NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

TOWNSHIP OF HORNEPAYNE, ONTARIO

APM-REP-06144-0003

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

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Township of Hornepayne, Ontario

Revision: 0 (Final)

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EXECUTIVE SUMMARY

In December 2011, the Township of Hornepayne, 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 Hornepayne area for safely hosting a deep geological repository (Step 3). This request followed successful completion of an initial screening conducted during Step 2 of the site selection process. The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated preliminary assessment report (NWMO, 2013).

This report presents the results of a desktop geoscientific preliminary assessment to determine whether the Hornepayne 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 Hornepayne and its periphery, which are referred to as the "Hornepayne area".

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

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, and overburden deposits;
- Interpretation of available geophysical surveys (magnetic, gravity, radiometric, electromagnetic);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on 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 Hornepayne area contains at least three general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. Two of these areas are within the Black-Pic batholith of the Wawa Subprovince. The other area is located within the metasedimentary rocks of the Quetico Subprovince.

The Black-Pic batholith and the metasedimentary rocks of the Quetico Subprovince hosting the three identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They have sufficient depth and extend over large

areas. The bedrock within the three potentially suitable areas has relatively good exposure. All three areas have low potential for natural resources and contain limited surface constraints.

While the identified general potentially suitable areas appear to have favourable geoscientific characteristics for hosting a deep geological repository, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The main uncertainties are associated with the influence of the geological subprovince boundary that cross-cuts the Hornepayne area, the presence of numerous dykes, the low resolution of available geophysical data over most of the Hornepayne area, and the variable degree of metamorphism that the metasedimentary rocks experienced in the geological past.

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

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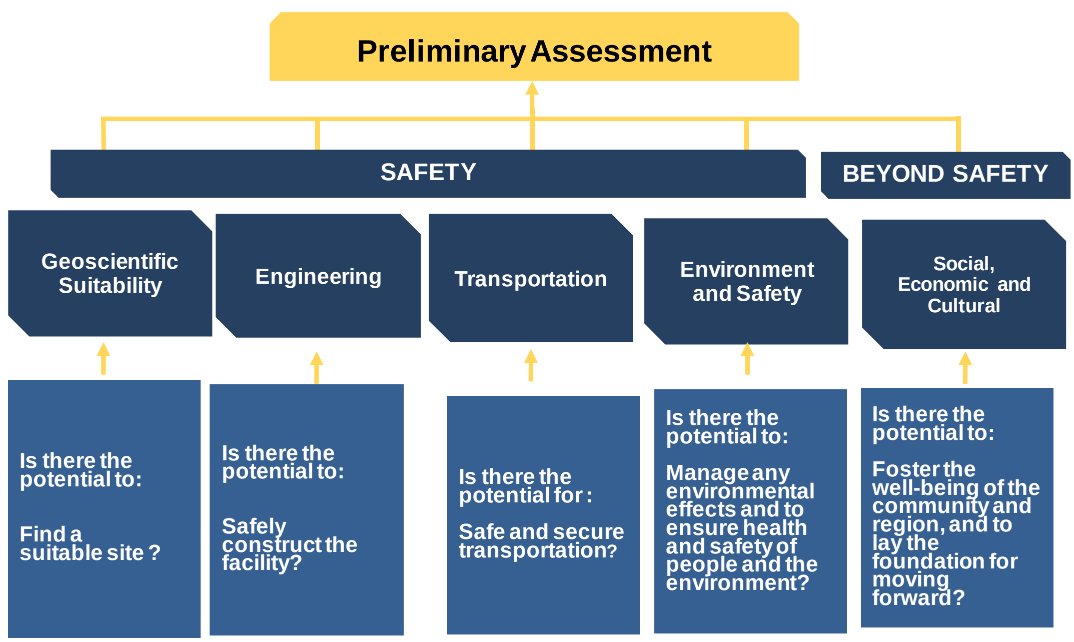
1 INTRODUCTION

1.1 Background

In December 2011, the Township of Hornepayne, 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 Hornepayne area for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process (Golder, 2011).

The overall preliminary assessment is a multidisciplinary study integrating both technical and community well-being assessments as illustrated in the diagram below. The five components of the preliminary assessment address geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. A brief description of the project, the 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 Hornepayne 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 involves preliminary field investigations that include high resolution geophysical surveys, geological mapping and the drilling of deep boreholes.

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

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

1.2 Desktop Geoscientific Preliminary Assessment Approach

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

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

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, and overburden deposits;
- Interpretation of available geophysical surveys (magnetic, gravity, radiometric, electromagnetic);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on 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 details of these various studies are documented in three supporting documents: terrain analysis (JDMA, 2013); geophysical interpretation (PGW, 2013); and lineament interpretation (Geofirma, 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 geoscientific suitability of potential sites is 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 Hornepayne area using key geoscientific characteristics that can realistically be assessed at this stage of the assessment based on available information (Section 7.2). The second step assessed whether identified potentially suitable areas have the potential to ultimately meet all of the safety functions outlined above (Section 7.3).

1.4 Available Geoscientific Information

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

1.4.1 <u>DEM, Satellite Imagery and Geophysics</u>

The digital elevation model (DEM) data for the Hornepayne area is the Canadian Digital Elevation Data (CDED), a 1:50,000 scale, 20 m resolution, elevation model constructed by Natural Resources

Canada (NRCan) using provincial data created through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (MNR) (Table 1.1; GeoBase, 2011).

Table 1.1 Summary of DEM, Satellite and Geophysical Source Data Information for the Hornepayne Area

Dataset	*Product*	*Source*	*Resolution*	*Coverage*	*Acquired*	*Additional Comments*
DEM	Canadian Digital Elevation Data (CDED);1:50,000 scale	Geobase	20 m	Entire Hornepayne area	1978-1995	Hill-shaded used for mapping
Satellite Imagery	Spot5; Orthoimage, multispectral/ panchromatic	Geobase	10 m (panchromatic) 20 m (multispectral)	Entire Hornepayne area	2006 -2007	Good Coverage
	Landsat-7; Orthoimage, multispectral/ panchromatic	USGS	15 m (panchromatic) 30 m (multispectral)	Entire Hornepayne area	2002	Good Coverage
Geophysics	Regional Magnetic Compilation (Ontario #3, 8, and 17)	Geological Survey of Canada	805 m line spacing 305 m sensor height	Entire Hornepayne area	1962,1963, 1968	Lowest resolution dataset
	Geological Survey of Canada Gravity Data	Geological Survey of Canada	5-25 km/ground surface	Entire Hornepayne area	1946-1963	Widely-spaced point data
	Geological Survey of Canada Radiometric Data	Geological Survey of Canada	5000 m line spacing 120 m sensor height	Entire Hornepayne area	1982	Low resolution
	Manitouwadge Survey (GDS1205) Magnetic and Electromagnetic Data	Ontario Geological Survey	200 m line spacing 45 m sensor height	Covers western part of boundary between Wawa Subprovince and Quetico Subprovince	1989	Limited coverage but good quality dataset
	Oba-Kapuskasing Survey (GDS1024) Magnetic and Electromagnetic Data	Ontario Geological Survey	200 m line spacing 45 m sensor height	Covers southeast corner over greenstone belt bordering on Black-Pic batholith	1986	Limited usefulness due to minimal coverage in Hornepayne area

SPOT-5 satellite imagery for the Hornepayne area has a resolution of 20 m grid size for spectral data and 10 m grid size for panchromatic data. Landsat-7 imagery (30 m grid size for spectral data and 15 m grid size for panchromatic data) was used to augment the SPOT satellite imagery, which significantly improved the quality of the satellite images.

Airborne magnetic, electromagnetic and radiometric data were collected from the Ontario Geological Survey and the Geological Survey of Canada (GSC, 2012). Low-resolution magnetic data (805 m flight line spacing) obtained from the Geological Survey of Canada (GSC) provide complete coverage of the entire Hornepayne area (Table 1.1). Two additional magnetic/electromagnetic surveys were obtained from the Ontario Geological Survey (OGS, 2002; 2003) and provide higher resolution coverage over on the west side and in the southeast corner of the Hornepayne area (Figure 1.2). A search was conducted for additional geophysical surveys performed in the Hornepayne area by the mining industry but it was determined that no surveys were available that would improve the geophysical coverage (PGW, 2013). Gravity data for the Hornepayne area was acquired from the GSC and consists of an irregular distribution of 35 gravity stations, comprising roughly a station every 10 to 15 km. Radiometric data was acquired from the GSC providing low-resolution (5 km flight line spacing) coverage over the entire Hornepayne area.

1.4.2 Geology

Bedrock mapping for the entire Hornepayne area was mapped at a scale of 1:250,000 by Santaguida (2001) and Johns and McIlraith (2003). The mapping by Johns and McIlraith (2003) more accurately delineates the boundary between the Quetico and Wawa subprovinces and the greenstone belts in the area compared to the OGS Bedrock Geology of Ontario (MRD 126) (OGS, 2011b) mapping.

Additional bedrock mapping is available at scales varying from 1:31,680 to 1:3,168,000 covering portions of the Hornepayne area. Milne (1964) mapped plutonic and metasedimentary rocks in the northwest corner of the Hornepayne area. Fenwick (1965) built upon previous preliminary mapping done outside of the southwest corner of the Hornepayne area, to develop a map of intrusive and volcanic rocks including some early mapping of geological structure. Giguere (1972) mapped the intrusions, metasedimentary rocks and the greenstone belts in the western part of the Hornepayne area. This mapping was extended from the Township of Hornepayne to the Township of Manitouwadge by Williams and Breaks (1996), which focused on the Quetico-Wawa subprovince boundary and the greenstone rocks. Siragusa (1976) mapped the southeast part of the Hornepayne area.

Direct information on regional geochronology and structural geology is limited in the Hornepayne area. The geological and structural history of the area discussed below integrates the results from studies undertaken elsewhere throughout and proximal to the regional area, drawing particularly on information from the Manitouwadge area, west of Hornepayne.

The Quaternary geology of the Hornepayne area is available at 1:100,000 scale as part of the Northern Ontario Engineering Terrain Study (Gartner and McQuay, 1980a; 1980b). The NOEGTS mapping covers the entire Hornepayne area.

Geological bedrock mapping coverage is good for the western part and the area along the southern boundary of the Hornepayne area. Only regional-scale mapping is available for the remaining northern and eastern parts of the Hornepayne area. Figure 1.2 shows a summary of available geological map coverage and geophysical data surveys for the Hornepayne area.

National seismicity data sources were reviewed to provide an indication of seismicity in the Hornepayne area (Hayek et al., 2011; NRCan, 2012).

1.4.3 Hydrogeology and Hydrogeochemistry

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

No information is available on deep groundwater flow systems or deep hydrogeochemistry for the Hornepayne area so inferences have been made based on studies at similar geological settings elsewhere in the Canadian Shield. Specific reports/studies include: Frape et al. (1984), Raven et al. (1985), Raven and Gale (1986), Frape and Fritz (1987), Gascoyne et al. (1987), Farvolden et al. (1988), Trainer (1988), Gascoyne (1994, 2000, 2004), Everitt et al. (1996), Ophori and Chan (1996), Stevenson et al. (1996), McMurry et al. (2003), Ryan et al. (2007), Svensson and Rhén (2010), Gupta et al. (2012) and Holland (2012).

1.4.4 Natural Resources – Economic Geology

Information regarding the mineral resource potential for the Hornepayne area has been obtained from a variety of sources including reports on the Hornepayne area (Gartner and McQuay, 1980a; 1980b; Williams, 1991; Williams and Breaks, 1996; Breaks et al., 2003), the Abandoned Mines Information System (AMIS) database (MNDM, 2011), as well as the Mineral Deposit Inventory (MDI) database (OGS, 2011a), the Assessment File Research Imaging (AFRI) database (MNDM, 2012a) and the CLAIMaps database (MNDM, 2012b).

The Assessment File Research Imaging (AFRI) database contains information on mineral exploration and mining activity in the Province of Ontario. Information from the AFRI database has routinely been used in OGS reports and in journal publications. The Abandoned Mines Information System (AMIS) contains the location of abandoned and inactive mines sites. The database has records on mining related features including mining hazards and abandoned mines and is considered to be a good quality dataset but not to be complete. The CLAIMaps and MDI databases contain up-to-date information on mining claims, mineral occurrences, producing mines, and past producing mines with and without mineral reserves.

1.4.5 Geomechanical Properties

There was no available site-specific information on rock geomechanical properties of potentially suitable geologic units within the Hornepayne area. Available information on rock geomechanical properties, including rock strength, rock quality, thermal conductivity and in-situ stress for potentially suitable geologic units of the Hornepayne area are inferred from data collected from similar geologic settings elsewhere in the Canadian Shield and internationally, including work done by Atomic Energy of Canada Ltd. (AECL) as part of the Canadian Nuclear Fuel Waste Management Program in the 1980s and 1990s, and recently at Chalk River Laboratories as part of geological waste management studies.

Rock strength and rock quality data for granitic rocks of the Canadian Shield are available from AECL's Underground Research Laboratory (URL) near Pinawa Manitoba (Baumgartner et al., 1996; Martino et al., 1997; Martino and Chandler, 2004) and AECL's Atikokan research area in Ontario (Stone et al., 1989; Sikorsky, 1996). Rock strength and rock quality data for metasedimentary and gneissic rocks are available from AECL's Chalk River research area (Annor et al., 1979; Raven, 1980; Larocque and Annor, 1985; Sikorsky et al., 2011). Similar data for mafic (gabbroic) rocks are available from AECL's East Bull Lake research area (McCrank et al., 1989; Sikorsky, 1996).

Information on in-situ stress in crystalline rocks is available from AECL's Underground Research Laboratory (Martin, 1990; Thompson and Chandler, 2004), Chalk River Laboratories (Thompson et al., 2011), mines in the Canadian Shield (Herget 1973, 1980; Arjang and Herget (1997), as well as from reviews and assessments of in-situ stress databases for the Canadian Shield (Kaiser and Maloney, 2005; Maloney et al., 2006).

2 PHYSICAL GEOGRAPHY

2.1 Location

The Township of Hornepayne is located in north-central Ontario approximately 400 km north of Sault Ste. Marie, 340 km east of Thunder Bay and 260 km west of Timmins as shown on Figure 1.1. The Township of Hornepayne has an area of 205 km^2 and the Hornepayne area is 4,800 km^2. The settlement area of Hornepayne is situated on Highway 631, approximately 100 km north of Highway 17. The closest settlements to the Township of Hornepayne are White River, approximately 100 km south and Hearst, approximately 130 km northeast. The background image on Figure 2.1 is a false colour composite of SPOT-5 satellite imagery for the Hornepayne area taken in 2006. The composite image was created by assigning a primary colour (red, green and blue) to three of the SPOT-5 multispectral bands. Different materials reflect and absorb solar radiation differently at different wavelengths and therefore have varying intensities within each of the SPOT bands. When combined into a single image, the chosen colour scheme approaches a “natural” representation, where, for example, vegetation appears in shades of green.

2.2 Topography and Landforms

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

The Hornepayne area lies in the Abitibi Uplands physiographic region, a broadly rolling surface of Canadian Shield bedrock that occupies most of north-central Ontario (NRCan, 2011). Within this area, the terrain contains numerous lakes and bedrock which is typically either exposed at surface or shallowly covered with Quaternary glacial deposits or post-glacial organic soils (Thurston, 1991).

Elevations within the Hornepayne area generally range from about 483 metres above sea level (mASL) near the southwest corner of the Hornepayne area down to approximately 263 mASL in the northeast corner of the area (Figure 2.2). The settlement area of Hornepayne is located along Highway 613 and is at approximately 340 mASL. The broad upland within the southwest quadrant of the area is informally referred to here as the Obakamiga Upland, representing the only large continuous part of the Hornepayne area where elevations exceed about 345 m. Local elevations in the Obakamiga Upland exceed 480 mASL on the north and west sides of Obakamiga Lake.

The Obakamiga Upland contains knobs and ridges with elevation changes of 30 to 60 m typically occurring over ground distances of 250 to 1,000 m, and some of the extreme knobs and ridges rising 100 m above the surrounding landscape over short ground distances. The flanks and in some cases the tops of many of the rock ridges display cliffs in the SPOT imagery (Figure 2.1). Most of the hills are less than 1 km long and less than 500 m wide, with a range of shapes displayed from compact and flat on top to elongate narrow ridges. There is also a locally elevated area in the northern part of the Hornepayne area, north of Nagagamisis Lake (Figure 2.2). This is an area of increased overburden thickness and kettle lakes created by an interlobate kame moraine known as the Arnott Moraine (Figure 2.3).

Areas of steep slope form the margins of many of the rugged landforms in the Hornepayne area, particularly rock ridges (JDMA, 2013). As steep slopes in the Hornepayne area are often associated with bedrock topography, with some exceptions (e.g., Arnott Moraine, abandoned shorelines, modern river valleys), the presence of steep slopes in this landscape is generally indicative of minimal overburden cover. Many of the areas lacking steep slopes are relatively flat due to the presence of overburden filling the topographic lows.

The major elevation gradient in the Hornepayne area is established by the contrast provided by the rugged, bedrock-controlled highland in the southwest quadrant of the area and the lowland glaciolacustrine plain (and other Quaternary materials) covering much of the other three quadrants. The Obakamiga Upland is underlain by gneissic tonalite of the Black-Pic batholith and metasedimentary rocks of the Quetico Subprovince. The low lying areas in the northeastern part of the Hornepayne area are associated with the metasedimentary rocks of the Quetico Subprovince and granite-granodiorite intrusions into the metasedimentary rocks.

2.3 Watersheds and Surface Water Features

The Hornepayne area is located in both the Lake Superior drainage basin of the Atlantic Ocean watershed and within the Hudson Bay drainage basin of the Arctic Ocean watershed. The continental divide separating these two major watersheds occurs in the highlands south and west of Obakamiga Lake (Figure 2.4) in the southwest corner of the Hornepayne area. The Foch, Obakamiga and Shekak rivers are the main watercourses draining the Obakamiga Upland in the southwest corner of the Hornepayne area.

The overall surface water drainage in the Hornepayne area is shown on Figure 2.4. The southwest corner of the Hornepayne area drains through the White River sub-sub drainage area into northeastern Lake Superior. This includes flow from the narrow basin surrounding Gum Lake and the Gum River and the small basin containing Tocheri Creek (JDMA, 2013). The remainder of the surface flow in the Hornepayne area is directed to the north and northeast within the Nagagami and Upper Kabinakagami river tertiary watersheds that are within the larger Kenogami river secondary watershed. Surface flow within this secondary watershed is directed towards James Bay through the Lower Albany secondary watershed.

The Township of Hornepayne is located within the drainage area of the Shekak River which has its origin in a series of lakes and creeks to the south of the Hornepayne area and flows north-easterly where it is joined by the Nagagamisis River east of Nagagamisis Lake. The Shekak River joins the Nagagami and Kabinakagami rivers to form the Kenogami River that enters the Albany River downstream from Ogoki.

As part of the terrain analysis, JDMA (2013) carried out a drainage basin analysis in order to confirm and, where possible, partition the most detailed available mapping of watersheds by the MNR. The resulting mapping is shown on Figure 2.4, which includes the divides that delineate the three tertiary-scale watersheds associated with the three main river systems in the Hornepayne area (Nagagami, Kabinakagami and White rivers), as well as several quaternary-scale watersheds that further compartmentalize surface drainage.

The Hornepayne area contains a large number of lakes of various sizes (Figure 2.4), with roughly 8.5% (404 km^2) of the area occupied by water bodies. There are three lakes greater than 20 km^2, including Nagagami Lake, Obakamiga Lake and Nagagamisis Lake (Table 2.1). These large lakes are sufficiently large to conceal the surface expression of lineaments up to about ten kilometres in length, and nests of lakes have additional potential to conceal or reveal lineaments, especially when the lakes are located in areas where lineaments are obscured by overburden deposits. The vast majority of lakes in the area are very small in size (less than 1-2 km^2). There are concentrations of small kettle lakes associated with the Arnott Moraine and with the two eskers mapped about 10 km south of the Township of Hornepayne. To some extent, the larger lakes in the area may conceal the surface expression of geological structures. However, the larger lakes in the area display a mixture of circular shorelines formed in surficial materials and straight shorelines controlled by geological structures. The circular portion of a lakeshore is generally indicative of that portion of the lake resting over thicker overburden deposits.

Table 2.1 Size of Lakes Larger than 20 km^2 in the Hornepayne Area

Lake	***Perimeter (km)***	***Area (km^2)***
Nagagami Lake	70.3	54.1
Obakamiga Lake	136.5	29.4
Nagagamisis Lake	70.6	25.0

The wetlands mapped in the Hornepayne area are all very small (less than 1.0 km^2). An obvious concentration of unmapped wetlands occurs in a 20 km radius around Nagagami Lake (Figure 2.4). The larger wetlands in the Hornepayne area occur in association with the larger lakes, which reflects the distribution of the more extensive and thicker, poorly drained overburden deposits in the area. Outside of these areas, the lack of extensive wetlands is a product of the absence of extensive and thick, poorly drained overburden deposits. Most of the wetlands are elongate features located within linear depressions in the bedrock.

2.4 Land Use and Protected Areas

Figure 2.5 shows a summary of land disposition and ownership within the Hornepayne area, including known protected areas. The vast majority of the Hornepayne area is unpatented public Crown land. The townships of Lange, Dowsley, Alderson and Derry, which are located in the eastern part of the Hornepayne area, are private lands. Some smaller parcels of private land are also found within and proximate to the Township of Hornepayne. Small parcels of private land are found on the shores of several lakes including Nagagami, Nagagamisis, Obakamiga, Granite Hill, Larkin and Kabinakagamisis lakes and several smaller lakes. Small parcels of non-freehold public land are present on Nagagami Lake and within the Township of Hornepayne. A federal land – Indian Reserve is situated east of the southeast corner of the Township of Hornepayne.

2.4.1 Land Use

Land use within the 205 km^2 Township of Hornepayne consists of residential, commercial and industrial uses within the 4 km^2 settlement area centred on the intersection on Highway 631 and the CN railway line, and predominately unoccupied forest, wetland, lakes and exposed bedrock outside of the settlement area. The municipal airport is located about 2.5 km south of the settlement area. There is an active forestry industry with managed wood lots in the western part of the Township. There are no active mines in the Township.

Land use within the Hornepayne area outside of the Township is predominantly unoccupied Crown land consisting of forest, wetland, lakes and exposed bedrock. There are managed woodlots located throughout the Hornepayne area, in particular south of Nagagamisis and Nagagami lakes and near Lascelle Lake, southeast of the Township. There are no active mines in the Hornepayne area.

2.4.2 Parks and Reserves

There are no provincial parks or conservation reserves within the Township of Hornepayne. The only park within the Hornepayne area is the 425 km^2 Nagagamisis Provincial Park (Figure 1.1). The park is located in the vicinity of Nagagami and Nagagamisis lakes, approximately 15 km to the north of the Township, and contains the former Nagagami Lake Provincial Nature Reserve which was incorporated into the Park, as well as a Forest Reserve.

2.4.3 Heritage Sites

The cultural heritage screening examined known archaeological and historic sites in the Hornepayne area. 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, 2011).

There are 21 known archaeological sites in the Hornepayne area, one of which is located within the Township boundaries. The registered archaeological site within the Township is a pre-contact Aboriginal isolated find (a chert flake), on the south shore of Wicksteed Lake, north of the settlement area of Hornepayne. In the early 1970s an archaeological survey of Nagagamisis Provincial Park documented the presence of 15 archaeological sites. Of these sites all are Lake Woodland and /or historic Algonkian with the exception of one historic Euro-Canadian trading post. The most recent work conducted in the region was an intensive archaeological survey conducted within portions of Nagagamisis Provincial Park. A cultural heritage assessment in 2000 and 2001 documented 14 pre-contact Aboriginal sites and 20 heritage value sites were also identified and documented in the Nagagamisis area (Hearst Forest Management Inc., 2007). Additionally, the Nagagamisis area contains more than 30 culturally modified trees that were used by First Nations peoples to mark burial sites, campsites and portages. This is the first large-scale occurrence of these First Nations heritage features to be located in Ontario. The Nagagami Lake area is also the location of five known archaeological sites three Aboriginal pre-contact sites and two historic Euro-Canadian sites

Archaeological potential is established by determining the likelihood that archaeological resources may be present on a subject property. In archaeological potential modelling, a distance to water criterion of 300 m is generally employed for primary water courses, including lakeshores, rivers and large creeks, as well as secondary water sources, including swamps and small creeks (Government of Ontario, 2011). The archeological potential of the Hornepayne area is considered high given the sites already documented and the proximity to primary water courses with known archaeological sites.

There are no National Historic Sites in the Hornepayne area (Parks Canada, 2012), and no Provincial Heritage Trust Sites in the Hornepayne area (Ontario Heritage Trust, 2012).

The presence of local heritage sites would need to be further confirmed in discussion with the community and Aboriginal peoples in the area, if the community is selected by the NWMO and remains interested in continuing with the site selection process.

3 GEOLOGY

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

The Hornepayne area is underlain by 3 to 2.6 billion year old bedrock of the Superior Province of the Canadian Shield – a stable craton created from an assemblage of Archean-age plates, accreted juvenile arc terranes and sedimentary basins of Proterozoic age that were subsequently and progressively amalgamated over a period of more than 2 billion years (Figure 3.1). The Canadian Shield forms the stable core of the North American continent.

The Superior Province covers an area of approximately 1,500,000 km^2 stretching from the Ungava region of northern Québec through the northern part of Ontario and the eastern portion of Manitoba, and extending south through to Minnesota and the northeastern part of South Dakota. The Superior Province has been historically subdivided into various regionally extensive east-northeast-trending subprovinces based on lithology, age, genesis and metamorphism (e.g., Langford and Morin, 1976; Card and Ciesielski, 1986; Card, 1990) as shown on Figure 3.1. However, the subdivision of the Superior Province has been recently revised in terms of lithotectonic terranes and domains (Percival and Easton, 2007; Stott et al., 2010). Terranes are defined as tectonically-bounded regions with characteristics distinct from adjacent regions prior to their accretion into the Superior Province, while domains refer to lithologically distinct portions within a terrane (Stott et al., 2010). Figure 3.2 shows the terrane subdivision of the Central Superior Province, and that the Hornepayne area lies within the Quetico Basins terrane and the Wawa-Abitibi terrane.

The Hornepayne area lies across the boundary of the Quetico and the Wawa subprovinces (Figure 3.3). To the east, the Quetico and Wawa subprovinces are truncated by the Kapuskasing structural zone (Figures 3.1 and 3.2) that separates these subprovinces from the Abitibi Subprovince sometimes referred to as the Abitibi-Wawa Belt.

The Quetico Subprovince is about 1,000 km long by 75 km wide and is composed of mainly gneissic and migmatized metasedimentary rocks, and to a lesser extent by granitic intrusions and injections of partial melts into the metasedimentary succession. The deposition of the metasedimentary rocks in the southern Quetico Subprovince boundary was initiated approximately 2.698 billion years ago, and its termination is constrained to around 2.688 billion years ago (Zaleski et al.,1999). Given the geological history of the Quetico Subprovince, the more migmatitic matrix of the metasedimentary rocks forms complex folds and refolds and some of the plutons appear to form metamorphosed, doubly-plunging domical structures. The Quetico Subprovince also hosts young Neoarchean, late tectonic alkalic and mafic to ultramafic intrusions plus several swarms of Paleoproterozoic (ca. 2.500-1.600 billion year old) diabase dykes (Stott and Josey, 2009).

The Wawa Subprovince is approximately 900 km long by 150 km wide. It is composed primarily of Archean greenstone belts and granitic intrusions, with smaller mafic intrusive rocks locally present. The granitic rocks comprise about 70 to 80% of the subprovince area, with the greenstone belts occurring in two main linear concentrations: one along the Wawa-Quetico subprovince boundary, and the other in the southern part of the subprovince. Diabase dykes, largely of Proterozoic age, occur in "swarms" in the entire Superior Province including the Quetico and Wawa subprovinces.

3.1.2 Geological History

Direct information on the geological and structural history of the Hornepayne area is limited. The geological and structural history summarized below integrates the results from studies undertaken elsewhere throughout and proximal to the regional area shown on Figure 3.3, drawing particularly on information from the Manitouwadge area (Williams and Breaks, 1996; Peterson and Zaleski, 1999; Zaleski et al., 1999; Zaleski and Peterson, 2001). It is understood that there are potential problems in applying a regional D_x numbering system into a local geological history (Section 3.1.3 below). Nonetheless, the summary below represents an initial preliminary interpretation for the Hornepayne area, which may be modified after site-specific information has been collected.

Accordingly, the geological and structural history of the Hornepayne area can be summarized as a succession of tectonic events following one major episode of volcanism within the northern margin of the Wawa Subprovince, concurrent with and followed by clastic sedimentation and iron formation deposition dominantly within the Quetico Subprovince (Williams and Breaks, 1996; Peterson and Zaleski, 1999; Zaleski et al., 1999; Zaleski and Peterson, 2001). Table 3.1 provides a simplified summary of the geological history of the Hornepayne area.

Proterozoic reactivation of Archean faults is suspected based on thermal resetting of biotite radiometric ages to Paleoproterozoic ages in this region (Manson and Halls, 1997), relatable to the uplift of the Kapuskasing structural zone to the east.

Little information is available for the geological history of the Hornepayne area for the period following the onset of development of the Midcontinent Rift ca. 1.1 billion years ago.

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

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

Table 3.1 Summary of the Geological and Structural History of the Hornepayne Area

Time Period (billion years ago)	***Geological Event***
ca. 2.72	Oceanic arc to plume-generated volcanism and synvolcanic, trondhjemitic plutonism along the northern margin of the western Wawa-Abitibi terrane due to northward subduction of volcanic-dominated micro-continents (e.g., Wawa-Abitibi terrane) (White et al., 2003; Percival et al., 2006). Deposition of clastic sedimentary rocks in the Quetico basin. Emplacement of the oldest (tonalite) phase of the Black-Pic batholith (Jackson et al., 1998).
ca. 2.696 to 2.689	Commencement of the diachronous Shebandowanian Orogeny (ca. 2.695 to 2.677 billion years ago) involving collision of the Wawa-Abitibi micro-continental terrane with terranes to the north. (Peterson and Zaleski, 1999; Percival et al., 2006).
ca. 2.689 to 2.687	Emplacement of the monzodiorite phase (2.689 billion years old) of the Black-Pic batholith (Zaleski et al., 1999).
ca. 2.687 to 2.680	Regional D_2 deformation coeval with the peak amphibolite facies regional metamorphism, and local granulite facies metamorphism. Partial melting of clastic sedimentary rocks in the Quetico basin.
ca. 2.680	A 2.68 billion-year-old granite intrusion cuts the Loken Lake pluton (in Township of Manitouwadge), a foliated potassium feldspar-megacrystic granodiorite, and the D_2 fabrics and thereby provides a minimum age for regional D_2 deformation. The 2.68 billion-year-old Nama Creek pluton (in Township of Manitouwadge) is a tabular-shaped, foliated potassium feldspar-porphyritic monzonite-monzodiorite with incipient migmatization; it is folded by D_3 deformation and wraps around the boundary between the Black-Pic batholith and the metavolcanic rocks of Manitouwadge-Hornepayne greenstone belt and thereby provides a maximum age for D_3 deformation.
ca. 2.679 to 2.677	Regional D_3 deformation that produced the major east-northeast-trending upright folds in response to northwestward directed collisional transpression recorded across the Wawa-Abitibi terrane boundary with the Quetico metasedimentary gneisses to the north. (Percival et al., 2006). Late D_3 ductile faults (D_4 of Williams and Breaks, 1989) and kink folds (D_4 of Peterson and Zaleski, 1999) occurred during cooling across the terrane boundary, notably in the migmatitic metasedimentary rocks of the Quetico Subprovince.
ca. 2.679	The Everest Lake pluton, a sheet-like intrusion along the Quetico-Wawa contact near Manitouwadge, displays incipient migmatization and thereby constrains a period of metamorphism to be contemporaneous with D_3 deformation.
ca. 2.677	The Banana pluton of foliated granodiorite (in Township of Manitouwadge) contains an apparent D_3 foliation folded around a D_4 antiform at the east end of the Manitouwadge greenstone belt. D_4 structures include the curved deflection of F_3 axial traces and their eastward convergence or truncation near the Quetico boundary (Peterson and Zaleski, 1999). Interference of D_3 structures by D_4 are preserved locally within the metasedimentary rocks of the Quetico Subprovince.
ca. 2.673 to 2.671	Metamorphism (cooling?) of migmatized tonalite gneiss intruding migmatized Quetico metasedimentary basin north of Hornepayne, accompanied by muscovite-bearing granitic intrusions. Syn-orogenic granitic plutons and gabbroic intrusions occur across the Hornepayne area both in the Quetico basin and intruding the Black-Pic batholith. Late brittle (D_5) fault overprint.
ca. 2.45	Intrusion of the northwest-trending Matachewan diabase dyke swarm.
ca. 2.17	Intrusion of the northeast-trending Biscotasing diabase dyke swarm.
ca. 2.126 to 2.101	Intrusion of the north- to northeast-trending Kapuskasing (Marathon) diabase dyke swarm (Halls et al., 2008).
ca. 1.947 to 1.9	Proterozoic brittle fault overprint and reactivation of regional-scale Archean faults (Peterman and Day, 1989; Percival and Peterman, 1994), collectively treated as D_6 events.
ca. 1.1 to 1.0	Onset of development of Mid-Continent Rift and emplacement of northeast-trending Abitibi dykes south and southeast of the Hornepayne area.

3.1.3 Regional Structural History

As summarized in Table 3.1, at least 6 episodes of penetrative strain (D_1 to D_6) are interpreted to have affected the Hornepayne area. The following sequence of tectonic deformation (D_x) events may characterize the Hornepayne area based on the documented structural history of the area around the Township of Manitouwadge situated approximately 70 km to the west (Williams and Breaks, 1996; Peterson and Zaleski, 1999; Zaleski et al., 1999; Zaleski and Peterson, 2001).

- D_0 primary bedding and lithologic layering is locally preserved in strongly deformed sedimentary and volcaniclastic units.
- D_1 regional tectonic deformation is locally evident in the metasedimentary rocks of the Quetico Subprovince and as a ductile fault in the Manitouwadge area. S_1 foliations outline D_2 folds.
- D_2 defines the regional schistosity as an axial planar S_2 fabric within amphibolite grade metavolcanic and metasedimentary rocks, migmatitic rocks and differentiated layering in tonalite. S_2 foliations dipped northward and L_2 lineations plunge north to northeastward outside of the domain of D_3 deformation.
- D_3 deforms D_2 fabrics and produced major synform and antiform structures plunging shallowly westward or eastward, accompanied by late-stage east-trending and northwest-trending dextral shear zones and faults, and northeast-trending sinistral shear zones in the Manitouwadge – Hornepayne region. Z asymmetry of F_3 folds is characteristic and reflects northwest-directed transpressive deformation.
- Late D_3 ductile faults (D_4 of Williams and Breaks, 1989) and kink folds (D_4 of Peterson and Zaleski, 1999) occurred during cooling across the terrane boundary, notably in the migmatitic metasedimentary rocks of the Quetico Subprovince.
- D_4 local refolding of D_3 structures occurs most typically but very locally preserved within the metasedimentary rocks of the Quetico Subprovince.
- D_5 applies to later brittle faults and fractures trending northwest, northeast and northward. These brittle structures mark a period of crustal cooling under residual stress and affect rocks of the narrow, dominantly amphibolitic supracrustal belts as well as synvolcanic and synorogenic plutons, gneisses and the Black-Pic batholith. Some faults and fractures may have been reactivated during later D_6 Proterozoic events.
- D_6 events consist of collectively potential early Proterozoic faults and reactivation on Archean faults. Reactivation of Archean faults, coincident with thermal resetting of biotite radiometric ages in the Hornepayne region, would have developed during far-distant collision of the Trans-Hudson Orogen with the Superior Province as well as related uplift of the Kapuskasing structural zone to the east.

