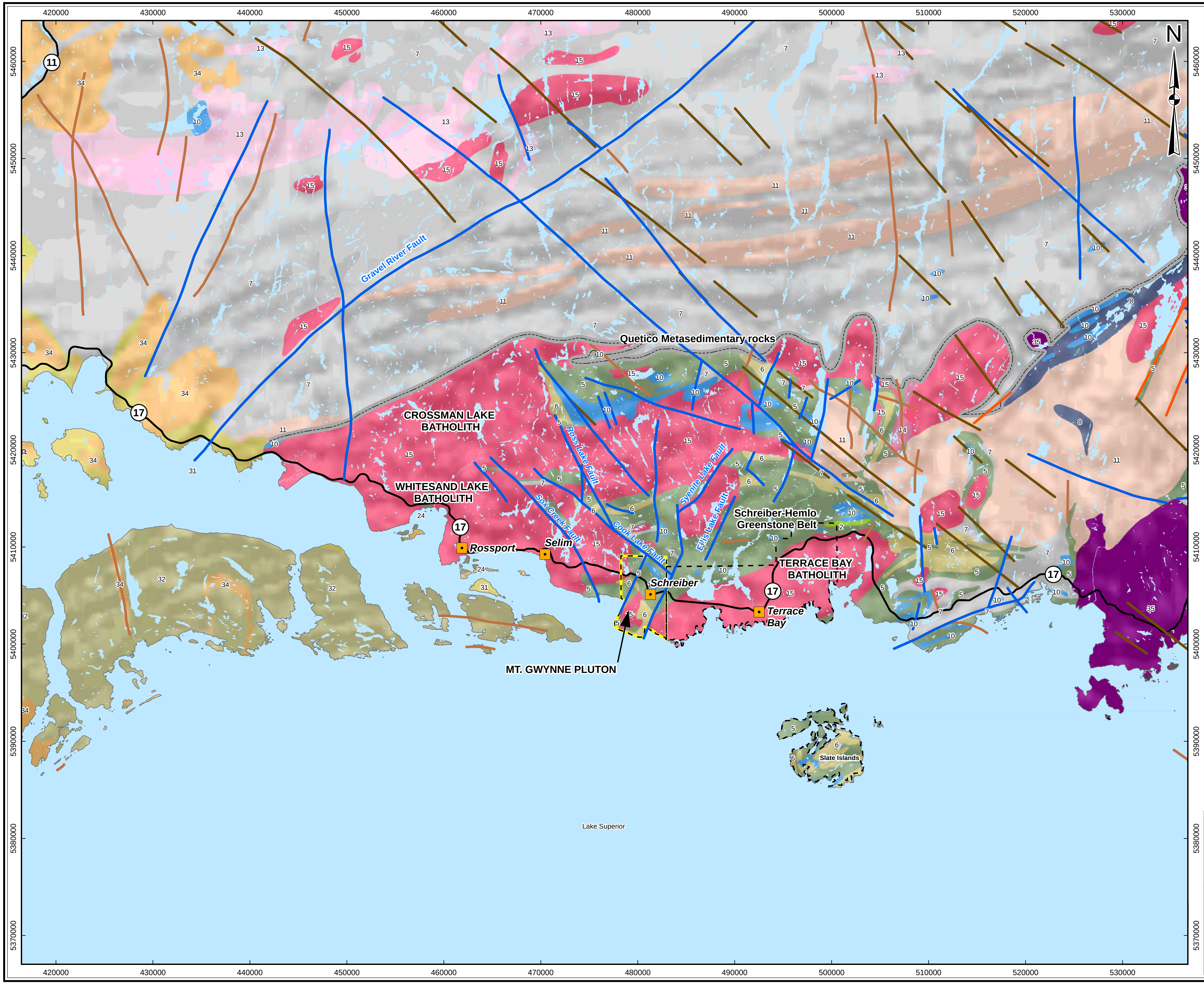
Data Sources:
Bedrock Geology: OGS, MRD 126 - Rev 1 (2011)
Terrane Divisions: MRD 278, Stott (2010)
Cities/Towns: LIO Cities and Towns
Geophysical Underlay: #7 GSC, 800m Line Spacing

AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Terrane Subdivision of North-Central Ontario

DESIGN	GHF	14 Aug 2012	FIGURE 3.2	REVISION 3
GIS	GHF	28 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:1,250,000



Legend

- ▣ City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- ▬ Waterbody
- — Mapped Faults
- - - Quetico-Wawa Subprovince Boundary

Mapped Dyke

- — Marathon, Kapuskasing or Biscotasing Mafic Dyke
- — Matachewan Mafic Dyke
- — Dyke (Other)

Bedrock Geology

- ▬ 35. Alkalic Intrusive Suite and Carbonatite
- ▬ 34. Mafic intrusive rocks (Keweenawan age)
- ▬ 32. Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.
- ▬ 31. Sibley Gp.
- ▬ 24. Animikie Gp.
- ▬ 15. Massive granodiorite to granite
- ▬ 14. Diorite-monzodiorite-granodiorite suite
- ▬ 13. Muscovite-bearing granitic rocks
- ▬ 11. Gneissic tonalite suite
- ▬ 10. Mafic and ultramafic rocks
- ▬ 8. Migmatized supracrustal rocks
- ▬ 7. Metasedimentary rocks
- ▬ 6. Felsic to intermediate metavolcanic rocks
- ▬ 5. Mafic to intermediate metavolcanic rocks
- ▬ 2. Felsic to intermediate metavolcanic rocks

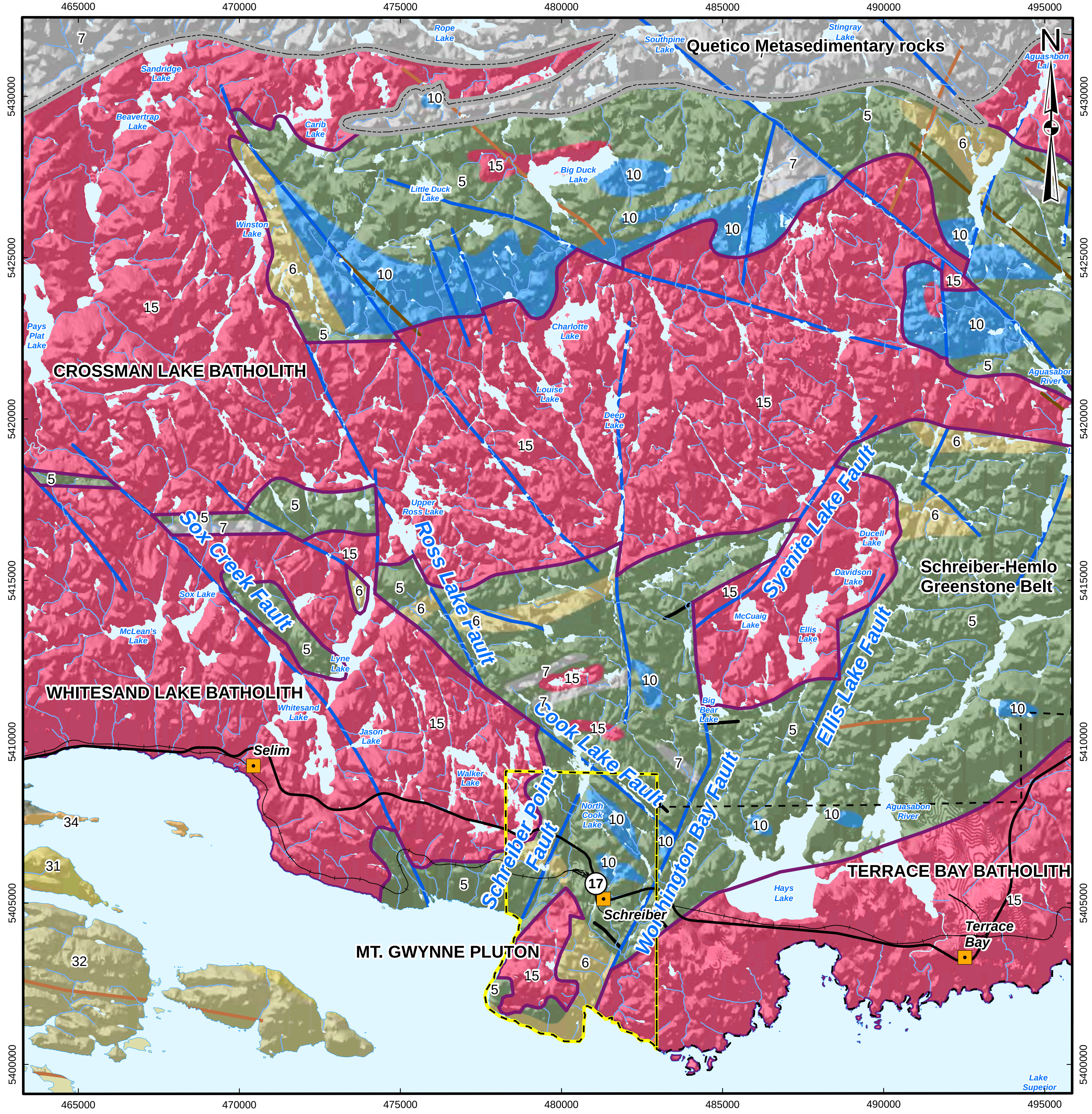
Data Sources:
Batholith: Generalized from OGS 2006
Bedrock: OGS MRD 126-REV1 (1:250,000)
Faults: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Base Data: MNR LIO, obtained 2009-2013
Underlay: Hillshade DEM, MNR Elevation and Slope

AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Regional Geology of the Schreiber Area

DESIGN	PRM	02 Apr 2012	FIGURE 3.3	REVISION 3
GIS	GHF	25 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:375,000



LEGEND

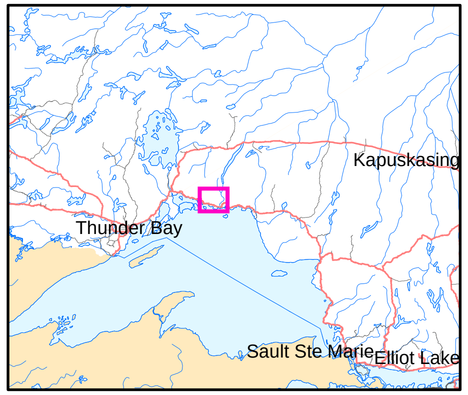
- ■ City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- —+— Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▭ Waterbody, Permanent
- — Mapped Fault
- — Iron Formation
- - - Quetico-Wawa Subprovince Boundary
- ▭ Outline of batholith/pluton

Mapped Dyke

- — Marathon, Kapuskasing or Biscotasing Mafic Dyke
- — Matachewan Mafic Dyke
- — Dyke (Other)

Bedrock Geology (Youngest to Oldest)

- ▨ 34. Mafic intrusive rocks (Keweenawan age)
- ▨ 32. Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.
- ▨ 31. Sibley Gp.
- ▨ 24. Animikie Gp.
- ▨ 15. Massive granodiorite to granite
- ▨ 11. Gneissic tonalite suite
- ▨ 10. Mafic and ultramafic rocks
- ▨ 7. Metasedimentary rocks
- ▨ 6. Felsic to intermediate metavolcanic rocks
- ▨ 5. Mafic to intermediate metavolcanic rocks
- ▨ 2. Felsic to intermediate metavolcanic rocks



Data Sources:
Bedrock: OGS MRD 126-REV1 (1:250,000)
Faults: OGS MRD 126-REV1 (1:250,000)
Dykes: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 2009-2013
Underlay: Hillshade DEM, MNR Elevation and Slope

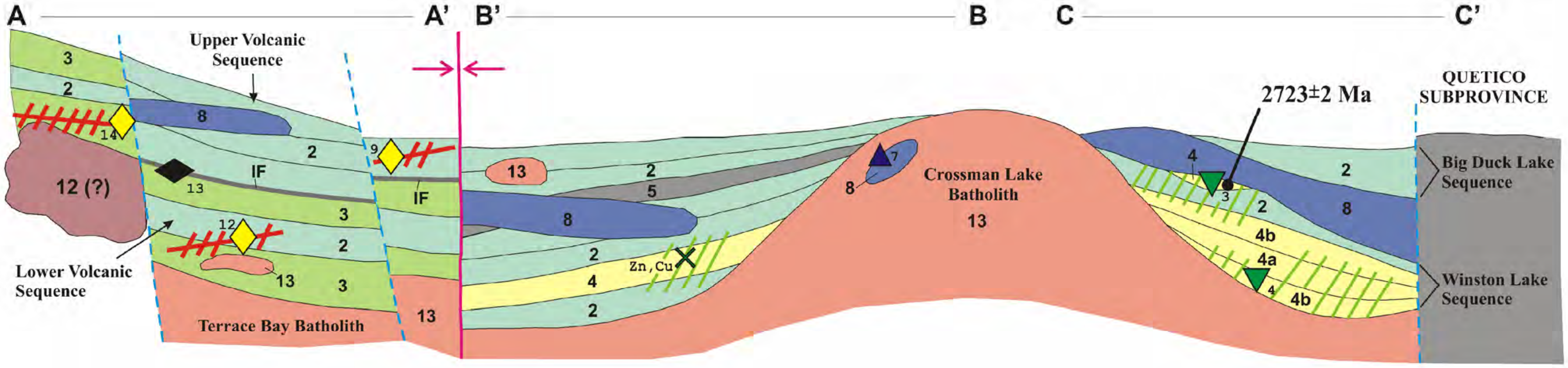
5 km

AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Local Bedrock Geology of the Schreiber Area

DESIGN	GHF	14 Aug 2012	FIGURE 3.4	REVISION 4
GIS	GHF	25 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



▭ lithologic contact

╌ fault

⫽ shear

→|← syncline

▨ hydrothermal alteration

Mineral Deposits

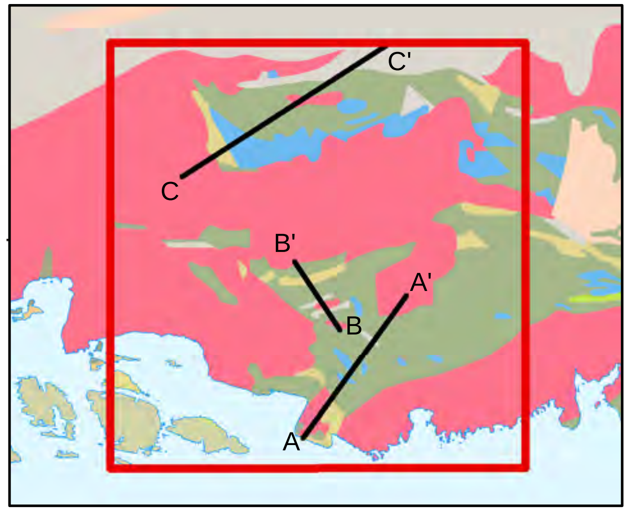
◆ Vein-hosted Au±Ag (9 - McKenna-McCann Mine; 12- Harkness-Hayes Mine; 14 - North Shores Mine)

◆ Banded Iron Formation Fe - S±Au (13 - Morley Pyrite Mine)

▲ Magmatic Ni-Cu-Pt-Pd Massive Sulphide (7 - Nicopor Prospect)

▼ ✕ Zn, Cu Volcanic-hosted Zn-Cu-Ag-Au Massive Sulphide (3 - Winston Lake Mine; 4 - Pick Lake Deposit; X - Victoria Lake Occurrence)

Schematic cross section of the Schreiber greenstone belt (after Santaguida, 2002 - OGS Map 2665 rev.)