3.1.4 Mapped Regional Structure

There is one regional-scale east-trending fault, and numerous northeast- and northwest-trending smaller-scale faults mapped (OGS, 1991) within the Hornepayne area (Figure 3.3). The east-trending fault runs along the Wawa-Quetico subprovince boundary in the western half of the Hornepayne area, extending well beyond it. The mapped northwest- and northeast-trending faults parallel Paleoproterozoic diabase dykes of the Matachewan swarm and the Biscotasing - Marathon/Kapuskasing suite.

The relative sequence of Archean faulting across the Hornepayne area indicates that the oldest faults tend to be more ductile and trend eastward, concurrent with or followed by northwest and northeast-trending ductile to brittle-ductile faults, followed by late, brittle north-trending faults. Subsequent brittle faulting of uncertain age occurs along each of these trends.

The structural style across the Quetico-Wawa subprovince boundary is well characterized by structural mapping conducted over the years from Minnesota (Schultz-Ela and Hudleston, 1991) to the Shebandowan greenstone belt, west of Thunder Bay (Stott and Schwerdtner 1981; Williams et al., 1991) and the Manitouwadge-Hornepayne greenstone belt (Peterson and Zaleski, 1999; Zaleski et al., 1999; and Zaleski and Peterson, 2001).

The boundary separating the Wawa greenstone-granite terrane and the metasedimentary rocks of the Quetico Subprovince is characterized as a major shear zone. However, evidence for faulting along the subprovince boundary is usually not well documented. Inferred faults on the compilation map of Johns and McIlraith (2003) are based on earlier mapping, typically derived from air photo lineament interpretations. In the Manitouwadge area, mapping by Zaleski and Peterson (2001) has recorded no evidence of faulting along the subprovince boundary, either from lack of geophysical offsets or insufficient bedrock exposure. Similarly, other sections along the Wawa-Quetico boundary, west of Thunder Bay for example, show little or no evidence of continuous faulting (Williams et al., 1991). Interpretation of available geophysical data in the Hornepayne area as part of this preliminary assessment (PGW, 2013) recognized a high abundance of subparallel lineations along the Wawa-Quetico subprovince boundary that are most likely associated with an approximately 15 km wide zone of deformation straddling the mapped subprovince boundary.

In general, it can be anticipated that the presence of major Neoarchean faults and related fault splays or parallel faults may have accompanied the late dextral strike-slip movement along the subprovince boundary; this movement terminated the main stage of terrane assembly that occurred episodically between terranes across the breadth of the Superior Province (Percival et al., 2006). In general, two major penetrative deformations are observed along the length of the Quetico Subprovince and the adjacent boundary with the Wawa Subprovince. The first deformation event is pre- to syn-metamorphic. The second penetrative deformation either refolds or overprints the first and is responsible for the widespread upright to moderately inclined, east-plunging folds highlighted by the lithologic layering in the Manitouwadge-Hornepayne greenstone belt west of the Hornepayne area and locally by iron formations folded within the metasedimentary rocks of the Quetico Subprovince.

It is important to anticipate the presence of such folded stratigraphy within the Quetico metasedimentary belt and potentially related upright folds and elliptical domical structures in granodiorite gneisses in the adjacent Black-Pic batholith. These large fold structures are interpreted as a consequence of oblique, south-southeast directed collision between granite-greenstone subprovinces (terranes), following northward subduction of terranes evidenced from Lithoprobe studies in Ontario (e.g., Percival et al., 2006), during the final tectonic assembly of the Superior Province at around 2.7 to 2.6 billion years ago. Concurrent with and following this penetrative collisional deformation across the subprovince boundary, thrust faulting occurred at least locally (e.g., central Uchi Subprovince; Stott and Corfu, 1991) followed by dextral strike-slip fault movement along or close to most subprovince boundaries. The strike-slip faults may display evidence of ductile shear zones or splays into nearby parallel greenstone belts. This succession of events is well illustrated in the Beardmore-Geraldton area along the northern margin of the Quetico Subprovince (e.g., Lafrance et al., 2004).

As mentioned in section 3.1.1 and described in section 3.2.1.5, rocks of the Wawa and Quetico subprovinces in the Hornepayne area host numerous dyke swarms. There is some uncertainty in 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).

3.1.5 Metamorphism

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in a few publications since the 1970s, including a symposium proceedings (Fraser and Heywood, 1978), and issues of The Canadian Mineralogist in 1997 and 2000 (e.g., Kraus and Menard, 1997; Menard and Gordon, 1997; Berman et al., 2000; Easton, 2000a and 2000b; and Berman et al., 2005). The thermochronologic record for major parts of the Canadian Shield is given in a number of studies supported by government surveys and represented by Berman et al. (2005), Bleeker and Hall (2007), Corrigan et al. (2007), and Pease et al. (2008).

In general, there is limited local preservation of pre-Neoarchean metamorphism within the Canadian Shield (e.g., Breaks and Bartlett, 1991; Percival and Skulski, 2000). The Superior Province largely preserves low pressure – low to high temperature Neoarchean metamorphism, from ca. 2.710 to 2.640 billion years ago, but there is a widespread tectonothermal overprint of Archean crust by Paleoproterozoic deformation and typically amphibolite facies metamorphism across the Churchill Province through northernmost Ontario under the northern Hudson Bay lowland, western Manitoba, northern Saskatchewan and Nunavut (e.g., Skulski et al., 2002; Berman et al., 2005).

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

Sub-greenschist facies metamorphism in the Superior Province is restricted to limited areas, notably within the central Abitibi greenstone belt (e.g., Jolly, 1978; Powell et al., 1993). Most late orogenic shear zones in the Superior Province experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through $^{40}Ar/^{39}Ar$ dating to ca. 2.5 billion years ago, the value of which remains unclear (Powell et al., 1995). The distribution of contrasting grades of metamorphism is a consequence of relative uplift, block rotation and erosion from Neoarchean orogenesis and subsequent local Proterozoic orogenic events and broader epeirogeny during Proterozoic and Phanerozoic eons. In northwestern Ontario, the concurrent post-Archean effects are limited to poorly documented reactivation along faulted Archean terrane boundaries (e.g., Kamineni et al., 1990 and references therein).

In northeastern Ontario, the Kapuskasing structural zone, east of the Township of Hornepayne, documents a preservation of ca. 1.9 billion years ago thrust-uplifted, westward tilted Archean crust exposing greenschist facies rocks from <10 km depth in the west near the settlement area of Wawa to granulite facies metamorphism in the east side of the zone through erosion up to 30 km depth (Percival and West, 1994). Approximately 1 billion years ago far-field reactivation of faults by compression from the Grenville orogeny caused potential but poorly documented lower greenschist metamorphism along pre-existing faults are largely restricted to the vicinity of Lake Nipigon and near Lake Superior (Manson and Halls, 1994).

Overall, most of the Canadian Shield, outside of unmetamorphosed, late tectonic plutons, contains a complex episodic history of metamorphism largely of Neoarchean age with broad tectonothermal overprints of Paleoproterozoic age around the Superior Province and culminating at the end of the Grenville Orogeny ca. 0.95 billion years ago.

3.1.6 Erosion

There is no specific information on erosion rates for the Hornepayne 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

Information on local bedrock geology for the Hornepayne area (Figure 3.4) was obtained from the various published reports for the area, geological maps (Section 1.5.1), and the geophysical interpretation of the area conducted as part of this preliminary assessment (PGW, 2013). Findings from the geophysical interpretation, terrain analysis study and lineament interpretation carried out as part of the preliminary assessment of the Hornepayne area (Geofirma, 2013; JDMA, 2013; PGW, 2013) are integrated in this report to provide insight on the lithological variability, structures and extent of the overburden cover for each of the potentially suitable geological units in the Hornepayne area identified in the Initial screening (Golder, 2011).

Geophysical data has high resolution within the western portion of the Hornepayne area in the area of the Obakamiga Uplands (PGW, 2013). In this area, airborne geophysical data are available on 200 m line spacings. High resolution geophysical data are also available from a survey flown over the greenstone belt in the extreme southeastern corner of the Hornepayne area (PGW, 2013). In this area, airborne geophysical data are also available on 200 m line spacings. For the balance of the Hornepayne area, the geophysical data is of low resolution, with 805 m line spacings.

3.2.1 Bedrock Geology

The bedrock geology of the Hornepayne area is shown on Figure 3.4, and a conceptual cross section across the Quetico-Wawa boundary is shown on Figure 3.5. The total magnetic field and the first vertical derivative of the residual field over the Hornepayne area are shown on Figures 3.6 and 3.7, respectively. The regional Bouguer gravity data are shown on Figure 3.8.

The geology of the Hornepayne area is dominated by metasedimentary rocks and granite-granodiorite intrusions of the Quetico Subprovince, and the foliated/gneissic tonalite and granite-granodiorite intrusions of the Black-Pic batholith of the Wawa Subprovince (Figure 3.4).

3.2.1.1 Metasedimentary Rocks of the Quetico Subprovince

The metasedimentary rocks of the Quetico Subprovince comprise the Quetico metasedimentary gneiss domain - a long, linear subprovince dominated by a mix of metasedimentary migmatite, tonalitic gneiss, amphibolite slivers of remnant mafic metavolcanic rock, granodiorite of uncertain origin, paragneiss, granitic rocks derived from partial melts of metasedimentary rocks and metamorphosed clastic sedimentary rocks. The precursor sedimentary rocks are typically composed of turbidite successions derived from the erosion of adjacent volcanic arcs (granite-greenstone terranes) either adjacent to the Quetico basins or conceivably derived from other granite-greenstone terranes hundreds of kilometres away (Ojakangas, 1985; Zaleski et al., 1999). The deposition of the original sedimentary rocks was initiated approximately 2.698 billion years ago, and its termination is constrained to approximately 2.688 billion years ago (Zaleski et al., 1999). The migmatites formed as a result of high-grade metamorphism of the original sedimentary rocks. The low-pressure, high temperature metamorphism that occurred in the area produced partial melting of the precursor sedimentary rocks, resulting in the formation of migmatites comprising two or more petrographically distinct components.

The metasedimentary rocks of the Quetico Subprovince are dominated by highly metamorphosed and migmatized clastic sedimentary rocks of dominant greywacke composition. Small amounts of ironstone, conglomerate, and ultramafic wacke and siltstone are also present locally (Williams, 1991). In the Hornepayne area, these are mainly migmatite and biotite-quartz-feldspar paragneiss, having a strong compositional layering and exhibiting small-scale folds, boudinage and shearing (Williams and Breaks, 1996). Sheeting of granitic material throughout the rocks is common, as is migmatitic veining and mafic sheeting in the extreme southern portions of the subprovince (Williams, 1989).

Plutons, granitic dykes and tonalite gneiss (for example, just north of the Township of Hornepayne) within the Quetico Subprovince, contain various proportions of clastic metasedimentary inclusions. Approximately 40 km northwest of the Township of Hornepayne, the volume of granitic rock within the migmatized metasedimentary rocks can comprise up to 75% granitic rock as mapped by Milne (1964), either as injected bodies or in-situ semi-conformable partial melt derived from the metasedimentary rocks. Owing to the limited mapping of the Quetico Subprovince in the Hornepayne area, much of the bedrock geology north of the Township of Hornepayne has been generalized by Johns and McIlraith (2003) as migmatite and biotite-quartz-feldspar paragneiss.

The metasedimentary gneisses and migmatites of the Quetico Subprovince are typically steeply dipping and have an estimated thickness of at least 7.5 km (Percival, 1989), although the thickness of these metasedimentary rocks along the border of the Quetico and Wawa subprovinces may be somewhat less, as the metasedimentary rocks are thought to be underlain by rocks of the Wawa Subprovince near the subprovincial boundary (Figure 3.5, Percival, 1989).

The Quetico Subprovince predominantly shows a weak magnetic background, likely reflecting lithologies composed of low magnetic mineral content. In addition, the magnetic signal throughout the entire Quetico Subprovince tends to reflect the presence of the northwest-trending Matachewan dyke swarm. Adjacent to the subprovince boundary, magnetic data shows an east-west trending high response that extends several kilometres to the north into the metasedimentary rocks, and is characterized by numerous subparallel lineations (Figures 3.6, 3.7 and 3.11). Based on the OGS bedrock geology map this unit is mapped as undifferentiated metasedimentary rocks. However, the higher magnetic response suggests that these bedrock units located adjacent to the subprovince boundary contain a higher concentration of magnetic minerals, and may reflect a change in the bedrock lithology and higher degree of heterogeneity within the subsurface. The high abundance of subparallel lineations evident in the metasedimentary rocks is most likely associated with a deformation zone extending north and south of the subprovince boundary (PGW, 2013).

The resolution of the gravity data is insufficient to be used for interpretation of geological units and boundaries. However a zone of gravity high is observed in the migmatitic unit in the western part of the Hornepayne area (Figure 3.8) indicating the likely presence of denser rock in this area. A higher gravity response located immediately north of the subprovince boundary that is roughly 10 to 15 km wide, correlates well with the east-west oriented anomaly interpreted from the magnetic data. The gravity lows in the northern part of the Hornepayne area reflects the combined lower densities of the mixed metasedimentary rocks and the granitic-granodioritic unit.

3.2.1.2 Granite-Granodiorite of the Quetico Subprovince

Approximately 10 and 20 km to the north of the Township of Hornepayne are two large east-trending muscovite-bearing granitic intrusions (Figure 3.4), each approximately 7 km by 30 km in size and likely derived from partial melting of the metasedimentary rocks (Percival, 1989; Williams, 1991). Similar, though smaller, bodies are mapped approximately 20 km to the east of the Township. No information regarding the age, thickness, or lithological/mineralogical composition of these bodies was found in the available literature. There is some uncertainty whether these bodies are the end point of in-situ migmatization of the metasedimentary rocks or true intrusions.

The geophysical interpretation of the Hornepayne area (PGW, 2013) suggests the geological boundaries of the granite-granodiorite unit are not very well delineated in any of the geophysical datasets. Within the magnetic data, the units typically show subtle outlines that are slightly elevated in magnitude with an east-northeast orientation. Based on the magnetic data, the identified responses are poorly coincident with the mapped rock units, where several magnetic responses tend to be smaller in area compared to the boundaries presented in the bedrock geology map shown on Figure 3.4. This interpretation suggests that the uniform distribution of granite – granodiorite units, as shown on Figure 3.4, may reflect a more complicated lithological heterogeneity in the area. The sparse gravity data do not distinguish the granite-granodiorite from the mixed metasedimentary rocks in the northern part of the Hornepayne area (Figure 3.8).

3.2.1.3 Black-Pic Batholith of the Wawa Subprovince

The Black-Pic batholith is a regionally-extensive intrusion that roughly encompasses an area of 3,000 km^2 covering the southern half of the Hornepayne area and extending west and south beyond the Hornepayne area (Figures 3.3 and 3.4; Fenwick, 1967; Stott, 1999).

The Black-Pic batholith is a multiphase intrusive unit that includes hornblende-biotite monzodiorite, tonalite and pegmatitic granite; although foliated to gneissic granodiorite to tonalite are the main rock types (Milne, 1968). Younger plutons in this batholith are largely restricted to the margins of it, adjacent to greenstone belts. Within the Hornepayne area, this batholith is described as a gneissic tonalite suite that contains local associated lineated to foliated biotite and/or amphibole-bearing tonalite and granite-granodiorite phases (Williams and Breaks, 1996; Johns and McIlraith, 2003).

The age of emplacement of the Black-Pic batholith is poorly constrained. The tonalite phase, the oldest regional phase of this batholith near Hemlo-Schreiber, has been dated at ca. 2.720 billion years old (Jackson et al., 1998), whereas a monzodiorite phase near Manitouwadge has been dated at ca. 2.689 billion years old (Zaleski et al., 1999). The thickness of the batholith is not known, but may be expected to be greater than 1 to 3 km (Percival et al., 2012; Figure 3.5).

The Black-Pic batholith is interpreted to be a domal structure, with slightly dipping foliations radiating outwards from the center. Within the batholith, Williams and Breaks (1989) found that deeper levels of the tonalite suite are strongly foliated with a sub-horizontal planar fabric. Upper levels of the tonalite are frequently cut with granitic sheets of pegmatite and aplite and are generally more massive (Williams and Breaks, 1989).

Within the Black-Pic batholith, zones of metavolcanic rocks and of massive granodiorite to granite exist and the contact between these rocks and the tonalitic rocks of the Black-Pic batholith is relatively gradational with extensive sheeting of the tonalitic unit (Williams and Breaks, 1989; Williams et al., 1991). Of note in the Black-Pic batholith is a massive to foliated granitic to granodioritic intrusion located in the southeastern part of the Hornepayne area that extends south of the Hornepayne area. The geophysical interpretation of the Black-Pic batholith (PGW, 2013) shows that the gneissic tonalite suite of the batholith displays very subtle magnetic variability, with a fairly uniform magnetic background that gradually increases toward the granite granodiorite rocks to the east. This gradual increase towards the east may reflect subtle changes in the lithology corresponding to higher magnetic mineral content, or may also be associated with the dominating effect of the interpreted dykes observed within the poor resolution magnetic data, making the boundaries of these rock units difficult to differentiate. Areas of lowest magnetic response are evident in the gneissic tonalite suite in the south-central and southwest parts of the Hornepayne area (Figure 3.7).

South of the mapped subprovince boundary, the Black-Pic batholith displays a sharp magnetic contact characterized by numerous subparallel high amplitude lineations that is approximately 5 to 6 km wide. Bedrock units adjacent to the boundary are mapped as foliated tonalite, gneissic-tonalite and a number of thin east-trending mafic metavolcanic units. The high magnetic response along the boundary implies a change in the bedrock lithology reflected by a higher concentration of magnetic minerals, and potentially a higher degree of lithological heterogeneity. The subparallel lineations observed on magnetic data may reflect a zone of deformation about 15 km wide that straddles the mapped Wawa-Quetico subprovince boundary (PGW, 2013). The broad gravity low in the southwest of the Hornepayne area (Figure 3.8) likely reflects a thickening of the gneissic tonalite suite in this area. Locally, minor amounts of greenstone units correlate fairly well with weak gravity highs, particularly in the area around Wilson Lake and north of Obakamiga Lake.

The area of massive to foliated granite-granodiorite mapped in the southeast to south-central parts of the Hornepayne area is confirmed in the geophysical interpretation (PGW, 2013), although it is of smaller extent in the geophysical interpretation than in the existing OGS mapping (Figure 3.4). This granitic-granodioritic intrusion shows subdued aeromagnetic signature that is slightly elevated relative to the surrounding gneissic tonalite suite. The granite-granodiorite unit also correlates well with a gravity low.

3.2.1.4 Greenstone Belts

The intermediate to mafic metavolcanic rocks occurring along the Quetico-Wawa subprovince boundary along the southern edge of the Township of Hornepayne are part of the Manitouwadge-Hornepayne greenstone belt (Figure 3.4). The rocks in this part of the greenstone belt occur in a belt that is 1 to 2 km in width, and are composed of variably-dipping, highly deformed and variably metamorphosed intermediate to mafic volcanic rocks. These metavolcanic rocks are generally bounded by migmatized metasedimentary rocks to the north and the tonalitic rocks of the Black-Pic batholith to the south (Williams and Breaks, 1996). The greenstone belt is broader and more structurally and lithologically complex to the west of the Hornepayne area in the vicinity of Manitouwadge (approximately 70 km to the west); however, closer to the Township of Hornepayne, the belt is comprised primarily of mafic metavolcanic rocks (amphibolite, mafic schist and gneiss), with localized units of gabbroic, ultramafic and anorthositic composition (Williams et al., 1991; Williams and Breaks, 1996). The thickness of the greenstone belt is not known and is in part obscured by overlying metasedimentary rocks along the contact with the Quetico Subprovince (Percival, 1989). Metavolcanic rocks of the greenstone belt have been dated as ca. 2.720 billion years old (Zaleski et al., 1999).

Mafic metavolcanic rocks are also present in the southeast, southwest and northeast parts of the Hornepayne area (Johns and McIlraith, 2003). The slivers of mafic metavolcanic rock in the Wawa Subprovince near Wilson Lake and Cholette Lake are mapped as amphibolite, mafic schist and gneiss, locally garnetiferous. The mafic metavolcanic rocks in the southeast and northeast corners of the Hornepayne area are mapped as mainly basalt and locally andesite or dacite.

3.2.1.5 Mafic Dykes

Paleoproterozoic diabase dykes are abundant across the Hornepayne area, dominated by the northwest-trending Matachewan swarm, ca. 2.45 billion years ago (Heaman, 1997). The northeast-trending dykes comprise two suites: the ca. 2.17 billion year old Biscotasing suite and the ca. 2.11 billion year old Marathon/Kapuskasing suite (Halls et al., 2008). Both sets of diabase dykes cross-cut all other rock types in the Hornepayne area, including the metasedimentary rocks, greenstone belts, and granitoid plutons of the Quetico and Wawa subprovinces. The abundant presence of the diabase dykes in this area tends to mask the magnetic signatures of the surrounding Archean bedrock lithologies (PGW, 2013).

A further, more detailed subdivision of the dyke swarms north of 49° 30' (north of Nagagami and Nagagamisis lakes and Beardmore to the west) was interpreted from aeromagnetic data by Stott and Josey (2009) based on orientation and previous work by Halls and others (Ernst and Halls, 1983; Halls and Davis, 2004; Halls et al., 2008).

Interpreted dykes in the Hornepayne area from aeromagnetic data are further discussed in the lineament investigation (Geofirma, 2013) and are summarized in Section 3.2.3 of this report.

3.2.2 Quaternary Geology

Information on Quaternary geology in the Hornepayne area is described in detail in the terrain report (JDMA, 2013) based on Northern Ontario Engineering Terrain Studies (NOEGTS) (Gartner and McQuay, 1980a; 1980b) and is summarized here.

The NOEGTS program was undertaken between 1977 and 1980 and divided the landscape into a set of distinct terrain units within which the engineering characteristics are broadly predictable. In many areas of northern Ontario, including the Hornepayne area, maps produced from these programs currently represent the best level of detail available for surficial geology mapping and descriptions of terrain conditions (JDMA, 2013). Major landforms and surficial geology mapped by the NOEGTS program are shown on Figure 2.3 after Gartner and McQuay (1980a; 1980b).

The Quaternary cover in the Hornepayne area is dominated by glacial deposits that accumulated with the progressive retreat of the Laurentide Ice Sheet during the late Wisconsinan glaciation. This most recent period of glaciation began approximately 115,000 years ago and reached its greatest extent 20,000 years before present, at which time the glacial ice front extended south of Ontario into what is now Ohio and Indiana (Barnett, 1992). The glacial retreat from the Hornepayne area is estimated at approximately 9,000 years ago (Barnett, 1992). Glacial erosion has generally removed any earlier deposits in the area.

The main direction of the most recent glacial advance in the Hornepayne area was from the north-northeast (Gartner and McQuay, 1980a). Ground moraine and glaciolacustrine deposits were laid down in the area east and northeast of the Township of Hornepayne as shown on Figure 2.3 (Gartner and McQuay, 1980a). These deposits combine to almost completely cover the bedrock in this part of the Hornepayne area. In the northeast part of the Hornepayne area the glaciolacustrine deposits are mapped as glaciolacustrine plains consisting of deep water deposits of stratified silt, sand and clay, with varved silt and clay being common.

An interlobate moraine (Arnott Moraine) was formed during a local re-advance of the ice sheet, which has been mapped as a series of kames in the vicinity of Nagagamisis Lake, in the northern part of the Hornepayne area. This moraine provides a potential source of sand and gravel. Quaternary deposits are more discontinuous in the western and southern parts of the Hornepayne area. The only significant Quaternary landforms within close proximity of the Township include two large esker complexes approximately 5 to 10 km to the south. These esker complexes consist of sands and gravels and can exceed 15 m in depth (Gartner and McQuay, 1980a).

Information on the thickness of Quaternary deposits within the Hornepayne area is largely derived from the terrain evaluation (JDMA, 2013). Measured thicknesses are limited to a small number of water well records for developed properties mostly within the Township and to a small number of diamond drill holes (OGS, 2005) completed within the Hornepayne area (see Section 4). A detailed account of recorded depths to bedrock in the Hornepayne area is provided by JDMA (2013), and depths generally range from 0 to 15 m, although greater thicknesses up to 38 m have been recorded in a few locations. Overburden is likely to be thickest in bedrock valleys and in the northern and eastern parts of the Hornepayne area where more extensive glaciofluvial and glaciolacustrine deposits are mapped.

Organic material is located in discontinuous areas throughout the Hornepayne area. The organic sediments vary considerably in thickness and areal extent and are associated with a high water table and extremely poor surface drainage.

The results of the terrain report (JDMA, 2013) show that the potentially suitable geologic units in the Hornepayne area have a wide range of overburden cover. The percentages of surficial area in each potentially suitable geologic unit mapped as bedrock and bedrock drift complex are 55% for the foliated/gneissic tonalite of the Black-Pic batholith, 51% for granite-granodiorite of the Black-Pic batholith, 41% for the metasedimentary rocks of the Quetico Subprovince, and 20% for the granite-granodiorite intrusions of the Quetico Subprovince. The remaining surficial areas of these geologic units are associated with overburden and surface water.

3.2.3 Lineament Investigation

A lineament investigation was conducted for the Hornepayne area using multiple datasets that included satellite imagery (Landsat/SPOT), digital elevation model data (CDED) and geophysical (aeromagnetic) survey data (Geofirma, 2013). The lineament investigation interpreted brittle (including brittle-ductile) structures, dykes and ductile features in the Hornepayne 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 Geofirma (2013) and key aspects of the lineament investigation are summarized in this section.

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

- **Ductile lineaments:** Features which were interpreted as being associated with the internal fabric of the rock units (including sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation) were classified as ductile lineaments. This category also includes recognizable penetrative shear zone fabric.

- **Brittle lineaments:** Features interpreted as fractures (joints or joint sets, faults or fault zones, and veins or vein sets), including those that offset the continuity of the ductile fabric described above, were classified as brittle lineaments. This category also includes brittle-ductile shear zones, and brittle partings interpreted to represent discontinuous re-activation parallel to the ductile fabric. At the desktop stage of the investigation, this category also includes features of unknown affinity. This category does not include interpreted dykes, which are classified separately (described below).

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

The desktop interpretation of remotely-sensed datasets necessarily includes a component of uncertainty as a result of data quality, scale of Hornepayne area, expert judgement, and to a certain extent, the quality of the pre-existing knowledge of the bedrock geology of the Hornepayne 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 and dykes were interpreted by two independent experts using a number of attributes, including certainty and reproducibility (Geofirma, 2013). The certainty attribute describes the clarity of the lineament within each dataset based on the expert judgement and experience of the interpreter (i.e., with what certainty a feature is interpreted as a lineament). Reproducibility was assessed in two stages (RA_1 and RA_2). Reproducibility Assessment RA_1 reflects the coincidence within each dataset between lineaments interpreted by the two experts. Reproducibility Assessment RA_2 reflects the coincidence of interpreted lineaments between the various datasets used.

In addition, ductile features were identified from the geophysical dataset by a single expert interpreter. These ductile features are included to provide context to our understanding of the tectonic history of the Hornepayne area, but were not included in the merged lineament sets or statistical analyses.

The Landsat/SPOT and CDED datasets (Figures 2.1 and 2.2, respectively) were used to identify surficial lineaments expressed in the topography, drainage and vegetation. The Landsat/SPOT dataset has a uniform resolution of 10 m (panchromatic) and 20 m (multispectral) over the entire Hornepayne area (JDMA, 2013, Geofirma, 2013). The CDED dataset is at a 1:50,000 scale, with a uniform 20 m resolution over the entire Hornepayne area (JDMA, 2013). The resolution of the Landsat/SPOT and CDED datasets allowed for the identification of surficial lineaments as short as a few hundred metres in length and provided sufficient detail to reveal surficial structural patterns (Geofirma, 2013). Aeromagnetic datasets (Figures 3.6 and 3.7) were used to identify linear geophysical anomalies indicative of bedrock structures. Regional low resolution data (at 805 m line spacing) is available for the entire Hornepayne area (Figure 1.2). High resolution data (200 m line spacing) are available for the Manitouwadge-Hornepayne greenstone belt and surrounding rocks near the subprovince boundary in the western part of the Hornepayne area and for the greenstone rocks around Cameron Lake in the extreme southeast corner of the Hornepayne area. The high resolution geophysical coverage allowed for the identification of geophysical lineaments on the order of 500 m or longer in length, while the regional geophysical coverage limited the resolution of geophysical lineaments to features on the order of 2 km or longer in length.

Figure 3.9 shows the combined surficial lineament interpretation of the Landsat/SPOT and CDED datasets (n = 1841 lineaments) using the results from RA_1, without any filtering of overlapping features. The Landsat/SPOT dataset yielded a total of 1,071 surficial lineaments, ranging from 0.23 to 50.3 km in length, with an arithmetic mean length of 4.5 km, while the CDED dataset yielded a total of 770 lineaments, ranging from 0.46 to 60.1 km long, with an arithmetic mean length of 6.7 km. The density and distribution of surficial lineaments was seen to be influenced by the more than 45% overburden coverage in the Hornepayne area, which masked and truncated the surface continuity of some lineaments. This is particularly evident in the north and northeast parts of the Hornepayne area, where thick overburden cover dominates and the density of surficial lineaments is low. Both the Landsat/SPOT and CDED datasets offered advantages to characterize the surficial lineaments. The higher resolution of the Landsat/SPOT imagery allowed for finer structures to be identified that were not resolved by the CDED data; but the CDED data often revealed subtle trends masked by the surficial cover captured in the Landsat/SPOT imagery. Both satellite and CDED datasets identified the same length-weighted lineament trends of north-northeast to northeast, east and northwest (Figure 3.9 inset).

The aeromagnetic dataset yielded a total of 479 lineaments (Figure 3.10), 89 interpreted as fractures (brittle structures) and 390 interpreted as dykes. The results shown on Figure 3.10 depict the results from the RA_1 analysis, binned into four length categories (< 1 km, 1 – 5 km, 5 – 10 km, > 10 km). The length of the geophysical brittle structures ranged from 2.4 to 77.9 km, with an arithmetic mean length of 14.6 km. The length of the geophysical dyke lineaments ranged from <1 to 121.4 km, with an arithmetic mean length of 8.5 km. The density and distribution of geophysical lineaments is influenced by the resolution of the geophysical coverage. This observation suggests that the metasedimentary rocks of the Quetico Subprovince and the rocks in the Black-Pic batholith may have a similar geophysical lineament density to other metasedimentary rocks and intrusions in the area where high resolution aeromagnetic data are available throughout the Hornepayne area. In addition, shorter lineaments could be present in areas other than those covered by high resolution aeromagnetic data, but remain undetectable due to the low resolution aeromagnetic coverage. The length-weighted lineament trends for the geophysical lineaments interpreted as fractures exhibit trends to northwest, north-northeast and east. Therefore similar trends are noted between the surficial and geophysical datasets.

The 390 lineaments identified as dykes (Figure 3.10), belong primarily to the northwest-trending suite of Matachewan dykes. A second minor set of dykes oriented northeast is related to the Biscotasing and Marathon/Kapuskasing swarms (Section 3.2.1.5). The number of interpreted dykes in particular areas is related to the resolution of the geophysical surveys, with more dykes mapped in the areas of high resolution aeromagnetic surveys in the western and extreme southeastern parts of the Hornepayne area (Figure 3.10).

Aeromagnetic features interpreted as ductile features have been mapped separately and are shown on Figure 3.11. Such features are useful in identifying the degree of ductile deformation within the greenstone belts and to a lesser extent in the gneissic and foliated intrusive rocks of the Hornepayne area. In particular, the high magnitude of ductile strain proximal to the subprovince boundary is evident on Figure 3.11. Figure 3.11 shows the increased occurrence of ductile structures in the metasedimentary rocks of the Quetico Subprovince and in the foliated and gneissic tonalite suites of the Black-Pic batholith near the subprovince boundary. It should be noted that the observed density of these features is also influenced by the resolution of the geophysical data.

The geophysical lineament data have advantages over surficial lineament data in that they are minimally affected by overburden cover, which may partially or completely mask surficial lineaments. Importantly, aeromagnetic data allow interpretation of lineaments from the surface to potentially great depths. The low reproducibility results (RA_1) for both geophysical brittle lineaments (5%) and dykes 32%) between interpreters indicates the indistinct nature of some of features in the available datasets, and the higher level of expert judgement necessary to select geophysical lineaments with low-resolution aeromagnetic data compared to surficial datasets.

Figure 3.12 shows the distribution of merged surficial and geophysical lineaments interpreted for the Hornepayne area, classified by length. The merged lineament dataset yielded a total of 1,868 lineaments, ranging from 126 m to 121.4 km in length, with an arithmetic mean length of 6.4 km. There were three lineament trends observed in the merged lineament dataset based on length-weighted frequency. These are a dominant northwest-trending set and two weakly interpreted sets oriented northeast and east. The northwest-trending lineament set includes both fractures and Matachewan dykes. The northeast-trending set comprises fractures and dykes of the Biscotasing and Marathon/Kapuskasing dyke swarms. The east-trending lineament set is principally composed of fractures that subparallel the subprovince boundary. Lineament orientation trends for the potentially suitable geologic units in the Hornepayne area (i.e., metasedimentary rocks and granite-granodiorite intrusions of the Quetico Subprovince, and the foliated/gneissic tonalite and granite-granodiorite intrusions of the Black-Pic batholith) are presented on Figure 3.13 and further discussed in the geologic unit specific sub-sections below.

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

- Longer lineaments generally have a higher certainty and reproducibility.

- There is a much greater coincidence between surficial lineaments (24% of the total merged fracture lineaments are interpreted from both CDED and SPOT) than between geophysical lineaments and surficial lineaments (2% of the total merged fracture lineaments are observed in geophysical data and at least one of the surficial datasets), presumably due to the fact that surficial lineaments interpreted from CDED and Landsat/SPOT are expressions of the same bedrock feature.

- The low coincidence between surficial and geophysical lineaments is presumably due to a variety of factors. For example, the structures identified in the aeromagnetic data may not have a surface expression; surficial features may not extend to great depth; structural features may not possess a magnetic susceptibility contrast with the host rock; surface expressions of lineaments may be masked by the presence of infilling or overburden; and the geometry of the feature (e.g., dipping versus vertical). These factors are further constrained by the resolution of the differing datasets. At 805 m flight line spacing, small features or those oriented at a low angle to the flight lines may not be discernible.

Figures 3.14 to 3.17 were produced to provide some insight into the influence of lineament length on the distribution of lineament density across the Hornepayne area. This set of figures shows the progressive filtering (removing) of lineaments corresponding to the same length bins used above (< 1 km, 1 – 5 km, 5 – 10 km, > 10 km), and with the remaining lineaments plotted on top of the calculated lineament density as a coloured gradient map. In other words, Figure 3.14 includes all lineaments shown on Figure 3.12 and with a background showing the same information as a lineament density gradient map (in km/km^2). Figure 3.15 filters out the < 1 km long lineaments and so the underlying density gradient map represents only those lineaments 1 km in length or greater. The same is done, in a step-wise manner, for Figures 3.16 (filtering all lineaments < 5 km) and for Figure 3.17 (filtering all lineaments < 10 km). The density plots with lineament lengths filtered are presented to allow one to more clearly see the longer lineaments. In, general, these figures show that filtering out the shorter lineaments greatly increases the spacing (reduces density) between lineaments, including those areas having exposed bedrock and higher resolution aeromagnetic surveys. For example, Figure 3.17 shows that the Black-Pic batholith west of Hwy 631, in the Bone Lake area contains relatively few lineaments that are longer than 10 km, leaving large volumes of rock between interpreted long lineaments. Also, filtering out the shorter lineaments appears to reduce the effects of both overburden cover (in the case of surficial lineaments) and low resolution aeromagnetic surveys on lineament density. For example, the metasedimentary rocks of the Quetico Subprovince and the Black-Pic batholith in the western part of the Hornepayne area with well-exposed bedrock and high resolution aeromagnetic surveys exhibit very high lineament densities when all lineaments are shown but the lineament density is greatly reduced and becomes more comparable to other areas when the shorter lineaments are filtered out.