CROSS SECTION LOCATIONS
SEE FIGURE 3.4 FOR INSET MAP LEGEND

Legend for Cross Section (from OGS Map 2665 rev.)

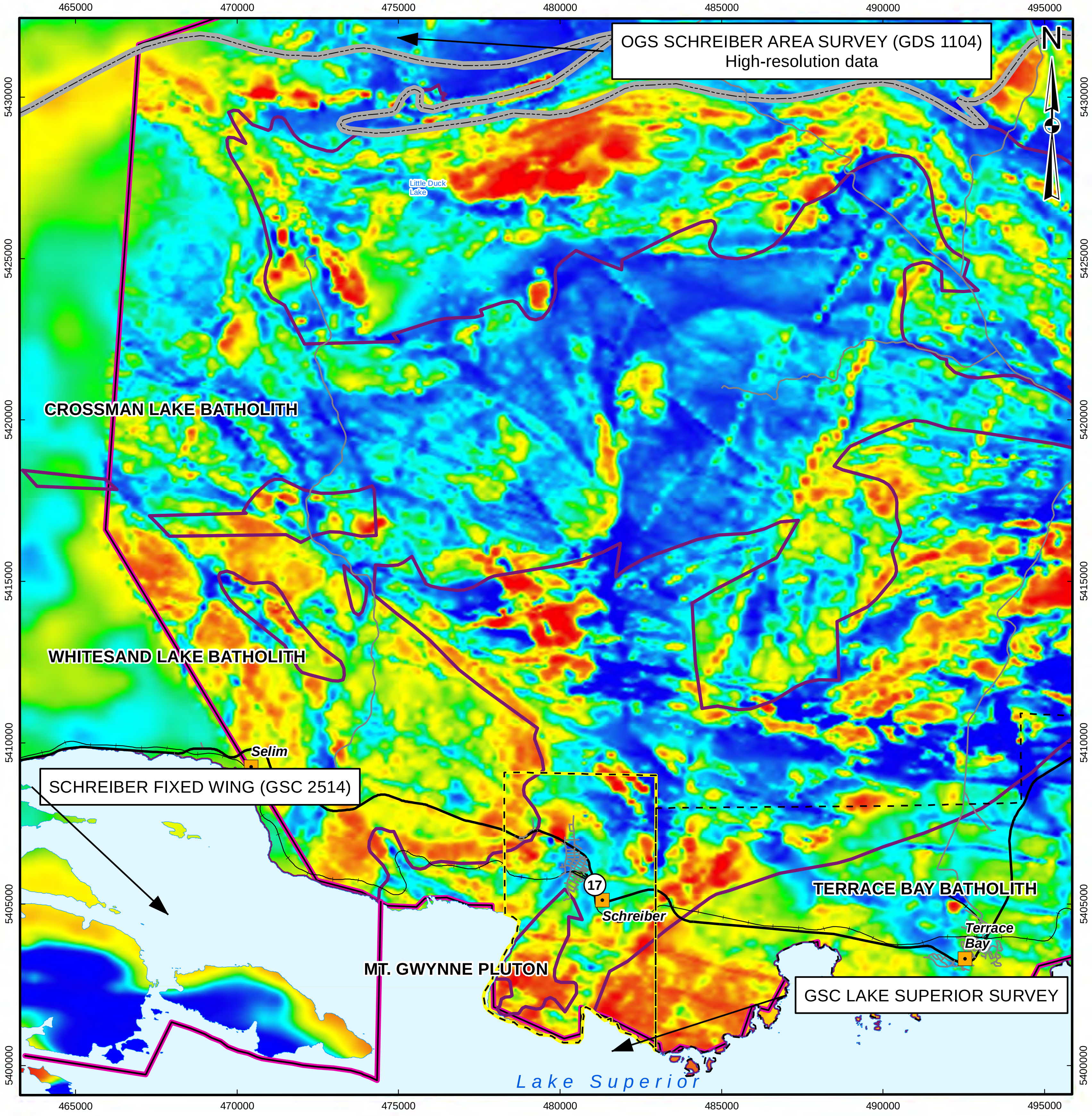
🟨	13 - Granite-Granodiorite	⬜	4a - Massive to foliated flows
⬛	12 - Diorite-Monzonite-Granodiorite	🟨	4b - Pyroclastic Rocks
🟥	8 - Gabbro	🟩	3 - Felsic and Intermediate Volcanic Rocks
🟧	5 - Clastic Sedimentary Rocks	🟩	2 - Mafic Volcanic Rocks
🟦	4 - Felsic Volvanic Rocks		

Data Sources:
Santaguida 2002, Map 2665 Rev.

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Schreiber Area Schematic Cross Section

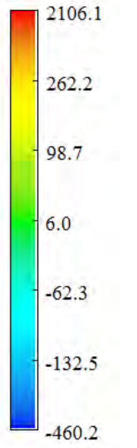
DESIGN	GHF	14 Aug 2012	FIGURE 3.5	REVISION 2
GIS	GHF	25 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		Scale Not Shown

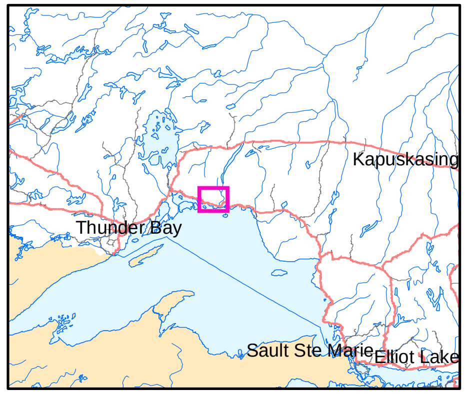


Legend

- 🟧 City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- ━ Main Road
- ─ Local Road
- ┼ Railway
- ▭ Geophysical Data Source
- ┅ Quetico-Wawa Subprovince Boundary
- ▭ Outline of batholith/pluton

Residual Total Magnetic Field (nT)





Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Batholith: Generalized from OGS 2006
OGS Schreiber Area Survey (GDS 1104)
GSC Magnetic 200m Compilation
Mira Geosciences, 2013

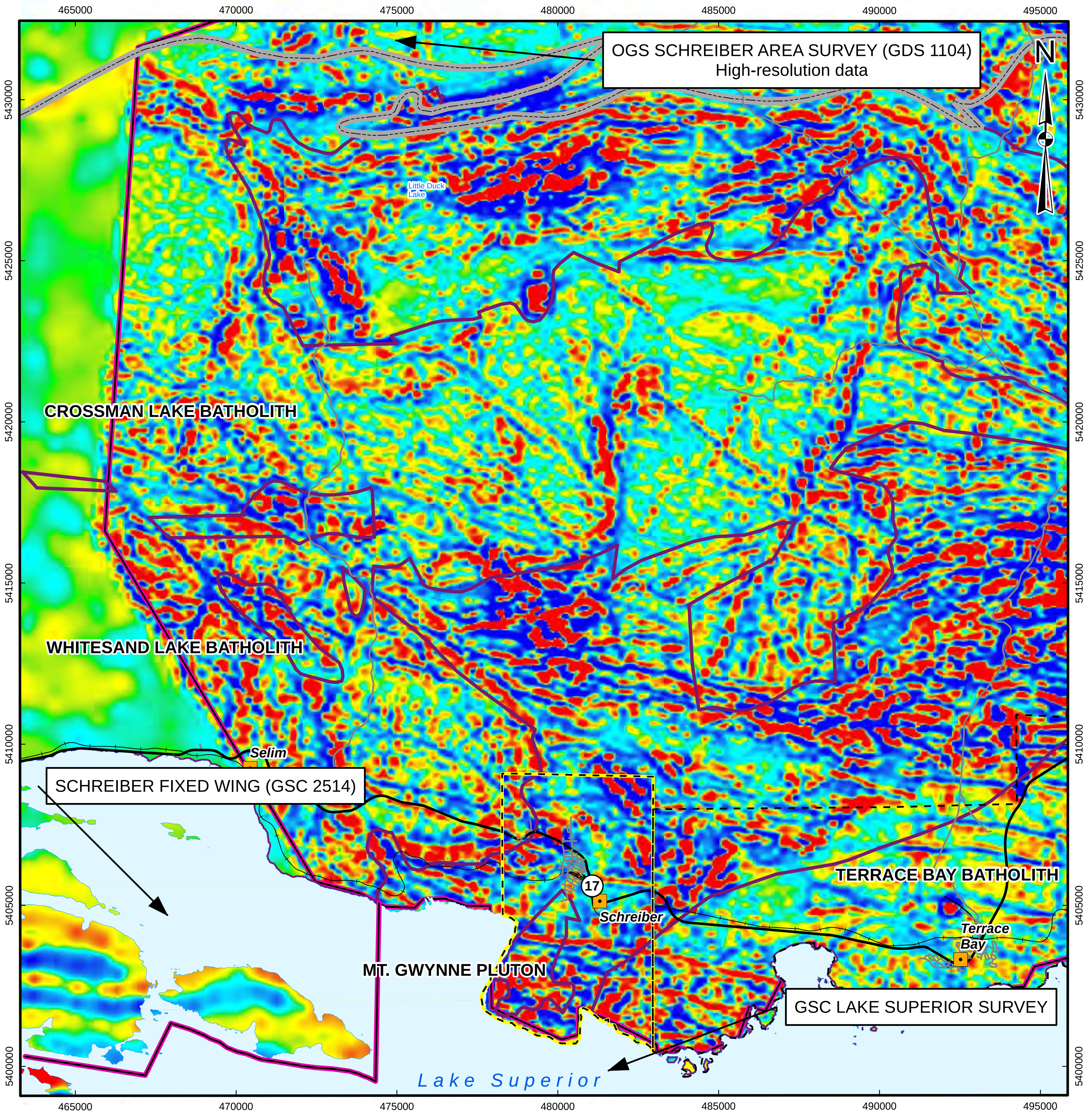
5 km

Mira Geoscience AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geophysical Data Analysis
Reduced to Pole Residual Magnetic Field
in the Schreiber Area

DESIGN	GHF	14 Aug 2012	**FIGURE 3.6**	REVISION 7
GIS	JA/GHF	25 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000

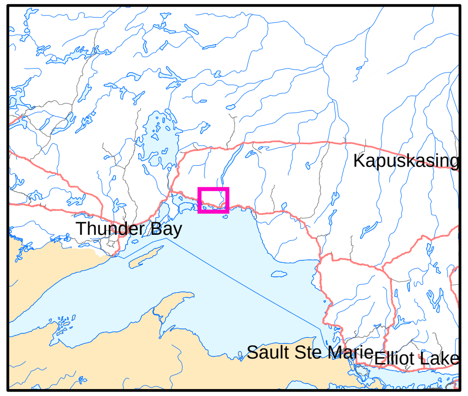


Legend

- ▪ City / Towns
- ⬚ Township of Schreiber
- ⬚ Township of Terrace Bay
- — Main Road
- — Local Road
- ┼ Railway
- ▭ Geophysical Data Source
- ┅ Quetico-Wawa Subprovince Boundary
- ▭ Outline of batholith/pluton

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

2.6
0.4
0.1
0.0
-0.2
-0.5
-2.2



Data Sources:
Base Data; MNR LIO, obtained 2009-2013
Batholith: Generalized from OGS 2006
OGS Schreiber Area Survey (GDS 1104)
GSC Magnetic 200m Compilation
Mira Geosciences, 2013