Figure 3.18 shows the combined datasets (i.e., mapped regional faults and dykes, interpreted brittle lineaments, interpreted dyke lineaments and interpreted ductile features), which helps provide a structural understanding of the Hornepayne area. Because of the large number of brittle lineaments and dykes, it is difficult to see in the figure the coincidence of interpreted lineaments and mapped faults and dykes in the Hornepayne area, as illustrated on Figure 3.4. As discussed in the lineament investigation for the Hornepayne area (Geofirma, 2013), there are 19 mapped faults as shown on Figure 3.4. These 19 faults have three orientations; northwest, northeast and east, which are consistent with the trends determined from the lineament analysis, and described above.

Sixteen of the mapped faults are associated with specific interpreted lineaments and the trends of these faults correspond with the major lineament trends of northwest, northeast and east. The three mapped faults that were not identified in the lineament interpretation (Geofirma, 2013) are all northeast-trending features located within and near the Township of Hornepayne. The east-trending set of lineaments evident from satellite and geophysical datasets are reflective of ductile deformation as well as brittle deformation events associated with the collisional tectonics along the subprovince boundary.

Review of Figure 3.18 shows there is very good coincidence of mapped dykes and dykes interpreted as part of the lineament assessment, in terms of orientation, length and location throughout the Hornepayne area. Such coincidence is expected, as mapped and interpreted dykes are derived from the same aeromagnetic surveys.

Review of Figures 3.9, 3.10, 3.12 and 3.14 to 3.17 shows that overall lineament density as defined by the presence of final merged fractures and dykes is variable across the Hornepayne area and within potentially suitable geologic units. The factors that appear to influence mapped lineament density are amount of overburden cover, the resolution of the aeromagnetic surveys, and proximity to the subprovince boundary – a known zone of structural intensity and complexity.

One aspect of uncertainty associated to the interpretation of dyke lineaments is the likelihood that thin dykes, while known to be present in the host rock, are too small to be identified with any confidence from the geophysical data. For example, Halls (1991) characterizes 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) suggest further that narrow dykes may produce anomalies of insufficient magnetic intensity to be traced with any confidence. In addition, Halls (1982) discusses the bifurcating and branching geometry of the Matachewan dykes which was also determined based on detailed field mapping. One particularly well-mapped area within the Matachewan swarm highlights the complex nature of the dyke distribution in the field (Halls, 1982), which further indicates that the detailed geometrical arrangement of the dykes at the outcrop scale cannot be resolved with any confidence from the available geophysical dataset. This latter point is important with regard to uncertainty in 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).

Another aspect of uncertainty associated with the high density of diabase dykes observed/interpreted in the Hornepayne area relates to the likelihood that the predominance of the dyke signal in the geophysical dataset will mask evidence of the underlying lithological character and the ductile and brittle structure within the host rock. For example, in areas of high dyke density, and where the dykes are offset by brittle faults, the true fault offset is ambiguous in the aeromagnetic dataset (West and Ernst, 1991). Dyke spacing on the order of 10’s to 100’s of metres in several locations across the Hornepayne area (e.g., Figure 10 of the lineament interpretation; Geofirma, 2013) suggests that underlying structure in the host rock may be under-identified in these areas of increased dyke density.

The following subsections describe the characteristics of the interpreted lineaments for each of the main potentially suitable rock units in the area, as well as the relative age of the lineaments identified in the Hornepayne area. Note that the statistics presented in the discussion below include a count of all interpreted features that intersect even a small portion of the unit of interest being discussed. Therefore, the same interpreted features can be counted more than once if it extends into more than one unit of interest. The total number of features discussed below may be greater than the total number of features interpreted for the Hornepayne area.

3.2.3.1 Metasedimentary Rocks of the Quetico Subprovince

A total of 836 lineaments consisting of 662 fractures and 174 dykes were mapped over the 1,934 km^2 area of the metasedimentary rocks of the Quetico Subprovince (Figure 3.12). Many of the long interpreted lineaments occur in the western part of this geological unit where both bedrock exposure and geophysical survey resolution are high. Comparison of Figure 3.9 (surficial lineaments) and Figure 3.10 (geophysical lineaments) shows that density of surficial lineaments in the metasedimentary rocks of the Quetico Subprovince is greater than the density of geophysical fracture lineaments and that there are fewer shorter length geophysical fracture lineaments than shorter length surficial lineaments. Both the interpreted surficial lineaments (Figure 3.9) and geophysical lineaments (Figure 3.10) show similar trends with dominant northwest and subordinate north-northeast to northeast and east orientations observed (Figure 3.13).

Interpreted fracture lineaments in the metasedimentary rocks of the Quetico Subprovince identified 8 of the 9 mapped faults as shown on Figure 3.4. The northeast-trending fault mapped by the OGS extending from the settlement area of Hornepayne was not identified in the lineament assessment. Both Matachewan and Biscotasing-Marathon/Kapuskasing dykes cross the metasedimentary rocks of the Quetico Subprovince. The majority of these mapped dykes were identified in the lineament assessment (Figure 3.10).

Based on Figure 3.14 and considering overburden cover, the central part of the metasedimentary rocks of the Quetico Subprovince northeast of the Township have lower apparent total lineament densities.

3.2.3.2 Granite-Granodiorite of the Quetico Subprovince

A total of 300 lineaments consisting of 218 fractures and 82 dykes were mapped over the 743 km^2 area of the granite-granodiorite of the Quetico Subprovince (Figure 3.12). Most of the long interpreted lineaments extend beyond these small elongated intrusives into the surrounding metasedimentary rocks. Comparison of Figure 3.9 (surficial lineaments) and Figure 3.10 (geophysical lineaments) shows that density of surficial lineaments in the granite-granodiorite of the Quetico Subprovince is greater than the density of geophysical fracture lineaments and that there are fewer shorter length geophysical fracture lineaments. Both the interpreted surficial lineaments (Figure 3.9) and geophysical lineaments (Figure 3.10) show similar trends with dominant northwest and subordinate northeast and east orientations observed (Figure 3.13).

The only mapped fault in muscovite/biotite-bearing granite-granodiorite intrusions of the Quetico Subprovince in the north central part of the Hornepayne area (Figure 3.4) was identified in the lineament investigation. Both Matachewan and Biscotasing-Marathon/Kapuskasing dykes cross the granite-granodiorite intrusions of the Quetico Subprovince and represent a significant fraction of the mapped lineaments due to the presence of overburden cover on these rocks.

Based on Figure 3.14 and considering overburden cover both of the elongated granite-granodiorite intrusions of the Quetico Subprovince northeast of the Township have comparable apparent total lineament densities.

3.2.3.3 Foliated/Gneissic Tonalite of Black-Pic Batholith

A total of 857 lineaments consisting of 700 fractures and 157 dykes were mapped over the 1,654 km^2 area of the foliated and gneissic tonalite suites of the Black-Pic batholith (Figure 3.12). Many of the long interpreted lineaments occur in the western and north-central parts of this geologic unit where both bedrock exposure and geophysical survey resolution are high and the subprovince boundary is nearby. Comparison of Figure 3.9 (surficial lineaments) and Figure 3.10 (geophysical lineaments) shows that density of surficial lineaments in the foliated and gneissic tonalite of the Black-Pic batholith is greater than the density of geophysical fracture lineaments and that there are fewer shorter length geophysical fracture lineaments. Both the interpreted surficial lineaments (Figure 3.9) and geophysical lineaments (Figure 3.10) show similar trends with dominant northwest and subordinate northeast and east orientations observed (Figure 3.13).

Interpreted fracture lineaments in the massive to foliated and gneissic tonalite suites of Black-Pic batholith identified 9 of 11 mapped faults as shown on Figure 3.4. Two northeast-trending mapped faults located in the southeast corner of the Township of Hornepayne and immediately east of this location were not identified in the lineament assessment. Both Matachewan and Biscotasing-Marathon/Kapuskasing dykes cross the foliated and gneissic tonalite suites of the Black-Pic batholith. The majority of these mapped dykes were also identified in the lineament assessment.

Based on Figure 3.14 and considering overburden cover, the foliated and gneissic tonalite suites of the Black-Pic batholith in the southern part of the Hornepayne area west of Hwy 631 and between Granitehill and Obakamiga lakes have lower apparent total lineament densities.

3.2.3.4 Granite-Granodiorite of the Black-Pic Batholith

A total of 243 lineaments consisting of 180 fractures and 63 dykes were mapped over the 331 km^2 area of the massive to foliated granite-granodiorite of the Black-Pic batholith (Figure 3.12). Many of the long interpreted lineaments extend beyond this intrusive into the surrounding gneissic tonalite of the Black-Pic batholith. Comparison of Figure 3.9 (surficial lineaments) and Figure 3.10 (geophysical lineaments) shows that density of surficial lineaments in the foliated granite-granodiorite of the Black-Pic batholith is much greater than the density of geophysical fracture lineaments due to a greater number of identified surficial lineaments, and that there are fewer shorter length geophysical fracture lineaments. Both the interpreted surficial lineaments (Figure 3.9) and geophysical lineaments (Figure 3.10) show similar trends with dominant northwest and subordinate north-northeast orientations observed (Figure 3.13). The subordinate east trend evident in the other geologic units is not present in the massive to foliated granite-granodiorite of the Black-Pic batholith most likely due to its greater distance from the east-trending subprovince boundary.

Interpreted fracture lineaments in the massive to foliated granite-granodiorite of the Black-Pic batholith identified both of the short mapped faults found in the southeast corner of the Hornepayne area (Figure 3.4). Northwest-trending Matachewan dykes are dominant in the massive to foliated granite-granodiorite of the Black-Pic batholith. The majority of these mapped Matachewan dykes and the subordinate northeast-trending Biscotasing-Marathon/Kapuskasing dykes were identified in the lineament assessment.

Based on Figure 3.14 and considering overburden cover, the massive to foliated granite-granodiorite of the Black-Pic batholith in the southeast part of the Hornepayne area has moderate apparent total lineament densities that are lowest in the central part of the geologic unit.

3.2.3.5 Relative Age Relationships of Lineaments

The relative ages of faulting across the Hornepayne area suggest that the oldest faults tend to trend east, overprinted by northwest-trending dextral faults and northeast-trending sinistral faults, and possibly late north-trending faults. In the Hornepayne area, the most prominent faults are related to the northwest- and northeast-trending faults that were likely reactivated during the Proterozoic. Evidence for east-oriented faulting along the subprovince boundary in the Hornepayne area is not well documented. Inferred faults on the compilation map of Johns and McIlraith (2003) are based on earlier mapping, typically derived from earlier air photo lineament interpretations. North-trending late faults are not common in the Hornepayne area although their occurrence to the west near Manitouwadge is known.

Most episodes of late movement along faults in the Hornepayne area probably terminated by Keweenawan time, ca. 1.100 billion years ago, during the development of the Midcontinent Rift along Lake Superior. Northeast-trending dykes of this age (Abitibi swarm) crosscut all major north- and northwest-trending faults without displacement (West and Ernst, 1991) in the area south and southeast of the Hornepayne region, and these dykes which are subparallel to Biscotasing and Kapuskasing dykes likely extend into the southeast Hornepayne area.

Given the issues of variable resolution and irregularly distributed overburden cover, it is difficult at the desktop stage of the preliminary assessment of potential suitability to assign temporal relationships with any degree of confidence to the identified lineaments. The only distinction that can be made is between older ductile and younger brittle features, albeit with the caveat that many of the ‘ductile’ lineaments may have developed under brittle conditions and have simply re-activated the pre-existing ductile fabric. Therefore, a tentative preliminary interpretation of the lineament dataset is that the identified ductile (i.e. stratigraphic and foliation-related) lineaments originated largely as pre-ca. 2.680 billion year old features while the brittle lineaments (including dyke lineaments) may be considered to be composite D_3-D_6 structures that were formed during a protracted period of time (after ca. 2.680 billion years ago).

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

The Hornepayne area lies in 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 presents the location of earthquakes with a magnitude 3 or greater that are known to have occurred in

Canada from 1627 until 2010; no seismic events exceeding a magnitude of 6 are recorded within 500 km of the Hornepayne area. Although Hayek et al. (2011) indicate that the general Western Superior Province has experienced a number of low magnitude, shallow seismic events (generally 5 km focal depth), all recorded earthquakes in the region since 1982 had a magnitude lower than 3. Figure 3.20 shows the locations and magnitudes of seismic events recorded in the National Earthquake Database (NEDB) for the period between 1985 and 2011 in the Hornepayne area (NRCan, 2012). Over this time period, all recorded seismic events in the area had magnitudes less than 3 (Nuttli Magnitude). As of May 2012, the most recent earthquake was on March 4, 2011, and was a 2.4 magnitude event, located 32 km south of the settlement area of Hornepayne.

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

3.3.2 Neotectonic Activity

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

The movement and interaction of tectonic plates creates horizontal stresses that result in the compression of crustal rocks. The mean of the current major horizontal principal stress orientation in central North America based on the World Stress Map (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 Hornepayne area is typical of many areas of the Canadian Shield, which have been subjected to numerous glacial cycles during the last million years. Continental-scale tectonic movements are therefore overprinted by 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 Hornepayne 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, 2006). The vertical velocity contours developed from the lake water level datasets compared well with the postglacial rebound models, which in turn indicated that present day rebound rates in the Hornepayne area should be well below 10 mm/yr, likely between 2 and 4 mm/yr. As a result of the glacial unloading, principal stress magnitudes and orientations are changed. Seismic events could be associated with these post-glacial stress changes as a result of reactivation of existing fracture zones. In addition, natural stress release features can include elongated compressional ridges or pop-ups such as those described by McFall (1993) and Karrow and White (2002).

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

Under the appropriate conditions, glaciolacustrine deposits may preserve neotectonic features indicative of paleo-seismic activity (JDMA, 2013). Existence of such features can be used to extend the seismic record for a region well into the past. Figure 2.3 shows extensive areas of glaciolacustrine plain deposits in the Hornepayne area based on NOEGTS mapping by Gartner and McQuay (1980a; 1980b). These silt and clay glaciolacustrine deposits are widespread in the northern and eastern parts of the Hornepayne area and are also present in the southern and western parts of the Hornepayne area.

4 HYDROGEOLOGY AND HYDROGEOCHEMSITRY

4.1 Groundwater Use

Information concerning groundwater use in the Hornepayne area was obtained principally from the Ontario Ministry of the Environment Water Well Information System (WWIS) database (MOE, 2012). The locations of known water wells are shown on Figure 4.1. The Township of Hornepayne has historically obtained its municipal water supply from wells sourcing the shallow overburden aquifer; however, the Township replaced its groundwater supply with a new system sourcing surface water from Moonlight Lake, located approximately 2.7 km southeast of the settlement area of Hornepayne.

The WWIS database contains a total of 71 water well records for the Hornepayne area. These records provide useful information on lithology, well yield, and static water level, as indicated in Table 4.1 below. The MOE water well records show that groundwater use in the Hornepayne area is limited and restricted to a small number of domestic/residential uses. Water wells in the Hornepayne area obtain water from the overburden and shallow bedrock.

Table 4.1 Water Well Record Summary for the Hornepayne Area

Water Well Type	*Number of Wells*	*Total Well Depth (m)*	*Static Water Level (mBGS)*	*Tested Well Yield (L/min)*	*Depth to Top of Bedrock (mBGS)*
Overburden	38	3-29	0.3-13.4	0-182	Not Applicable
Bedrock	33	11-119	0.6-8.5	0-15	0.6-38

4.2 Overburden Aquifers

A total of 38 overburden wells are recorded for the Hornepayne area, ranging from 3 to 29 m in depth. Well yields are variable with recorded values of 0 to 182 L/min. 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 overburden aquifers. The static water levels in the overburden wells range from less than 1 m to 13.4 mBGS.

The limited number of well records and their concentration in the vicinity of the settlement area of Hornepayne limits the available information regarding the extent and characteristics of the overburden aquifers in the Hornepayne area.

4.3 Bedrock Aquifers

No information was found on deep groundwater conditions in the Hornepayne area at a typical repository depth of approximately 500 m. In the Hornepayne area there are 33 well records that can be confidently assigned to the shallow bedrock aquifer, ranging in depth from 11 to 119 m, with most wells being 20 to 60 m deep. The measured pumping rates in these wells range from 0 to 15 L/min. These values reflect the purpose of the wells (private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from the aquifers. Long-term groundwater yield in fractured bedrock will depend on the number and size of fractures, their connectivity, transmissivity, storage and on the recharge properties of the fracture network in the larger regional aquifer. The static water levels in the bedrock wells range from less than 1 m to 8.5 mBGS.

The Ministry of the Environment Water Well Information System database indicates that no potable water supply wells are known to exploit aquifers at typical repository depths in the Hornepayne area or anywhere else in the Ontario part of the Canadian Shield.

4.4 Regional Groundwater Flow

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

No information was found in the available literature regarding groundwater recharge rates and temporal patterns in the Hornepayne area. However, it is expected to be typical for the Canadian Shield region with elevated recharge in spring and fall, reduced recharge in late summer, and essentially no recharge during frozen winter conditions. Rivard et al. (2009) analyzed trends in groundwater levels and surface-water base-flow over the past 50 years throughout Canada. This analysis found no significant temporal trend with respect to long-term changes in surface water drainage and a stable to slight downward trend with respect to regional groundwater levels in northwestern Ontario.

On a regional scale, shallow (i.e. within approximately the upper 100 m of overburden and fractured bedrock) groundwater flow across the Hornepayne area can be expected to mimic surface water flow systems, with groundwater divides coinciding with drainage divides and discharge occurring in topographic lows. Within each of the tertiary-scale watersheds (Figure 2.4), local topography and terrain conditions will influence the distribution and nature of smaller-scale, localized, groundwater flow systems. Steep slopes and the general absence of thick overburden deposits in the areas mapped as bedrock terrain should promote surface runoff and minimize groundwater recharge. Where permeable deposits cover the bedrock, recharge areas should occur within highlands and along local positively expressed topographic features forming drainage divides such as ridges and local uplands. Thicker drift deposits are present in the valleys and trench bottoms, and these deposits are expected to represent the most significant local discharge zones in the bedrock terrain. Groundwater discharge in these areas occurs into creeks, rivers, lakes and wetlands. Gartner and McQuay (1980a; 1980b) as part of NOEGTS work indicate that bedrock terrain in the Hornepayne area is generally well drained, and that bedrock-controlled lineaments in this terrain are expressed as linear depressions that often contain water and reworked glacial-fluvial deposits of sand and gravel.

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

There is little known about the hydrogeologic properties of the deep bedrock in the Hornepayne area, as no deep boreholes have been advanced for this purpose. Experience from other areas with similar types of rock in the Canadian Shield has shown that active groundwater flow in bedrock is generally confined to shallow fractured localized systems, and is dependent on the secondary permeability associated with the fracture networks (Trainer, 1988; 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 Research Area and Atikokan range from approximately 10^{-15} to 10^{-10} m/s (Ophori and Chan, 1996 and 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} to less than 10^{-12} m/s below a depth of 400 to 500 m. While deeper into the bedrock, fracture frequency tends to decline, and eventually the movement of ions is diffusion dominated, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion limited conditions.

The orientation of fracture networks relative to the orientation of the maximum horizontal compressive stress may also influence permeability. In this case, a lower effective hydraulic conductivity would be predicted for fractures oriented at a high angle to the maximum compressive stress axis compared to otherwise identical low angle fractures. Horizontal stress measurements from various locations in the Canadian Shield (Kaiser and Maloney, 2005; Maloney et al., 2006) indicate that the axis of maximum horizontal stress is oriented predominantly in the west-southwest direction. This is generally consistent with the World Stress Map; however, anomalous stress orientations are known to exist in the Canadian Shield (Brown et al., 1995). A 90° change in azimuth of the maximum compressive stress axis was identified in the near surface in the Whiteshell area of Manitoba (Brown et al., 1995) while a roughly north orientation of maximum horizontal compressive stress was found for the Sioux Falls Quartzite in South Dakota (Haimson, 1990). In view of the general paucity of data and the anomalous stress orientations in midcontinent, caution is warranted in extrapolating a west-southwest stress orientation to the Hornepayne area without site-specific data.

There is no site-specific information on the hydraulic characteristics of the dykes interpreted for the Hornepayne 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).

Regional groundwater flow in the Hornepayne area was assessed using surface water elevations, surface drainage directions and ground surface elevations based on the expectation that the regional groundwater table will be a subdued reflection of topography. Because of the large amount of exposed bedrock in the Hornepayne area the groundwater table for most of the area including all of the bedrock highlands will be present within the bedrock, likely within several metres of ground surface. Exceptions to this assumption will occur within the overburden-infilled bedrock valleys of the major rivers and drainage courses (e.g., Shekak, Kabinakagami and Foch rivers) as well as the areas of substantial overburden cover located in the northern and eastern parts of the Hornepayne area. In these areas of thick overburden the groundwater table will be present within the overburden. In the north-central and northeastern lowlands and bedrock valleys, especially in the Shekak River valley, the overburden will act as a local discharge area for bedrock groundwater. In the local highland areas with overburden cover (e.g., north of Kabinakagami Lake, north of Nagagami and Nagagamisis lakes) the overburden will serve as a groundwater recharge area to the underlying bedrock and adjoining overburden deposits.

Based on the available topographic and drainage information, groundwater in the Hornepayne area is conceptualized as being recharged in the bedrock highlands west and southwest of Hornepayne area and flows predominantly northward and eastward via local discharge to lakes and river valleys to the regional discharge locations of the Nagagami-Nagagamisis lakes and the Shekak River. Groundwater flow in area south and east of the Shekak River is from the bedrock highlands south and southeast to the Shekak River valley and drainage course. Groundwater flow also likely occurs radially from a local highland located immediately northeast of the Township of Hornepayne. These estimates of regional groundwater flow conditions in the bedrock will be locally affected by the presence of faults and major structural and lithological discontinuities that have hydraulic properties different from that of the bulk bedrock.

The exact nature of deep groundwater flow systems in the Hornepayne area will need to be evaluated at later stages of the assessment, through the collection of site-specific information.

4.5 Hydrogeochemistry

No information on groundwater geochemistry at repository depth was found for the Hornepayne 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 that extends to a depth of about 150 m, and a deep, saline water flow system (Singer and Cheng, 2002; Gascoyne, 2004).

Gascoyne et al. (1987) investigated the saline groundwater to 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 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 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 Research 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 will need to be evaluated at later stages of the assessment, via site-specific studies.

5 NATURAL RESOURCES - ECONOMIC GEOLOGY

The OGS released a new 2011 version of the Mineral Deposit Inventory (OGS, 2011a). There were no new mineral occurrences compared to the previous database.

The mining claims database (MNDM, 2012b) is updated regularly by MNDM. The version used in this report was obtained on June 26, 2012.

Another new data source used in this report is the Abandoned Mines Information System or AMIS (MNDM, 2011), which contains data on the abandoned mines and inactive mines for the Province of Ontario, including the Hornepayne area.

5.1 Petroleum Resources

The Hornepayne area is located in a crystalline geological setting where the potential for petroleum resources is negligible. No hydrocarbon exploitation or exploration activities are known to occur in the Hornepayne area.

5.2 Metallic Mineral Resources

Figure 5.1 shows the areas of active exploration interest as evidenced by active mining claims, as well as known mineral occurrences identified in the Ontario Geological Survey's Mineral Deposit Inventory Version 2 (OGS, 2011a). The AMIS (MNDM, 2011) and Mineral Deposit Inventory (OGS, 2011a) databases show there are no currently or past producing mines in the Hornepayne area.

Metallic mineralization occurrences in the Hornepayne area include copper, copper-nickel, sulphur/pyrite (iron), iron and uranium.

5.2.1 Base Metals

The few base metal and sulphide occurrences reported in the Hornepayne area are associated with greenstone slivers along the subprovince boundary and within the Black-Pic batholith as shown on Figure 5.1. Economic base metals are found in volcanogenic massive sulphide (VMS) deposits in the Manitouwadge-Hornepayne greenstone belt mostly west of the Hornepayne area. The easternmost edge of this greenstone belt continues more or less parallel to the subprovince boundary and becomes discontinuous in the Hornepayne area (Williams and Breaks, 1996; Figure 3.3). Williams and Breaks (1996) identified four main lithographic environments that are amenable to base metal sulphide showings in the Manitouwadge-Hornepayne greenstone belt:

1. Sporadically, as veins and disseminations within mafic metavolcanic rocks;

2. Associated with ferruginous altered rocks rich in garnet and amphibole, found adjacent to contacts between mafic and intermediate to felsic metavolcanic rock units;

3. Within metamorphosed layered gabbroic to anorthositic plutons; and

4. Within pegmatitic to appinitic segregations in ultramafic rocks associated with homogeneous quartz diorite-tonalite plutons.

These conditions are still generally restrictive to the geology surrounding the Manitouwadge synform about 70 km west of the Hornepayne area and are less applicable to the assemblage in the Hornepayne area where the economic viability of documented occurrences has not been proven yet. However, there remains the potential for mineralization in the portion of the Manitouwadge-Hornepayne greenstone belt that lies within the Hornepayne area.

5.2.2 Precious Metals

No precious metal mineralization has been identified in the Hornepayne area. Silver was historically mined in the Geco, Willroy and Nama Creek mines approximately 50 km west of the Township of Hornepayne, near the Manitouwadge synform and gold was mined at the historic Hiawatha Mine near the Dayohessarah-Kabinakagami greenstone belt approximately 30 km southeast of the Township. However, the potential for this type of mineralization in the Hornepayne area is low (Williams, 1991).

5.2.3 Uranium

There is one discretionary mineral occurrence of uranium in the metasedimentary rocks of the Quetico Subprovince on the east side of the Hornepayne area (Figure 5.1). No information was found regarding the mineralization of this discretionary occurrence and its economic viability has not been proven yet.

5.2.4 Rare Metals

Rare earth minerals have not been identified in the Hornepayne area. However pegmatites containing rare elements are potentially present throughout the Quetico Subprovince, from the Wisa Lake area approximately 450 km to the west of Hornepayne, to Hearst approximately 90 km to the northeast (Breaks et al., 2003).

5.3 Non-Metallic Mineral Resources

Known non-metallic mineral resources within the Hornepayne area include sand and gravel, stone, garnet, diopside, graphite and peat. There is a discretionary occurrence of peat in the northwest portion of the Hornepayne area (Figure 5.1).

5.3.1 Sand, Stone and Gravel

Gartner and McQuay (1980a; 1980b) estimated a low potential for sand, gravel and stone resources in the Hornepayne area. Portions of rock outcrop in the area may have the potential to be used as crushed stone resources, but no quarrying is known to have occurred in the Hornepayne area. The tonalitic gneisses of the Black-Pic batholith represent a potential source of dimension stone where homogeneous exposures with few fractures can be found (Williams and Breaks, 1996).

5.3.2 Diamonds

No diamond-bearing kimberlites or lamproites have been identified in the Hornepayne area, although the potential for the Canadian Shield to host economic diamond deposits has been demonstrated by a number of mines in the Northwest Territories and Ontario (Williams and Breaks, 1996).

5.3.3 Industrial Minerals

A graphite occurrence, called the Miller graphite occurrence, has been documented approximately 30 km west of the Township of Hornepayne (Figure 5.1). Graphite-rich beds of medium-grained granular textured quartzites are found interbedded within the metasedimentary rocks of the Quetico Subprovince. Canadian International Minerals Inc. has joined a prospecting syndicate that has obtained the claim for the graphite occurrence (Newswire, 2012), although the economic viability of this occurrence has not been proven.

Diopside and garnet have been known to occur in pods within migmatitic rocks in the Hornepayne area (Williams and Breaks, 1996), but no economically viable deposits have been identified.

5.4 Abandoned Mine Sites

The AMIS database (MNDM, 2011) contains data on the abandoned mines and inactive mines for the Province of Ontario, including the Hornepayne area. Some of the abandoned/inactive mines were for mineral exploration, and do not necessarily indicate these were producing sites. Also, the AMIS data base is not considered to be complete, some abandoned/inactive mines may not be contained in the database.

There are no entries in the AMIS database for abandoned or inactive mines in the Hornepayne Area.

6 GEOMECHANICAL PROPERTIES

Geomechanical information including intact rock properties, rock mass properties and in-situ stresses are needed to design stable underground openings, and to predict the subsequent behaviour of the rock mass around these openings. As such, geomechanical information associated with a potential host rock can be used when addressing several geoscientific, safety-related factors defined in the site selection process document (NWMO, 2010). There is no readily available geomechanical information on the potentially-suitable geologic units in the Hornepayne area.

Table 6.1 summarizes available geomechanical information from bedrock units elsewhere in the Canadian Shield for granitic and metasedimentary gneissic rocks similar to those of interest in the Hornepayne area. These sites are the Lac du Bonnet granite at AECL's Underground Research Laboratory (URL) in Pinawa, Manitoba; the Eye-Dashwa granite near Atikokan, Ontario; the Indian Lake batholith, Revell batholith and Basket Lake batholith granites near Ignace, Ontario; and orthogneisses and paragneisses at Chalk River, Ontario. The majority of the geomechanical characterization work for the URL was conducted on these rocks as part of AECL's Nuclear Fuel Waste Management Program in the 1990s.

6.1 Intact Rock Properties

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

No information on intact rock properties is available for the Hornepayne area. In the absence of site-specific information, at this early stage of the site assessment process it is useful to look at the geomechanical properties of other intact crystalline rocks. Data on intact rock strengths and elastic properties of gneissic rocks including paragneisses and orthogneisses are available from studies completed at the Chalk River Laboratories. Based on data reported by Annor et al. (1979) and Larocque and Annor (1985) uniaxial compressive strengths of 100-200 MPa, tangent elastic moduli of 80-100 GPa and Poisson's ratio of 0.2-0.3 may be expected for metasedimentary rocks and gneisses. These reported ranges of geomechanical properties may be representative of metasedimentary and foliated/gneissic rocks in the Hornepayne area.

Data on intact rock strengths and elastic properties of massive granitic intrusions are available from studies completed at the granitic Lac du Bonnet batholith and the granitic Eye-Dashwa Lake pluton. Based on data reported by Annor et al. (1979), Larocque and Annor (1985), Stone et al. (1989) and Baumgartner et al. (1996), uniaxial compressive strengths of 140-230 MPa, tangent elastic moduli of 60-90 GPa and Poisson's ratio of 0.2-0.3 may be expected for massive granitic to granodioritic intrusive rocks. These reported ranges of geomechanical properties may be representative of intact intrusive granitic/granodioritic rocks of potentially suitable geologic units in the Hornepayne area.

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

Property	*Lac du Bonnet Granite*	*Eye-Dashwa Lake Granite*	*Indian Lake Batholith Granite*	*Revell & Basket Lake Batholith Granite*	*Chalk River Gneiss*
Uniaxial Compressive Strength (MPa)	185 ± 24[b,e]	212 ± 26[c]	180[a]	NA	100-200[d]
Split Tension Strength (Brazilian) (MPa)	4 to 9[d]	NA	NA	NA	NA
Porosity (%)	0.35[b]	0.33[b]	NA	NA	NA
P-wave velocity (km/s)	NA	NA	NA	NA	NA
S-wave velocity (km/s)	NA	NA	NA	NA	NA
Density (Mg/m^3)	2.65[b]	2.65[b]	2.6[c]	2.6[c]	NA
Young's Modulus (GPa)	66.8[b,e]	73.9[b]	NA	NA	80-100[d]
Poisson's Ratio	0.27[b,e]	0.26[b]	NA	NA	0.2-0.3[d]
Thermal Conductivity (W/(mK))	3.4[b]	3.3[b]	NA	NA	NA
Coef. Thermal Expansion ($x10^{-6}/^{o}C$)	6.6[b]	15[b]	NA	NA	NA

NA = Not Available

[a]Brisbin et al. (2005)
[b]Stone et al. (1989)
[c]Szewcyk and West, (1976)
[d]Annor et al. (1979); Laroque and Annor (1985)
[e]Baumgartner et al. (1996)

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 of the fractures tend to dominate the overall mechanical response of the rock mass.

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. In general, there will be a downward decreasing fracture density from highly fractured rocks in shallow horizons (ca. < 300 metres below ground surface) to sparsely fractured intact rock at greater depths as 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.

There is no information available on rock mass properties of the granitic intrusions and metasedimentary rocks in the Hornepayne area. Typically, information on rock mass properties including rock quality and natural fracture frequency have been assessed based on borehole and core logging as well as surface outcrop fracture mapping. A wide range of rock quality and fracture frequency is expected for potentially suitable geologic units reflecting the site-specific structural and tectonic history and the proximity to major faults and fracture zones. Lacking site-specific information on rock mass properties for rocks in the Hornepayne area, data from sites with comparable geologic units in the Canadian Shield provides insight to possible rock mass properties in the Hornepayne area.

Data on rock quality and fracture frequency of gneissic rocks are available from studies completed at the Chalk River Laboratories. Data reported by Raven (1980) and Sikorsky et al. (2011) indicate the granodioritic-monzonitic gneiss at the Chalk River Laboratories site are moderately to highly fractured based on ISRM (1977) guidance with fair to excellent rock quality as determined from Rock Quality Designation calculations. Given the proximity of the Chalk River Laboratories property to the major Ottawa-Mattawa fault, rock quality and fracture frequency of metasedimentary and foliated/gneissic rocks in the Hornepayne area may be expected to be better than evidenced at Chalk River depending upon presence of, and proximity to, major structural discontinuities including regional and local scale faults and shear zones such as those anticipated near the subprovince boundary.

Data on rock quality and fracture frequency of massive granitic intrusions are available from studies completed at the granitic Lac du Bonnet batholith and the granitic Eye-Dashwa Lake pluton. Based on data reported by Stone et al. (1989) and Sikorsky (1996), granitic intrusions may range from unfractured to highly fractured, with fair to excellent rock quality. Similar rock quality and fracture frequency data are available for granodioritic gneisses based on data reported by Sikorsky et al. (2011) for the bedrock at the Chalk River Laboratories. These reported ranges of rock quality and fracture frequency may be representative of intrusive granitic-granodioritic rocks of potentially suitable geologic units in the Hornepayne area.

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

6.3 In-Situ Stresses

Knowledge of the in-situ stress 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 in potentially suitable geologic units in the Hornepayne area, although there have been in-situ stress measurements made in underground mines in the Wawa Subprovince outside of the Hornepayne area (Figure 6.1). The nearest in-situ stress measurements were taken in metasedimentary/metavolcanic rocks at depths of 1000 mBGS at the David Bell Mine located southwest of the Hornepayne area at Marathon, Ontario

(Kaiser and Maloney, 2005). The reported maximum principal stress data available from two sets of tests were 34.7 and 44.6 MPa oriented south, with the minimum principal stress being subvertical.

More extensive in-situ stress testing was done in metavolcanic rocks at depths of 360 to 810 mBGS at the MacLeod Mine located in the Municipality of Wawa. The minimum principal stress was vertical (Arjang and Herget, 1997). The reported maximum principal stress data available from 11 sets of tests ranged from 17.4 to 53.7 MPa with an average value of 32 MPa. The maximum principal stress was subhorizontal and oriented from the north-northwest to east-northeast (Kaiser and Maloney, 2005). The intermediate principal stress was also subhorizontal and comparable in magnitude to the maximum principal stress, suggesting a predominantly horizontally isotropic stress regime. Herget (1973) noted that some of the measured directions of maximum compressive stresses aligned with directions of maximum compression (north-northwest) deduced from kinematic analysis of slaty cleavage, transverse faults and fracture slickensides. A maximum principal stress direction of east-northeast is similar to that indicated by the World Stress Map (Zoback, 1992).

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 (Figure 6.1), 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 (Figure 6.1). The dataset presented by Maloney et al. (2006) indicate an average northeast 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 southern orientation of maximum horizontal compressive stress was found for the Sioux Falls Quartzite in South Dakota (Haimson, 1990), as well as in the Wawa Subprovince near Marathon, Ontario (David Bell Mine) (Kaiser and Maloney, 2005).