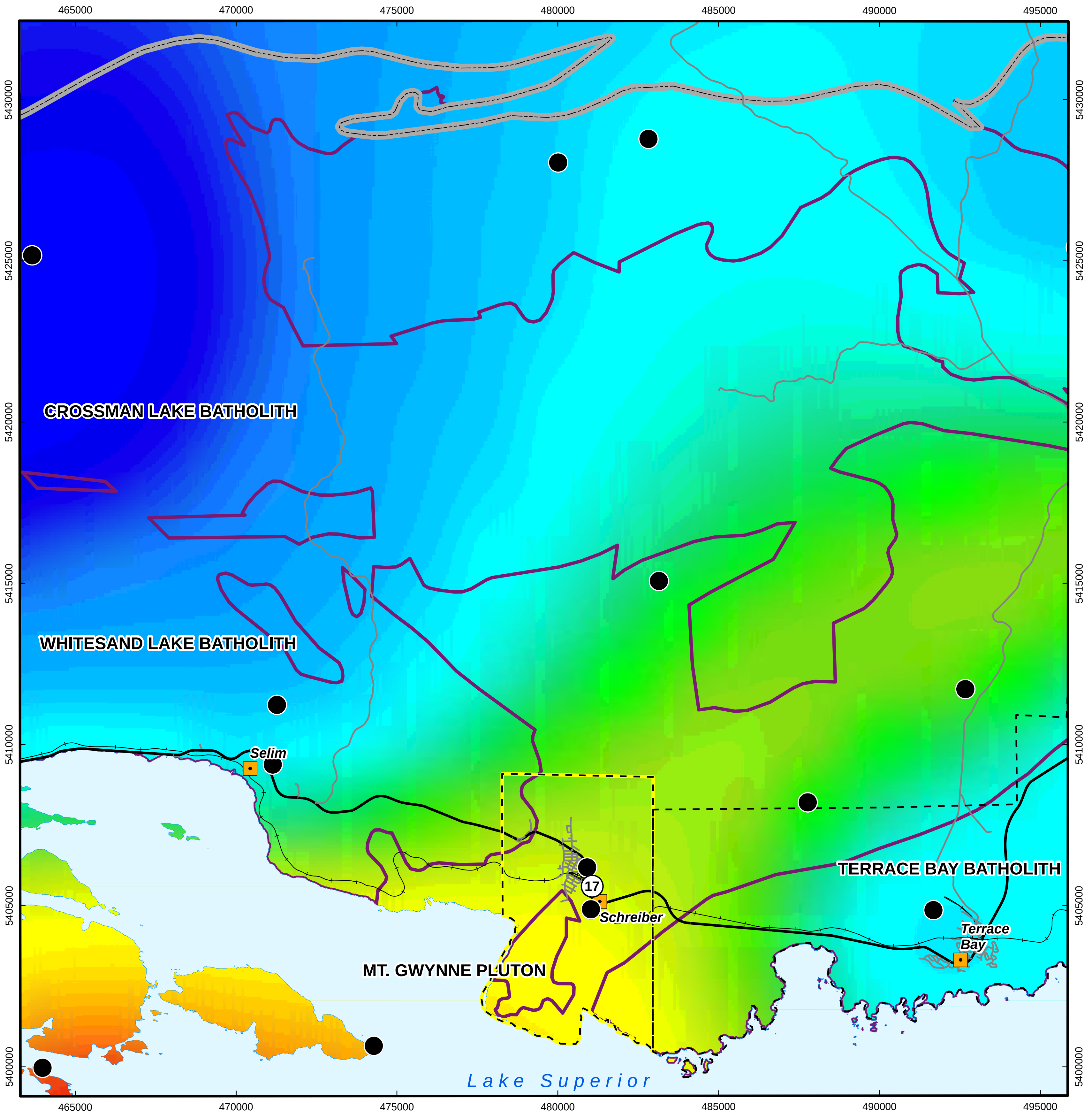
5 km

Mira Geoscience
AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geophysical Data Analysis
First Vertical Derivative of Reduced to Pole
Residual Magnetic Field in the Schreiber Area

DESIGN	GHF	14 Aug 2012	**FIGURE 3.7**	REVISION 7
GIS	JA/GHF	25 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000

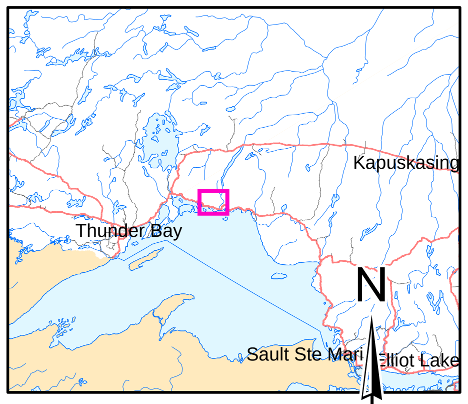


Legend

- 🟧 City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- ━ Main Road
- ─ Local Road
- ┼ Railway
- ● Station - Canadian Gravity Database
- ┅ Quetico-Wawa Subprovince Boundary
- ▭ Outline of batholith/pluton

Gravity Anamoly (mGal)

- 11.8
- -22.5
- -38.3
- -46.4
- -54.1
- -65.4
- -76.5



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Batholith: Generalized from OGS 2006
OGS Schreiber Area Survey (GDS 1104)
GSC Magnetic 200m Compilation
Mira Geosciences, 2013

5 km

Mira Geoscience AECOM

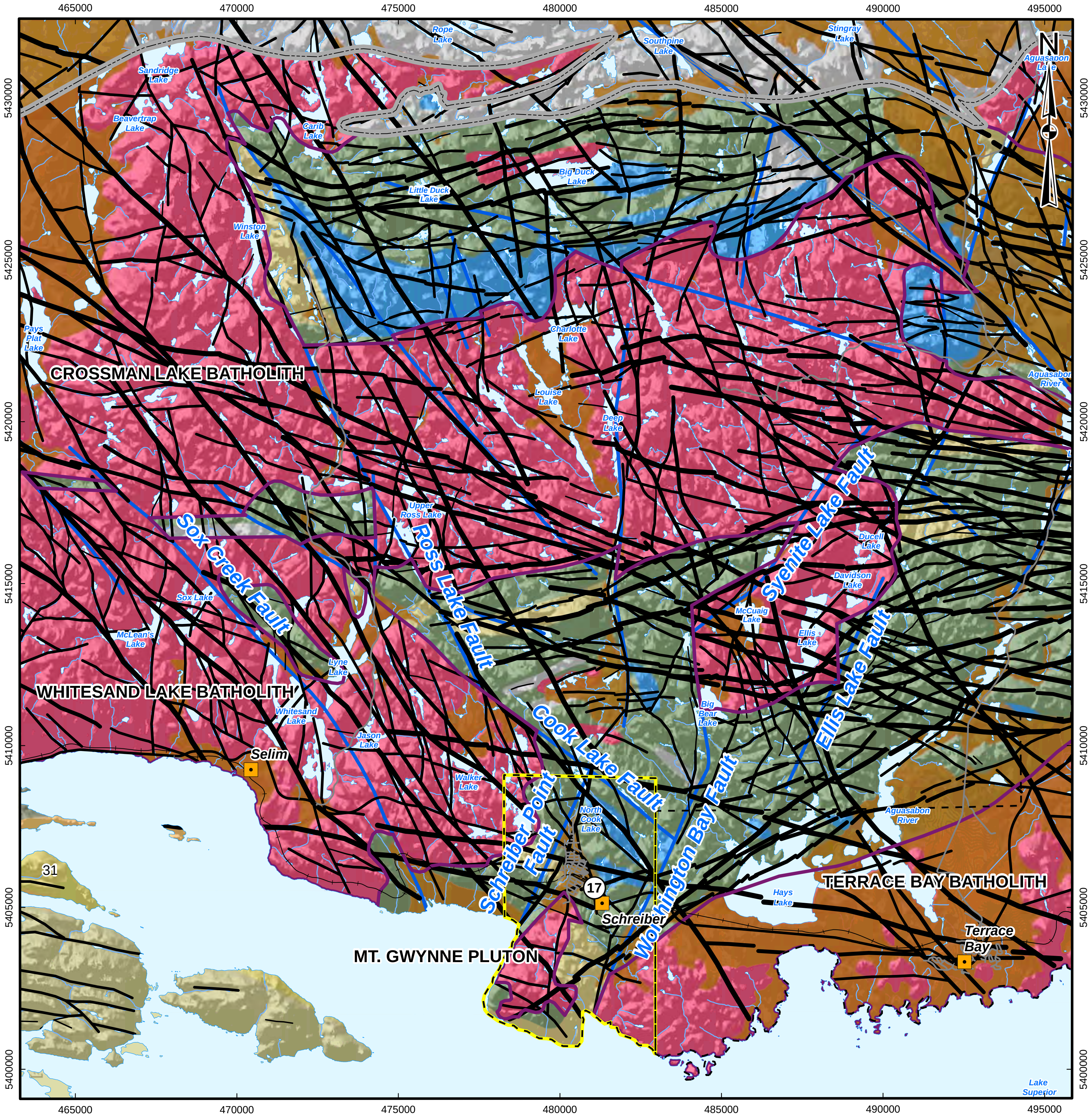
PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Geophysical Data Analysis
Bouguer Gravity Field with Station Locations
in the Schreiber Area

DESIGN	GHF	14 Aug 2012	**FIGURE 3.8**	REVISION 7
GIS	JA/GHF	25 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



LEGEND

- ▣ City / Towns
- ⬚ Township of Schreiber
- ⬚ Township of Terrace Bay
- — Main Road
- — Local Road
- —+— Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▭ Waterbody, Permanent
- — Mapped Fault
- - - Quetico-Wawa Subprovince Boundary
- ■ Overburden Cover
- ▭ Outline of batholith/pluton

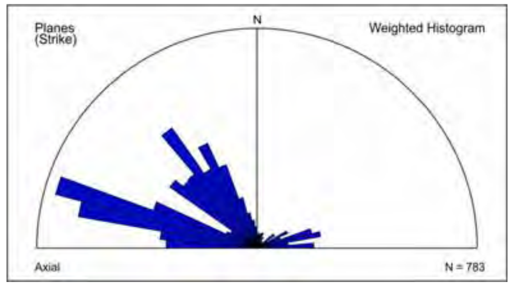
Surficial Lineament

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

Bedrock Geology (Youngest to Oldest)

- ■ 34. Mafic intrusive rocks (Keweenawan age)
- ■ 32. Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.
- ■ 31. Sibley Gp.
- ■ 24. Animikie Gp.
- ■ 15. Massive granodiorite to granite
- ■ 11. Gneissic tonalite suite
- ■ 10. Mafic and ultramafic rocks
- ■ 7. Metasedimentary rocks
- ■ 6. Felsic to intermediate metavolcanic rocks
- ■ 5. Mafic to intermediate metavolcanic rocks
- ■ 2. Felsic to intermediate metavolcanic rocks

SCHREIBER SURFICIAL LINEAMENTS - BRITTLE AND DYKE LINEAMENTS RA_2
LENGTH WEIGHTED FREQUENCY ROSE PLOT



Data Sources:
Lineaments: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Overburden: OGS MRD-160 (1:100,000), AECOM, 2013
Faults: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 2009-2013
Underlay: Hillshade DEM, MNR Elevation and Slope

5 km

srk AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Surficial Lineaments of the Schreiber Area

DESIGN	GHF	14 Aug 2012	FIGURE 3.9	REVISION 4
GIS	GHF	28 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000

LEGEND

- 🟧 City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- — Local Road
- —+— Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▭ Waterbody, Permanent
- — Mapped Fault
- — Mapped Dyke (MRD 126)
- — Interpreted Dyke (SRK, 2013)
- ▭ Higher Resolution Geophysical Survey
- - - Quetico-Wawa Subprovince Boundary
- ▭ Outline of batholith/pluton

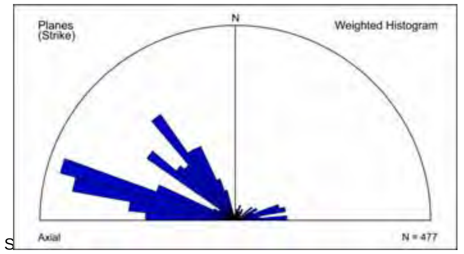
Geophysical Lineament

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

Bedrock Geology (Youngest to Oldest)

- 🟧 34. Mafic intrusive rocks (Keweenawan age)
- ▨ 32. Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.
- 🟨 31. Sibley Gp.
- ▨ 24. Animikie Gp.
- 🟥 15. Massive granodiorite to granite
- ▨ 11. Gneissic tonalite suite
- 🟦 10. Mafic and ultramafic rocks
- ▨ 7. Metasedimentary rocks
- 🟨 6. Felsic to intermediate metavolcanic rocks
- 🟩 5. Mafic to intermediate metavolcanic rocks
- 🟩 2. Felsic to intermediate metavolcanic rocks

SCHREIBER GEOPHYSICAL LINEAMENTS
BRITTLE AND DYKE LINEAMENTS RA_2
LENGTH WEIGHTED FREQUENCY ROSE PLOT



Data S
Lineaments: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Overburden: OGS MRD-160 (1:100,000), AECOM, 2013
Faults: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 2009-2013
Underlay: Hillshade DEM, MNR Elevation and Slope