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

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

6.4 Thermal Conductivity

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

There are no site-specific thermal conductivity values or detailed quantitative mineral compositions for the Hornepayne area. However, the mineralogy of the principal geologic units in the Hornepayne area is described in Section 3.2.1. Available information indicates that the compositions of some of these potentially suitable geologic units range from granite and granodiorite to tonalite. The range of measured thermal conductivity values for these rock types found in the literature are presented in Table 6.2.

Table 6.2 Thermal Conductivity Values for Granite, Granodiorite and Tonalite

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

[a]Petrov et al. (2005); [b]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]Fernández et al. (1986); [h]de Lima Gomes and Mannathal Hamza (2005);
[i]Andersson et al. (2007).

Although no thermal conductivity values are available for the Hornepayne area, some useful comparisons are also 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. Both intrusions were described as having similar mineralogical compositions, with quartz content generally varying between 23 and 27%. The average thermal conductivity for the Eye-Dashwa pluton was 3.3 W/(m˚K) based on 35 samples. The average thermal conductivity for the Lac du Bonnet batholith was 3.4 W/(m˚K) based on 227 samples.

The above literature values for thermal conductivity are considered useful for comparison purposes as part of this preliminary assessment. However, actual values and the effect of dykes on thermal conductivity will need to be determined at later stages of the assessment, during the collection of site-specific information.

7 POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE HORNEPAYNE AREA

7.1 Approach

The objective of the Phase 1 desktop geoscientific preliminary assessment is to assess whether the Hornepayne area contains general areas that have the potential to satisfy the geoscientific evaluation factors and safety functions outlined in the site selection process document (NWMO, 2010). The location and extent of general potentially suitable general 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 was assessed using the following key geoscientific characteristics:

- ***Geological setting:*** Areas of unfavourable geology identified during the initial screening (Golder, 2011) were not considered. Such areas include rocks of the Manitouwadge-Hornepayne greenstone belt, in the southern half of the Hornepayne area and along the subprovince boundary (Figure 3.4). These geologic units were considered not suitable due to their heterogeneity, structural complexity and potential for mineral resources. Metasedimentary and intrusive rocks in the northern half of the Hornepayne area, as well as rocks of the Black-Pic batholith were considered as potentially suitable host rocks.

- ***Structural Geology:*** Areas within or immediately adjacent to regional faults and shear zones were considered unfavourable. The main structural feature within the Hornepayne area is the Quetico-Wawa subprovince boundary, which cross-cuts the Hornepayne area (Figure 3.4). It is characterized as a regional shear zone, with an interpreted deformation zone of about 15 kilometres wide (PGW, 2013). The thickness of potentially suitable units was also considered when identifying potentially suitable areas. Metasedimentary rocks of the Quetico Subprovince are estimated to be about 7.5 km thick. The Black-Pic batholith is expected to be greater than 1 to 3 km in thickness, which is largely sufficient for the purpose of siting a deep geological repository.

- ***Lineament Analysis:*** In the search for potentially suitable areas, there is a preference to select areas that have a relatively low density of lineaments, particularly a low density of longer lineaments as they are more likely to extend to greater depth than shorter lineaments. For the purpose of this assessment, all interpreted lineaments (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 m of overburden deposits would not be amenable to trenching for the purpose of structural mapping. This consideration is consistent with international practices related to site characterization in areas covered by overburden deposits (e.g. Finland; Andersson et al., 2007). At this stage of the assessment, preference was given to areas with greater mapped bedrock exposures. The extent of bedrock exposure in the Hornepayne area is shown on Figure 2.3. Areas mapped as bedrock terrain are assumed to be covered, at most, with a thin veneer of overburden and are therefore considered amenable to geological mapping.

- ***Protected Areas:*** The only provincial park in the Hornepayne area is the Nagagamisis Provincial Park (425 km^2), which overlies a portion of the granitic and metasedimentary rocks in the northern half of the Hornepayne area (Figure 1.1). This provincial park was excluded from consideration.

- ***Natural Resources:*** The potential for natural resources in the Hornepayne area is shown on Figure 5.1. Areas with known potential for exploitable natural resources were excluded from further consideration. These include the metavolcanic rocks of the Manitouwadge-Hornepayne greenstone belt. The mineral potential of the potentially suitable geological units identified above is considered to be low. At this stage of the assessment, areas of active mining claims located in geologic environments judged to have low mineral resource potential were not systematically excluded.

- ***Surface Constraints:*** Areas of obvious topographic constraints (e.g., density of steep slopes), large water bodies (wetlands, lakes), and accessibility were considered for the identification of potentially suitable areas. While areas with such constraints were not explicitly excluded at this stage of the assessment, they are considered less preferable than areas without such constraints, all other factors being equal. The distribution of surface water bodies across the Hornepayne area is relatively uniform (Figure 1.1), with larger lakes covering part of the metasedimentary rocks (e.g. Nagagami and Nagagamisis lakes), and portions of the Black-Pic batholith (e.g. Obakamiga, Kabinakagamisis and Cameron lakes). Topography is generally flat, with a more rugged terrain in the southwestern sector of the Hornepayne area (Figure 2.2). Most of the central and northeastern portions of the Hornepayne area are accessible by Highway 631 and a number of existing logging roads. Access to the western part and portions of the eastern part of the Hornepayne area by the existing road network is limited (Figure 1.1).

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the above key geoscientific characteristics revealed that the Hornepayne area contains general areas where there is a potential to find suitable sites for hosting a deep geological repository. These general areas are located within the Black-Pic batholith and the metasedimentary rocks of the Quetico Subprovince. Figure 7.1 shows features illustrating some of the key characteristics and constraints used to identify general potentially suitable areas, including: bedrock geology; protected areas; areas of thick overburden cover; surficial and geophysical lineaments, existing road network, the potential for natural resources and mining claims. Zoomed-in views of the Black-Pic batholith and the metasedimentary rocks of the Quetico Subprovince are shown on Figures

7.2 and 7.3, respectively. The legend of each figure includes a 2 km by 3 km box to illustrate the approximate extent of suitable rock that would be needed to host a repository.

The following sections provide a summary of how the key geoscientific characteristics discussed above were applied to the various geological formations within the Hornepayne 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 Black-Pic Batholith

As discussed in section 3.2.1.3, the Black-Pic batholith is a large multiphase intrusion that extends over the southern half of the Hornepayne area. It was emplaced between approximately 2.720 and 2.689 billion years ago and is mostly composed of tonalite, with associated granite-granodiorite phases (Figures 3.4 and 7.1). The thickness of the batholith is unknown, but based on the regional extent of the intrusion it is expected to be greater than 1 to 3 km (Szewcyk and West, 1976; Percival et al., 2012). The east-west trending Wawa-Quetico subprovince boundary separates the Black-Pic batholith from the metasedimentary rocks of the Quetico Subprovince to the north. The subprovince boundary is characterized as a major shear zone. Also, interpretation of available geophysical data in the Hornepayne area recognized a high abundance of subparallel lineations that are most likely associated with an approximately 15 km wide zone of deformation straddling the mapped subprovince boundary.

The Black-Pic batholith has low potential for natural resources, and is mostly free of protected areas and significant surface constraints (i.e., topography and large water bodies). Identification of potentially suitable areas within this intrusion was mainly based on geological setting, structural geology (e.g., setback from the Wawa-Quetico subprovince boundary), lineament analysis and overburden cover.

Two general potentially suitable areas were identified in the Black-Pic batholith. One potentially suitable area was identified along the south-central margin of the Hornepayne area, south of Hornepayne Lakes and between Mitchell Lake and Star Lake. The other potentially suitable area lies in the western portion of the Black-Pic batholith, between Granitehill Lake, Cholette Lake and Obakamiga Lake (Figures 7.1 and 7.2). Both areas show relatively good bedrock exposure and are fairly away from the subprovince boundary. However, given the resolution of available data, the potential impact of the subprovince boundary on the suitability of the two identified areas would need to be further assessed during subsequent site evaluation stages. The magnetic signature over the gneissic tonalite in the two potentially suitable areas is the most subdued of the entire Black-Pic batholith (Figures 3.6 and 3.7), which may suggest lithological homogeneity (PGW, 2013).

Additional insight into the potential suitability of the two identified areas is provided by the analysis of interpreted lineaments (section 3.2.3.3). The two areas identified in the south-central and western portions of the Black-Pic batholith encompass areas of low density of geophysical lineaments, most of which have been interpreted as dykes (Figures 3.10 and 7.2). The density of geophysical lineaments in the western potentially suitable area remains low despite the higher resolution of available geophysical data as compared to the south-central area. Also, there appears to be good continuity between dykes interpreted on both potentially suitable areas despite the differences in data resolution.

Interpreted dykes within the two areas are generally consistent with those mapped by the Ontario Geological Survey, with spacing between geophysical dyke lineaments on the order of 3 to 5 km and well defined northwest and northeast orientations (Figures 3.10 and 7.2). As discussed in Section 3.2.1, the Hornepayne area contains numerous mapped and interpreted dykes as it lies within regional dyke swarms. Although a large number of these dykes are identifiable in the aeromagnetic data in the Hornepayne area, there still remain some uncertainties regarding the distribution and structural impact of the dykes. As discussed in section 3.2.3, main uncertainties are related to: the potential for smaller-scale dykes to be present between interpreted dykes; the potential underestimation of geophysical brittle (fractures) and ductile lineaments due to the predominance and masking effect of the dyke signal in the geophysical dataset; and the potential damage that may have been caused to the host rock during dyke emplacement.

The assessment of potentially suitable areas within the Black-Pic batholith also took into consideration interpreted surficial lineaments. Figure 3.9 shows the surficial lineament density within the Black-Pic batholith to be generally moderate with some high density areas in the west where bedrock exposure is predominant and along the subprovince boundary. However, surface lineament density over the general potentially suitable areas in the south-central and western portions of the batholith is amongst the lowest of the intrusion, despite good bedrock exposure, suggesting a less fractured rock mass in these areas. At the desktop stage of the assessment it is uncertain if surficial lineaments represent real bedrock structure and how far they extend to depth, particularly the shorter lineaments.

The distribution of lineament density as a function of lineament length over the Black-Pic batholith is shown on Figures 3.14 to 3.17 for all lineaments and lengths greater than 1 km, 5 km and 10 km, respectively. Potentially suitable areas within the Black-Pic batholith show relatively low density of short (Figure 3.14) and long (Figure 3.17) lineaments. In general, the density of lineaments progressively decreases throughout the batholith and in the potentially suitable areas as shorter lineaments are filtered out. The density of surficial and geophysical lineaments within the south-central portion of the Black-Pic batholith is low regardless of filtering (Figures 3.14). It should be noted, however, that resolution of geophysical data in this area is low (805 m line spacing).

Potentially suitable areas identified in the Black-Pic batholith comprise predominantly Crown land (Figure 2.5), and do not contain any protected areas. The areas are free of active mining claims as shown on Figures 5.1 and 7.2. The area in the south-central portion of the batholith is easily accessible by Highway 631. However, accessibility to the potentially suitable area to the west is limited (Figure 1.1). Relief in these areas is moderate, and drainage is good. Lake/wetland cover in the area on the south-central portion of the batholith is low, while in the western potentially suitable area there are a number of relatively large lakes (e.g. Obakamiga and Granitehill lakes).

7.2.2 Metasedimentary Rocks of the Quetico Subprovince

The northern half of the Hornepayne area is underlain by metasedimentary rocks and granite to granodiorite intrusions of the Quetico Subprovince (Figures 3.4 and 7.1). Metasedimentary rocks of the Quetico Subprovince in the Hornepayne area are mostly composed of paragneisses and migmatites (i.e. highly metamorphosed sedimentary rocks that underwent partial melting). These metasedimentary rocks have an estimated thickness of about 7.5 km (Percival, 1989), although the thickness of this geologic unit is interpreted to slightly decrease along the border of the Quetico and Wawa subprovinces (Percival, 1989). The deposition of the original sedimentary rocks was initiated approximately 2.698 billion years ago, and its termination is constrained to approximately 2.688 billion years ago (Zaleski et al., 1999). As described in the previous section, the metasedimentary rocks are separated from the Black-Pic batholith by the Wawa-Quetico subprovince boundary that runs east-west through the middle of the Hornepayne area.

The metasedimentary rocks of the Quetico Subprovince have low potential for natural resources, and are mostly free of protected areas and significant surface constraints (i.e., topography and large water bodies). Therefore, the differentiating factors for identifying potentially suitable areas within these rocks were considered to be geological setting, structural geology (setback from the subprovince boundary), overburden cover and, to a limited extent, lineament analysis.

The assessment of the key geoscientific characteristics identified one general potentially suitable area located immediately northeast of the Township of Hornepayne, and east of Highway 631. The area shows good bedrock exposure (Figures 2.3 and 7.3) and lies away from the interpreted deformation zone associated with the subprovince boundary. As for the two other potentially suitable areas identified in the Black-Pic batholith, it is uncertain to what extent the suitability of this area is affected by the presence of the subprovince boundary and associated deformation. Also, while the bedrock in the potentially suitable area is mapped entirely as metasedimentary rock, lithological homogeneity is uncertain at this stage due to the varying degree of metamorphism that these rocks experienced in the past.

The identification of potentially suitable areas in the metasedimentary rocks also took into consideration the analysis of interpreted lineaments (section 3.2.3.1). Figure 3.10 shows that geophysical lineament density over the metasedimentary rocks of the Quetico Subprovince is generally low with higher density of geophysical lineaments in the western portion, where higher resolution geophysical data is available. The density of geophysical lineaments in the potentially suitable area northeast of the Township is fairly low. Northwest-trending lineaments in this area are interpreted as dykes, some of which are coincident with dykes mapped by the Ontario Geological Survey. Mapped and interpreted dykes in the Hornepayne area show distinct and well defined orientations. Northeast-trending lineaments in this area are interpreted as fractures, and are subparallel to a mapped, long fault (Figure 3.10). The spacing between interpreted/mapped dykes and fractures in the potentially suitable area are on the order of 1.5 to 3 km, and 1 to 4 km, suggesting the potential to for structurally bounded rock volumes of sufficient size to host a deep geological repository. However, as discussed in the previous section, there still remain inherent uncertainties regarding the distribution, density and structural impact of the dykes in the Hornepayne area.

Figure 3.9 shows that the density of surficial lineaments ranges from low to high within the Quetico Subprovince in the Hornepayne area, with the highest densities to the west along the subprovince boundary and where predominant bedrock exposure exists. Surficial lineament density over the identified potentially suitable area is fairly low despite good bedrock exposure, which suggests a less fractured rock mass.

The distribution of lineament density as a function of lineament length over the metasedimentary rocks of the Quetico Subprovince is shown on Figures 3.14 to 3.17 for all lineaments and lengths greater than 1 km, 5 km and 10 km, respectively. The figures show that, in general, the density of lineaments progressively decreases throughout the metasedimentary rocks and the general potentially suitable area as shorter lineaments are filtered out. The total density of surficial and geophysical lineaments within the potentially suitable area is low regardless of filtering (Figures 3.14 and 7.3).

The potentially suitable area northeast of the Township comprises predominantly Crown land (Figure 2.5), and does not contain any protected areas or active mining claims as shown on Figures 5.1 and 7.3. Access to this area is easy via an extensive network of recreation roads and Highway 631, and relief is moderate to high with numerous granitic knobs and domes characterizing the terrain. Drainage is good throughout the area with minimal lake/wetland cover.

In summary, three general potentially suitable areas were identified within the Black-Pic batholith and the metasedimentary rocks of the Quetico Subprovince based on geology, structural geology (i.e. offset from the subprovince boundary), bedrock exposure and lineament interpretation. These potentially suitable areas appear to have favourable lineament density, good bedrock exposure, low potential for economically exploitable natural resources, and lie away from the Wawa-Quetico subprovince boundary. The areas are also outside of protected areas and are generally accessible.

Inherent uncertainties remain in relation to the potential influence of the subprovince boundary; the potential presence of smaller-scale dykes not identifiable on aeromagnetic data; the potential underestimation of geophysical lineaments due to the masking effect of dykes on the aeromagnetic signal; and the potential damage of the host rock due to dyke emplacement. These uncertainties would need to be further assessed through more detailed field evaluations, including the acquisition and interpretation of higher resolution airborne geophysical surveys, field geological mapping and the drilling of boreholes.

7.2.3 Other Areas

No general potentially suitable areas were identified within the granite-granodiorite intrusions in either the Quetico or Wawa subprovinces. The granite-granodiorite intrusions of the Quetico Subprovince are of limited extent and in areas of extensive overburden cover and proximal to or covered by protected areas. In the Wawa Subprovince, the granite-granodiorite intrusions are in areas of high lineament density and extensive overburden cover (Figure 7.1).

Given the large geographic extent of the Hornepayne area, it may be possible to identify other general potentially suitable areas. However, the three areas identified are those judged to best meet the preferred site characteristics outlined in Section 7.1, based on the currently available information.

7.2.4 Summary of Geoscientific Characteristics of the General Potentially Suitable Areas

Table 7.1 provides a summary of key geoscientific descriptive characteristics of the general areas in the Black-Pic batholith and the metasedimentary rocks of the Quetico Subprovince in the Hornepayne area.

Table 7.1 Summary of Geoscientific Characteristics of the General Potentially Suitable Areas – Hornepayne Area

Geoscientific Descriptive Characteristic	***General Potentially Suitable Areas***		
	Black-Pic batholith (south-central area)	***Black-Pic batholith (western area)***	***Metasedimentary rocks (Quetico Subprovince)***
Composition	Foliated to gneissic tonalite	Foliated to gneissic tonalite	Metasedimentary rocks
Age	ca. 2.720 to 2.689 billion years	ca. 2.720 to 2.689 billion years	ca. 2.698 to 2.688 billion years
Inferred host rock thickness	> 1 to 3 km	> 1 to 3 km	> 7.5 km
Extent of geologic unit in the Hornepayne area	1,985 km^2	1,985 km^2	1,934 km^2
Relative proximity to mapped structures (faults, shear zones, subprovince boundaries, etc.)	Subprovince Boundary - 20 km Gravel River fault – 93 km Unnamed NW fault – 53 km Nearest mapped fault – 11 km	Subprovince Boundary – 14 km Gravel River fault – 77 km Unnamed NW fault (Quetico SP) – 55 km Nearest mapped fault – 5 km	Subprovince Boundary – 10 km Gravel River fault – 75 km Unnamed NW fault (Quetico SP) – 20 km Nearest mapped fault – 4 km
Structure: faults, foliation, dykes, joints	Low to moderate apparent surface lineament density Low apparent geophysical lineament density OGS mapped dykes	Moderate apparent surface lineament density Low to moderate apparent geophysical lineament density OGS mapped dykes	Low to moderate surface lineament density Low to moderate apparent geophysical lineament density One unnamed OGS mapped fault OGS mapped dykes
Aeromagnetic characteristics and resolution	Moderately noisy to quiescent, low resolution	Moderately noisy to quiescent, high resolution	Moderately noisy, low resolution
Terrain: topography, vegetation	Low to moderate relief, sparsely forested, outwash plains	Moderate to high relief, sparsely forested, several large lakes	Low to moderate relief, sparsely forested
Access	Good access via highway and via recreation road	Poor access - closest road is 14.3 km to east (collector) or 16 km to southeast (recreation road)	Good access via network of recreation roads and a highway
Resource potential	Low	Low	Low
Overburden cover	~46%	~35%	~31%
Drainage	Generally good (16% surface water)	Generally good (38% surface water)	Generally good (4% surface water)

7.3 Evaluation of the General Potentially Suitable Areas in the Hornepayne 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 three general potentially suitable areas in the Hornepayne area in the Black-Pic batholith and the metasedimentary rocks of the Quetico Subprovince 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 function 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.

As discussed in Section 3 and summarized in Table 7.1, available information reviewed as part of this preliminary assessment indicates that the estimated thicknesses of the Black-Pic batholith and the metasedimentary rocks of the Quetico Subprovince are at least 1 and 7.5 km, respectively. Therefore, the depth of the rock in the three potentially suitable areas identified in these geologic units (Section 7.2) is likely to extend well below typical repository depths (approximately 500 m), which would contribute to the isolation the repository from human activities and natural surface events.

Analysis of lineaments interpreted during this preliminary assessment (Sections 3.2.3) indicates that the three general areas in the Hornepayne area have the potential to contain structurally-bounded rock volumes of sufficient size to host a deep geological repository. The distribution of lineament density as a function of lineament length over the potentially suitable host rocks shows that the variable density and spacing of shorter brittle lineaments is strongly influenced by the amount of exposed bedrock and by geophysical data resolution (Figures 3.14 to 3.17). By classifying the lineaments according to length, this local bias is greatly reduced and the spacing between lineaments increases as shorter lineaments are filtered out. Longer lineaments are more likely to extend to greater depth than shorter lineaments. All three general areas exhibit lineament spacing between longer lineaments (i.e., those longer than 10 km) on the order of 3 to 5 km. The general areas are located away from regional deformation zones, such as that associated with the Wawa-Quetico subprovince boundary. However, the potential impact of this deformation zone on the three potentially suitable areas needs to be further assessed.

As discussed in Section 4.4, there is limited information on the hydrogeologic properties of the deep bedrock in the Hornepayne 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 three identified general areas. The potential for groundwater movement at repository depth is, in part, controlled by the fracture frequency, the degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of mineral infilling. Available information 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. At greater depths, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). However, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion-controlled conditions. Hydraulic conductivity values measured in crystalline rocks at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan range from approximately 10^{-15} m/s to 10^{-10} m/s (Ophori and Chan, 1996; Stevenson et al., 1996). Data reported by Raven et al. (1985) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400-500 m.

Also, experience from other areas with similar types of rocks in the Canadian Shield indicates that ancient faults, similar to those in the Hornepayne 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 Hornepayne area would need to be investigated at later stages of the site evaluation process.

Numerous dykes have been mapped and interpreted in the Hornepayne area, as it lies within a region of dyke swarms. 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.

Information on other geoscientific characteristics relevant to the containment and isolation function of a deep geological repository, such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, the thermal and geomechanical properties of the rock is limited for the Hornepayne 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 bedrock underlying the three general areas identified within the Hornepayne area (Sections 4. and 7.2). In the Hornepayne area, there is an additional uncertainty related to the potential impact of dykes on the thermal conductivity of the surrounding host rocks. Site specific mineralogical and hydrogeochemical characteristics, including pH, Eh and salinity, would need to be assessed during subsequent site evaluation stages.

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

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

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

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

The Hornepayne area is located in the Superior Province of the Canadian Shield, where large portions of land have remained tectonically stable for the last ca. 2.5 billion years (Percival and Easton, 2007). Although a number of low magnitude seismic events have been recorded near the Hornepayne area over the past 25 years, there are only three recorded earthquakes occurring in the Hornepayne area (Section 3.3) over the period 1985 to 2012, all of which were between magnitudes 2.0 to 3.0 (Nuttli Magnitude). As discussed in Sections 3.1 and 3.2, the east-west trending Wawa-Quetico subprovince boundary that cross-cuts the Hornepayne area is characterized as a regional shear zone. However the three identified general areas lie away from the subprovince boundary and its associated zone of deformation.

The geology of the Hornepayne area is typical of many areas of the Canadian Shield, which have been subjected to numerous glacial cycles during the last million years. Glaciation is a significant past perturbation that could occur again in the future. However, findings from studies conducted in other areas of the Canadian Shield suggest that deep crystalline rocks, particularly plutonic intrusions, have remained largely unaffected by past perturbations such as glaciation. Findings of a comprehensive paleohydrogeological study of the fractured crystalline rock at the Whiteshell Research Area, located within the Manitoba portion of the Canadian Shield (Gascoyne, 2004), 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 are ancient features. Subsequent geological processes such as plate movement and continental glaciation have typically caused reactivation of existing zones of weakness rather than the formation of large new zones of fractures.

Land in the Hornepayne area is still experiencing isostatic rebound following the end of the Wisconsinan glaciations (Section 3.3.2). Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella et al., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1-2 mm/yr) south of the Great Lakes. Lake level records (Mainville and Craymer, 2006) indicate that present day rebound rates in the Hornepayne area should be well below 10 mm/yr, likely between 2 and 4 mm/yr. There is no site-specific information on erosion rates for the Hornepayne area. However, as discussed in Section 3.1.6, the erosion rates from wind, water and past glaciations on the Canadian Shield are reported to be low.

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

7.3.3 Safe Construction, Operation and Closure of the Repository

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

This requires that:

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

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

From a constructability perspective, limited site-specific information is available on the local rock strength characteristics and in-situ stresses for the potentially suitable geologic units in the Hornepayne area. However, there is abundant information at other locations of the Canadian Shield with similar types of rock that could provide insight into what might be expected for the Hornepayne area in general. As discussed in Section 6, available information suggests that granitic and gneissic metasedimentary rock units within the Canadian Shield generally possess good geomechanical characteristics that are amenable to the type of excavation activities involved in the development of a deep geological repository for used nuclear fuel (Herget, 1973; Arjang and Herget, 1997; Everitt, 2002; McMurry et al., 2003; Chandler et al., 2004). The conceptual model developed by Kaiser and Maloney (2005), based on available stress measurement data, describes the variable stress state in the upper 1,500 m of the Canadian Shield. Although this model can be used as an early indicator of average stress changes with depth, significant variations such as the principal horizontal stress rotation and the higher than average stress magnitudes found at typical repository depth (500 m) at AECL's URL (Martino et al., 1997) could occur as a result of local variations in geological structure and rock mass complexity.

The three general areas are situated in areas having a reasonable amount of outcrop exposure. At this stage of the site evaluation process it is not possible to accurately determine the exact thickness of the overburden deposits in these areas due to the low resolution of available data. However, it is anticipated that overburden cover is not a limiting factor in any of the identified general areas.

In summary, the three identified general potentially suitable areas in the Hornepayne area have good potential to satisfy the safe construction, operation and closure function.

7.3.4 Isolation of Used Fuel from Future Human Activities

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

This requires that:

- The repository should not be located within rock units 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 geologic units containing groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.

The mineral potential in the Hornepayne area is limited to the rocks of the Manitouwadge-Hornepayne greenstone belt, which have been proved to have potential for economic mineralization west of the Hornepayne area (Section 5). No known economic mineralization has been identified to date within the Black-Pic batholith or the metasedimentary rocks of the Quetico Subprovince in or around the Hornepayne area.

The review of available information did not identify any groundwater resources at repository depth for the Hornepayne area. As discussed in Section 4, the MOE Water Well Information System (WWIS) database shows that all water wells known in the Hornepayne area obtain water from overburden or shallow bedrock sources ranging from 1 to 119 m. Experience from other areas in the Canadian

Shield with similar types of rock has shown that active groundwater flow in crystalline rocks is generally confined to shallow fractured localized systems (Singer and Cheng, 2002). The MOE WWIS indicates that no potable water supply wells are known to exploit aquifers at typical repository depths in the Hornepayne area or anywhere else in northern Ontario. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits potential yield, even if suitable water quality were to be found.

In summary, the potential for the containment and isolation function of a repository in the Hornepayne area to be disrupted by future human activities is low.

7.3.5 Amenability to Site Characterization and Data Interpretation Activities

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

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

As described in Section 3, the bedrock in the two general areas identified in the Black-Pic batholith is mapped as relatively homogeneous gneissic tonalite, geology that would not be difficult to characterize. While bedrock in the general area identified in the Quetico Subprovince is mapped entirely as metasedimentary, there is uncertainty on the lithological homogeneity based on interpretation of magnetic data. Also, lithological characteristics of the metasedimentary rocks in this area may be a bit more complex due to the variable degree of metamorphism and migmatization they have gone through. However at his stage of the assessment, such uncertainties are not considered to pose an impediment to site characterization.

Interpreted lineaments represent the observable two-dimensional expression of three-dimensional features. The ability to detect and map such lineaments is influenced by topography, the character of the lineaments (e.g., their width, orientation, age, etc.), and the underlying resolution of the data used for the mapping. Interpreted geophysical dyke lineaments in the entire Hornepayne area, including in the identified general areas, show distinct, very well defined orientations (i.e. northwest, and northeast), which aids the amenability to characterize these features. The degree of structural complexity associated to the orientation of lineament features in three dimensions will need to be further assessed through detailed site investigations in future phases of the site selection process.

The identification and field mapping of structures is strongly influenced by the extent and thickness of overburden cover and the presence of large water bodies. Extensive overburden deposits in the Hornepayne are mostly found to the north and east, although the three identified general areas have fairly good bedrock exposure. A few large lakes that could potentially conceal the surface expression of geological structures exist in the general area identified in the western portion of the Black-Pic batholith. However surface water bodies in the other two general areas are relatively small and sporadic in their distribution. The identified potentially suitable areas contain sufficient areas with exposed bedrock and limited water bodies to allow for surface bedrock mapping as part of detailed site characterization.

The general area in the south-central portion of the Black-Pic batholith, and that in the Quetico Subprovince are all accessible using exiting road networks. Access to the general area in the western portion of the Black-Pic batholith is limited.

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

8 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

The objective of the Phase 1 geoscientific preliminary assessment was to assess whether the Hornepayne area contains general areas that have the potential to satisfy the geoscientific site evaluation factors outlined in the 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 Hornepayne and its periphery, which are referred to as the “Hornepayne 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 Hornepayne area was limited or not available, the assessment drew on information and experience from other areas with similar geological settings on the Canadian Shield. The desktop geoscientific preliminary assessment included the following review and interpretation activities:

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, and overburden deposits;
- Interpretation of available geophysical surveys (magnetic, gravity, radiometric, electromagnetic);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on 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 Hornepayne area contains at least three general areas that have the potential to satisfy NWMO’s geoscientific site evaluation factors. Two of these areas are within the Black-Pic batholith of the Wawa Subprovince. The other area is located within the metasedimentary rocks of the Quetico geological Subprovince.

The Black-Pic batholith and the metasedimentary rocks of the Quetico Subprovince hosting the three identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They have sufficient depth and extend over large areas. The bedrock within the three potentially suitable areas has relatively good exposure. All three areas have low potential for natural resources and contain limited surface constraints.

While the identified general potentially suitable areas appear to have favourable geoscientific characteristics for hosting a deep geological repository, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The main uncertainties are associated with the influence of the geological subprovince boundary that cross-cuts the Hornepayne area, the presence of numerous dykes, the low resolution of available geophysical data over most of the Hornepayne area, and the variable degree of metamorphism that the metasedimentary rocks experienced in the geological past.

All three identified potentially suitable areas are away from the deformation zone associated with the Wawa-Quetico subprovince boundary. However, the potential impact of this deformation zone on the three potentially suitable areas needs to be further assessed.

The Hornepayne area contains numerous dykes as it lies within regional dyke swarms. While the spacing between mapped and interpreted dykes and lineaments appears to be favourable, the low resolution of available geophysical data and the dykes could be masking the presence of smaller scale dykes and fractures not identifiable from available data. Also, given the variable degree of metamorphism that the metasedimentary rocks have undergone in the geological past, the homogeneity of these rocks would need to be further assessed in subsequent site evaluation stages.

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

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10 REPORT SIGNATURE PAGE

Respectfully submitted,

Geofirma Engineering Ltd.

Sean Sterling, P.Eng., P.Geo.
Senior Geoscientist

Kenneth Raven, P. Eng., P.Geo.
Principal

APPENDIX A

Geoscientific Factors

Table A.1 Safety Factors, Performance Objectives and Geoscientific Factors

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

Safety Factors	*Performance Objectives*	*Evaluation Factors to be Considered*
Repository construction, operation and closure	**3.** The surface and underground characteristics of the site should be favourable to the safe construction, operation, closure and long-term performance of the repository.	**3.1** The strength of the host rock and in-situ stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities. **3.2** The soil cover depth over the host rock should not adversely impact repository construction activities. **3.3** The available surface area should be sufficient to accommodate surface facilities and associated infrastructure.
Human intrusion	**4.** The site should not be located in areas where the containment and isolation function of the repository are likely to be disrupted by future human activities.	**4.1** The repository should not be located within rock formations containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today. **4.2** The repository should not be located within geological formations containing exploitable groundwater resources (aquifers) at repository depth.
Site characterization	**5.** The characteristics of the site should be amenable to site characterization and site data interpretation activities.	**5.1** The host rock geometry and structure should be predictable and amenable to site characterization and site data interpretation.

APPENDIX B

Geoscientific Data Sources

Table B.1 Summary of Geoscientific Databases for the Hornepayne Area.

Database	***Description***	***Scale (Regional / Local)***	***Used? (Yes/ No)***
AFRI	The AFRI database contains the technical results from all exploration work carried out in Ontario. Data includes location, property ownership, type of work done, commodities sought for each assessment file and a link to a pdf version of each file. Spatial data is collected for each file in the form of polygons indicating property outlines.	Regional	Yes
AMIS (Abandoned Mines Information System Database)	AMIS is a database containing information on all known abandoned and inactive mine sites within the province of Ontario. There are currently 5,700 known abandoned mine sites scattered throughout the Province, which contain more than 16,400 mine features.	Regional	Yes
Bedrock Geology (MRD 126-Revision 1)	Bedrock Geology contains information about the solid rock underlying the Province of Ontario at a compilation scale of 1:250,000. Data includes: bedrock units, major faults, dyke swarms, iron formations, kimberlites and interpretation of the Precambrian bedrock geology underlying the Hudson Bay and James Bay lowlands Phanerozoic cover.	Regional	Yes
CLAIMaps	CLAIMaps contains active claims, alienations and dispositions. Data includes: links to further land tenure information.	Regional	Yes
Diabase Dykes (MRD 241)	Stott, G.M. and S.D. Josey, 2009. Post-Archean mafic (diabase) dykes and other intrusions of northwestern Ontario, north of latitude 49°30′; Ontario Geological Survey	Regional	Yes
Drill Holes	Drill Holes contains information on surface and underground drilling done as outlined by assessment files. Data includes: company name, company hole number, township and a link to the full drill hole record on Geology Ontario.	Regional	Yes
Earthquakes Canada (NEDB)	Geological Survey of Canada Earthquake Search (On-line Bulletin): http://www.earthquakescanada.nrcan.gc.ca/index- eng.php	Regional	Yes
Mineral Deposits Inventory (MDI)	The database contains an overview of mineral occurrences in the province of Ontario. The data includes the occurrence type (mineral or discretionary), primary and secondary commodity, deposit name and a link to the full record on Geology Ontario.	Regional	Yes
Geochemistry (MRD 242)	Stone, D. 2010. Geochemical analyses of rocks, minerals and soil in the central Wabigoon Subprovince area, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 242.	Regional	Yes
Geochronology (MRD 75)	Geochronology Data for Ontario; Ontario Geological Survey. The compilation covers all isotopic ages greater than 10 Ma for Ontario, and adjacent areas of Manitoba, Michigan, Minnesota, New York and Quebec.	Regional	No (redundant)
Geochronology (MRD 275)	Buse, S., D. Stone, D. Lewis, D. Davis and M.A. Hamilton, 2010. U/Pb Geochronology Results for the Atikokan Mineral Development Initiative	Local	Yes
Geotechnical Boreholes	Geotechnical Boreholes contains records of boreholes constructed during geotechnical investigations. Data includes: information on the Geological Stratum identified down each hole as well as the hole depth.	Regional	Yes

Database	***Description***	***Scale (Regional / Local)***	***Used? (Yes/ No)***
NOEGTS	Northern Ontario Engineering Geology and Terrain Study. Contains an evaluation of near-surface geological conditions such as material, landform, topography and drainage. Data includes: land form type, geomorphology, primary material, secondary material, topography and drainage condition, point features such as sand and gravel pits, sand dunes, drumlins, eskers, landslide scars and index maps to study areas.	Regional	Yes
Ontario Base Mapping	Land Information Ontario (LIO). Ontario Ministry of Natural Resources. Topography, roads, infrastructure, land cover and drainage. http://www.mnr.gov.on.ca/en/Business/LIO	Regional	Yes
Quaternary Geology (Data Set 14)	Ontario's Quaternary Geology at a compilation scale of 1:1000000. Ontario Geological Survey, 1997. Quaternary geology, seamless coverage of the province of Ontario: Ontario Geological Survey, Data Set 14. This layer includes Quaternary geology units, point features such as drumlins and glacial striae and line features such as eskers, shore bluffs and moraines.	Regional	Yes
WWIS (Water Wells)	Database containing water well records throughout Ontario from 1949 to present: http://www.ene.gov.on.ca/environment/en/mapping/index.htm	Regional	Yes

Table B.2 Summary of Geophysical Mapping Sources for the Hornepayne Area.

Product	***Source***	***Type***	***Line Spacing/ Sensor Height***	***Coverage***	***Date***	***Additional Comments***
Ontario #3	GSC	Fixed wing magnetic	805m/305m	Covers northeast part of Hornepayne area	1968	Recorded on analog charts, navigation and flightpath based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum.
Ontario #8	GSC	Fixed wing magnetic	805m/305m	Covers west part of Hornepayne area	1962	Recorded on analog charts, navigation and flightpath based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum.
Ontario #17	GSC	Fixed wing magnetic	805m/305m	Covers most of Hornepayne area (east, south)	1963	Recorded on analog charts, navigation and flightpath based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum.
GSC Gravity Coverage	GSC	Ground Gravity Measurements	5-25km/ surface	Entire Hornepayne area	1946-63	Bouguer gravity field, first vertical derivative, horizontal gradient and the isostatic residual gravity field were extracted from the GSC gravity compilation. Station locations were extracted from the point data.
GSC Radiometric Coverage	GSC	Fixed wing radiometric data	5000m/120m	Entire Hornepayne area	1982	Grids of potassium, equivalent uranium, equivalent thorium, natural air absorbed dose rate, and ratios of eU/K, eTh/K and eU/eTh were extracted from the GSC's nationwide radiometric compilation.
Manitouwadge Survey (GDS1205)	OGS , Donated by Noranda Eploration Company Ltd.	Helicopter magnetic, FDEM (Dighem IV 4 frequency)	200m/ MAG 45m FDEM 30m	Covers 1,199 km^2 in west part of Hornepayne area	1989	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic coverage, and provides electromagnetic coverage. The UHF navigation system was electronic but pre-dated GPS, so flightpath recovery was accurate but survey lines were not quite straight. The 1989 vintage of magnetic and electromagnetic equipment was relatively good compared to current FDEM systems. The data were reprocessed in 2002, which improved the quality.
Oba-Kapuskasing Survey (GDS1024)	OGS	Helicopter magnetic, FDEM (Aerodat 3 frequency)	200m/ MAG 45m FDEM 30m	Covers 106 km^2 in southeast corner of Hornepayne area	1986	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic coverage, and provides electromagnetic coverage. The radar navigation system was electronic but pre-dated GPS, so flightpath recovery was accurate but survey lines were not quite straight. The 1986 vintage of magnetic and electromagnetic equipment was relatively good compared to current FDEM systems. The data were reprocessed in 2003, which improved the quality.

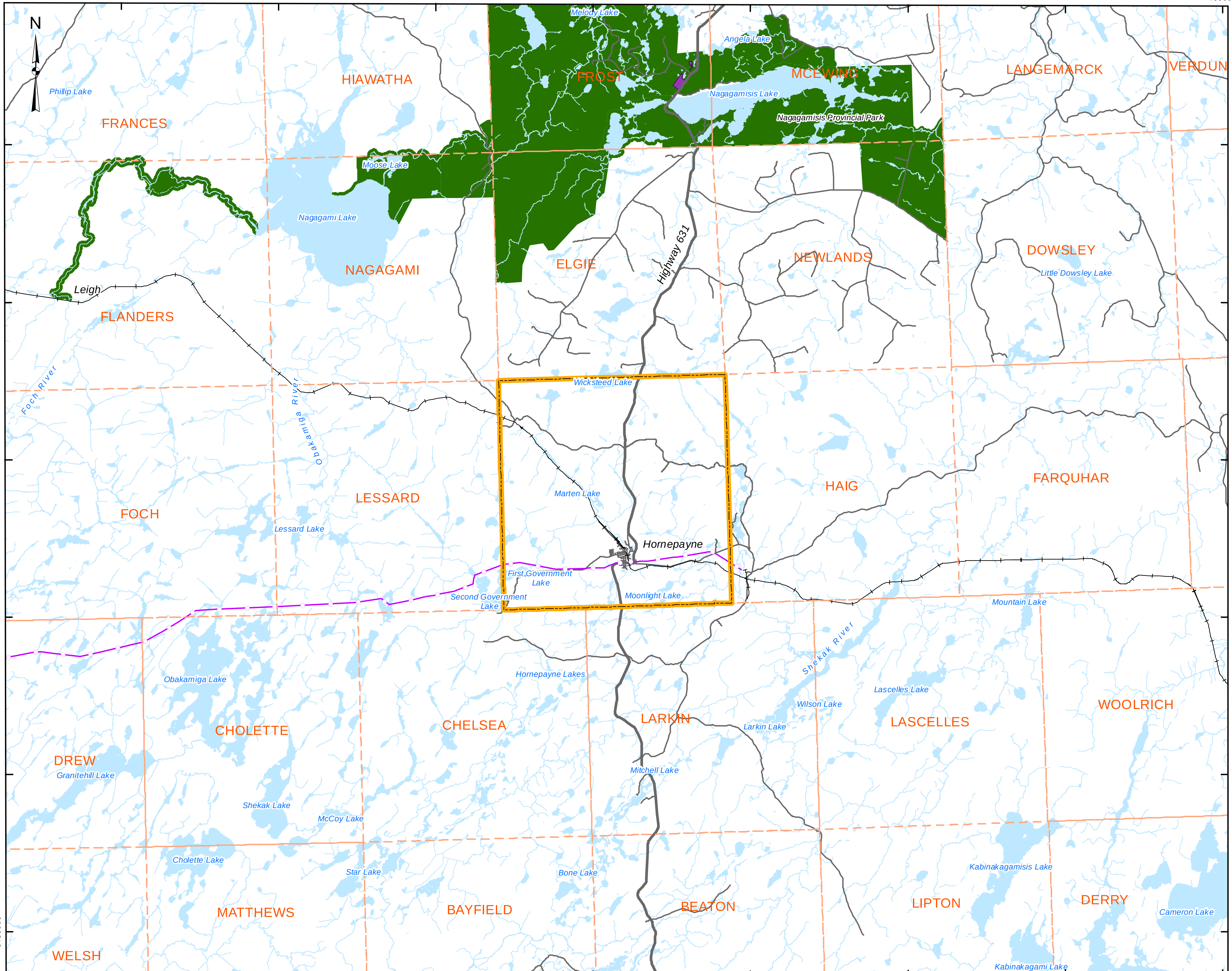
Table B.3 Summary of Geological Mapping Sources for the Hornepayne Area

Map Product	*Title*	*Author*	*Source*	*Scale*	*Date*	*Coverage*	*Additional Comments*
M2047	Flanders Lake area, Thunder Bay and Algoma districts	V.G. Milne	OMNDM	1:63360	1963	Partial	Early bedrock mapping for the NW part of the Hornepayne area
M2219	Granitehill Lake area, Thunder Bay and Algoma districts	J.F. Giguere	OMNDM	1:63360	1972	Partial	Early bedrock mapping for the western part of the Hornepayne area
M2355	Kabinakagami Lake, Algoma District	G.M. Siragusa	OMNDM	1:63360	1976	Partial	Early bedrock mapping for the southern part of the Hornepayne area
M2543	Bedrock Geology of Ontario East Central Sheet	Ontario Geological Survey	OMNDM	1:1000000	1991	Full	Digital data release MRD-126 Revision 1 described in Table 3 below
M2555	Quaternary Geology of Ontario East-Central Sheet	P.J. Barnett, A.P. Henry D. Babuin	OMNDM	1:1000000	1991	Full	Digital data Quaternary Data Set 14 described in Table 3 below
M2666	Precambrian Geology Compilation Series - White River Sheet	F. Santaguida	OMNDM	1:250000	2002	Partial	Compilation mapping of the southern part of the Hornepayne area
M2668	Precambrian Geology Compilation Series- Hornepayne Sheet	G.W. Johns S.J. McIlraith	OMNDM	1:250000	2003	Partial	Compilation mapping of the majority of the Hornepayne area
M5085	Hornepayne, NTS 42F/SE, data base map, northern Ontario engineering geology terrain study	D.F. McQuay	OMNDM	1:100000	1980	Partial	NOEGTS Quaternary sediments and drainge mapping carried out for the Hornepayne area
OFM 142	Geology of the Manitouwadge-Hornepayne area	H.R. Williams F.W. Breaks	OMNDM	1:50000	1990	Partial	Preliminary mapping of the western part of the Hornepayne area
OFR 5953	Geology of the Manitouwadge-Hornepayne Region, Ontario	H.R. Williams F.W. Breaks	OMNDM	1:3636363	1996	Partial	Regional bedrock mapping of the western part of the Hornepayne area
P0098	Flanders Lake area, districts of Thunder Bay and Algoma, Ontario	V.G. Milne	OMNDM	1:31680	1960	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the NW part of the Hornepayne area

Map Product	*Title*	*Author*	*Source*	*Scale*	*Date*	*Coverage*	*Additional Comments*
P0226	Magone area, districts of Algoma and Thunder Bay	K.G. Fenwick	OMNDM	1:31680	1964	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the SW part of the Hornepayne area
P0227	Dayohessarah Lake area, District of Algoma	K.G. Fenwick	OMNDM	1:31680	1964	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the SW part of the Hornepayne area
P0228	Gourlay Lake area, District of Algoma	K.G. Fenwick	OMNDM	1:31680	1964	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the SW part of the Hornepayne area
P0288	Dayohessarah Lake area, District of Algoma	K.G. Fenwick	OMNDM	1:63360	1965	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the SW part of the Hornepayne area
P0333	Black River area, northeast part, District of Thunder Bay	V.G. Milne	OMNDM	1:31680	1966	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the SW part of the Hornepayne area
P0335	Black River area, southeast part, District of Thunder Bay	V.G. Milne	OMNDM	1:31680	1966	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the SW part of the Hornepayne area
P0362	Stevens-Kagiano Lake area, District of Thunder Bay	M.E. Coates	OMNDM	1:63360	1966	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the western part of the Hornepayne area
P0473	Granitehill Lake area, districts of Thunder Bay and Algoma	J.F. Guigere	OMNDM	1:63360	1968	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the western part of the Hornepayne area

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
P0476	Hornepayne sheet, districts of Algoma and Cochrane, Sault Ste. Marie and Sudbury mining divisions, geological compilation series	P.E. Giblin	OMNDM	1:126720	1968	Partial	Preliminary Pleistocene and Precambrian geology mapping with some structural information for the southern part of the Hornepayne area
P0811	Geological series, Kabinakagami Lake area, Beaton and Breckenridge townships, District of Algoma	G.M. Siragusa	OMNDM	1:31680	1973	Partial	Detailed Pleistocene and Precambrian geology mapping with some structural information for the southern part of the Hornepayne area
P0812	Geological series, Kabinakagami Lake area, Lipton and Lizar townships, District of Algoma	G.M. Siragusa	OMNDM	1:31680	1973	Partial	Detailed Pleistocene and Precambrian geology mapping with some structural information for the southern part of the Hornepayne area
P0813	Geological series, Kabinakagami Lake area, Lipton and Lizar townships, District of Algoma	G.M. Siragusa	OMNDM	1:31680	1973	Partial	Detailed Pleistocene and Precambrian geology mapping with some structural information for the southern part of the Hornepayne area
P0911	Geological series, Nameigos-Simpson area, Nameigos and Doucett townships, District of Algoma	G.M. Siragusa	OMNDM	1:31680	1973	Partial	Detailed Pleistocene and Precambrian geology mapping with some structural information for the southern part of the Hornepayne area
P0912	Geological series, Nameigos-Simpson area, Mosambik and Cudney townships, District of Algoma	G.M. Siragusa	OMNDM	1:31680	1973	Partial	Detailed Pleistocene and Precambrian geology mapping with some structural information for the southern part of the Hornepayne area
P0913	Geological series, Nameigos-Simpson area, Nameigos and Doucett townships, District of Algoma	G.M. Siragusa	OMNDM	1:31680	1973	Partial	Detailed Pleistocene and Precambrian geology mapping with some structural information for the southern part of the Hornepayne area
P2108	Timmins data series, Lizar Township, District of Algoma	D.S. Hunt B.A. MacRae D. Maharaj	OMNDM	1:15840	1980	Partial	Detailed Pleistocene and Precambrian geology mapping with some structural information for the southern part of the Hornepayne area

Map Product	***Title***	***Author***	***Source***	***Scale***	***Date***	***Coverage***	***Additional Comments***
P3309	Precambrian Geology Dayohessarah Lake Area (North)	G.M. Stott K.L. Mahoney W.G. Zwiers	OMNDM	1:20000	1995	Partial	Detailed Precambrian geology mapping with some structural information for the southern part of the Hornepayne area
P3310	Precambrian Geology Dayohessarah Lake Area (Central)	G.M. Stott K.L. Mahoney W.G. Zwiers	OMNDM	1:20000	1995	Partial	Detailed Precambrian geology mapping with some structural information for the southern part of the Hornepayne area



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LEGEND

- Township of Hornepayne
- Geographic Township
- Forest Reserve
- Provincial Park
- Highway
- Local Road
- Railway
- Utility Line
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent

SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Township of Hornepayne and Surrounding Area

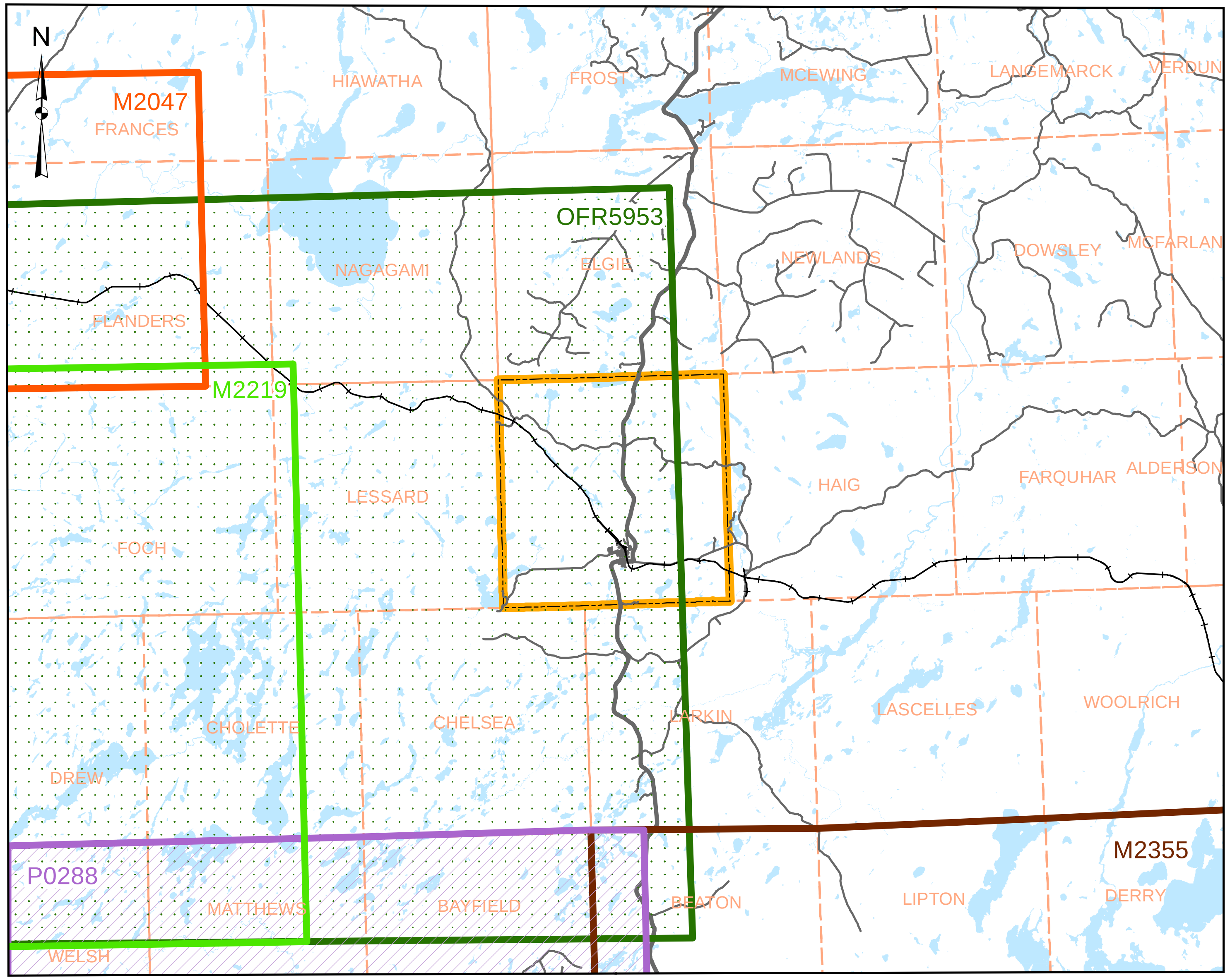
FIGURE 1.1

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

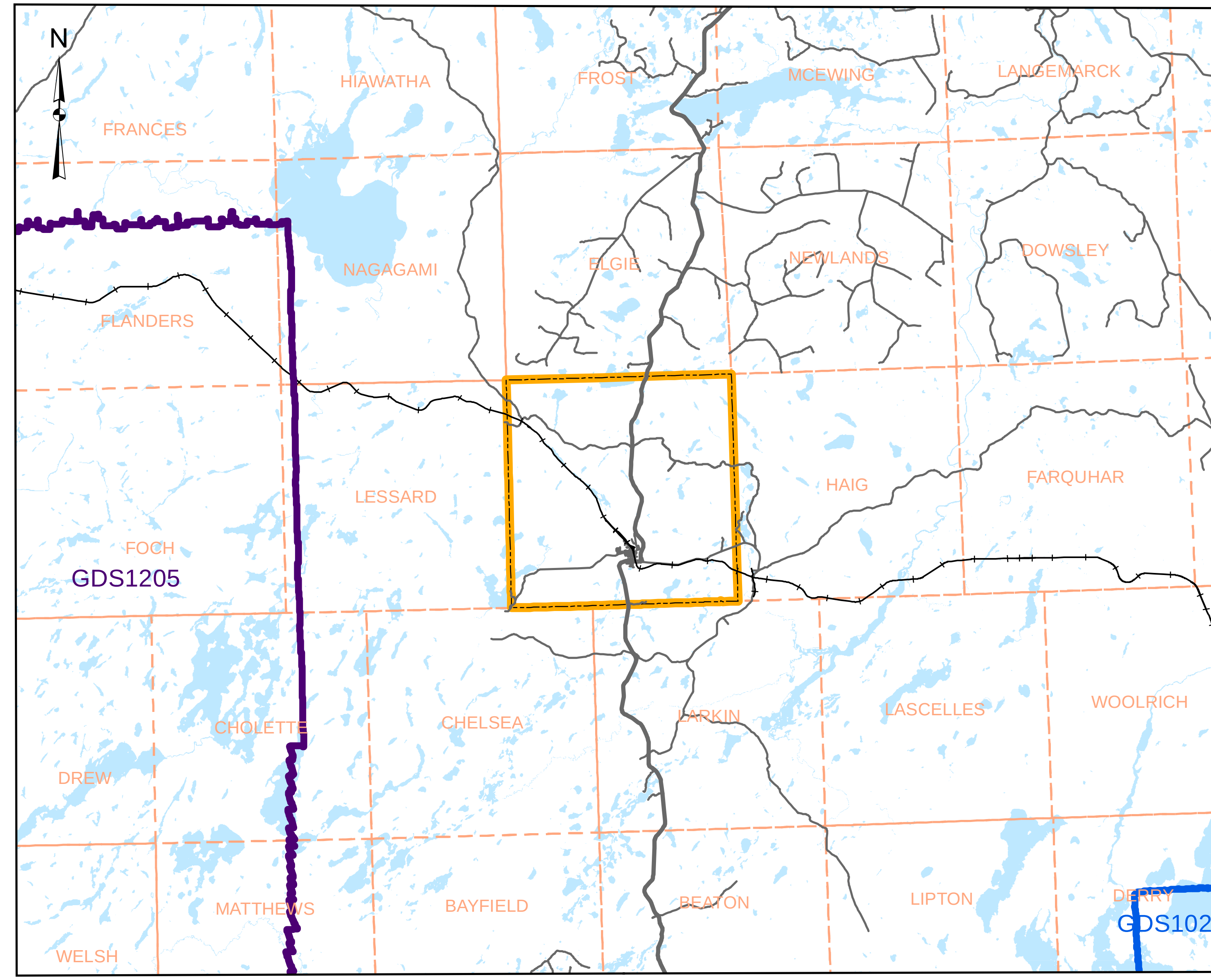
DATE: 30/07/2013

Geofirma Engineering Ltd

Geology Mapping Coverage



Geophysics Mapping Coverage



LEGEND

- Township of Hornepayne
- Geographic Township
- Highway
- Railway
- Water Area, Permanent

Detailed Geology Extent

- Fenwick, 1965 (P0288)
- Giguere, 1972 (M2219)
- Milne, 1964 (M2047)
- Siragusa, 1976 (M2355)
- Williams & Breaks, 1996 (OFR5953)

Full Geology Coverage

OGS Quaternary Geology of Ontario (Data Set 14)
OGS Bedrock Geology of Ontario 2011 (MRD 126)
Sataguida, 2001 (M2666),
Johns & McIlraith, 2003 (M2668)

Full Geophysics Coverage

GSC Gravity 1946-1963
GSC Radiometric 1982
GSC Magnetic 1962, 1963, 1968

Geophysical Survey Extent

- Oba-Kapuskasing Area (GDS1024)
- Manitouwadge Area (GDS1205)

SCALE 1:400,000

0 4 8 16 24 32
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Ontario Geological Survey, MNDM, 2012
Produced by Geofirma Engineering Ltd under license from
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PROJECT No. 10-214-4
NWMO Hornepayne Desktop Geoscientific
Preliminary Assessment of Potential Suitability

TITLE
Geoscience Mapping
and Geophysical Coverage
of the Hornepayne Area

FIGURE
1.2

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 06/11/2013

Geofirma Engineering Ltd

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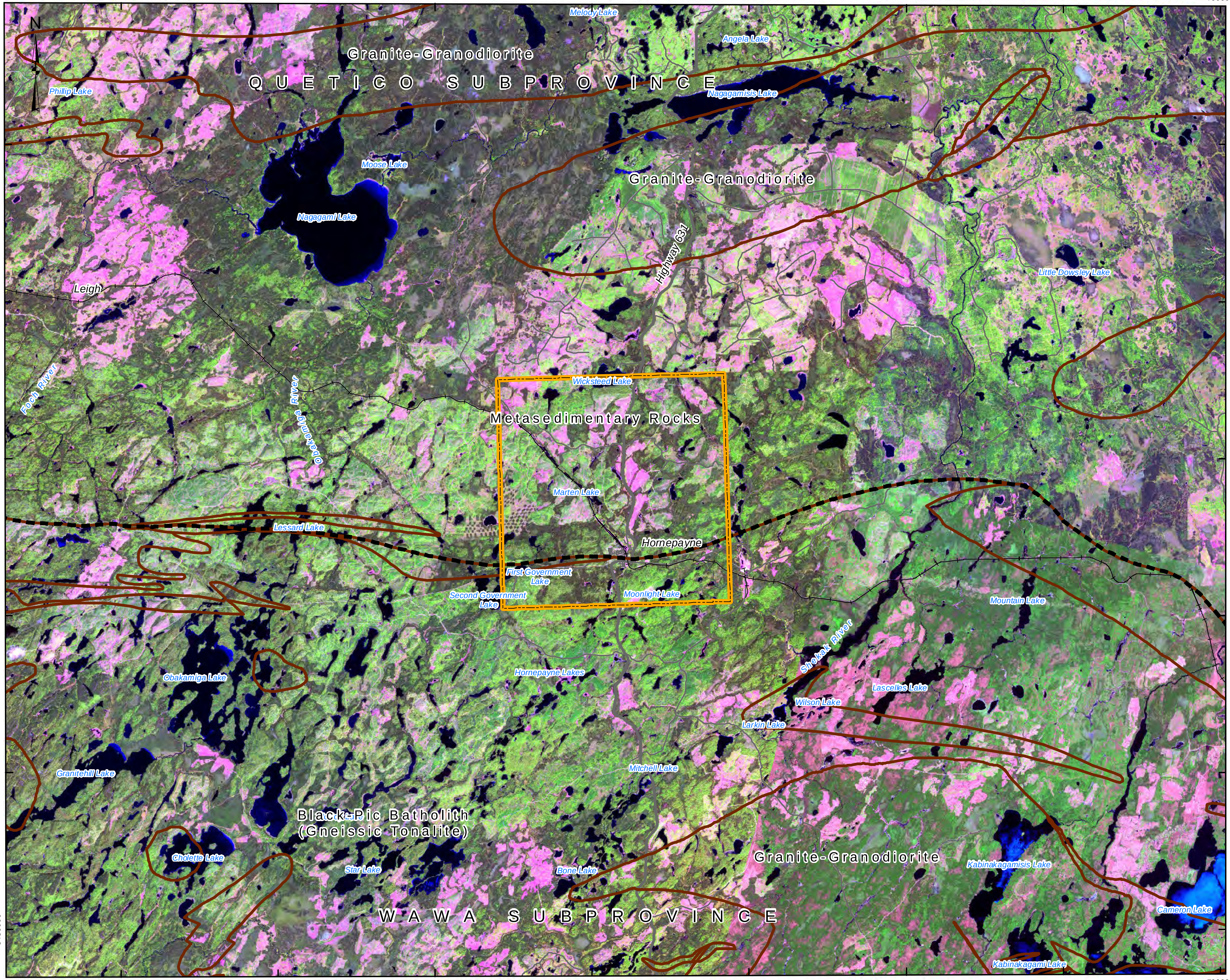

LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Subprovince Boundary
- Outline of Geologic Unit

INDEX MAP

Thunder Bay, Timmins, Ontario, Quebec, Lake Superior, Sault Ste Marie, Sudbury, North Bay, Ottawa, United States, Lake Huron, Georgian Bay, Owen Sound, Kingston, Lake Ontario, Toronto

SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Imagery: SPOT5 Band 2, 3 and 4, Geobase (20m resolution), 2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

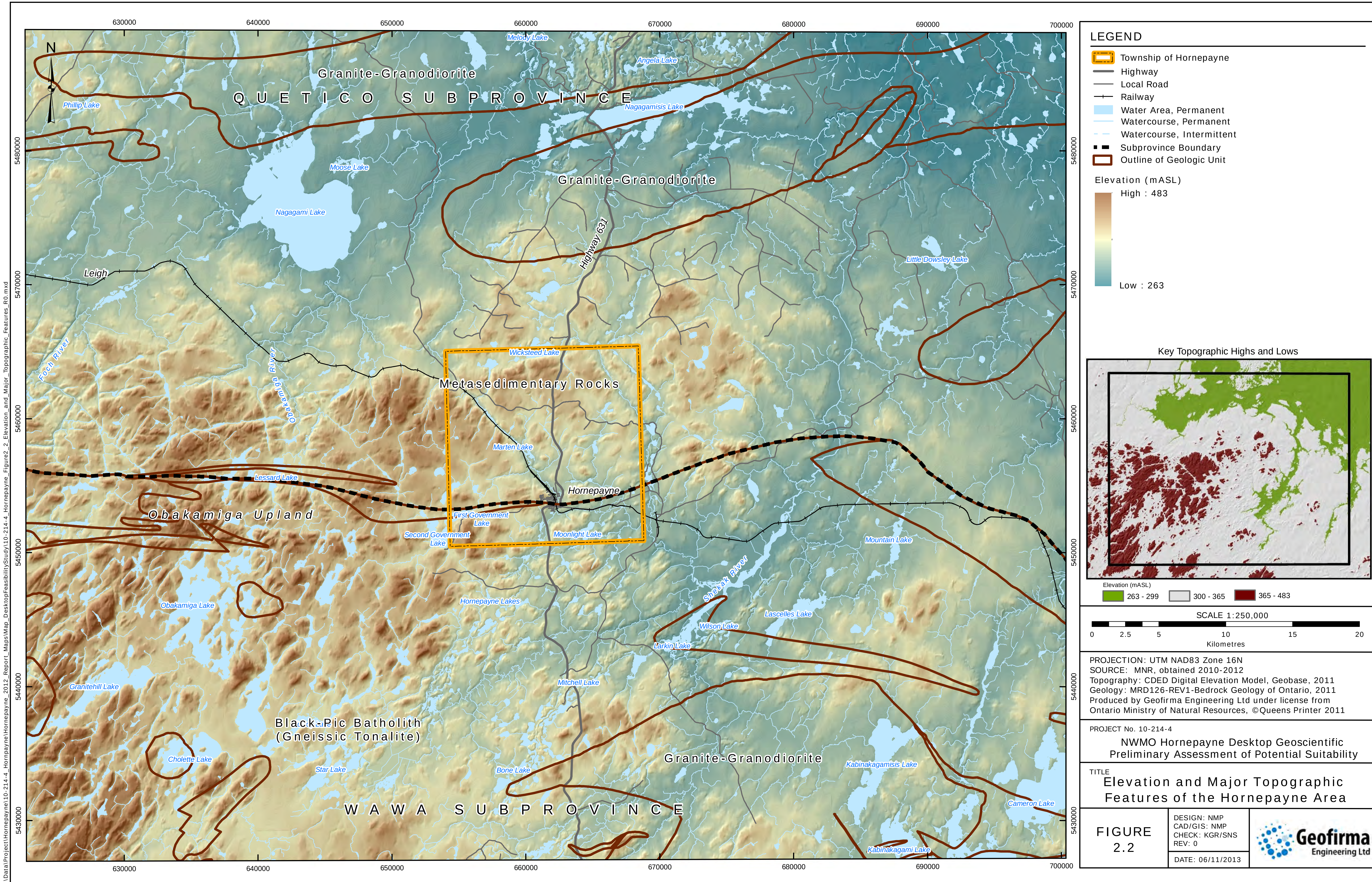
Satellite Imagery of the Hornepayne Area

FIGURE 2.1

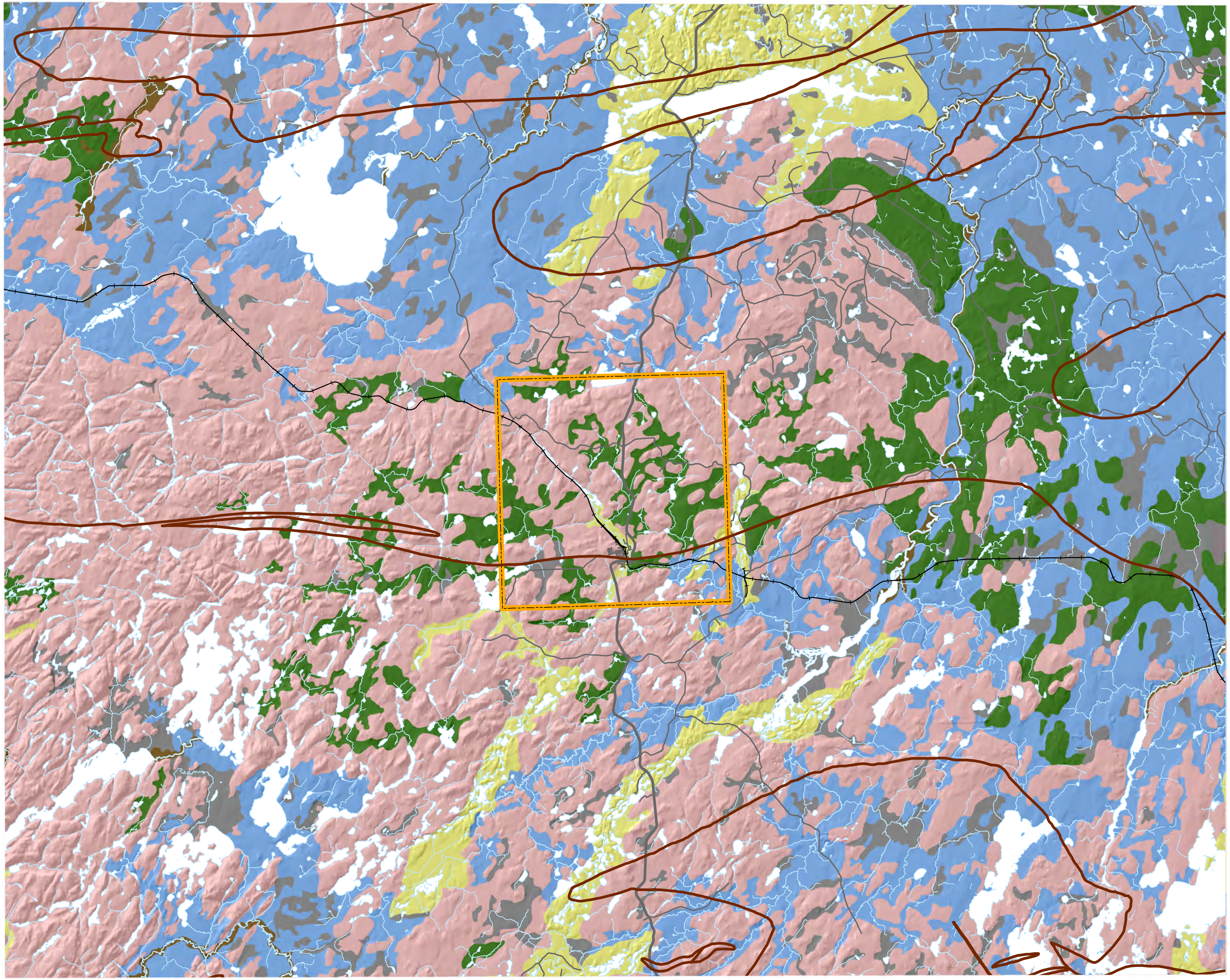
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0