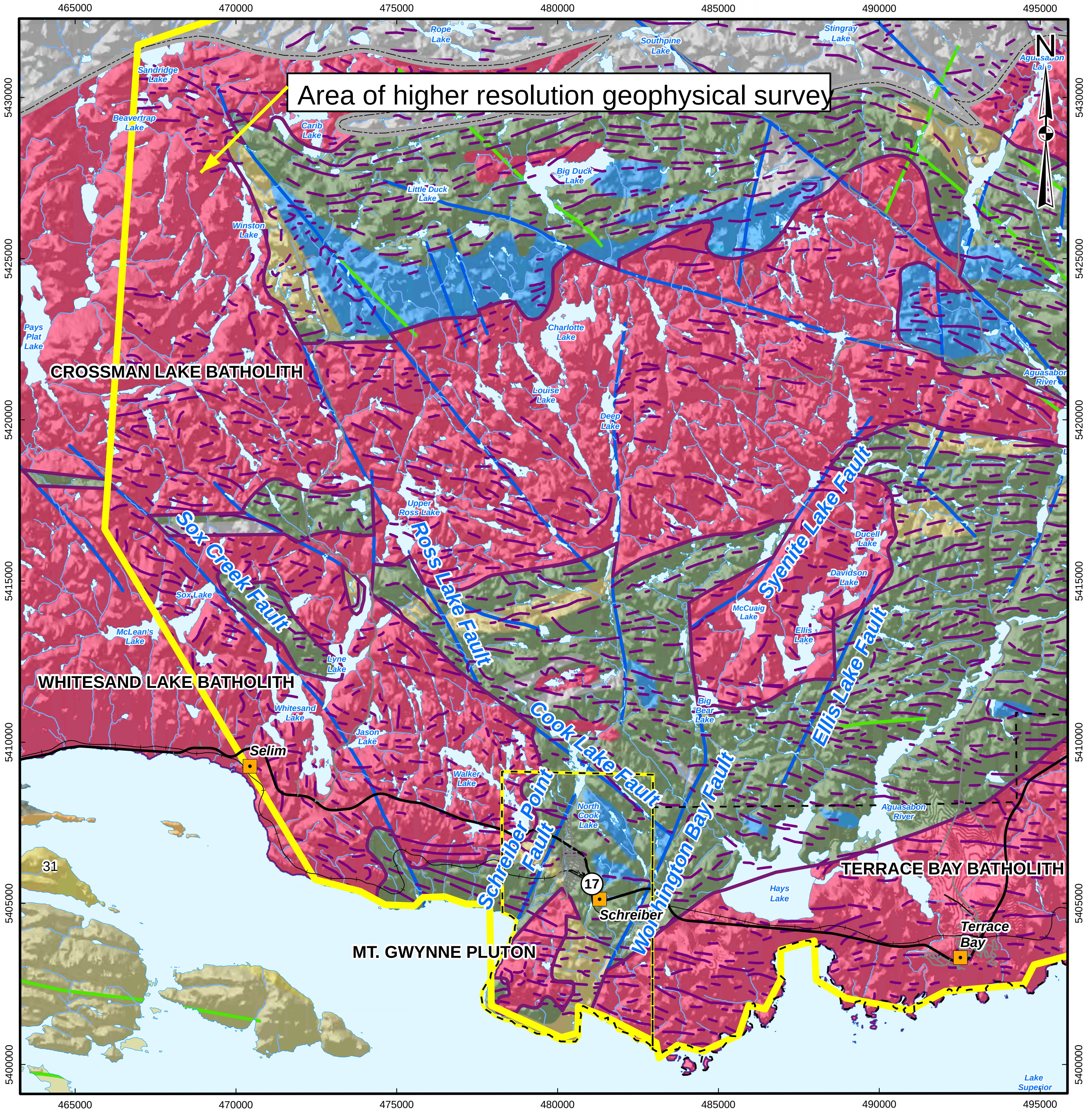
5 km

srk AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

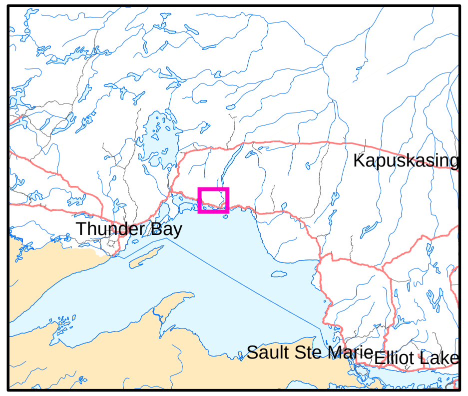
TITLE
Geophysical Lineaments of the Schreiber Area

DESIGN	GHF	14 Aug 2012	**FIGURE 3.10**	REVISION 4
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



LEGEND
- ▣ City / Towns
- ⬚ Township of Schreiber
- ⬚ Township of Terrace Bay
- ━ Main Road
- ─ Local Road
- ┼ Railway
- ─ Watercourse, Permanent
- ╌ Watercourse, Intermittent
- ▭ Waterbody, Permanent
- ━ Mapped Fault
- ━ Mapped Dyke
- ▭ Higher Resolution Geophysical Survey
- ━ Ductile Feature
- ╍ Quetico-Wawa Subprovince Boundary
- ▭ Outline of batholith/pluton

Bedrock Geology (Youngest to Oldest)
- ■ 34. Mafic intrusive rocks (Keweenawan age)
- ■ 32. Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.
- ■ 31. Sibley Gp.
- ■ 24. Animikie Gp.
- ■ 15. Massive granodiorite to granite
- ■ 11. Gneissic tonalite suite
- ■ 10. Mafic and ultramafic rocks
- ■ 7. Metasedimentary rocks
- ■ 6. Felsic to intermediate metavolcanic rocks
- ■ 5. Mafic to intermediate metavolcanic rocks
- ■ 2. Felsic to intermediate metavolcanic rocks



Data Sources:
Lineaments: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Faults: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
High Res. Survey: OGS-GDS 1104 (1999)
Base Data: MNR LIO, obtained 2009-2013
Underlay: Hillshade DEM, MNR Elevation and Slope

5 km

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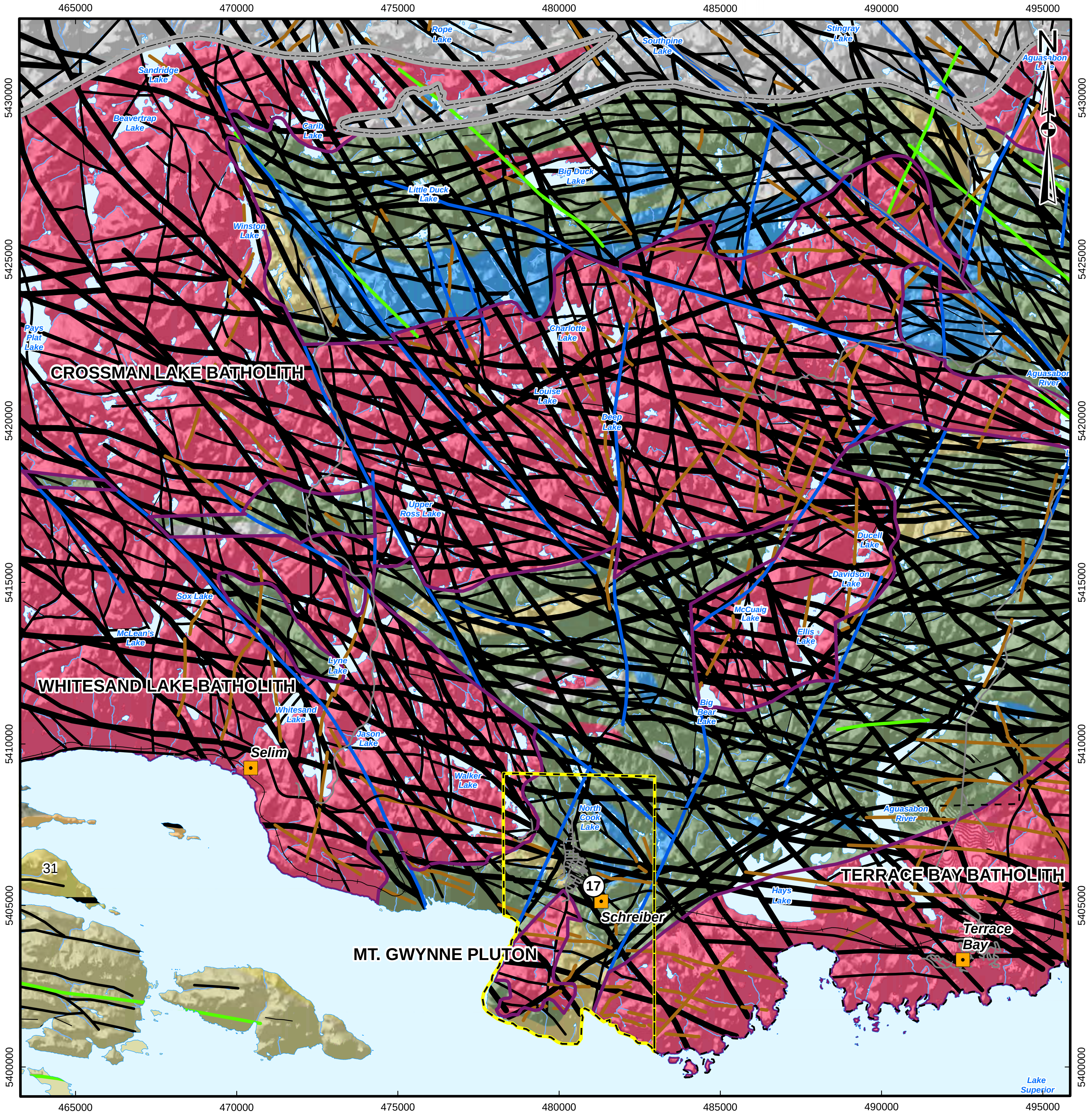
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Ductile Features of the Schreiber Area

DESIGN	GHF	08 Jan 2013	FIGURE 3.11	REVISION 4
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



LEGEND

■ City / Towns

▭ Township of Schreiber

▭ Township of Terrace Bay

— Main Road

— Local Road

—+— Railway

— Watercourse, Permanent

– – Watercourse, Intermittent

▭ Waterbody, Permanent

— Mapped Fault

— Mapped Dyke (MRD 126)

— Interpreted Dyke (SRK, 2013)

▬ Quetico-Wawa Subprovince Boundary

▭ Outline of batholith/pluton

Brittle Lineament (Surficial and Geophysical)

— < 1 km

— 1 - 5 km

— 5 - 10 km

— > 10 km

Bedrock Geology (Youngest to Oldest)

■ 34. Mafic intrusive rocks (Keweenawan age)

■ 32. Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.

■ 31. Sibley Gp.

■ 24. Animikie Gp.

■ 15. Massive granodiorite to granite

■ 11. Gneissic tonalite suite

■ 10. Mafic and ultramafic rocks

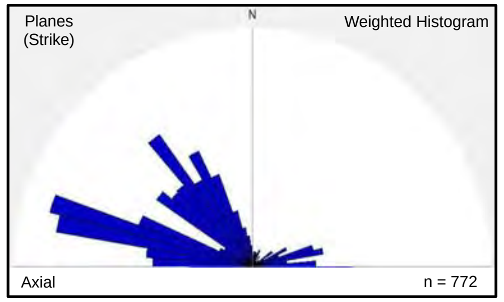
■ 7. Metasedimentary rocks

■ 6. Felsic to intermediate metavolcanic rocks

■ 5. Mafic to intermediate metavolcanic rocks

■ 2. Felsic to intermediate metavolcanic rocks

SCHREIBER BRITTLE AND DYKE LINEAMENTS
LENGTH WEIGHTED FREQUENCY ROSE PLOT



Data Sources:
Lineaments: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Faults: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 2009-2013
Underlay: Hillshade DEM, MNR Elevation and Slope

5 km

srk AECOM

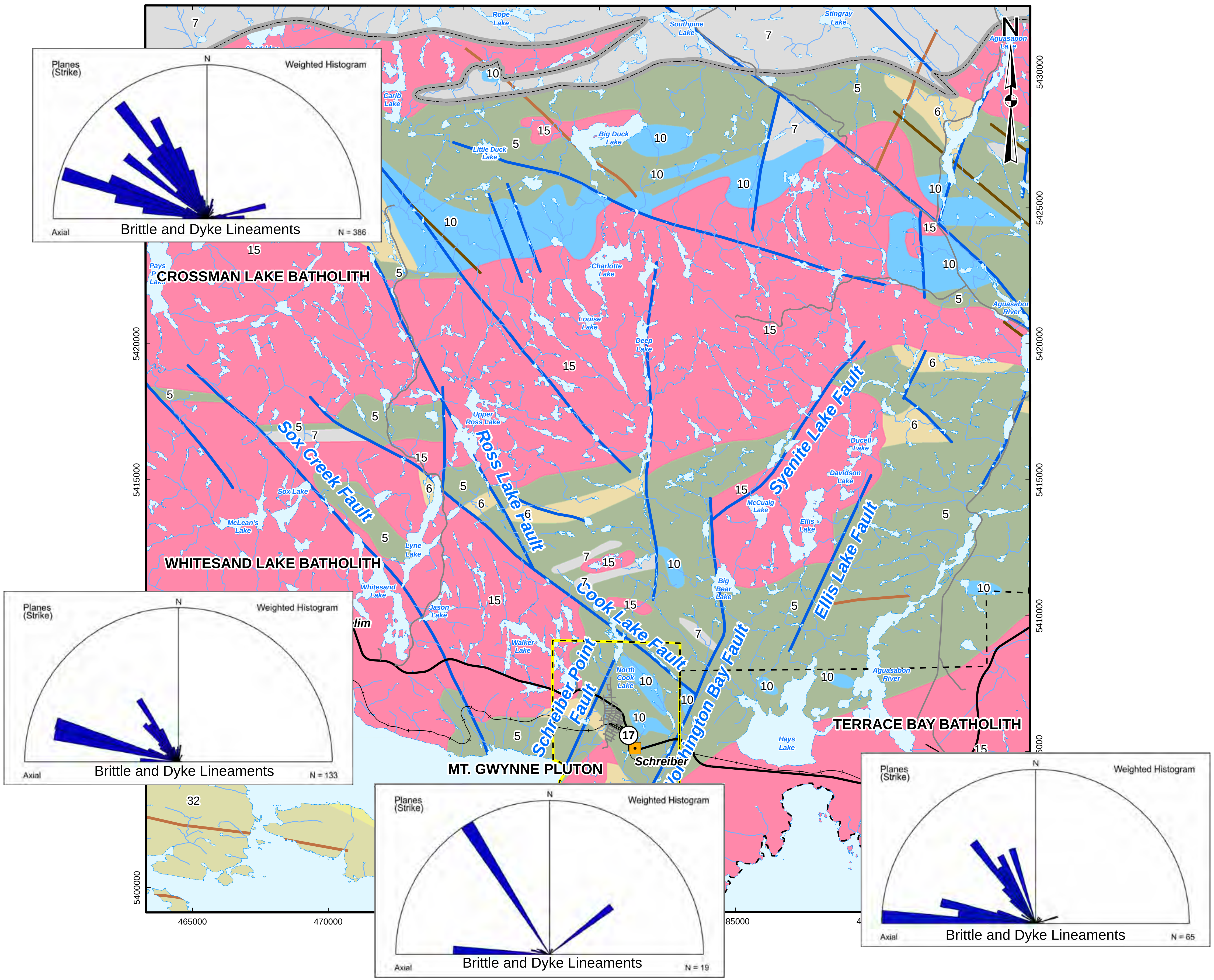
PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Brittle and Dyke Lineaments of the Schreiber Area