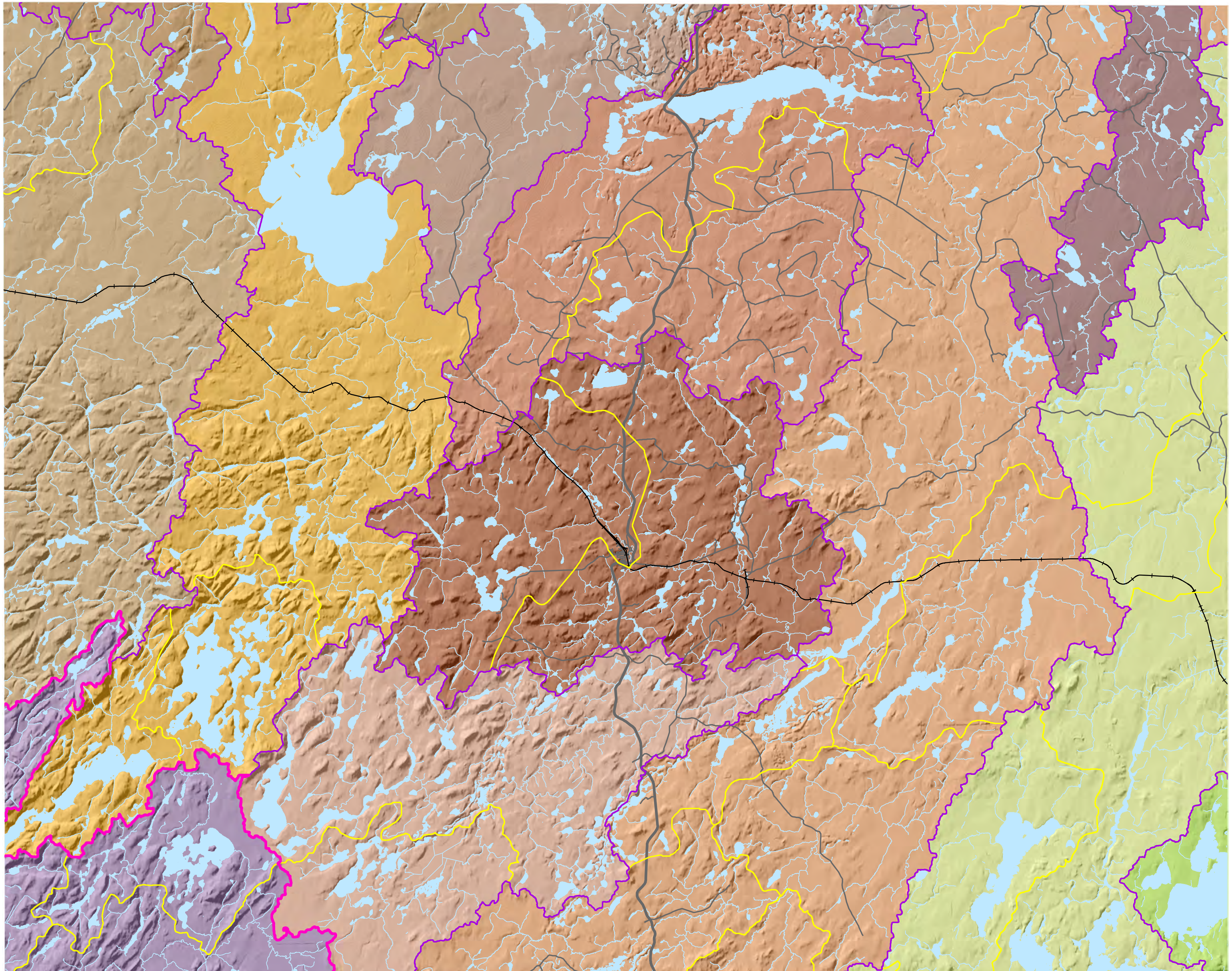
DATE: 19/08/2013

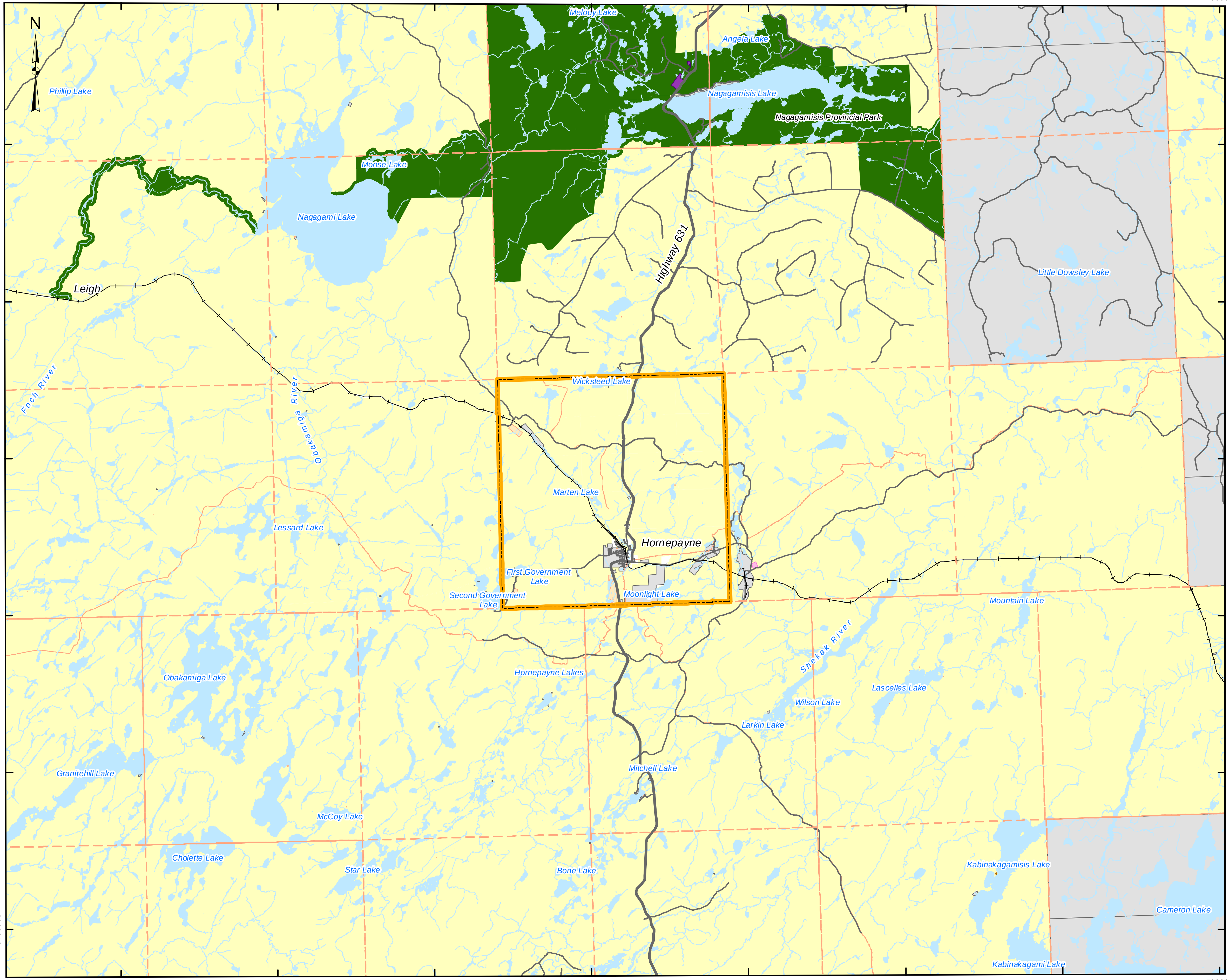
Geofirma Engineering Ltd



Granite-Granodiorite
QUETICO SUBPROVINCE
Granite-Granodiorite
Metasedimentary Rocks
Obakamiga Upland
Black-Pic Batholith
(Gneissic Tonalite)
Granite-Granodiorite
WAWA SUBPROVINCE
Hornepayne
Leigh
Highway 631
Melody Lake
Angela Lake
Phillip Lake
Nagagamisis Lake
Moose Lake
Nagagami Lake
Little Dowsley Lake
Foch River
Obakamiga River
Wicksteed Lake
Marten Lake
Lessard Lake
First Government Lake
Second Government Lake
Moonlight Lake
Mountain Lake
Shekak River
Obakamiga Lake
Hornepayne Lakes
Lascelles Lake
Wilson Lake
Larkin Lake
Granitehill Lake
Mitchell Lake
Cholette Lake
Star Lake
Bone Lake
Kabinakagamisis Lake
Cameron Lake
Kabinakagami Lake
N
630000
640000
650000
660000
670000
680000
690000
700000
5430000
5440000
5450000
5460000
5470000
5480000
LEGEND
Township of Hornepayne
Highway
Local Road
Railway
Water Area, Permanent
Watercourse, Permanent
Watercourse, Intermittent
Subprovince Boundary
Outline of Geologic Unit
Elevation (mASL)
High : 483
Low : 263
Key Topographic Highs and Lows
Elevation (mASL)
263 - 299
300 - 365
365 - 483
SCALE 1:250,000
0 2.5 5 10 15 20
Kilometres
PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Topography: CDED Digital Elevation Model, Geobase, 2011
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ©Queens Printer 2011
PROJECT No. 10-214-4
NWMO Hornepayne Desktop Geoscientific
Preliminary Assessment of Potential Suitability
TITLE
Elevation and Major Topographic
Features of the Hornepayne Area
FIGURE
2.2
DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 06/11/2013
Geofirma
Engineering Ltd
G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure2_2_Elevation_and_Major_Topographic_Features_R0.mxd







LEGEND

- Township of Hornepayne
- Geographic Township
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Forest Reserve
- Provincial Park
- Crown Land - Non-Freehold Dispositions Public
- Crown Land - Unpatented Public Land
- Federal Land - Indian Reserve
- Private Land

INDEX MAP

Thunder Bay, Timmins, Lake Superior, Ontario, Quebec, Sault Ste Marie, Sudbury, North Bay, Ottawa, United States, Lake Huron, Georgian Bay, Owen Sound, Kingston, Lake Ontario, Toronto

SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012, NWMO
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Land Disposition and Ownership within the Hornepayne Area

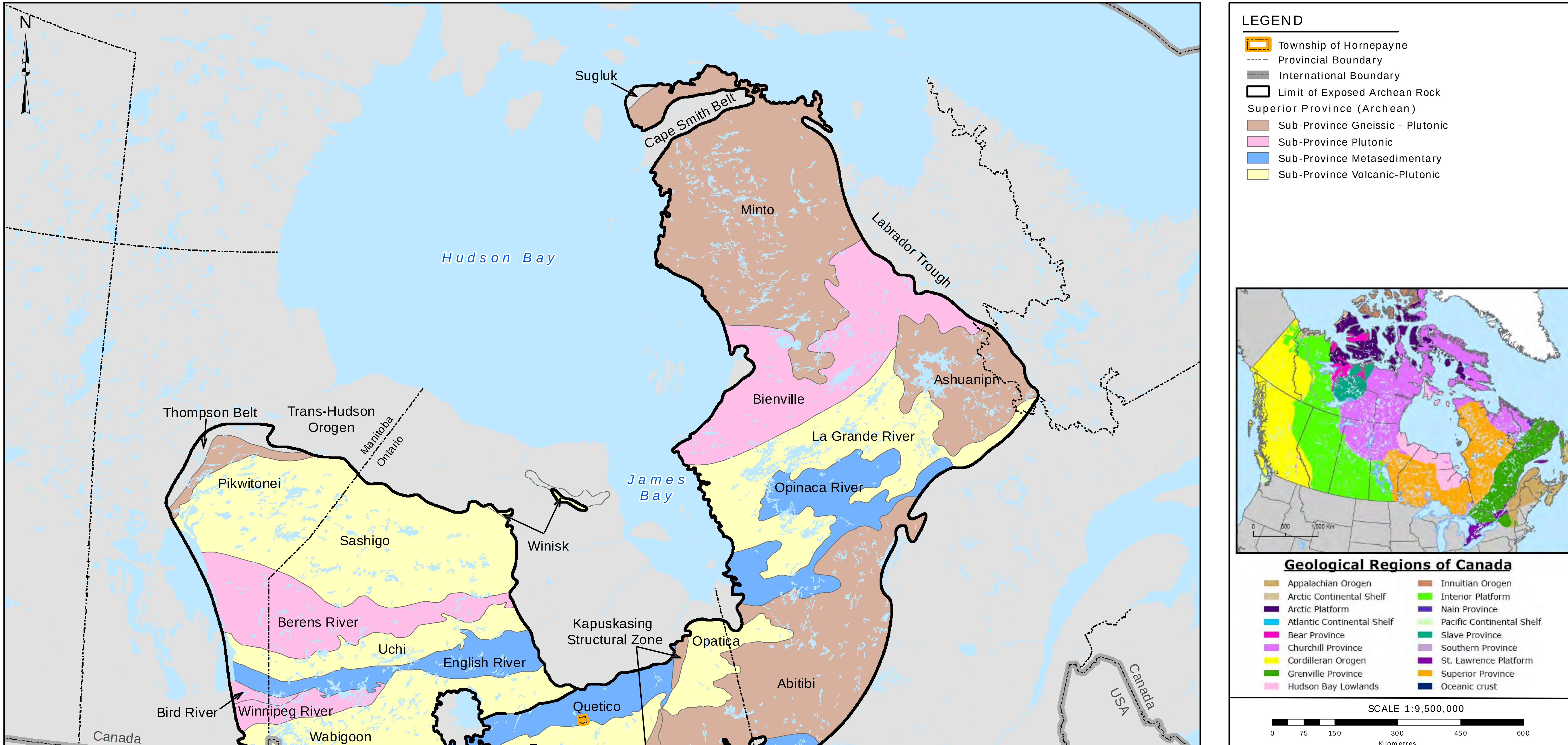
FIGURE 2.5

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 19/08/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure2_5_Land_Disposition_Ownership_R0.mxd



PROJECTION: NAD 1983 Canada Atlas Lambert
SOURCE: NRC, Geobase, obtained 2009-2012, ESRI Canada
Geology of Ontario: Subprovinces of the Superior Province
Canadian Shield, Modified from Card and Ciesieski, 1986
Geology: Geological Map of Canada 1996, Map D1860A
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ©Queens Printer 2011

PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific
Preliminary Assessment of Potential Suitability

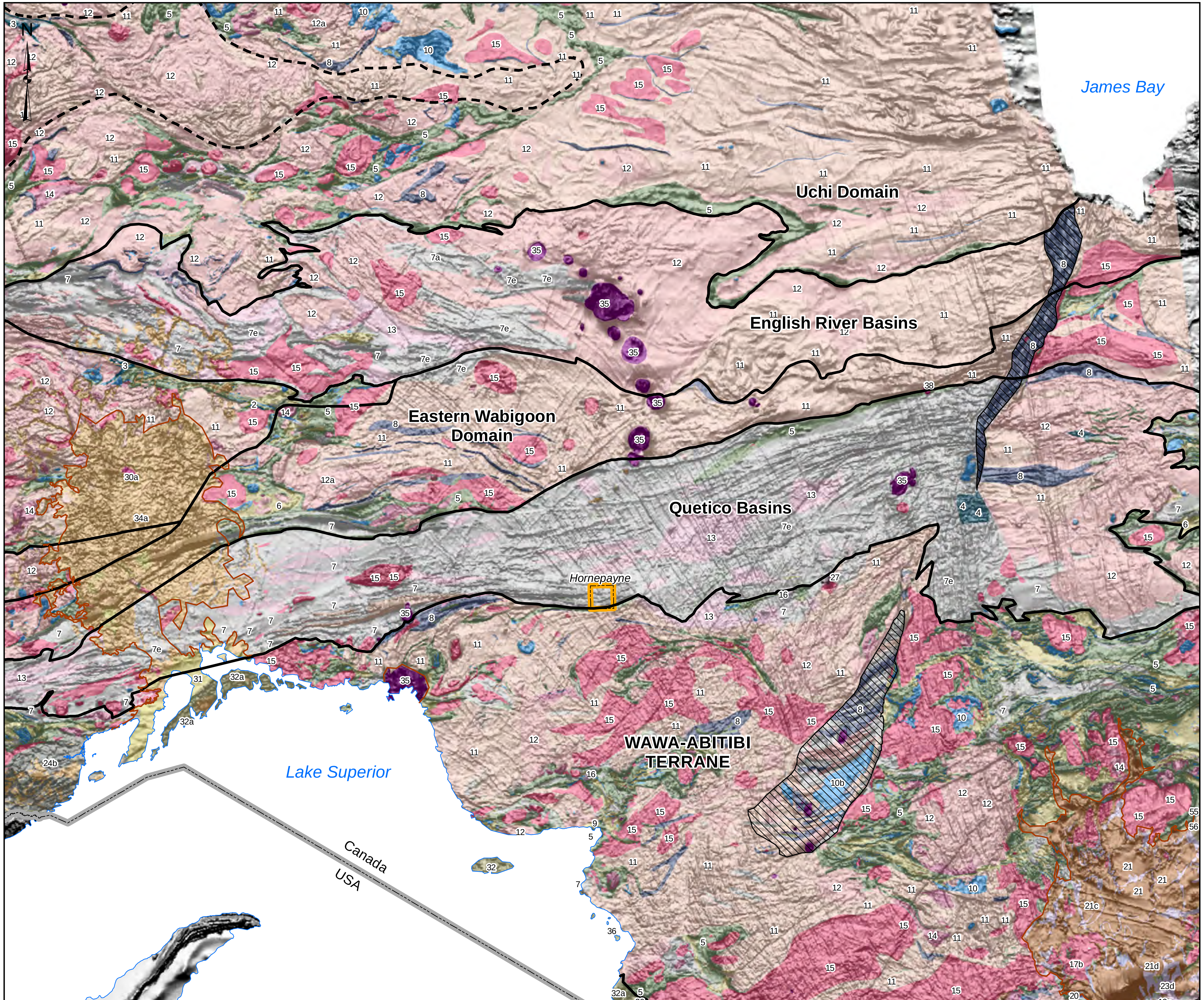
TITLE Subdivision of the Superior Province of the Canadian Shield

FIGURE 3.1

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 19/08/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornpayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_1_Subdivision_of_the_Superior_Province_CanadianShield_R0.mxd



LEGEND

- Township of Hornepayne
- Kapuskasing Structural Zone
- Proterozoic Embayment
- Terrane Boundary
- Domain Boundary

Bedrock Geology

- 56 Sandstone, shale, dolostone, siltstone
- 55 Shale, limestone, dolostone, siltstone
- 38 Carbonate-alkalic intrusive suite (450 to 600 Ma)
- 36 Jacobsville Gp.; Oronto Gp
- 35 Carbonatite-alkalic intrusive suite (1.0 to 1.2 Ga)
- 34 Mafic and related intrusive rocks (Keweenawan age)
- 32 Osler Gp., Maminse Point Fm., Michipicoten Island Fm.
- 31 Sibley Gp.
- 30 Felsic intrusive rocks
- 27 Carbonatite-alkalic intrusive suite (ca. 1.9 Ga)
- 24 Sedimentary Rocks (Animikie Group): wacke, shale, iron formation, limestone, minor volcanic rocks, conglomerate, taconite, aldal chert, carbonate rocks, argillite-tuff
- 23 Mafic and related intrusive rocks
- 21 Cobalt Gp.: siltstone,argillite, sandstone, conglomerate
- 20 Quirke Lake Gp.: sandstone, siltstone, conglomerate, limestone, dolostone
- 19 Hough Lake Gp.: siltstone, wacke, argillite, quartz-feldspar sandstone, conglomerate, sandstone
- 17 Mafic and ultramafic intrusive rocks
- 16 Hornblendite - nepheline syenite suite
- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rocks
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 4 Mafic to ultramafic metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks
- 2 Felsic to intermediate metavolcanic rocks

SCALE 1:2,500,000

0 20 40 80 120 160
Kilometres

PROJECTION: UTM NAD83 Zone16N
SOURCE: Basemap: Natural Resources Canada
Terrane: Stott, G., M.T. Corkery, J.A. Percival, M. Simard, J. Goutier 2010. A Revised Terrane Subdivision for the Superior Province; Ontario Geological Survey (MRD-278)
Geophysical underlay: Ontario #7, GSC, 800 m line spacing
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

PROJECT No. 10-214-4
NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE
Terrane Subdivision of the Central Superior Province

FIGURE 3.2

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 06/11/2013

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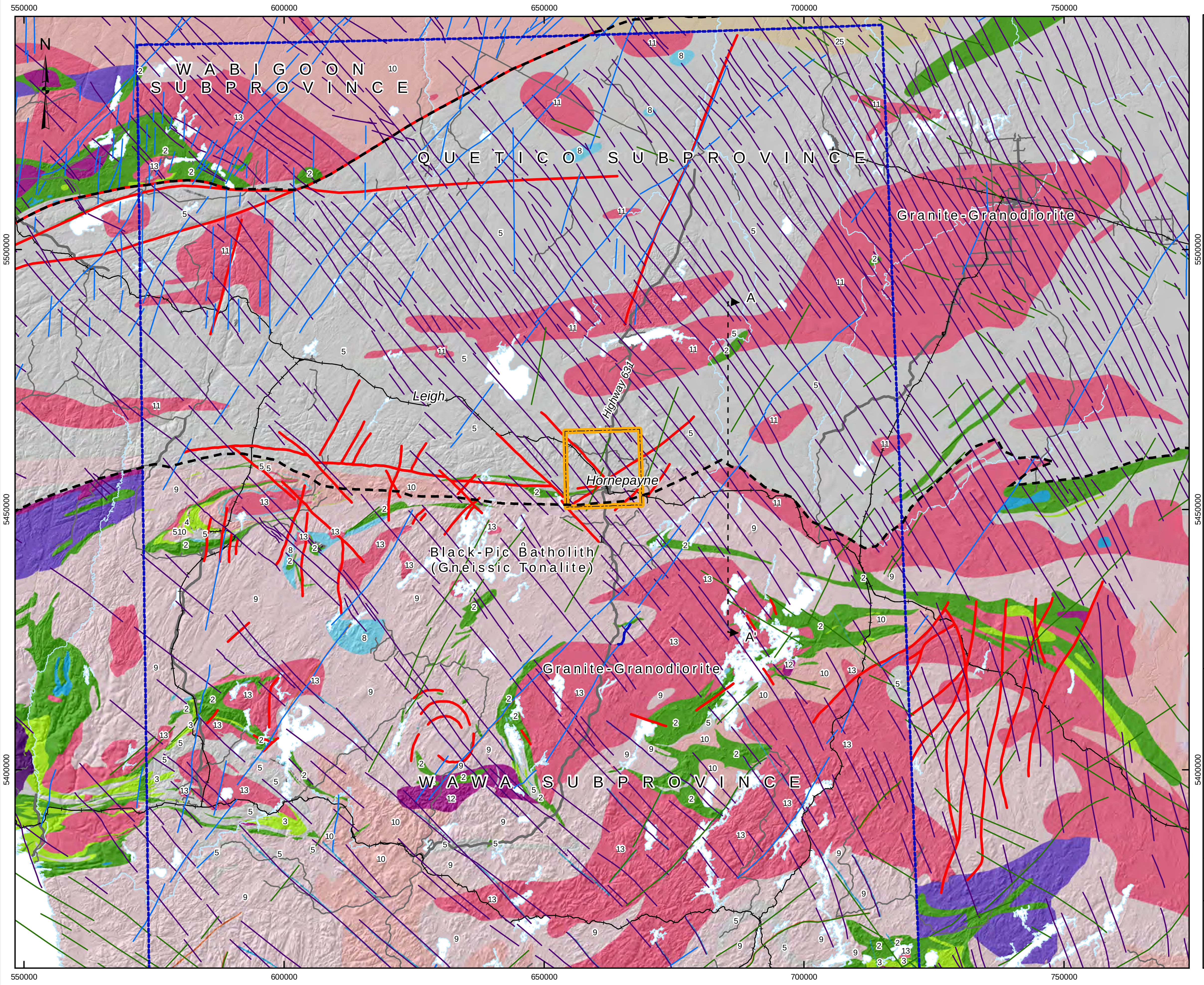
G:\Data\Project\Hornepayne\10-214-4_Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_2_Terrane_Subdivision_of_the_Central_Superior_Province_R0.mxd



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LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Updated OGS Geology Map Extent
- Subprovince Boundary
- Cross Section (Figure 3.5)
- Mapped Geological Fault

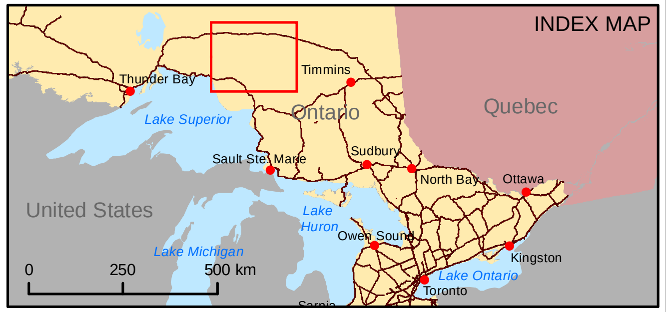
Mapped Dyke

- Abitibi, Biscotasing, Kapuskasing, or Marathon mafic dyke
- Matachewan mafic dyke
- Other

Bedrock Geology for Updated OGS Geology Map Extent

- 25 Sandstone, shale, dolostone, siltstone
- 13 Granite-granodiorite, massive to foliated
- 12 Diorite-monzonite-granodiorite
- 11 Granite-granodiorite, muscovite/biotite bearing
- 10 Foliated tonalite suite
- 9 Gneissic tonalite suite
- 8 Gabbro
- 5 Metasedimentary rocks
- 3 Felsic and intermediate volcanic rocks
- 2 Mafic volcanic rocks

Note: Refer to Figure 3.2 for Bedrock Geology legend outside of the Updated OGS Geology Map Extent



SCALE 1:725,000

0 5 10 20 30 40

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011, Unpublished OGS update 2012
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

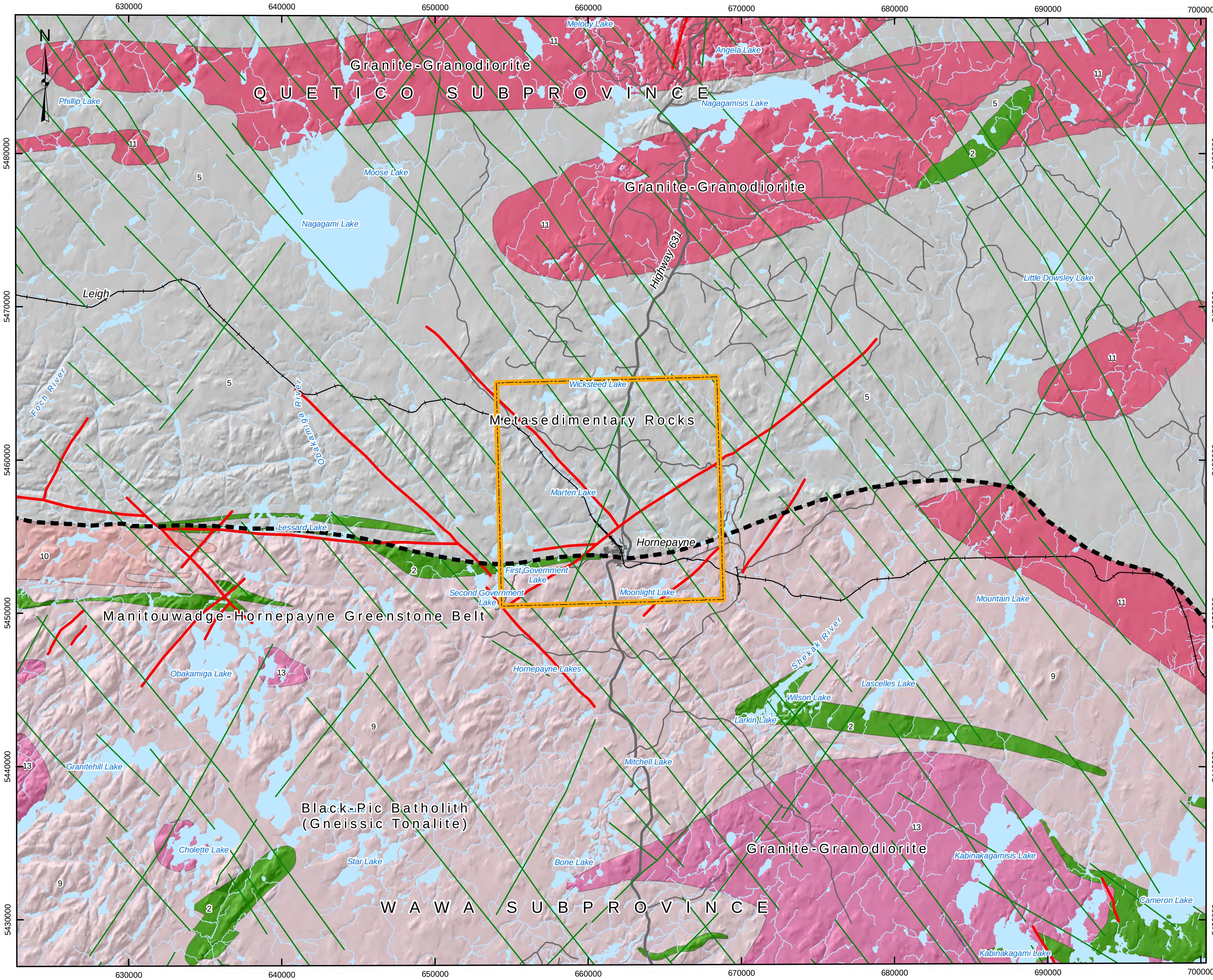
Regional Geology of the Hornepayne Area

FIGURE 3.3

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK:KGR/SNS
REV: 0

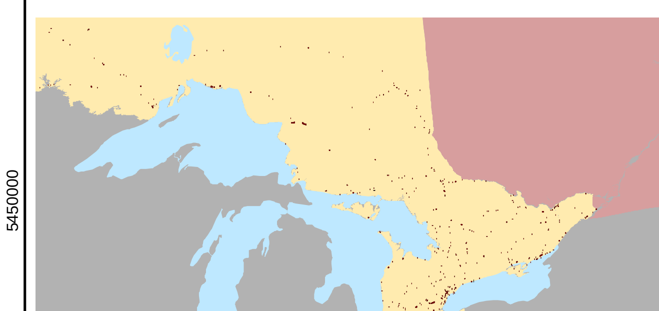
DATE: 06/11/2013

Geofirma Engineering Ltd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Mapped Geological Fault
- Mapped Dyke
- Subprovince Boundary



SCALE 1:250,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific
Preliminary Assessment of Potential Suitability

TITLE

Local Bedrock Geology
of the Hornepayne Area

FIGURE
3.4

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK:KGR/SNS
REV: 0

DATE: 07/11/2013

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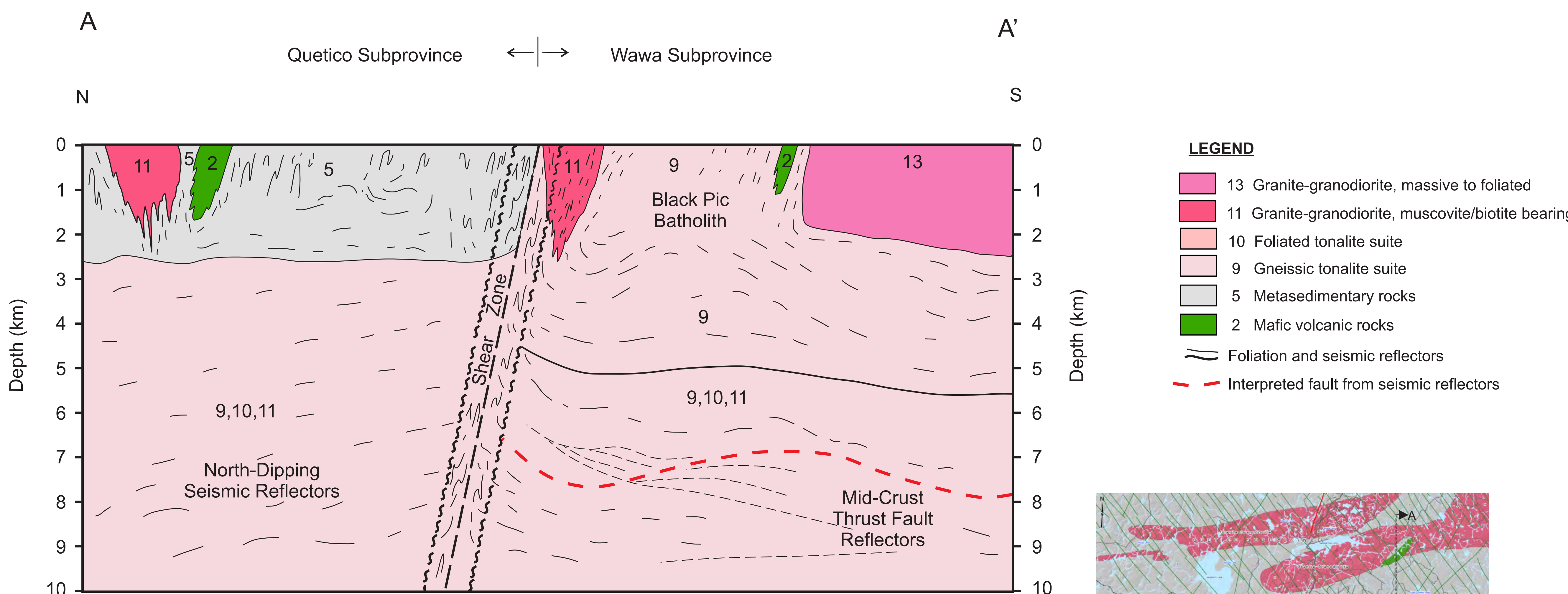
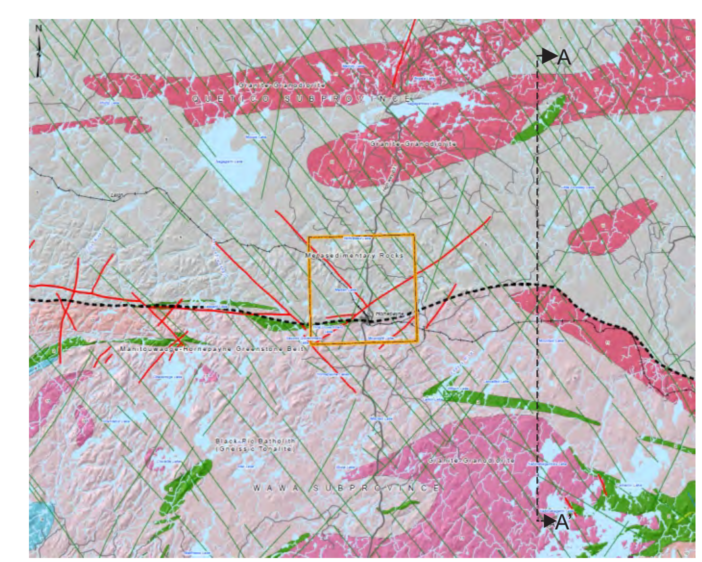
G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_4_Local_Bedrock_Geology_R0.mxd

CONCEPTUAL CROSS SECTION ACROSS
QUETICO-WAWA BOUNDARY



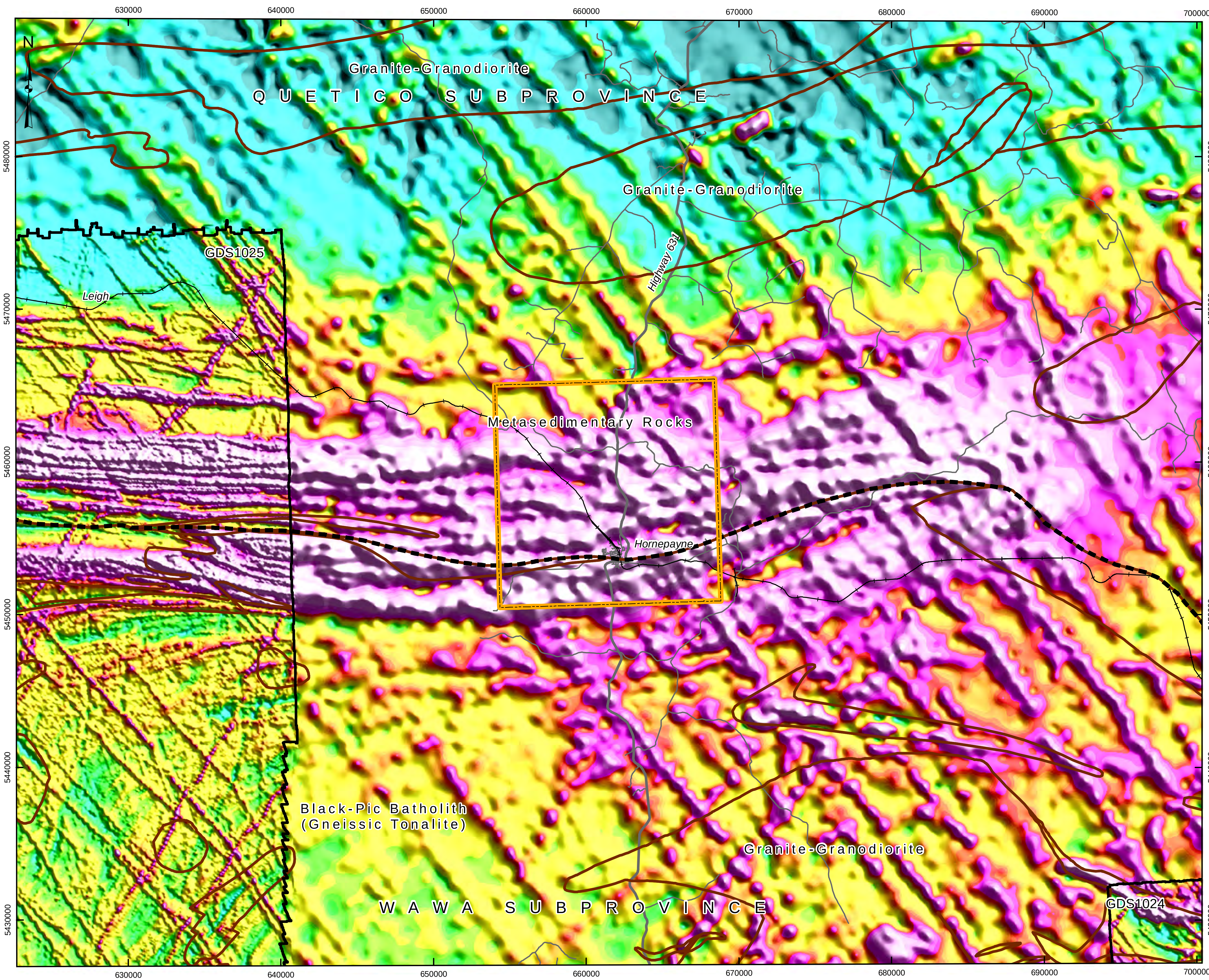
Vertical Exaggeration = 3x



Note: Subsurface reflectors based on Percival et al. (2006) and White et al. (2003)