DESIGN	GHF	14 Aug 2012	FIGURE 3.12	REVISION 4
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



LEGEND

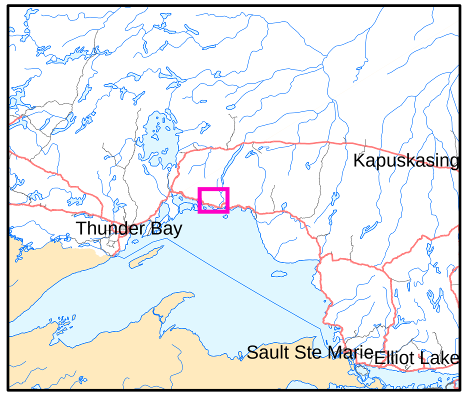
- ● City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- — Local Road
- ┼ Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▭ Waterbody, Permanent
- — Mapped Fault
- - - Quetico-Wawa Subprovince Boundary

Mapped Dyke

- — Marathon, Kapuskasing or Biscotasing Mafic Dyke
- — Matachewan Mafic Dyke
- — Dyke (Other)

Bedrock Geology (Youngest to Oldest)

- ■ 34. Mafic intrusive rocks (Keweenawan age)
- ■ 32. Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.
- ■ 31. Sibley Gp.
- ■ 24. Animikie Gp.
- ■ 15. Massive granodiorite to granite
- ■ 11. Gneissic tonalite suite
- ■ 10. Mafic and ultramafic rocks
- ■ 7. Metasedimentary rocks
- ■ 6. Felsic to intermediate metavolcanic rocks
- ■ 5. Mafic to intermediate metavolcanic rocks
- ■ 2. Felsic to intermediate metavolcanic rocks



Data Sources:
Lineament Orientation: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Faults: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Base Data: MNR LIO, obtained 2009-2013

5 km

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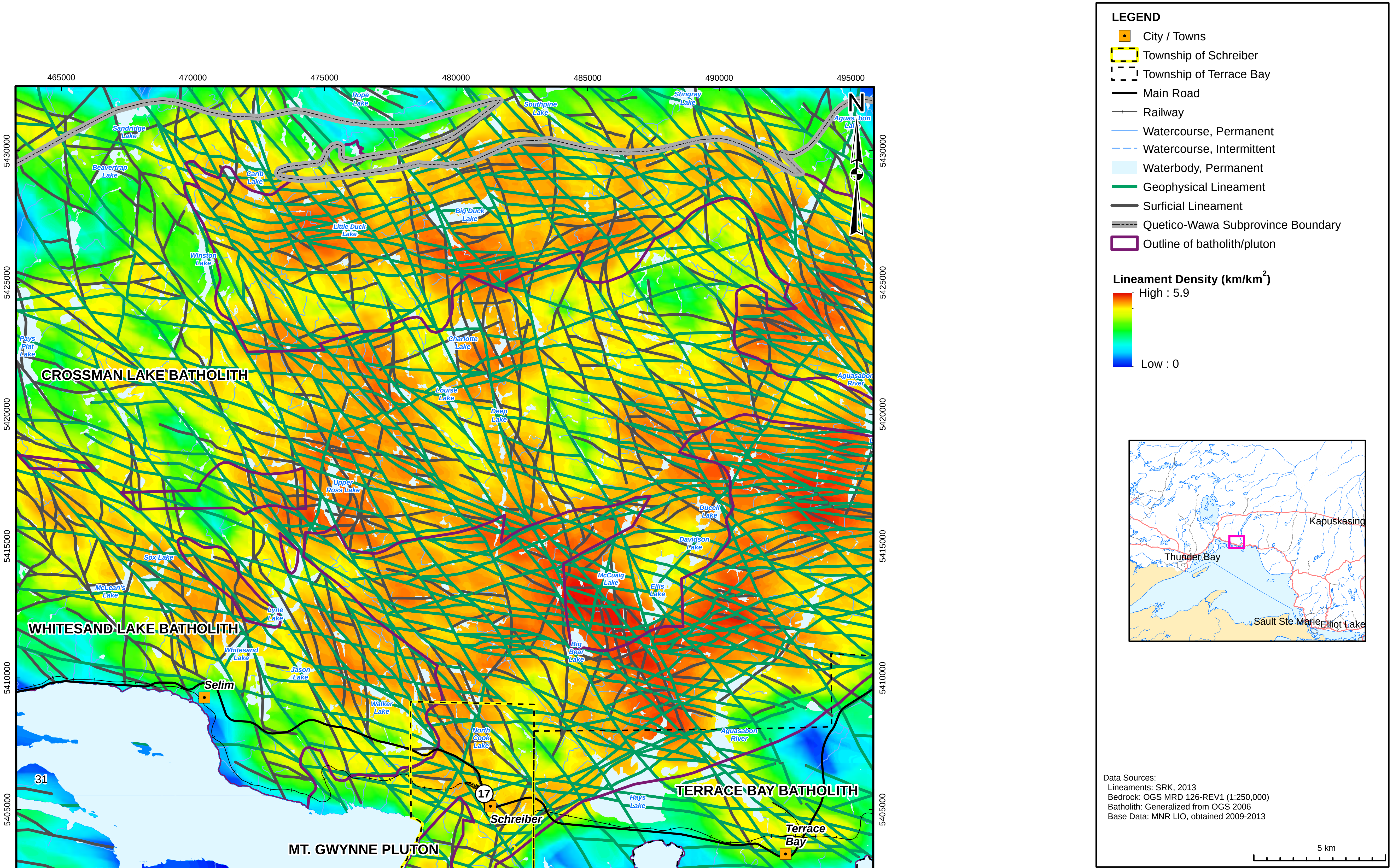
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Lineament Orientation of Principal Geological Units of the Schreiber Area (Brittle and Dyke Lineaments)

DESIGN	GHF	14 Aug 2012	FIGURE 3.13	REVISION 4
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



Data Sources:
Lineaments: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 2009-2013

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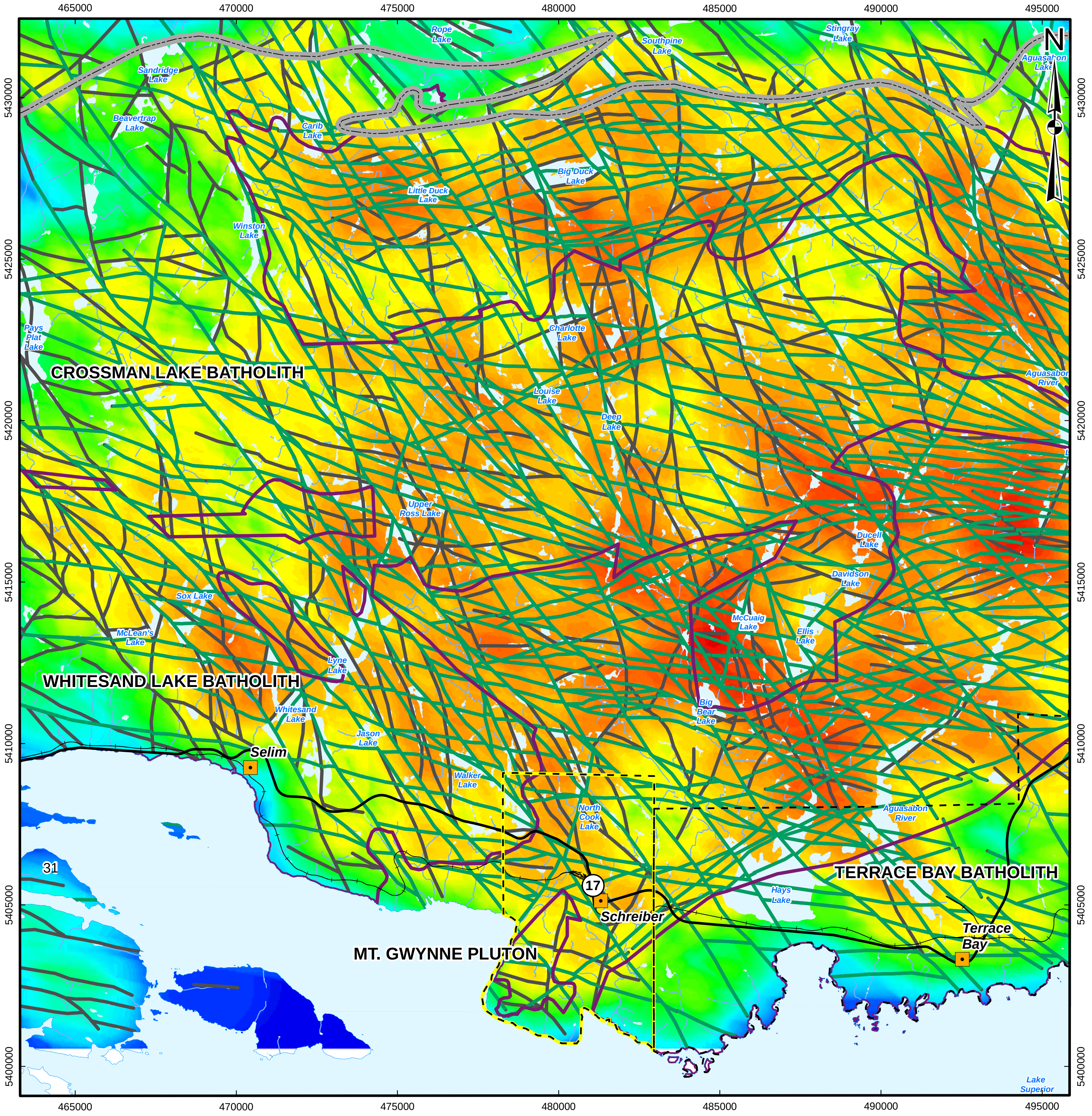
PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Lineament Density Calculated for Lineaments in the Schreiber Area

DESIGN	JA	14 Aug 2012	**FIGURE 3.14**	REVISION 4
GIS	GHF	28 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



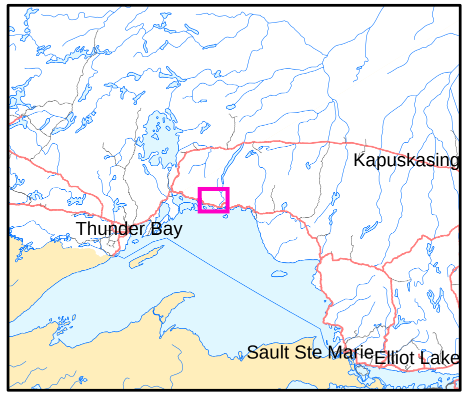
LEGEND

- ▣ City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- —+— Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▭ Waterbody, Permanent
- — Geophysical Lineament (>1 km)
- — Surficial Lineament (>1 km)
- ═ Quetico-Wawa Subprovince Boundary
- ▭ Outline of batholith/pluton

Lineament Density (km/km^2)

High : 5.9

Low : 0



Data Sources:
Lineaments: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 200-2013

5 km

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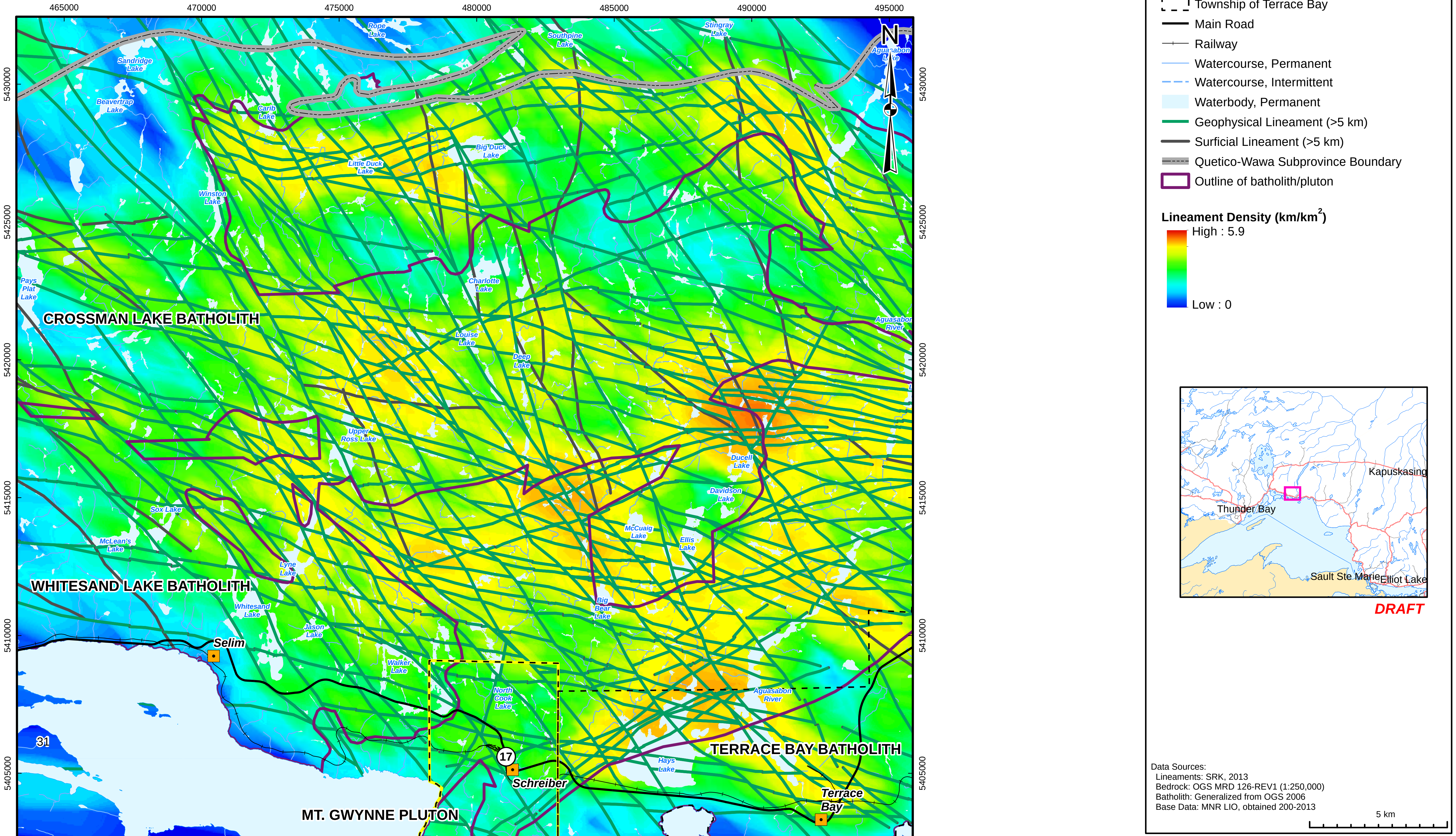
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