Conceptual Geologic Cross Section - Hornepayne Area NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability		Prepared by: ADG Reviewed by: KGR
FIGURE 3.5	Doc. No.:10-214-3_Hornepayne_Fig3_5_Cross_Section_R0	Date: Aug 19, 2013

Geofirma
Engineering Ltd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Subprovince Boundary
- Outline of Geologic Unit
- Higher Resolution Geophysical Surveys

Residual Total MagneticField (nT)

610, 470, 350, 240, 180, 140, 110, 80, 60, 40, 20, 0, -10, -30, -40, -50, -60, -80, -90, -100, -110, -130, -140, -160, -180, -210, -250

RTP (nT)

SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Airborne Geophysics: MAG PGW, 2013
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Total Magnetic Field (Reduced to Pole) of the Hornepayne Area

FIGURE 3.6

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 07/11/2013

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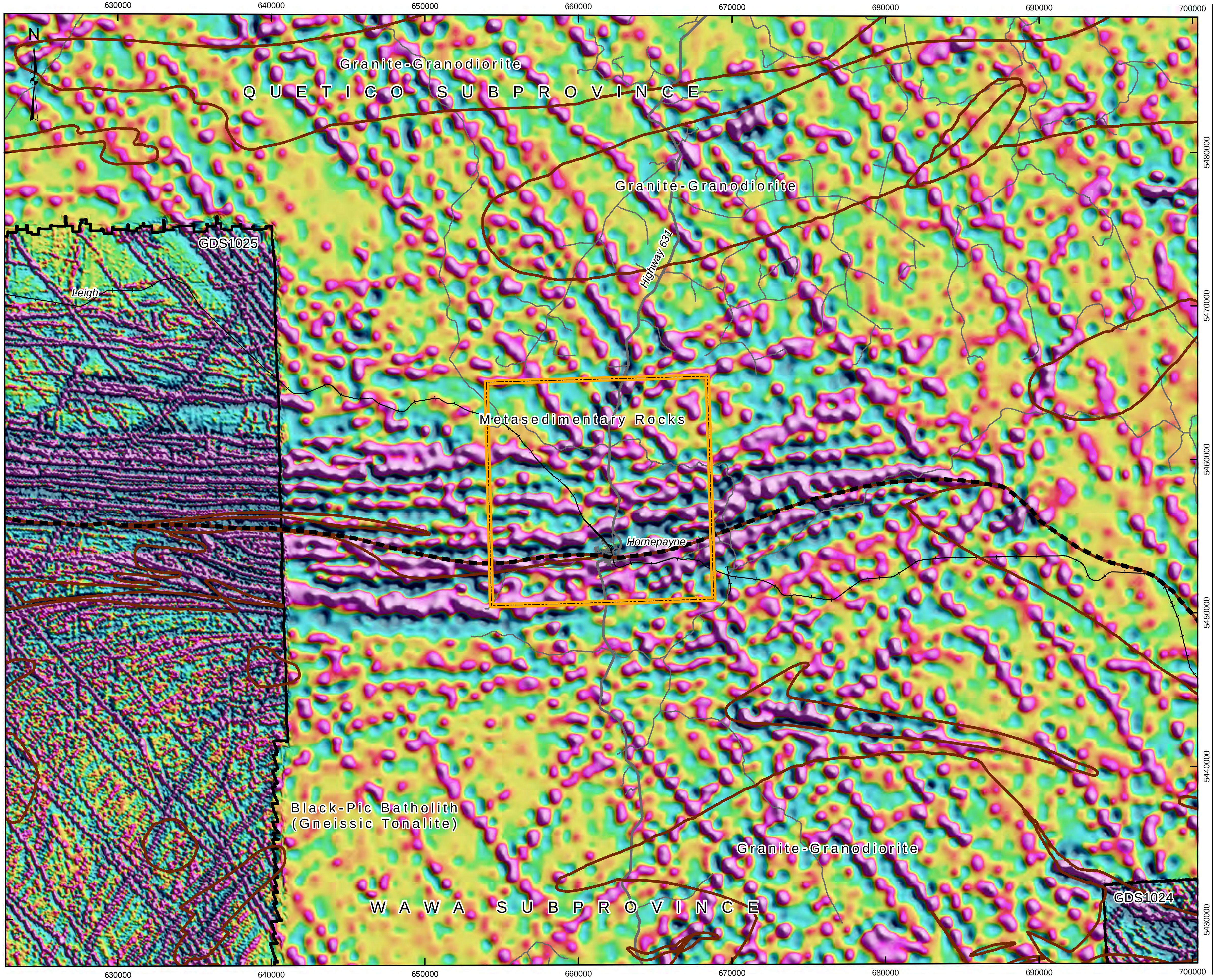
G:\Data\Project\Hornepayne\10-214-4_Hornpayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_6_Total_Magnetic_Field_R0.mxd



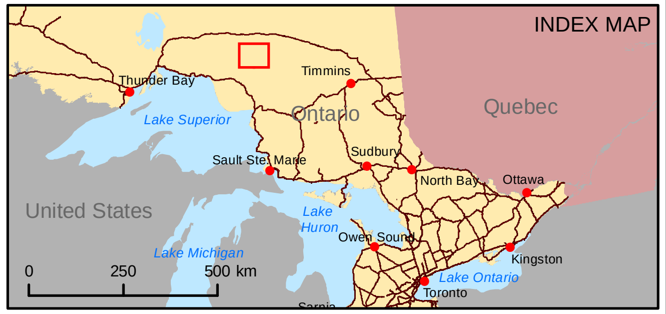
LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Subprovince Boundary
- Outline of Geologic Unit
- Higher Resolution Geophysical Surveys

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

0.64, 0.39, 0.28, 0.21, 0.16, 0.12, 0.09, 0.07, 0.05, 0.03, 0.01, 0.00, -0.01, -0.02, -0.03, -0.05, -0.06, -0.07, -0.08, -0.10, -0.11, -0.13, -0.16, -0.18, -0.22, -0.27, -0.34, -0.52

1VD of RTP (nT/m)



SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Airborne Geophysics: MAG (First Vertical Derivative), PGW, 2013
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

First Vertical Derivative (Reduced to Pole) of Magnetic Field for the Hornepayne Area

FIGURE 3.7

DESIGN: NMP
CAD/GIS: NMP
CHECK:KGR/SNS
REV: 0

DATE: 07/11/2013

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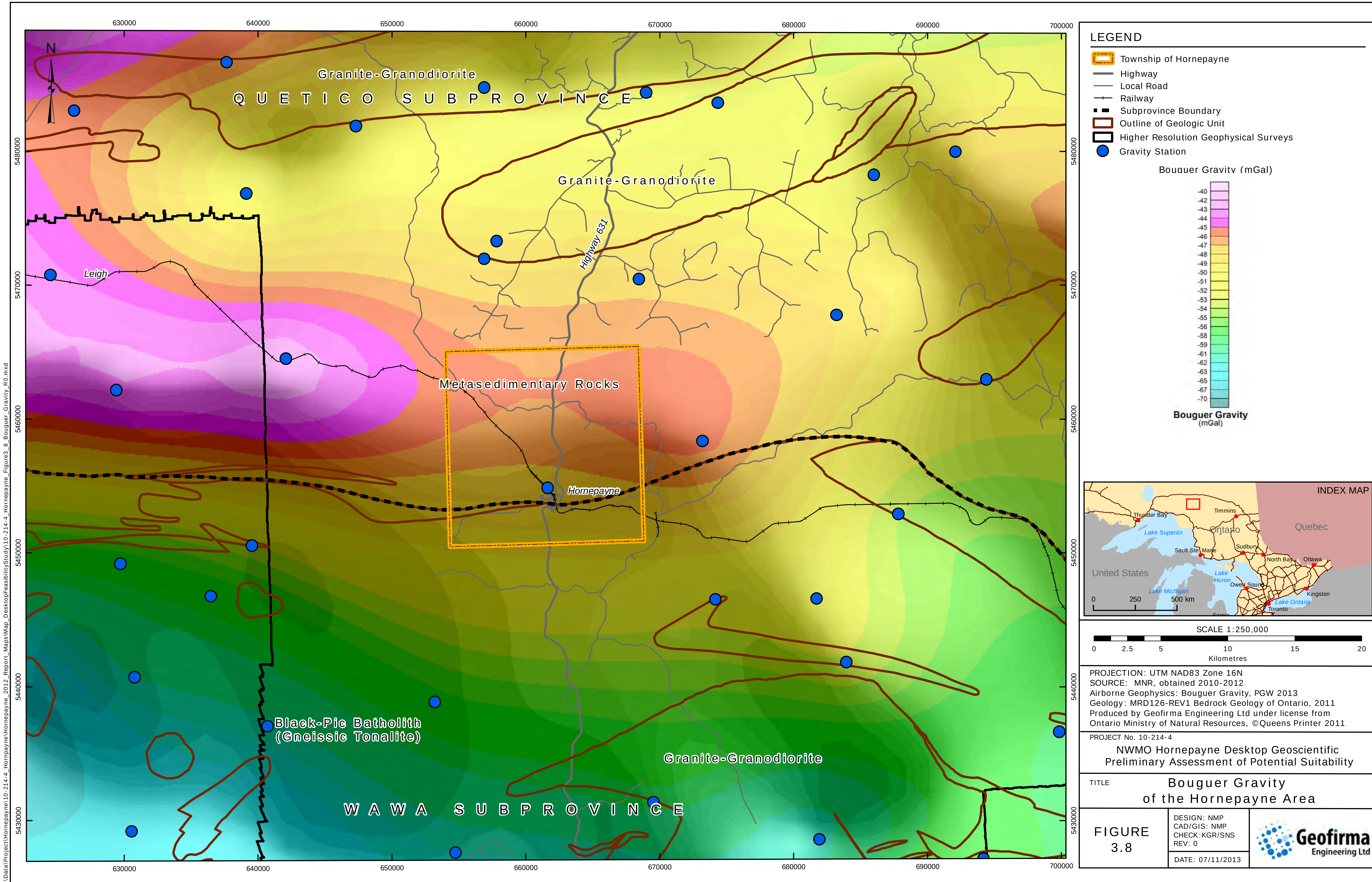
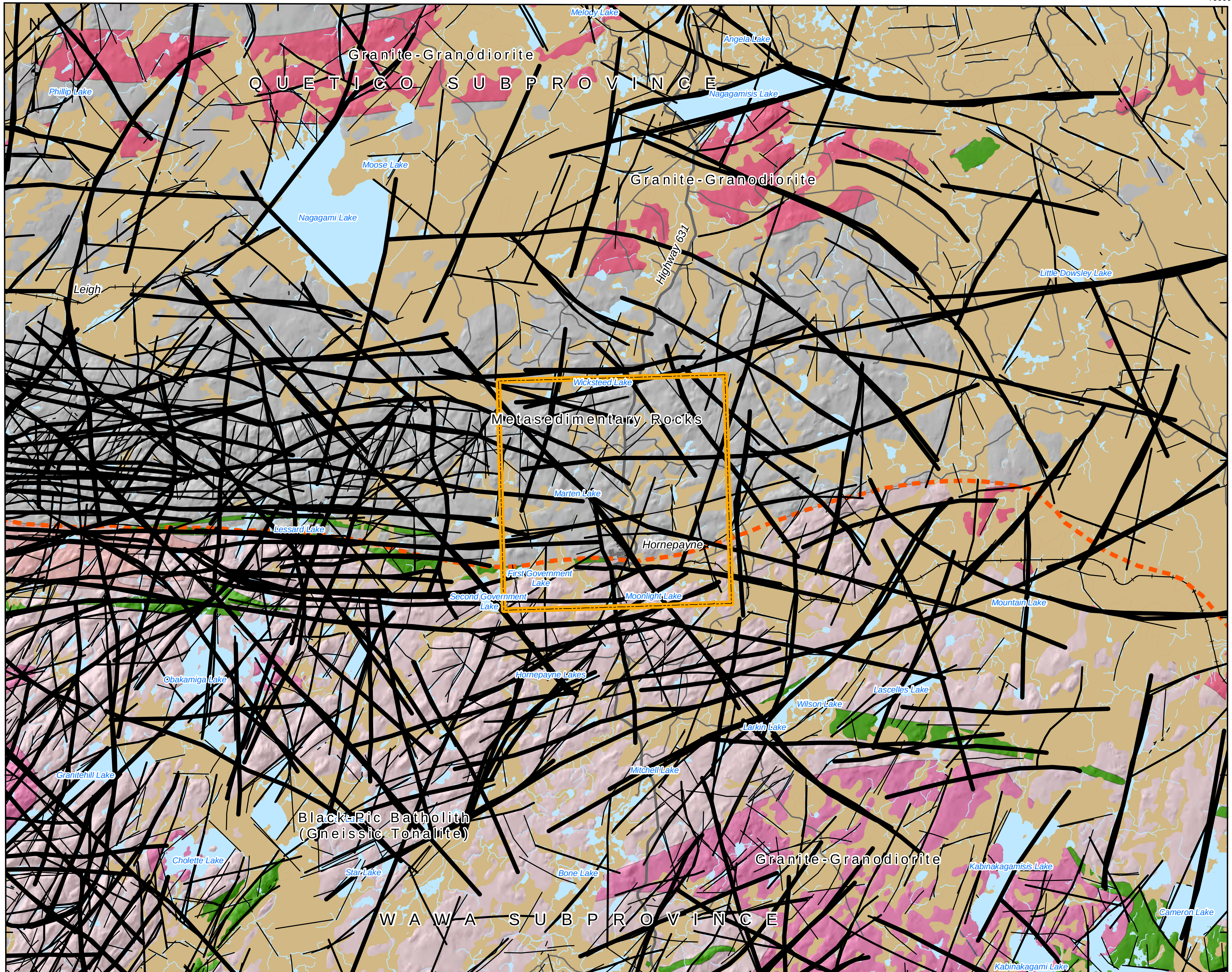
G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_7_First_Vertical_Derivative_Magnetic_Field_R0.mxd



Granite-Granodiorite
QUETICO SUBPROVINCE
Granite-Granodiorite
Highway 631
Leigh
Metasedimentary Rocks
Hornepayne
Black-Pic Batholith
(Gneissic Tonalite)
Granite-Granodiorite
WAWA SUBPROVINCE
N
630000
640000
650000
660000
670000
680000
690000
700000
5480000
5470000
5460000
5450000
5440000
5430000
LEGEND
Township of Hornepayne
Highway
Local Road
Railway
Subprovince Boundary
Outline of Geologic Unit
Higher Resolution Geophysical Surveys
Gravity Station
Bouguer Gravity (mGal)
-40
-42
-43
-44
-45
-46
-47
-48
-49
-50
-51
-52
-53
-54
-55
-56
-58
-59
-61
-62
-63
-65
-67
-70
Bouguer Gravity
(mGal)
INDEX MAP
Thunder Bay
Timmins
Ontario
Quebec
Lake Superior
Sault Ste. Marie
Sudbury
North Bay
Ottawa
United States
Lake Huron
Lake Michigan
Owen Sound
Kingston
Lake Ontario
Toronto
0 250 500 km
SCALE 1:250,000
0 2.5 5 10 15 20
Kilometres
PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Airborne Geophysics: Bouguer Gravity, PGW 2013
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ©Queens Printer 2011
PROJECT No. 10-214-4
NWMO Hornepayne Desktop Geoscientific
Preliminary Assessment of Potential Suitability
TITLE
Bouguer Gravity
of the Hornepayne Area
FIGURE
3.8
DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 07/11/2013
Geofirma
Engineering Ltd
G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_8_Bouguer_Gravity_R0.mxd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Areas with Overburden Cover
- Subprovince Boundary

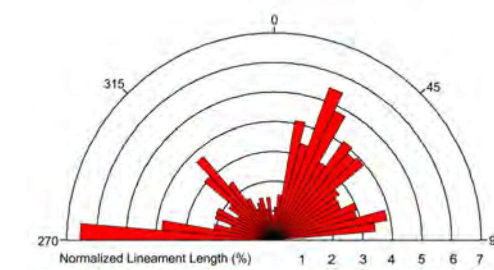
Surficial Lineament (CDED and SPOT)

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

Bedrock Geology

- 13 Granite-granodiorite, massive to foliated
- 11 Granite-granodiorite, muscovite/biotite bearing
- 10 Foliated tonalite suite
- 9 Gneissic tonalite suite
- 5 Metasedimentary rocks
- 2 Mafic volcanic rocks

Hornepayne Surficial Lineaments - Normalized Length in 5 Degree Azimuth Bins



SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Surficial Geology: NOEGTS-OGS MRD-160 (scale 1:100,000)
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

PROJECT No. 10-214-4
NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE
Surficial Lineaments of the Hornepayne Area

FIGURE 3.9

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 07/11/2013

Geofirma Engineering Ltd

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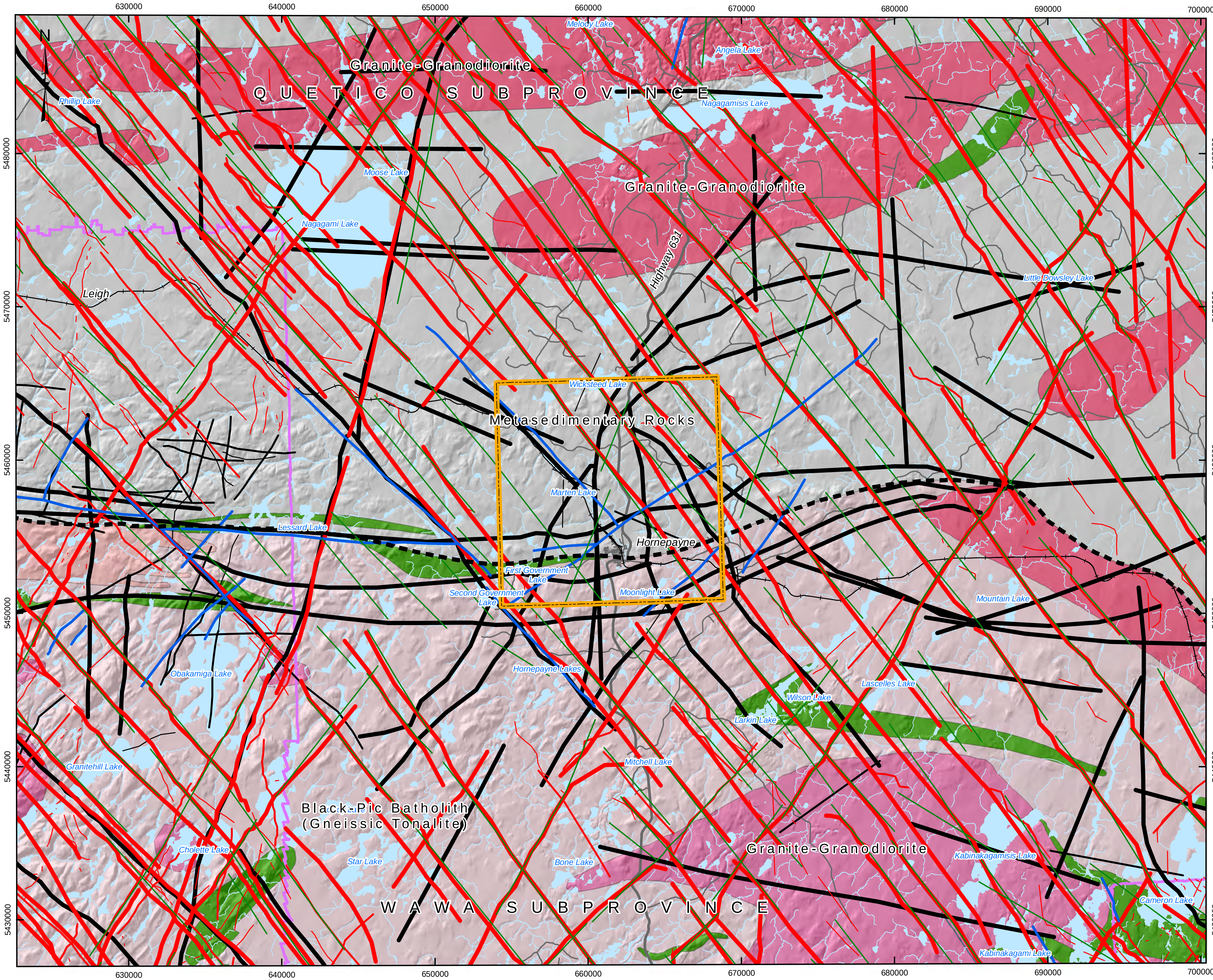
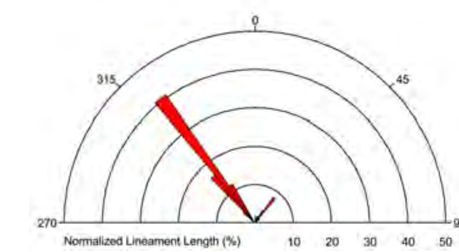


LEGEND

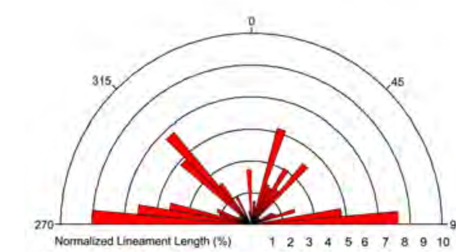
- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Mapped Geological Fault
- Mapped Dyke
- Higher Resolution Geophysical Surveys
- Subprovince Boundary

Fracture (length)	Dyke (length)
< 1 km	< 1 km
1 - 5 km	1 - 5 km
5 - 10 km	5 - 10 km
> 10 km	> 10 km

Hornepayne Geophysical Dykes -
Normalized Length in 5 Degree Azimuth Bins



Hornepayne Geophysical Fractures -
Normalized Length in 5 Degree Azimuth Bins



SCALE 1:250,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific
Preliminary Assessment of Potential Suitability

TITLE

Geophysical Lineaments of the Hornepayne Area

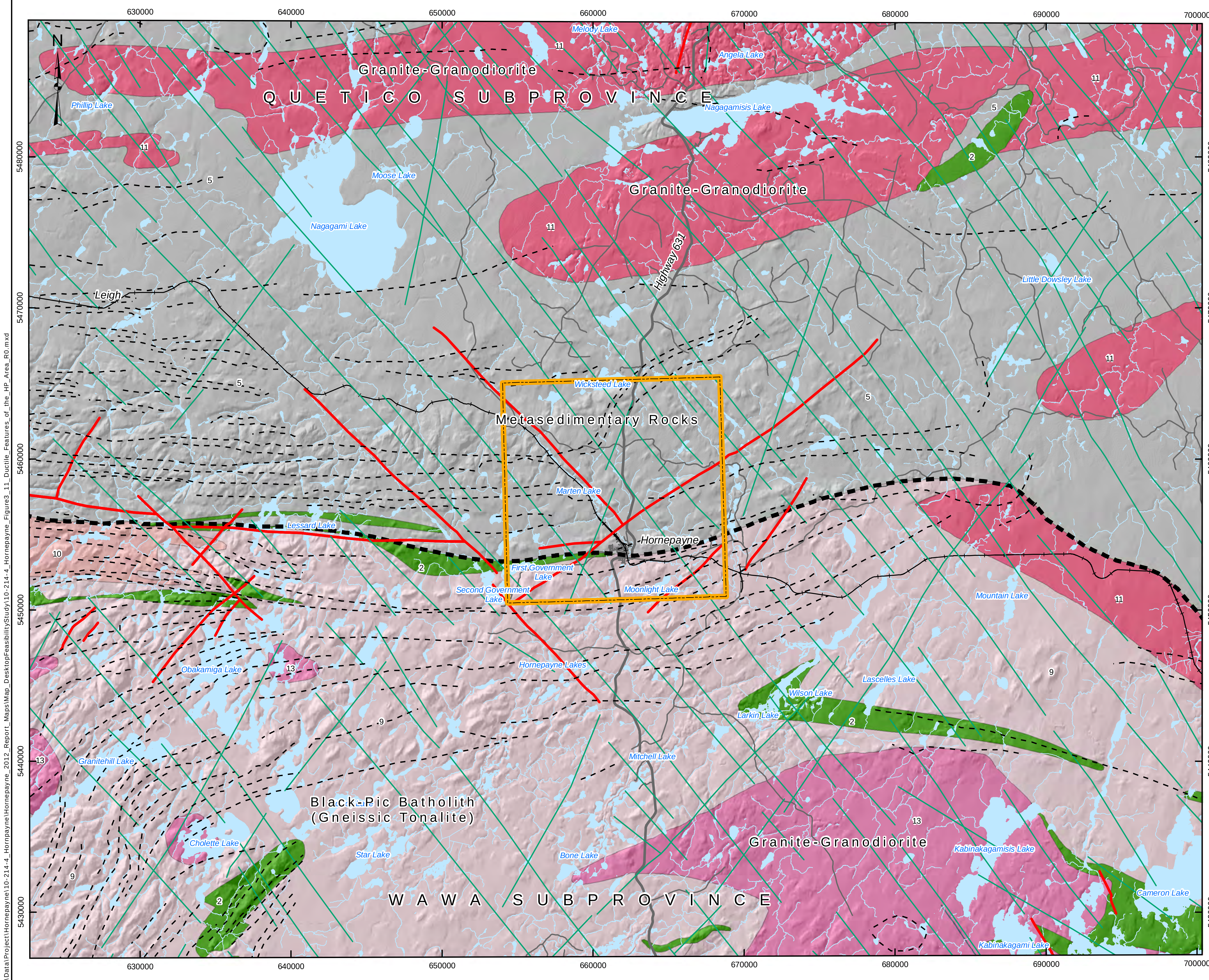
FIGURE 3.10

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0

DATE: 07/11/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_10_Geophysical_Lineaments_R0.mxd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Mapped Geological Fault
- Mapped Dyke
- Subprovince Boundary
- Ductile Lineament

Bedrock Geology

- 13 Granite-granodiorite, massive to foliated
- 11 Granite-granodiorite, muscovite/biotite bearing
- 10 Foliated tonalite suite
- 9 Gneissic tonalite suite
- 5 Metasedimentary rocks
- 2 Mafic volcanic rocks

INDEX MAP

SCALE 1:250,000

0 2.5 5 10 15 20 Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Ductile Lineaments of the Hornepayne Area

FIGURE 3.11

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0

DATE: 12/11/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4 Hornpayne\Hornepayne 2012 Report Maps\Map Desktop Feasibility Study\10-214-4 Hornepayne Figure3 12 Merged Lineaments Classification by Length R0.mxd

LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Subprovince Boundary

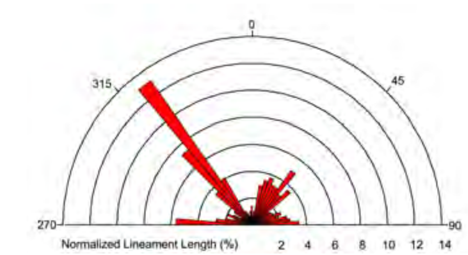
Surficial and Geophysical Fracture (length)

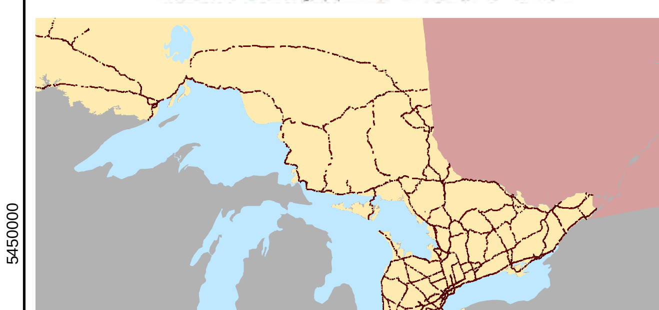
- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km

Dyke (length)

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

Hornepayne All Data - Normalized Length in 5 Degree Azimuth Bins





SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

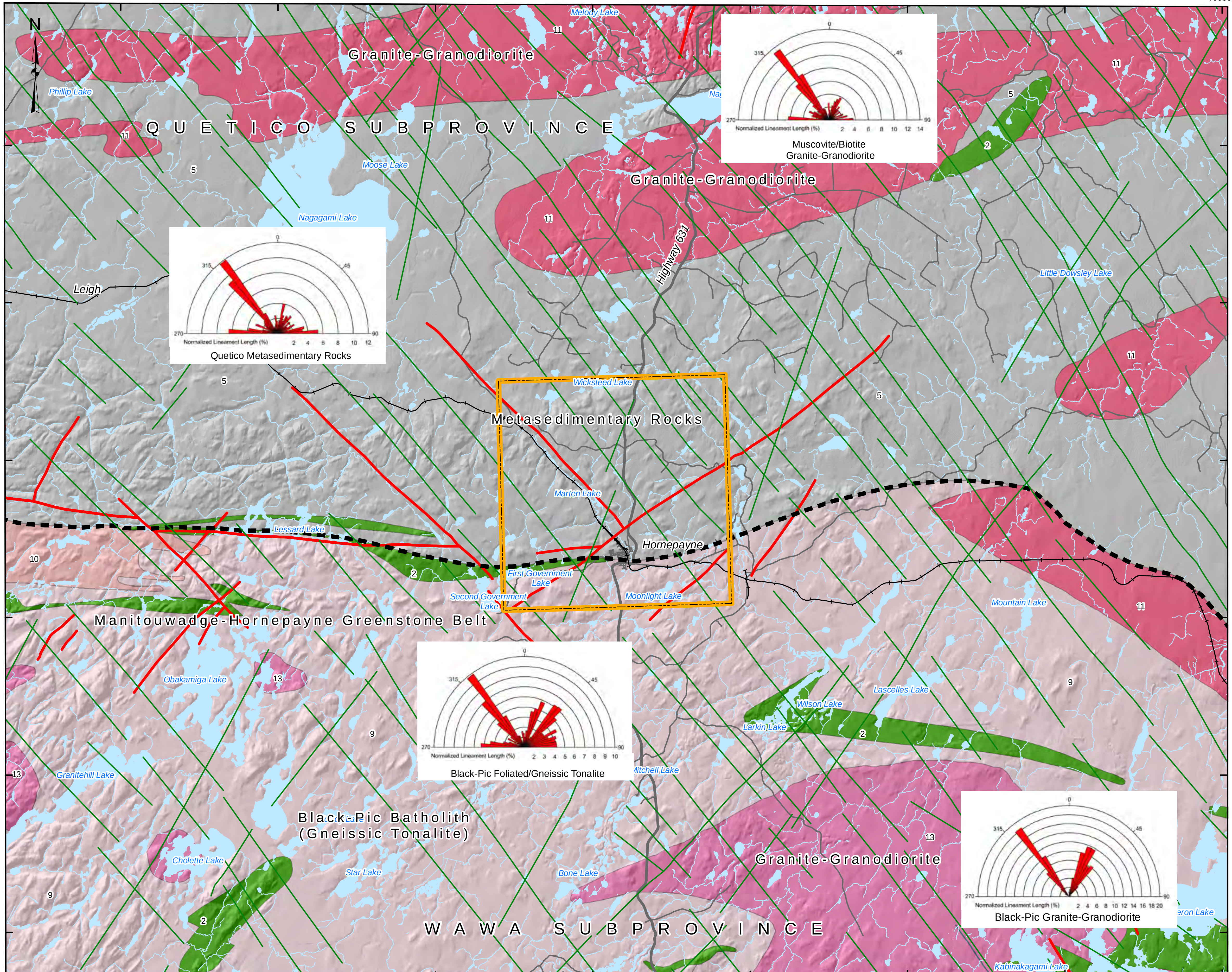
Merged Lineaments of the Hornepayne Area

FIGURE 3.12

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0

DATE: 07/11/2013

Geofirma Engineering Ltd



G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_13_Lineament_Orientations_of_Batholiths_and_Plutons_R0.mxd

LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Mapped Geological Fault
- Mapped Dyke
- Subprovince Boundary

Bedrock Geology

- 13 Granite-granodiorite, massive to foliated
- 11 Granite-granodiorite, muscovite/biotite bearing
- 10 Foliated tonalite suite
- 9 Gneissic tonalite suite
- 5 Metasedimentary rocks
- 2 Mafic volcanic rocks

SCALE 1:250,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

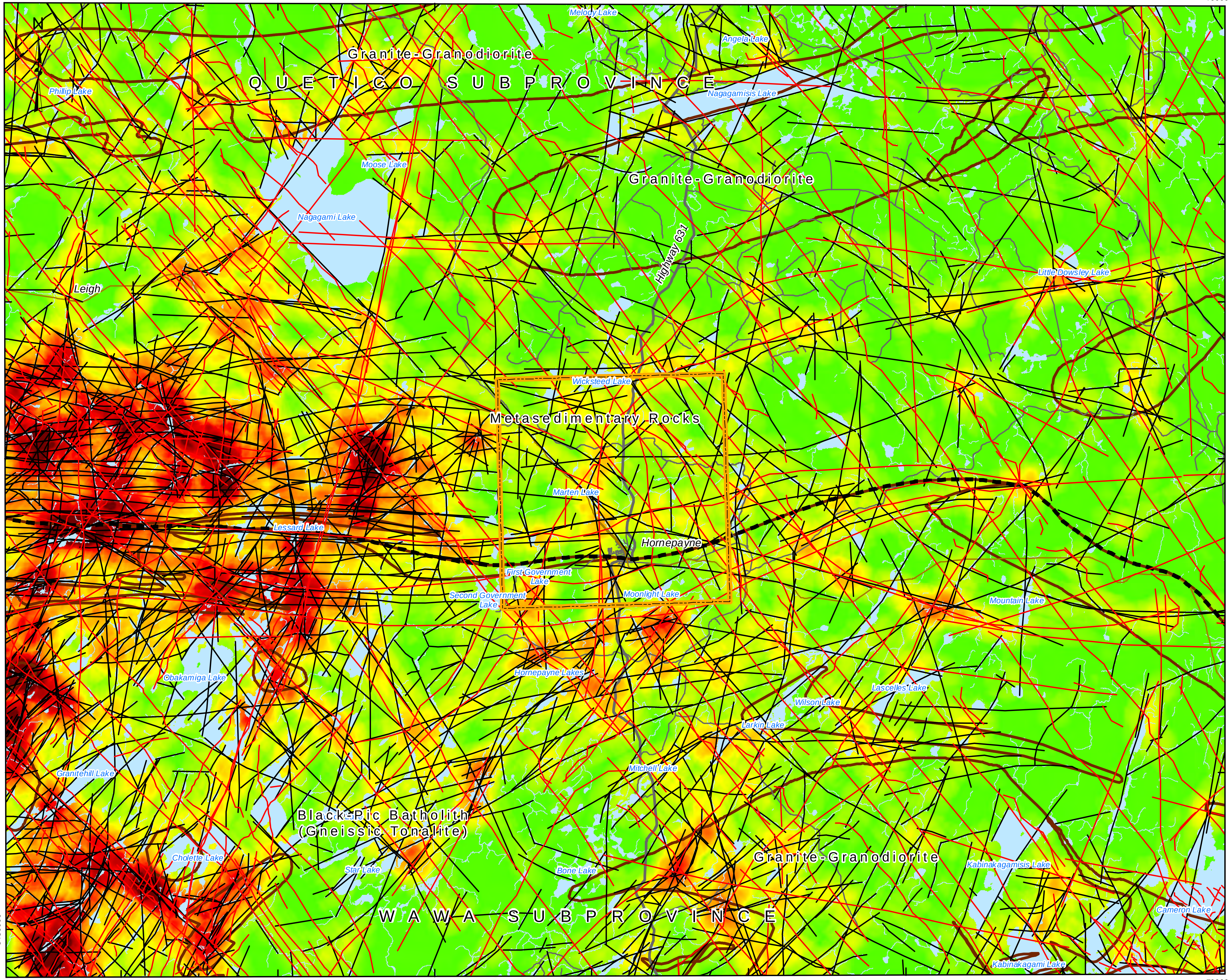
Lineament Orientations of Potentially Suitable Geologic Units of the Hornepayne Area