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

DESIGN		14 Aug 2012	**FIGURE 3.15**	REVISION 4
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



LEGEND
- City / Towns
- Township of Schreiber
- Township of Terrace Bay
- Main Road
- Railway
- Watercourse, Permanent
- Watercourse, Intermittent
- Waterbody, Permanent
- Geophysical Lineament (>5 km)
- Surficial Lineament (>5 km)
- Quetico-Wawa Subprovince Boundary
- Outline of batholith/pluton

Lineament Density (km/km^2)
High : 5.9
Low : 0

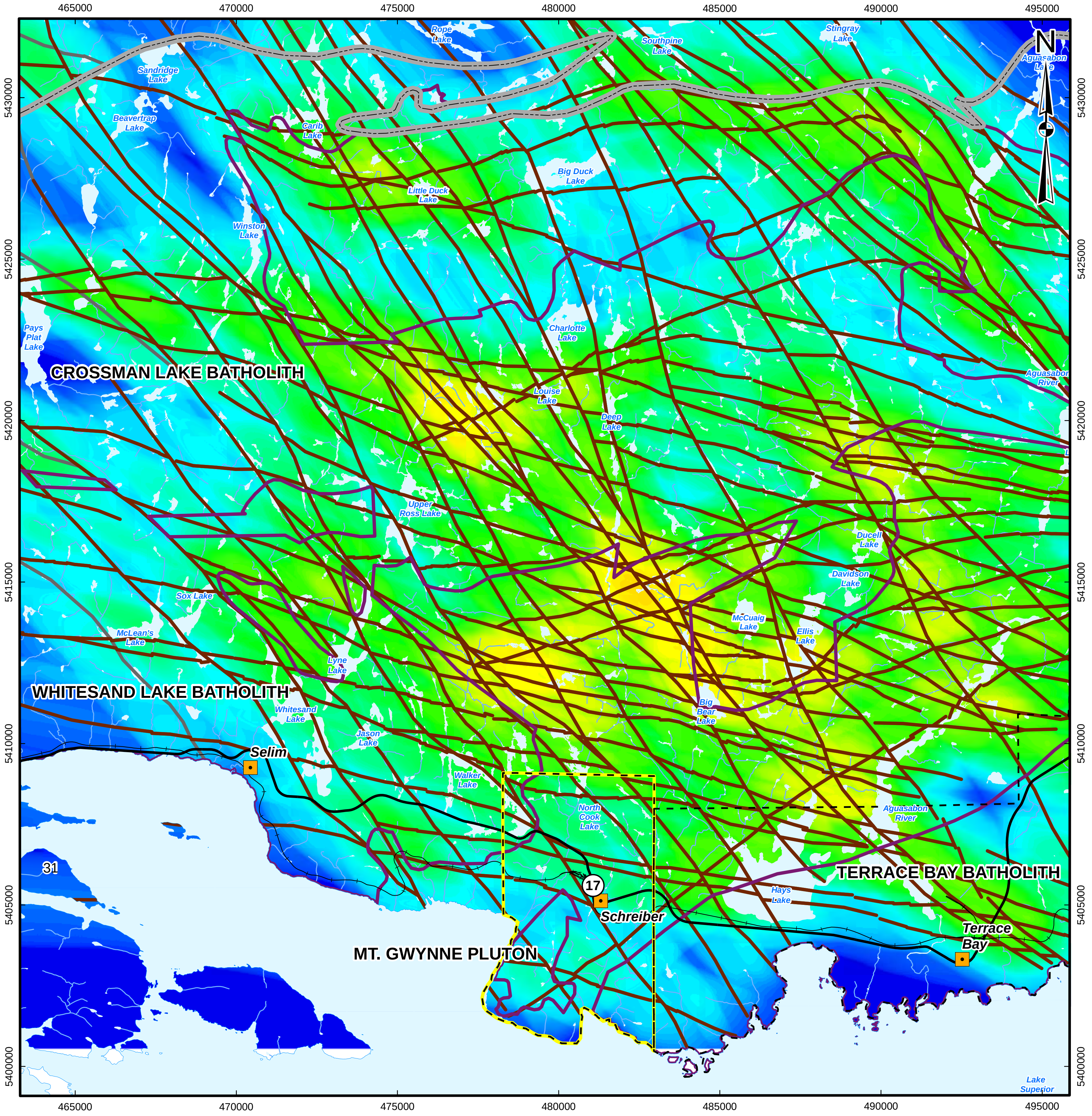
DRAFT

Data Sources:
Lineaments: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 200-2013

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Lineament Density Calculated for Lineaments >5 km in the Schreiber Area

DESIGN	GHF	14 Aug 2012	FIGURE 3.16	REVISION 4
GIS	GHF	30 Jan 2013		UTM ZONE 16
CHECK	CB	30 Jan 2013		NAD 1983
REVIEW	CB	30 Jan 2013		1:150,000



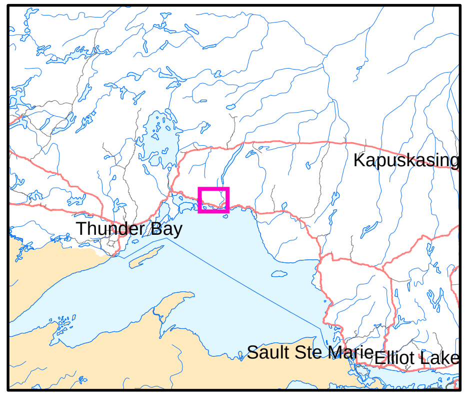
LEGEND

- ■ City / Towns
- ⬚ Township of Schreiber
- ⬚ Township of Terrace Bay
- — Main Road
- —+— Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ■ Waterbody, Permanent
- — Geophysical Lineament (>10 km)
- — Surficial Lineament (>10 km)
- ▬ Quetico-Wawa Subprovince Boundary
- ☐ Outline of batholith/pluton

Lineament Density (km/km^2)

High : 5.9

Low : 0



Data Sources:
Lineaments: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 2009-2013

5 km

srk AECOM

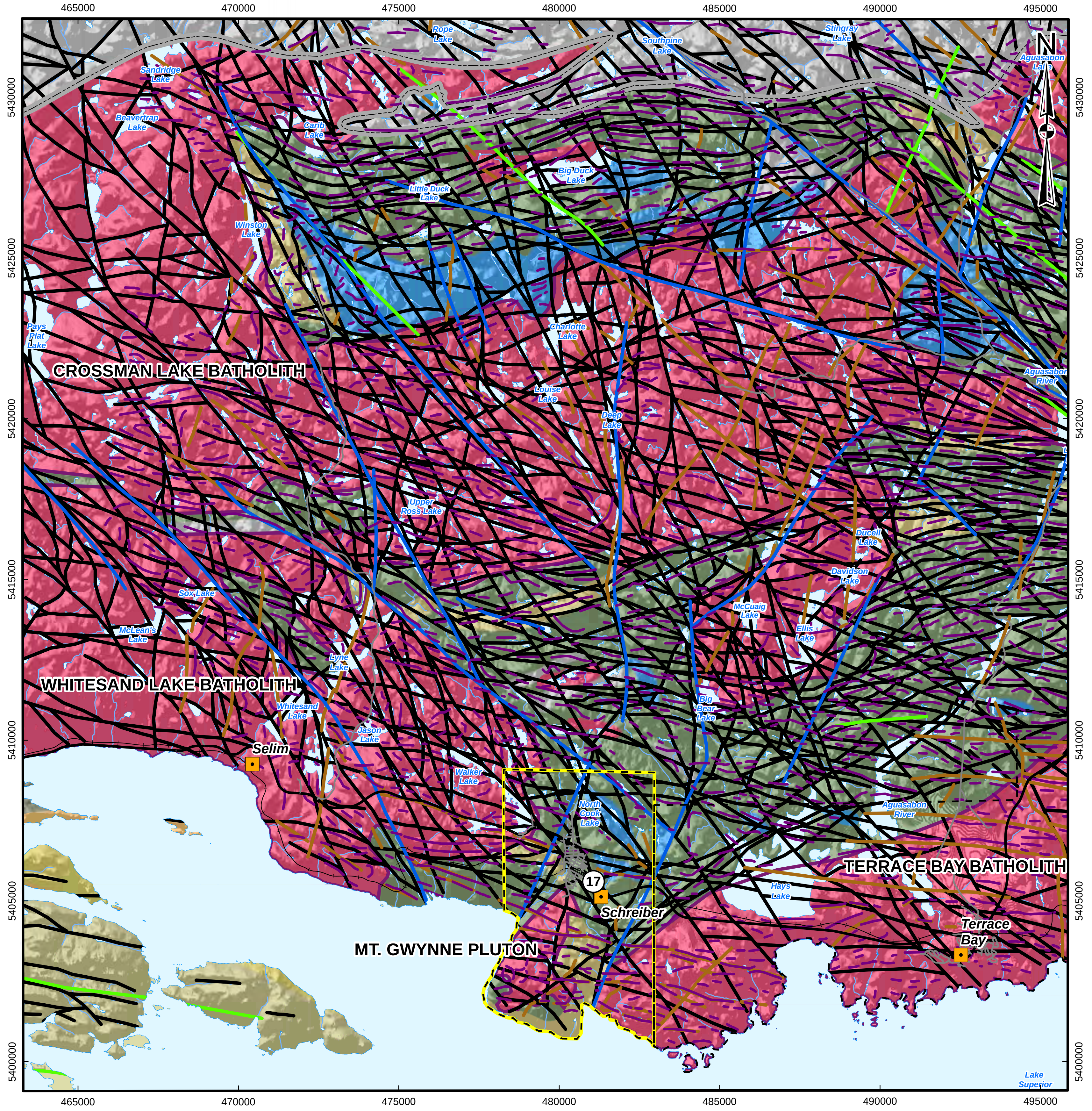
PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Lineament Density Calculated for Lineaments >10 km in the Schreiber Area

DESIGN	JA	14 Aug 2012	FIGURE 3.17	REVISION 3
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



LEGEND

- ■ City / Towns
- ⬚ Township of Schreiber
- ⬚ Township of Terrace Bay
- — Main Road
- — Local Road
- ┼ Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▭ Waterbody, Permanent
- — Mapped Fault
- — Mapped Dyke (MRD 126)
- — Interpreted Dyke (SRK, 2013)
- — Ductile Feature
- — Brittle Lineament
- ═ Quetico-Wawa Subprovince Boundary
- ▭ Outline of batholith/pluton

Bedrock Geology (Youngest to Oldest)

- ■ 34. Mafic intrusive rocks (Keweenawan age)
- ■ 32. Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.
- ■ 31. Sibley Gp.
- ■ 24. Animikie Gp.
- ■ 15. Massive granodiorite to granite
- ■ 11. Gneissic tonalite suite
- ■ 10. Mafic and ultramafic rocks
- ■ 7. Metasedimentary rocks
- ■ 6. Felsic to intermediate metavolcanic rocks
- ■ 5. Mafic to intermediate metavolcanic rocks
- ■ 2. Felsic to intermediate metavolcanic rocks

Data Sources:
Lineaments: SRK, 2013
Bedrock: OGS MRD 126-REV1 (1:250,000)
Faults: OGS MRD 126-REV1 (1:250,000)
Dike: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 2009-2013
Underlay: Hillshade DEM, MNR Elevation and Slope

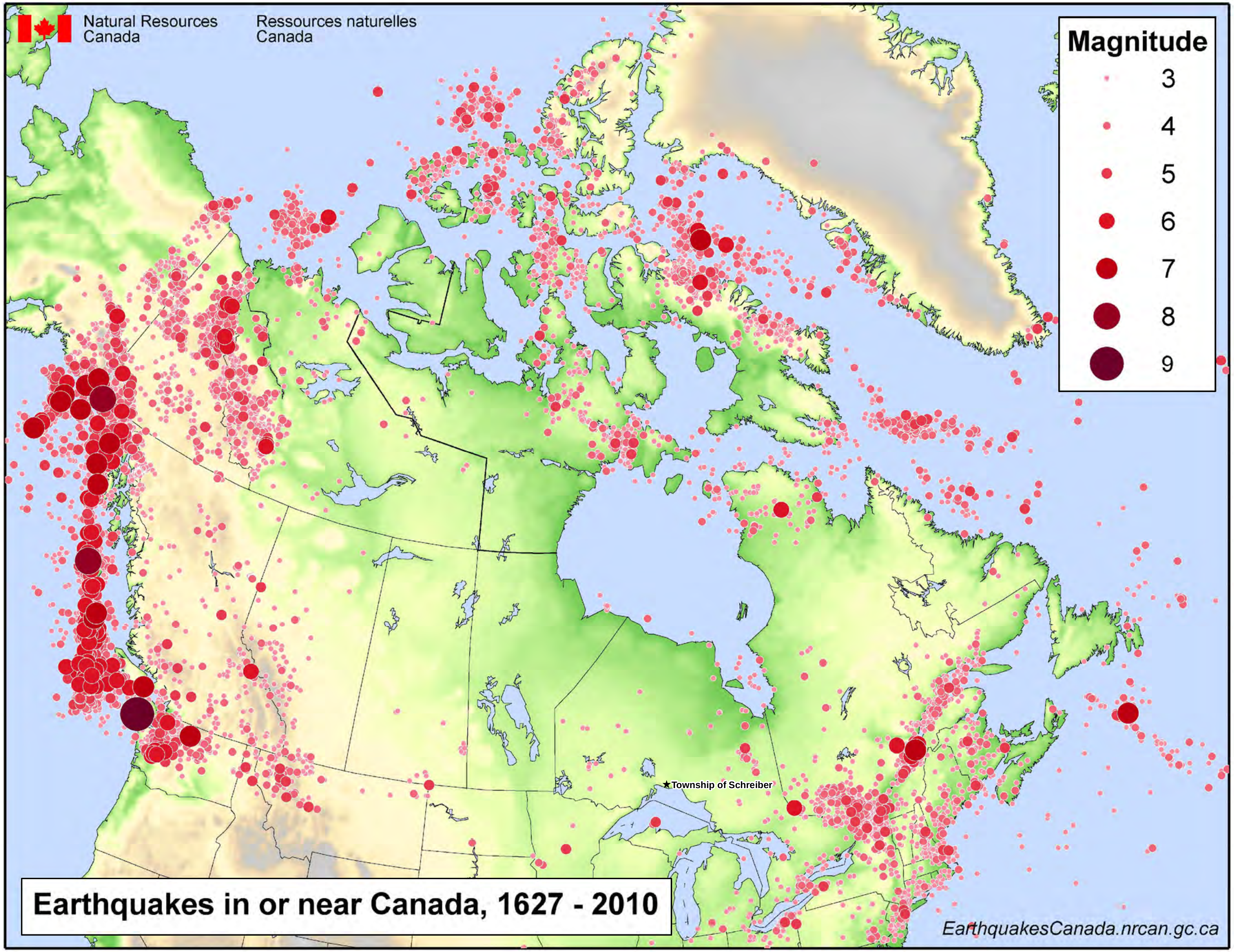
5 km

srk AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Combined Structural Features of the Schreiber Area

DESIGN	GHF	14 Aug 2012	FIGURE 3.18	REVISION 4
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



LEGEND

★ Township of Schreiber

Data Sources:
Seismic: NRCAN, Earthquake Map of Canada 1627-2010

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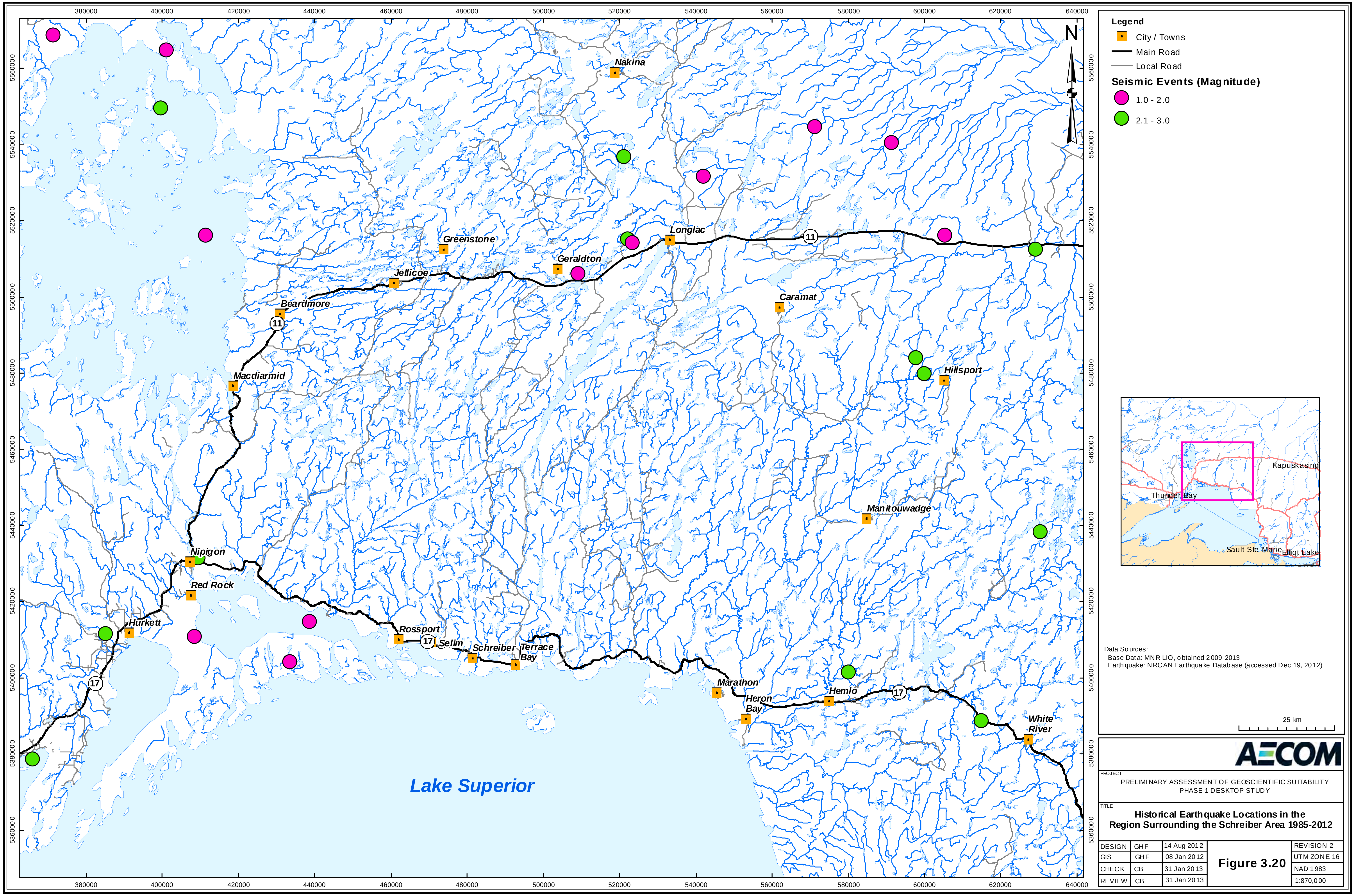
PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Earthquakes Map of Canada 1627-2010

DESIGN	GHF	14 Aug 2012	FIGURE 3.19	REVISION 3
GIS	GHF	19 Dec 2012		Scale as Shown
CHECK	CB	31 Jan 2013		
REVIEW	CB	31 Jan 2013		



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Earthquake: NRCAN Earthquake Database (accessed Dec 19, 2012)

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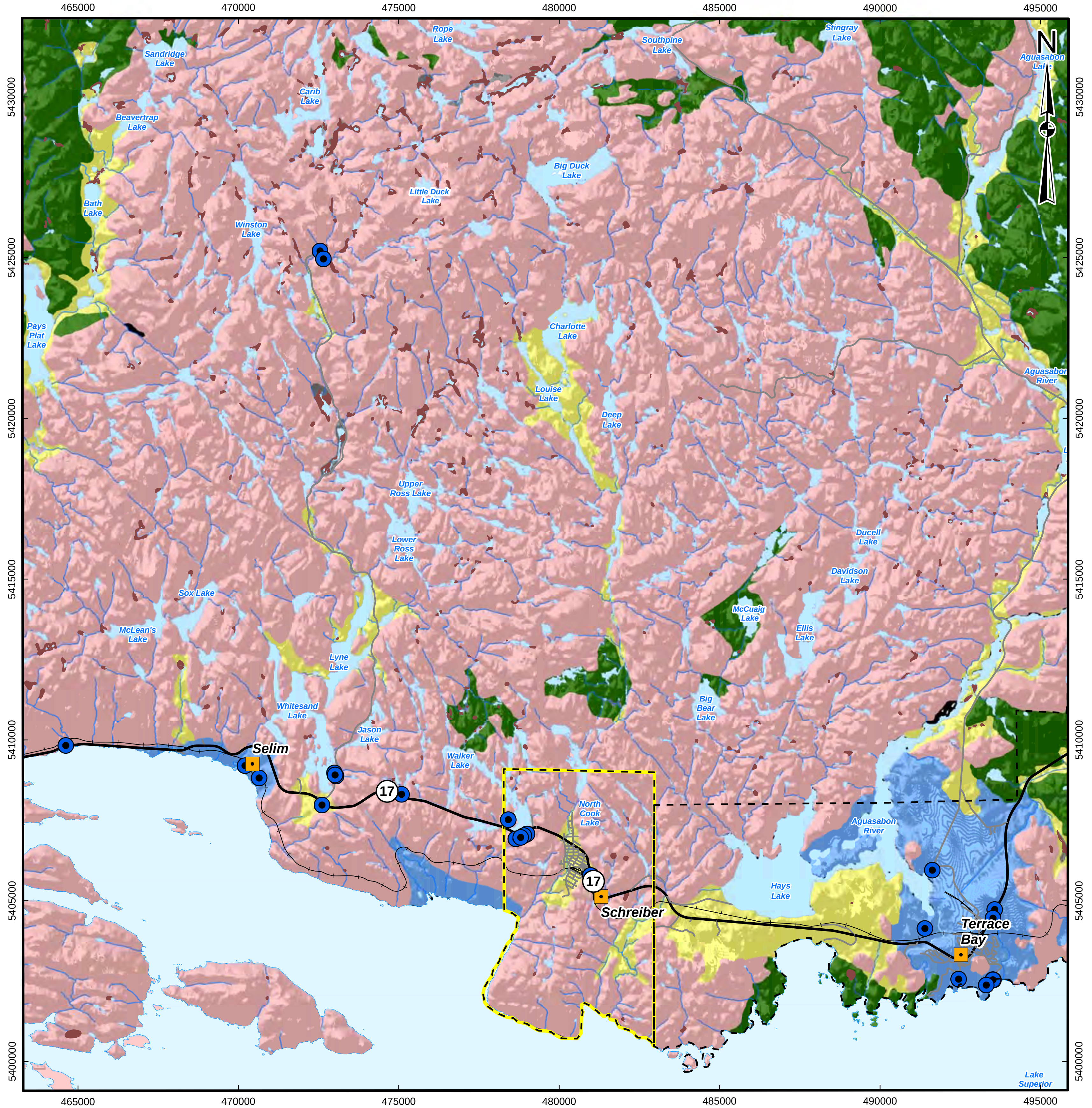
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Historical Earthquake Locations in the Region Surrounding the Schreiber Area 1985-2012

DESIGN	GHF	14 Aug 2012	Figure 3.20	REVISION 2
GIS	GHF	08 Jan 2012		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:870,000

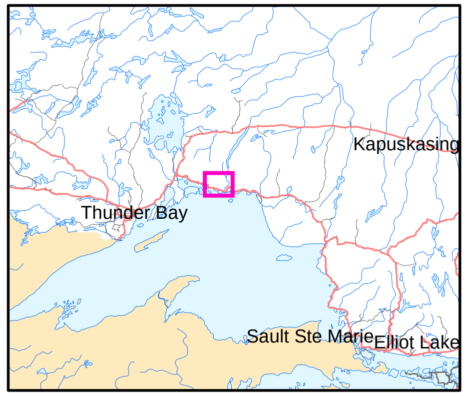


LEGEND

- ▪ City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- ● Water Well (MOE)
- — Main Road
- — Local Road
- ┼ Railway
- — Watercourse, Permanent
- - - Watercourse, Intermittent
- ▬ Waterbody (permanent)
- ▬ Wetland

Landform

- ▬ Morainal Terrain
- ▬ Glaciofluvial Terrain
- ▬ Glaciolacustrine Terrain
- ▬ Organic Terrain
- ▬ Bedrock Terrain



Data Sources:
Overburden: OGS MRD-160 (1:100,000), AECOM, 2013
Base Data: MNR LIO, obtained 2009-2013
Water Well: MOE Water Well Information System
Underlay: Hillshade DEM, MNR Elevation and Slope

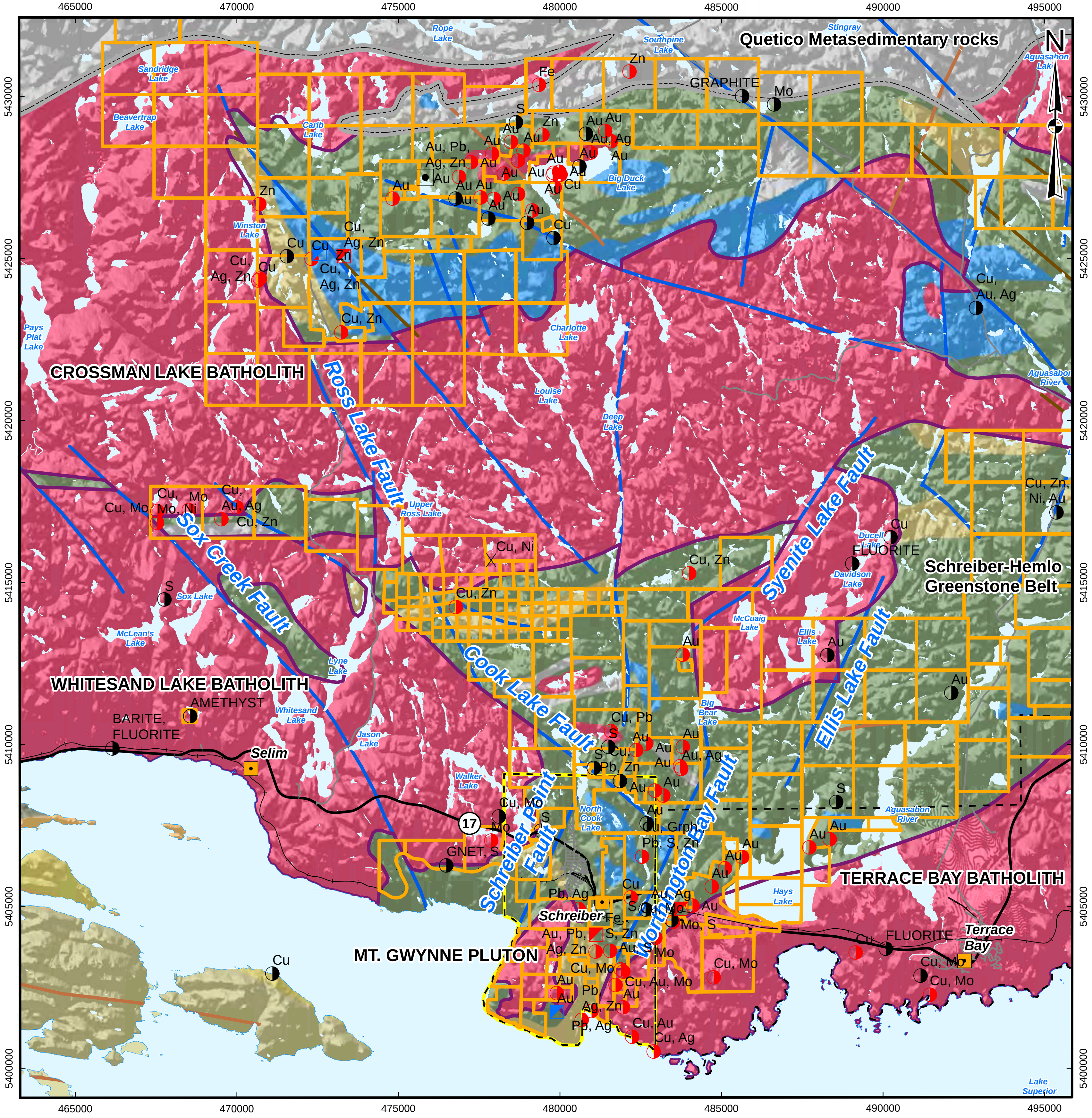
5 km

AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Groundwater Wells within the Schreiber Area

DESIGN	GHF	14 Aug 2012	**FIGURE 4.1**	REVISION 3
GIS	GHF	28 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



LEGEND

▣ City / Towns

⬚ Township of Schreiber

⬚ Township of Terrace Bay

— Main Road

— Local Road

┼ Railway

▭ Waterbody, Permanent

╳ Developed Prospect With Reserves

◐ Discretionary Occurrence

◐ Mineral Occurrence

◩ Past Producing Mine With Reserves

◩ Past Producing Mine Without Reserves

⊡ Prospect

— Mapped Fault

--- Quetico-Wawa Subprovince Boundary

▭ Active Claims

▭ Outline of batholith/pluton

Mapped Dyke

— Marathon, Kapuskasing or Biscotasing Mafic Dyke

— Matachewan Mafic Dyke

— Dyke (Other)

Bedrock Geology (Youngest to Oldest)

🟧 34. Mafic intrusive rocks (Keweenawan age)

▨ 32. Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.

🟨 31. Sibley Gp.

▨ 24. Animikie Gp.

🟥 15. Massive granodiorite to granite

▨ 11. Gneissic tonalite suite

🟦 10. Mafic and ultramafic rocks

⬜ 7. Metasedimentary rocks

▨ 6. Felsic to intermediate metavolcanic rocks

🟩 5. Mafic to intermediate metavolcanic rocks

🟩 2. Felsic to intermediate metavolcanic rocks

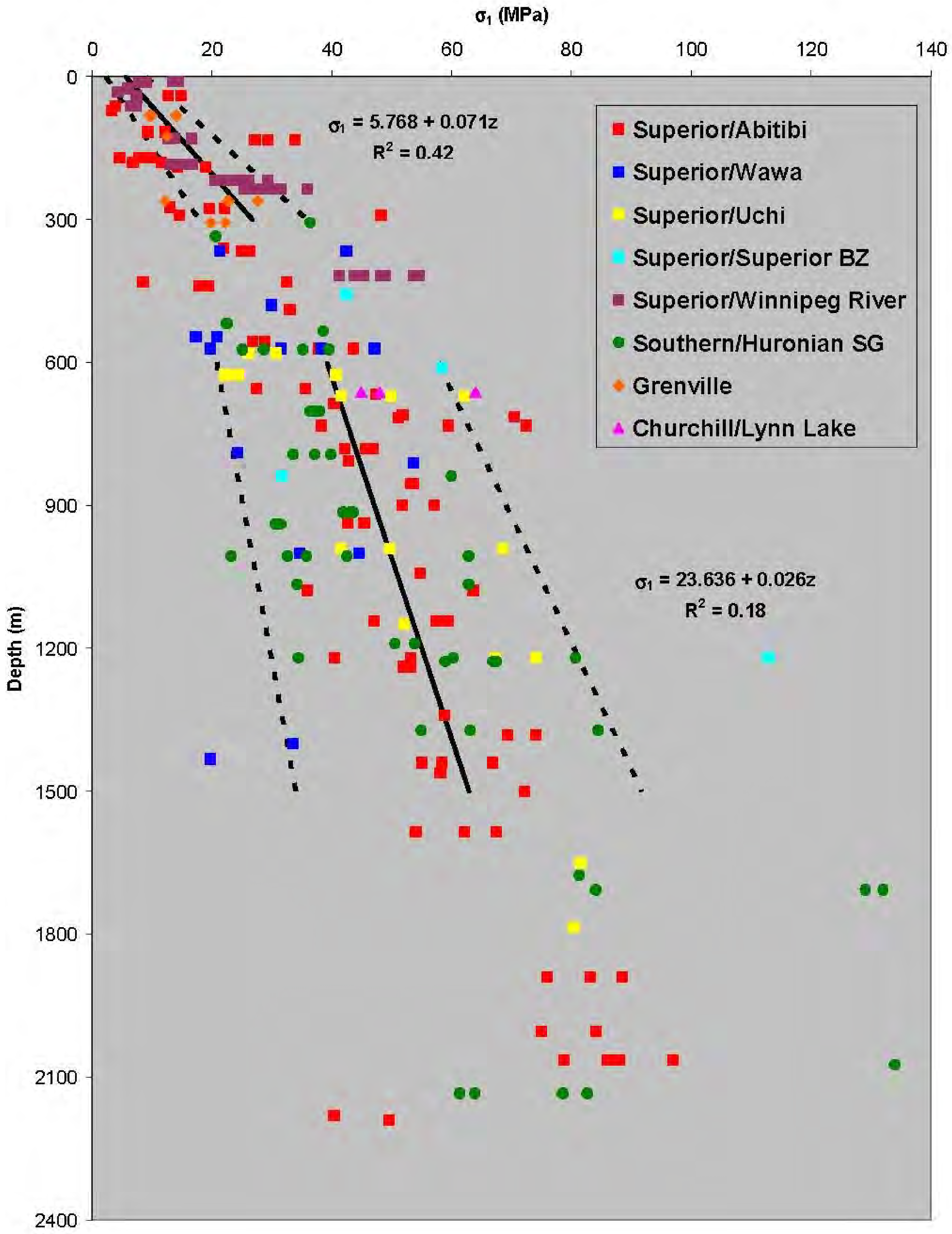
Data Sources:
Bedrock: OGS MRD 126-REV1 (1:250,000)
Faults: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Batholith: Generalized from OGS 2006
Base Data: MNR LIO, obtained 2009-2013
Active Mining Claims: MNDM, accessed December 19, 2012
Mineral Inventory: OGS MDI-2011
Underlay: Hillshade DEM, MNR Elevation and Slope

5 km

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Mineral Showings and Dispositions
of the Schreiber Area

DESIGN	GHF	14 Aug 2012	**FIGURE 5.1**	REVISION 4
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:150,000



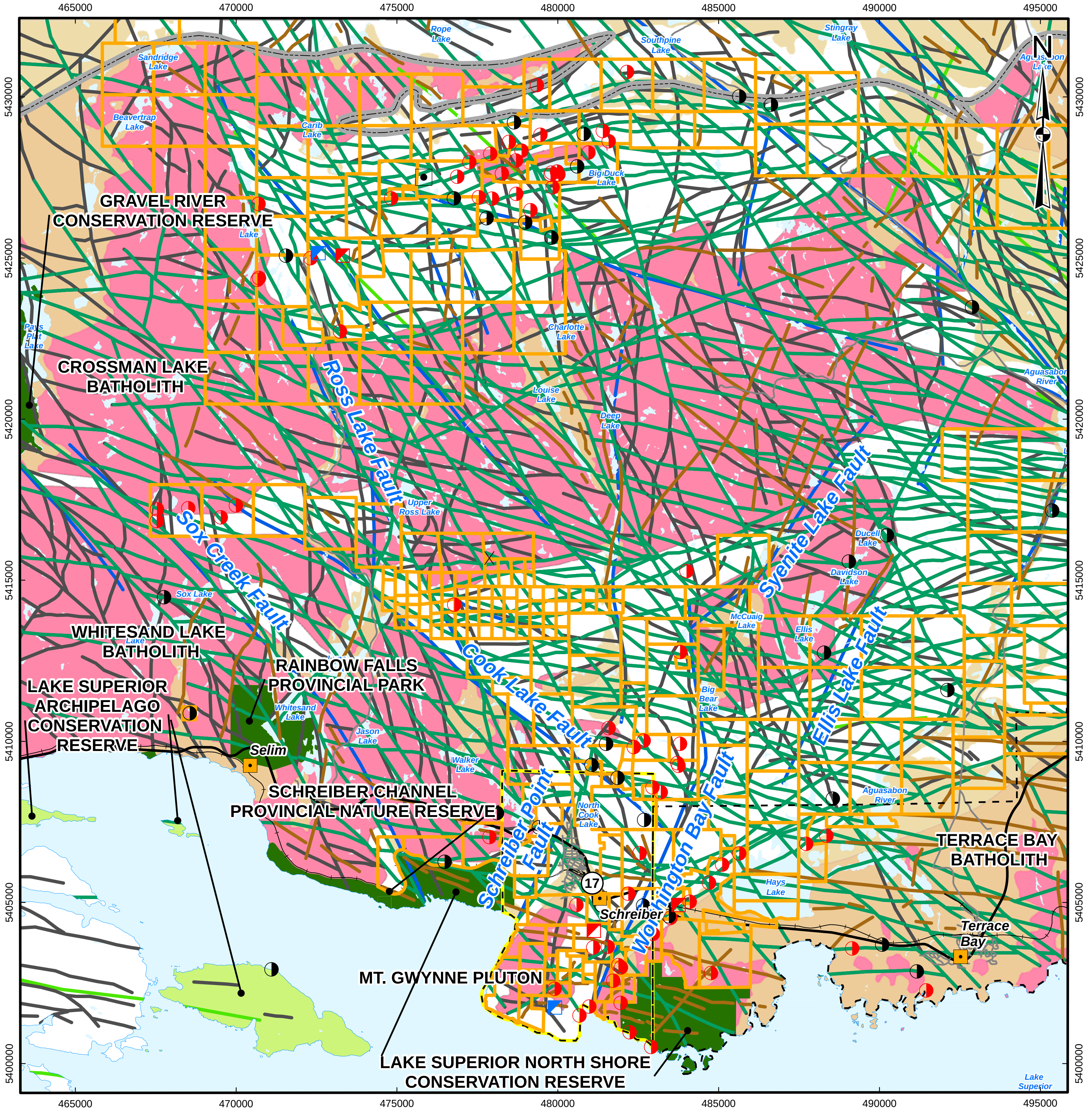
Data Sources:
Maloney, Kaiser, and Vorauer, 2006

AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

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

DESIGN	GHF	14 Aug 2012	**FIGURE 6.1**	
GIS	GHF	08 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		



LEGEND

- 🟧 City / Towns
- ▭ Township of Schreiber
- ▭ Township of Terrace Bay
- — Main Road
- — Local Road
- ┼ Railway
- ▭ Waterbody, Permanent
- X Developed Prospect With Reserves
- ◐ Discretionary Occurrence
- ◐ Mineral Occurrence
- ◩ Past Producing Mine With Reserves
- ◩ Past Producing Mine Without Reserves
- ● Prospect
- — Quetico-Wawa Subprovince Boundary
- — Mapped Fault
- — Mapped Dyke (MRD 126)
- — Interpreted Dyke (SRK, 2013)
- — Geophysical Lineament
- — Surficial Lineament
- ▭ Overburden Cover
- ☐ Unfavourable Geology
- ▭ Favourable Geology (exposed or thinly covered)
- 🟩 Protected Area
- ▭ Recommended Conservation Reserve
- ▭ Active Claims

Approximate Size of Repository Footprint

2 km
3 km

Data Sources:
Lineaments: SRK, 2013
Overburden: OGS MRD-160 (1:100,000), AECOM, 2013
Faults: OGS MRD 126-REV1 (1:250,000)
Dyke: OGS MRD 126-REV1 (1:250,000)
Base Data: MNR LIO, obtained 2009-2013
Active Mining Claims: MNDM, accessed December 19, 2012
Mineral Inventory: OGS MDI-2011

5 km

srk AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Key Geoscientific Characteristics of the Schreiber Area

DESIGN	GHF	14 Aug 2012	**FIGURE 7.1**	REVISION 4
GIS	GHF	31 Jan 2013		UTM ZONE 16
CHECK	CB	28 May 2013		NAD 1983
REVIEW	CB	28 May 2013		1:150,000