FIGURE 3.13

DESIGN: NMP
CAD/GIS: VMS/NMP
CHECK: KGR/SNS
REV: 0

DATE: 07/11/2013

Geofirma Engineering Ltd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Subprovince Boundary
- Outline of Geologic Unit

Brittle Lineament

- Surficial-Fracture
- Geophysical-Fracture and Dyke

Lineament Density (km / km^2)

8, 7, 6, 5, 4, 3, 2, 1, 0

INDEX MAP

SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011,
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Brittle Lineament Density Calculated for Lineaments in the Hornepayne Area

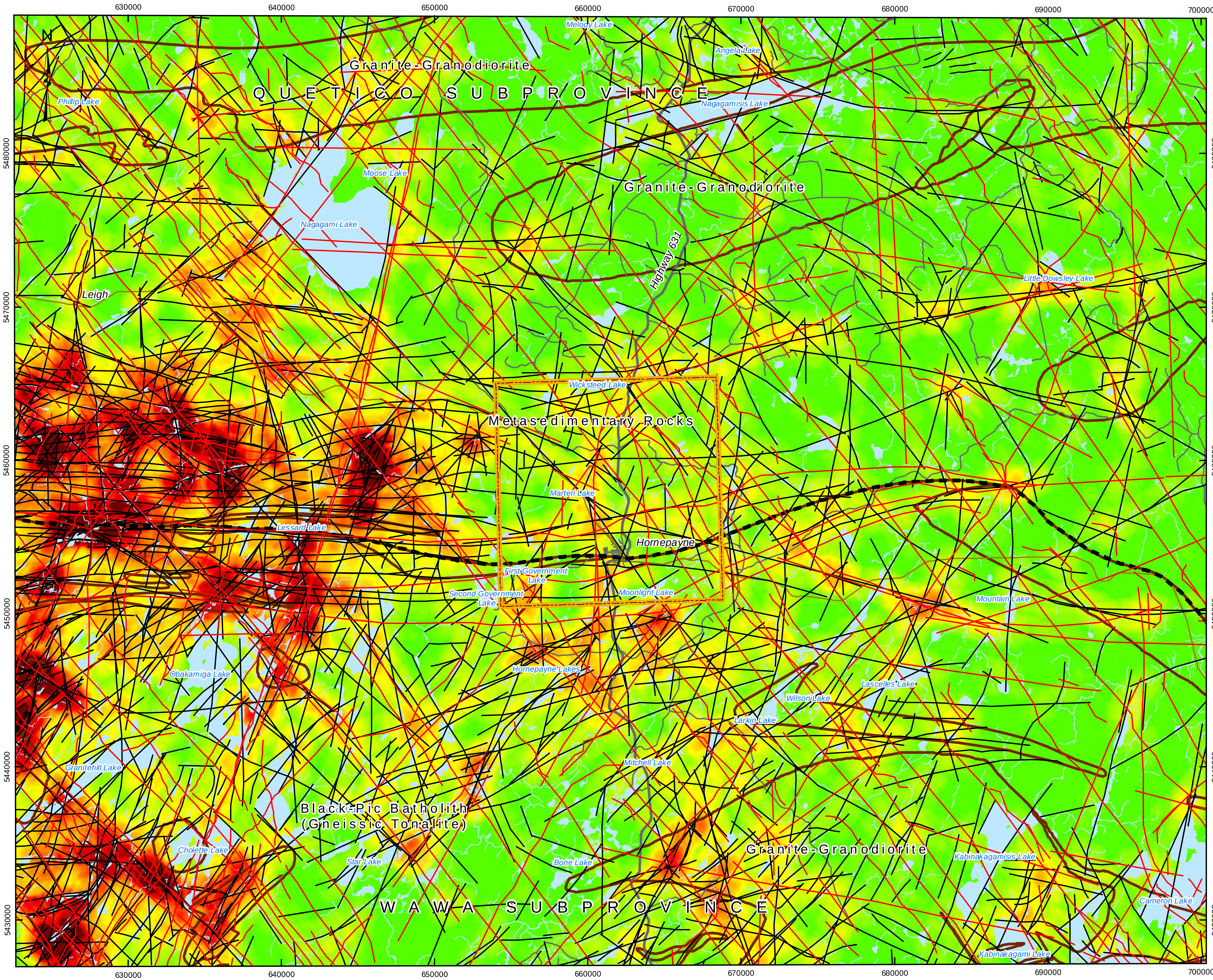
FIGURE 3.14

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 19/08/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_14_Brittles_Lineament_Density_R0.mxd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Subprovince Boundary
- Outline of Geologic Unit

Brittle Lineament

- Surficial-Fracture (>1 km)
- Geophysical-Fracture and Dyke (>1 km)

Lineament Density (km/km^2)

8
7
6
5
4
3
2
1
0

SCALE 1:250,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011,
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE Brittle Lineament Density Calculated for Lineaments (>1 km) in the Hornepayne Area

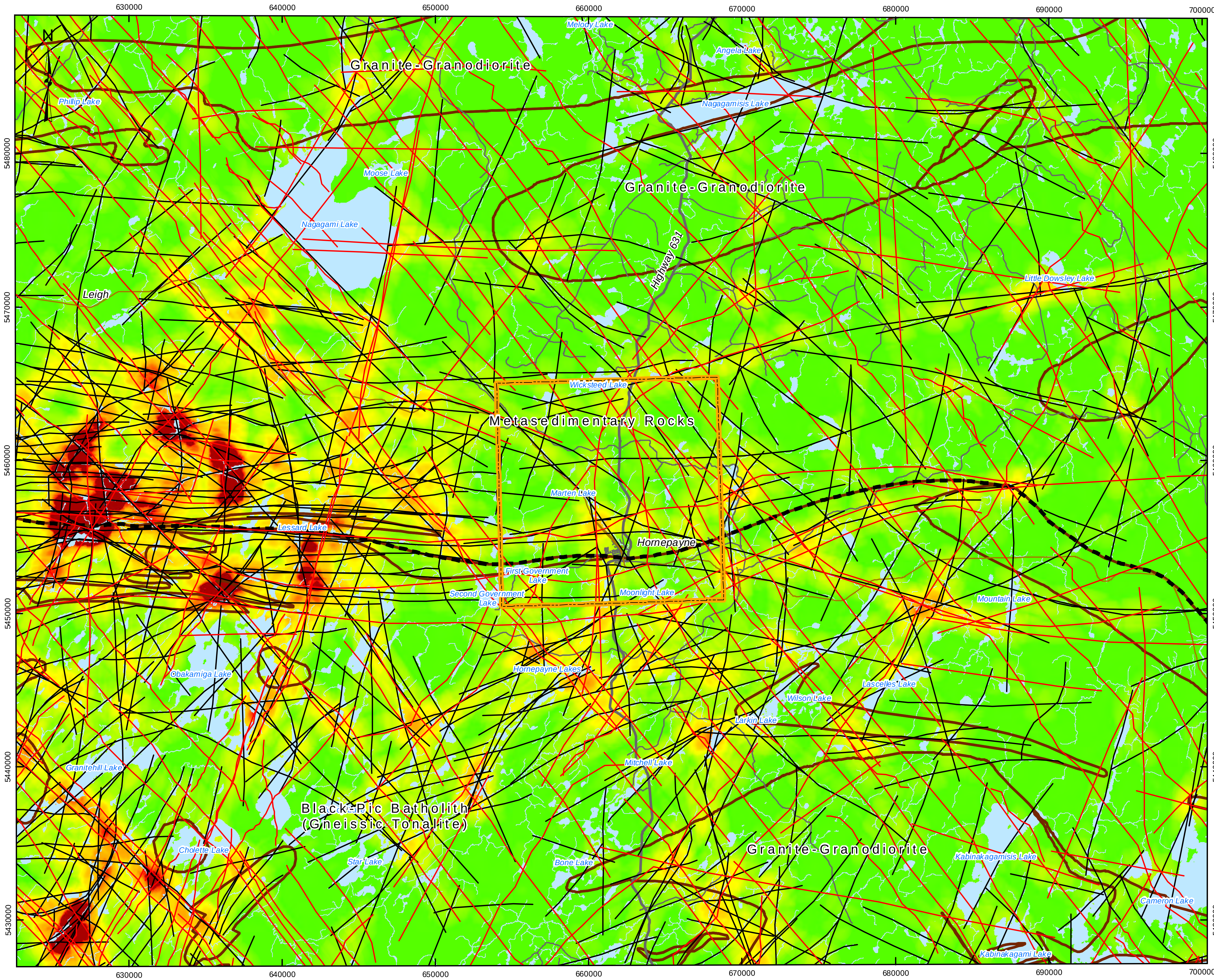
FIGURE 3.15

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 19/08/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornpayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_15_Brittles_Lineament_Density_LM_Length_1km_R0.mxd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Subprovince Boundary
- Outline of Geologic Unit

Brittle Lineament

- Surficial-Fracture (>5 km)
- Geophysical-Fracture and Dyke (>5 km)

Lineament Density (km/km^2)

8 7 6 5 4 3 2 1 0

SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011,
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
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NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE Brittle Lineament Density Calculated for Lineaments (>5 km) in the Hornepayne Area

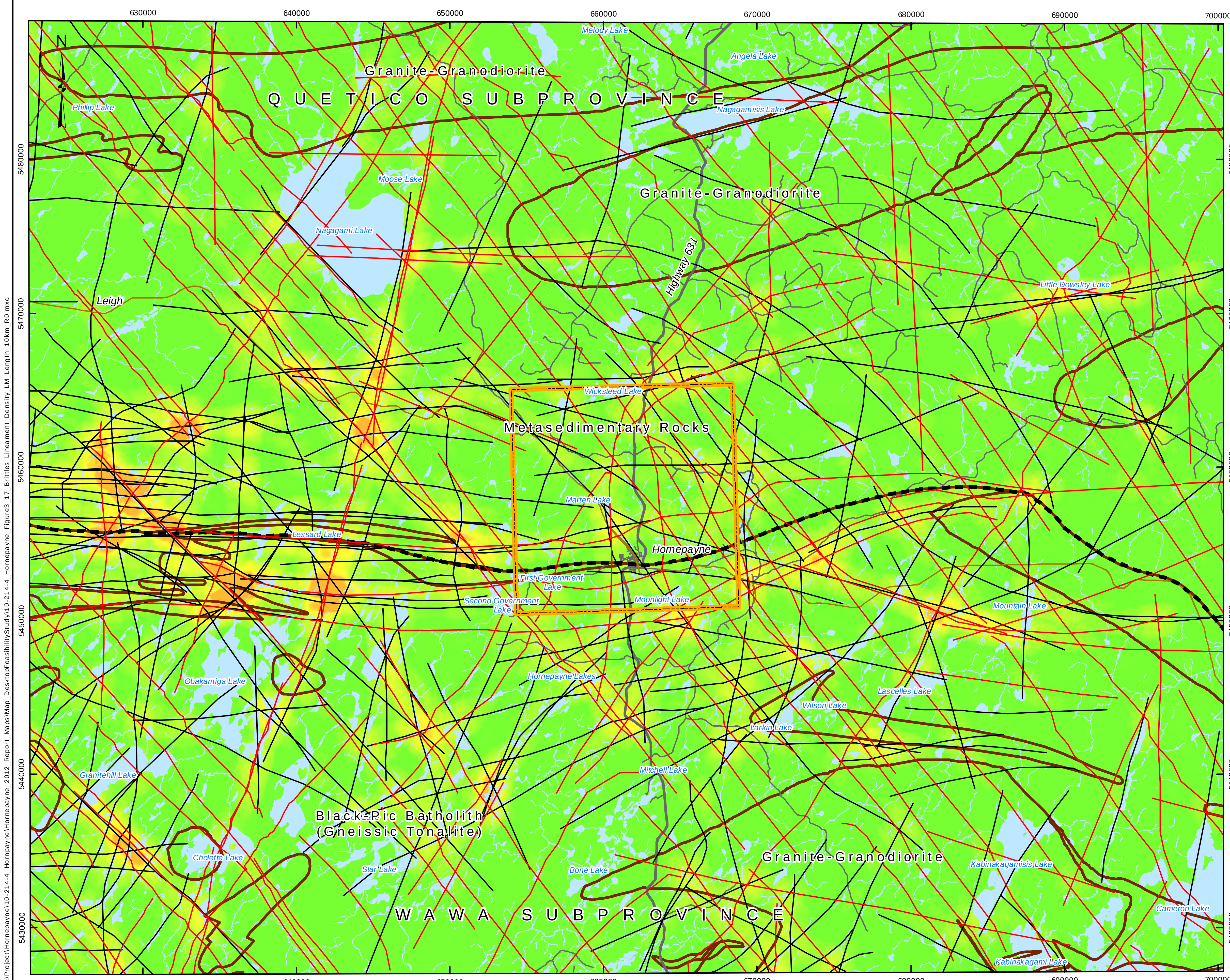
FIGURE 3.16

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 19/08/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornpayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_16_Brittles_Lineament_Density_LM_Length_5km_R0.mxd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Subprovince Boundary
- Outline of Geologic Unit

Brittle Lineament

- Surficial-Fracture (>10 km)
- Geophysical-Fracture and Dyke (>10 km)

Lineament Density (km/km^2)

8, 7, 6, 5, 4, 3, 2, 1, 0

SCALE 1:250,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011,
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Brittle Lineament Density Calculated for Lineaments (>10 km) in the Hornepayne Area

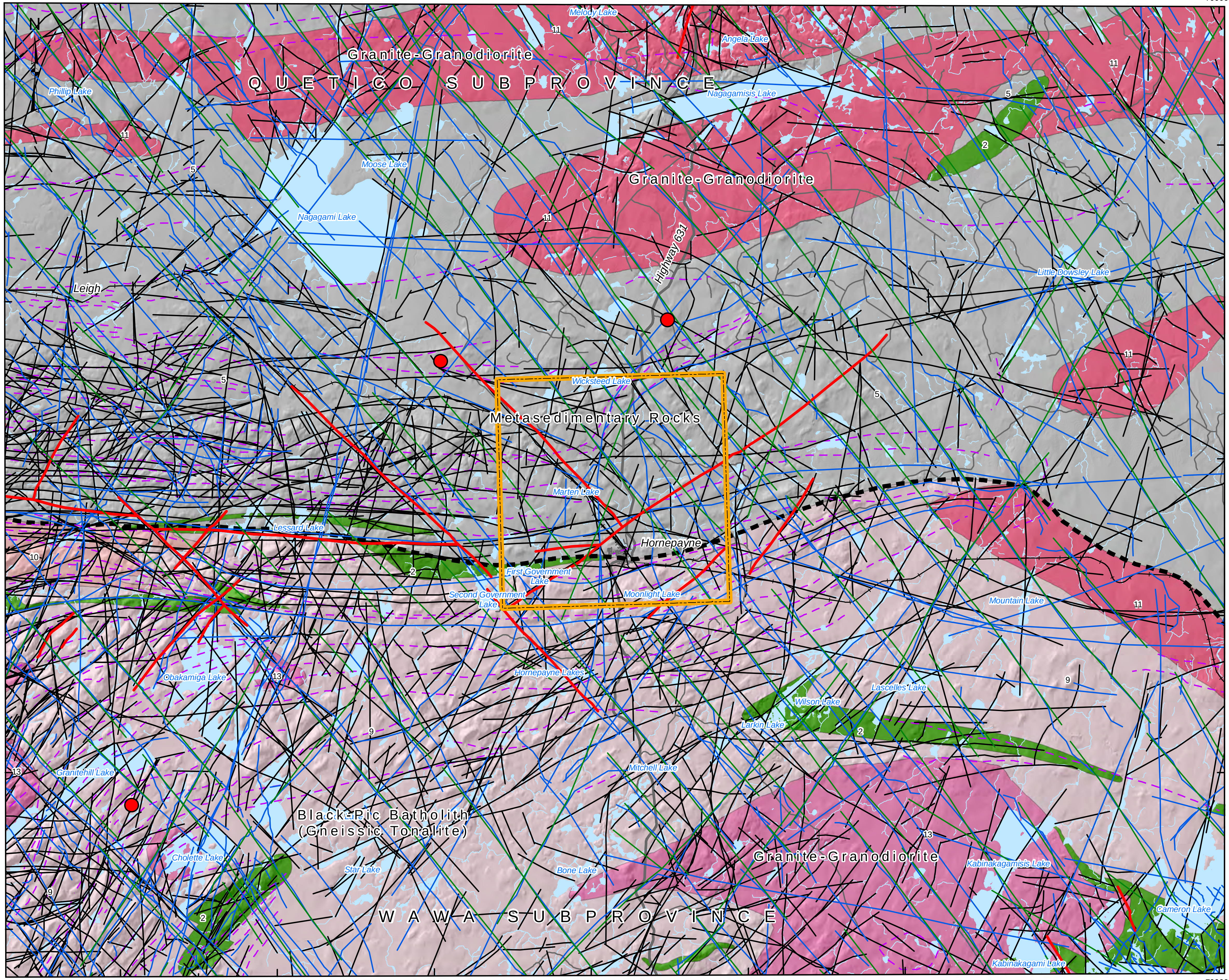
FIGURE 3.17

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 19/08/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornpayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_17_Brittles_Lineament_Density_LM_Length_10km_R0.mxd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Subprovince Boundary
- Mapped Geological Fault
- Mapped Dyke
- Ductile Lineament

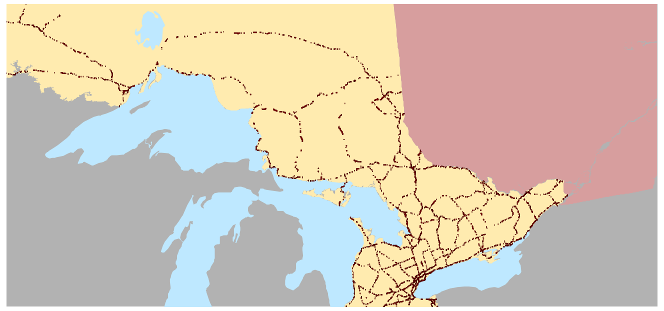
Brittle Lineament

- Surficial-Fracture
- Geophysical-Fracture and Dyke

Seismic Events (Magnitude)

- 2.0 - 3.0

*no events less than 2.0 and greater than 3 magnitude within mapping area



SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Seismic:Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), 1985-2011
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-4
NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE Combined Structural Features of the Hornepayne Area

FIGURE 3.18

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0

DATE: 07/11/2013

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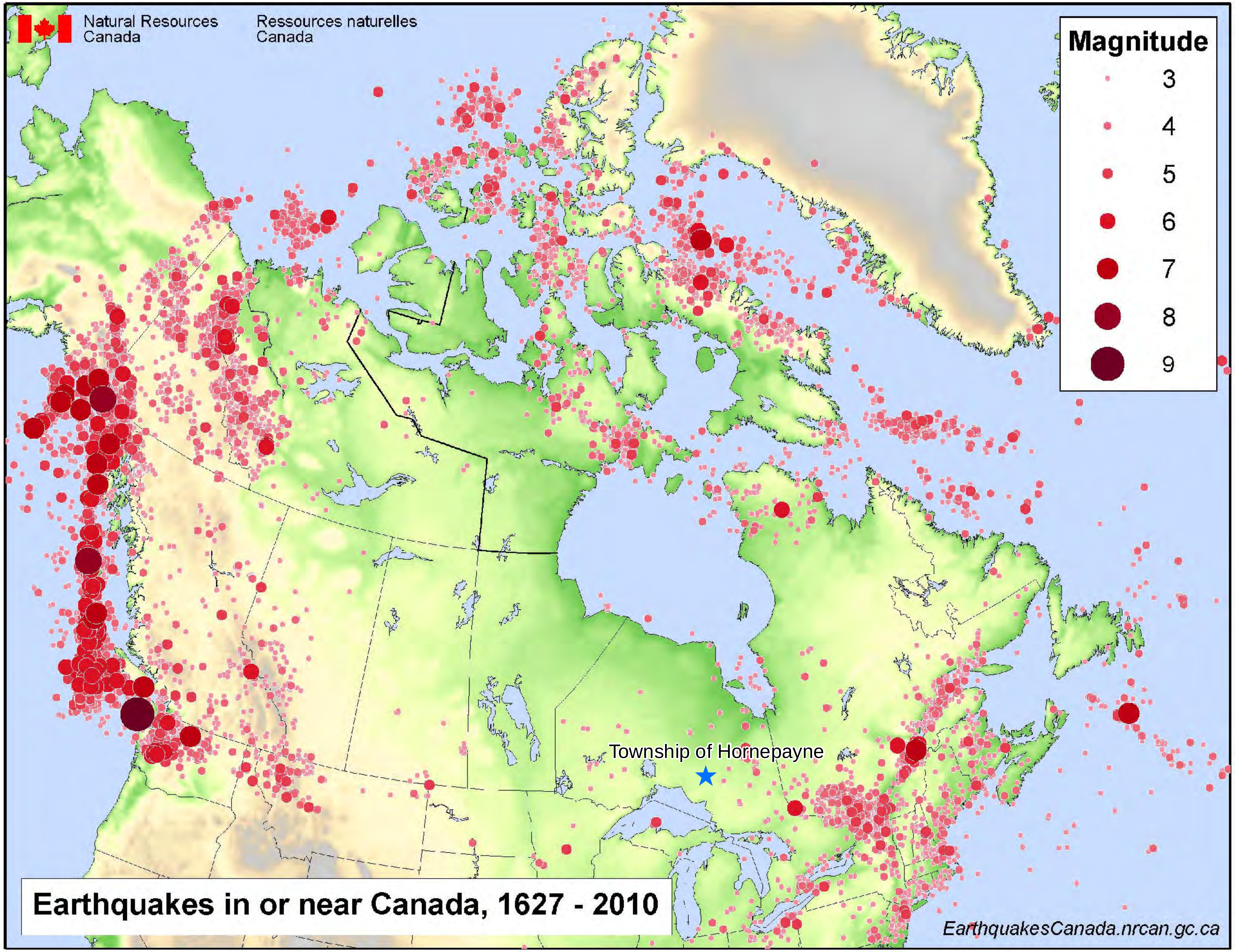
G:\Data\Project\Hornepayne\10-214-4_Hornpayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_18_Combined_Structural_Features_Map_R0.mxd



LEGEND

★ Township of Hornepayne

Not to Scale

PROJECTION: NA
SOURCE: Seismic: NRCAN, Earthquake Map of Canada 1627-2010

PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Earthquake Map of Canada 1627-2010

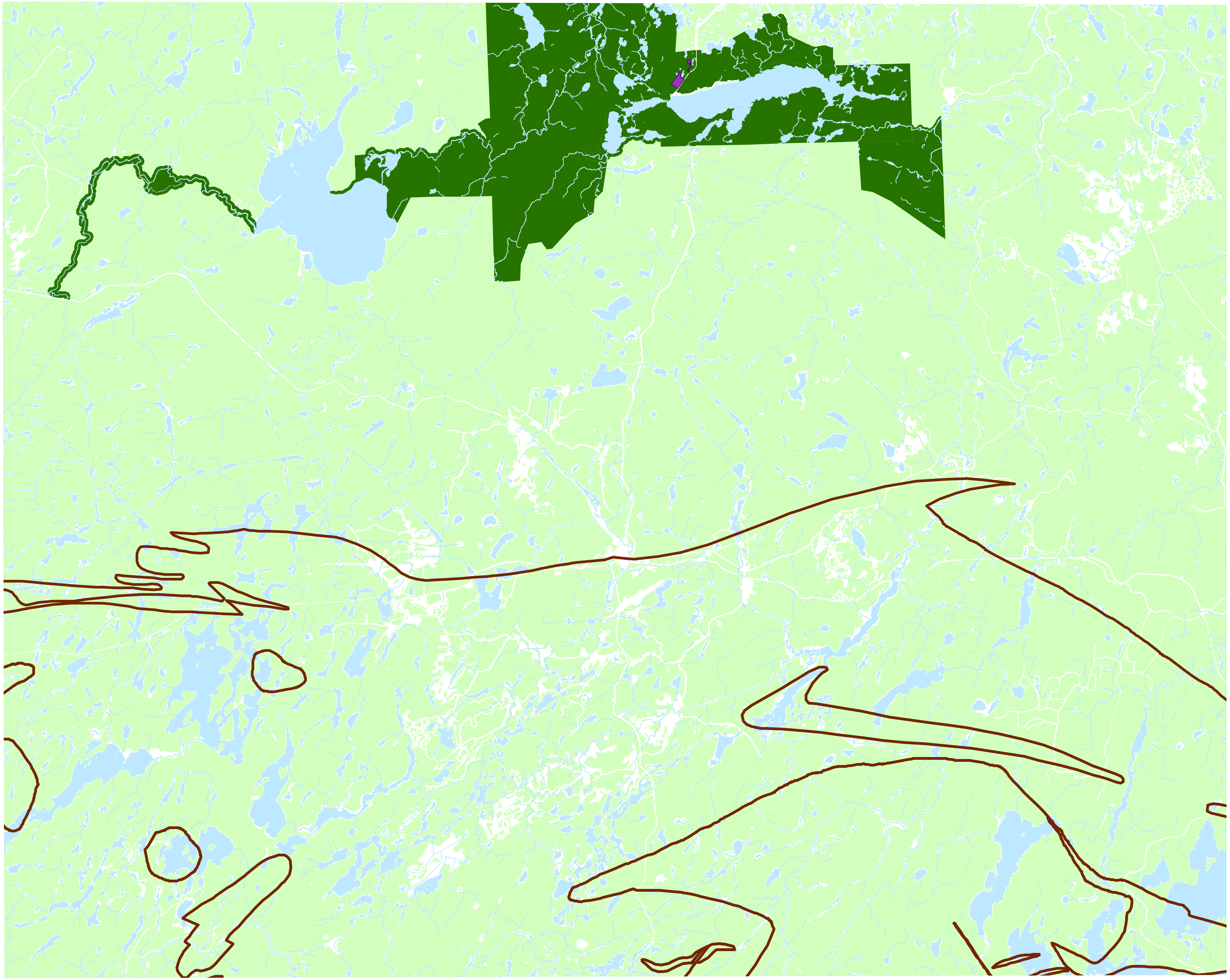
FIGURE 3.19

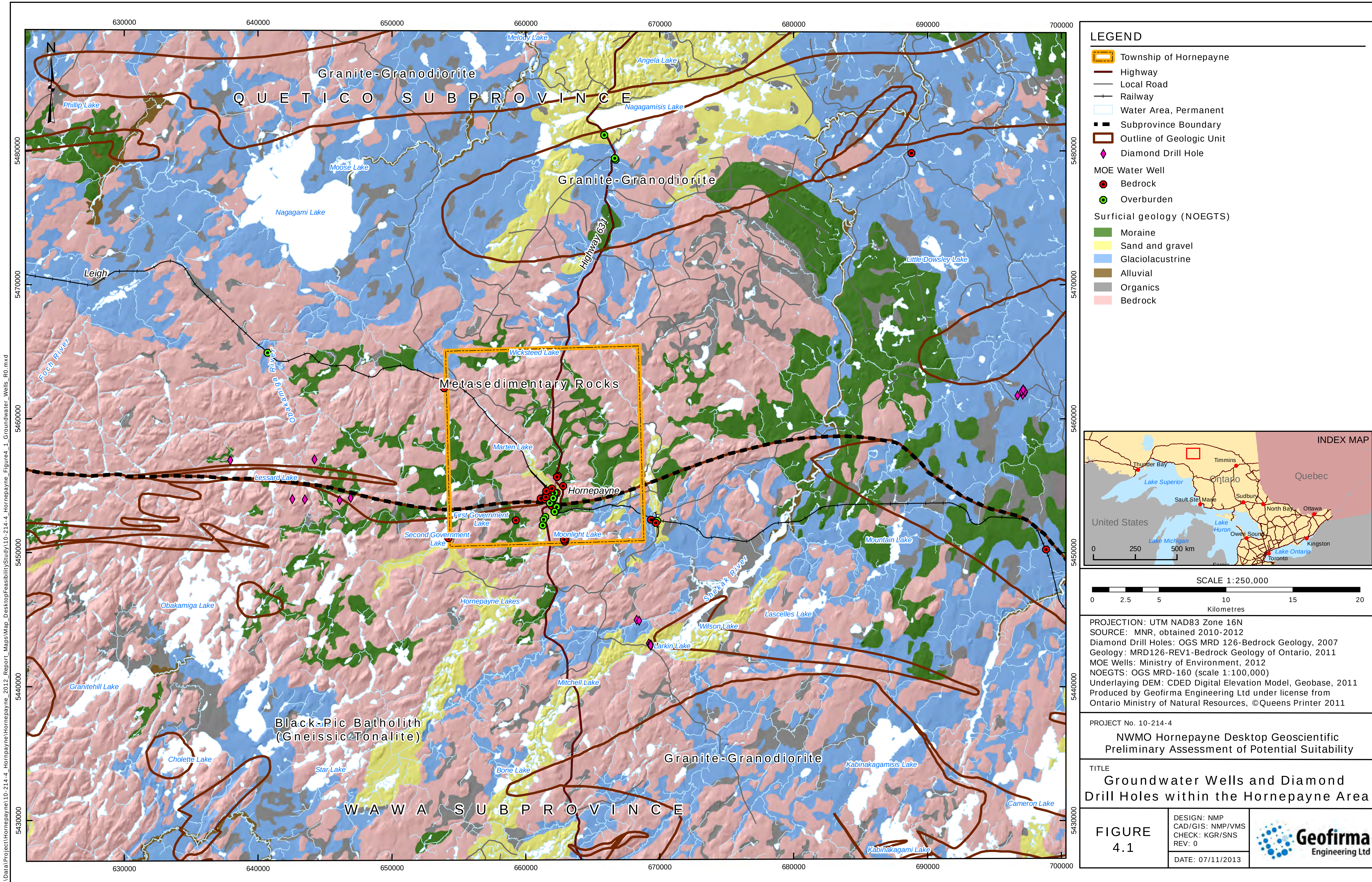
DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 20/08/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure3_19_Earthquakes_Map_of_Canada_1627_2010_R0.mxd




LEGEND
Township of Hornepayne
Highway
Local Road
Railway
Water Area, Permanent
Subprovince Boundary
Outline of Geologic Unit
Diamond Drill Hole
MOE Water Well
Bedrock
Overburden
Surficial geology (NOEGTS)
Moraine
Sand and gravel
Glaciolacustrine
Alluvial
Organics
Bedrock
INDEX MAP
Thunder Bay
Timmins
Lake Superior
Ontario
Quebec
Sault Ste Marie
Sudbury
North Bay
Ottawa
United States
Lake Huron
Owen Sound
Lake Michigan
Kingston
Lake Ontario
Toronto
0 250 500 km
SCALE 1:250,000
0 2.5 5 10 15 20
Kilometres
PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Diamond Drill Holes: OGS MRD 126-Bedrock Geology, 2007
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
MOE Wells: Ministry of Environment, 2012
NOEGTS: OGS MRD-160 (scale 1:100,000)
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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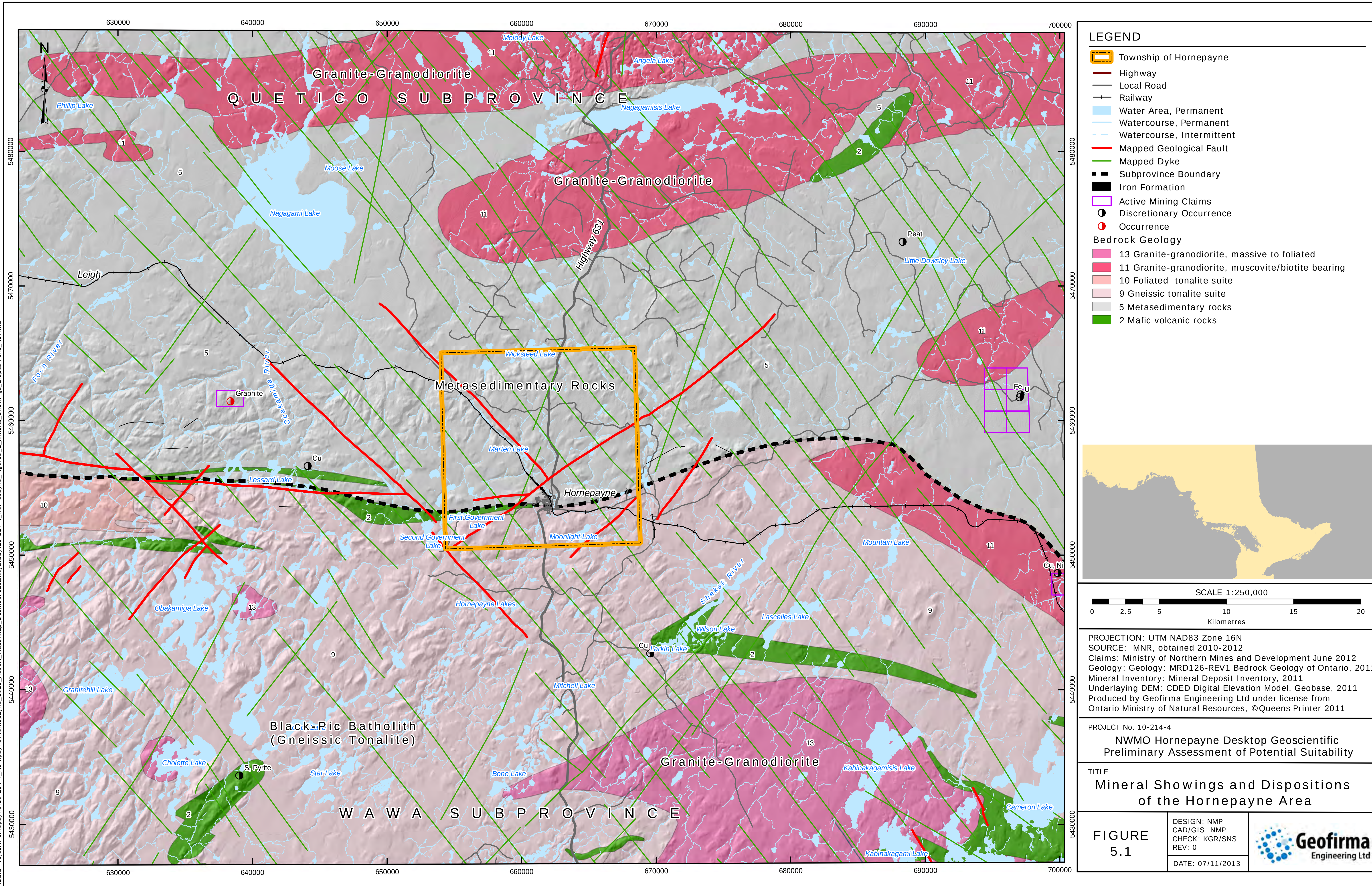
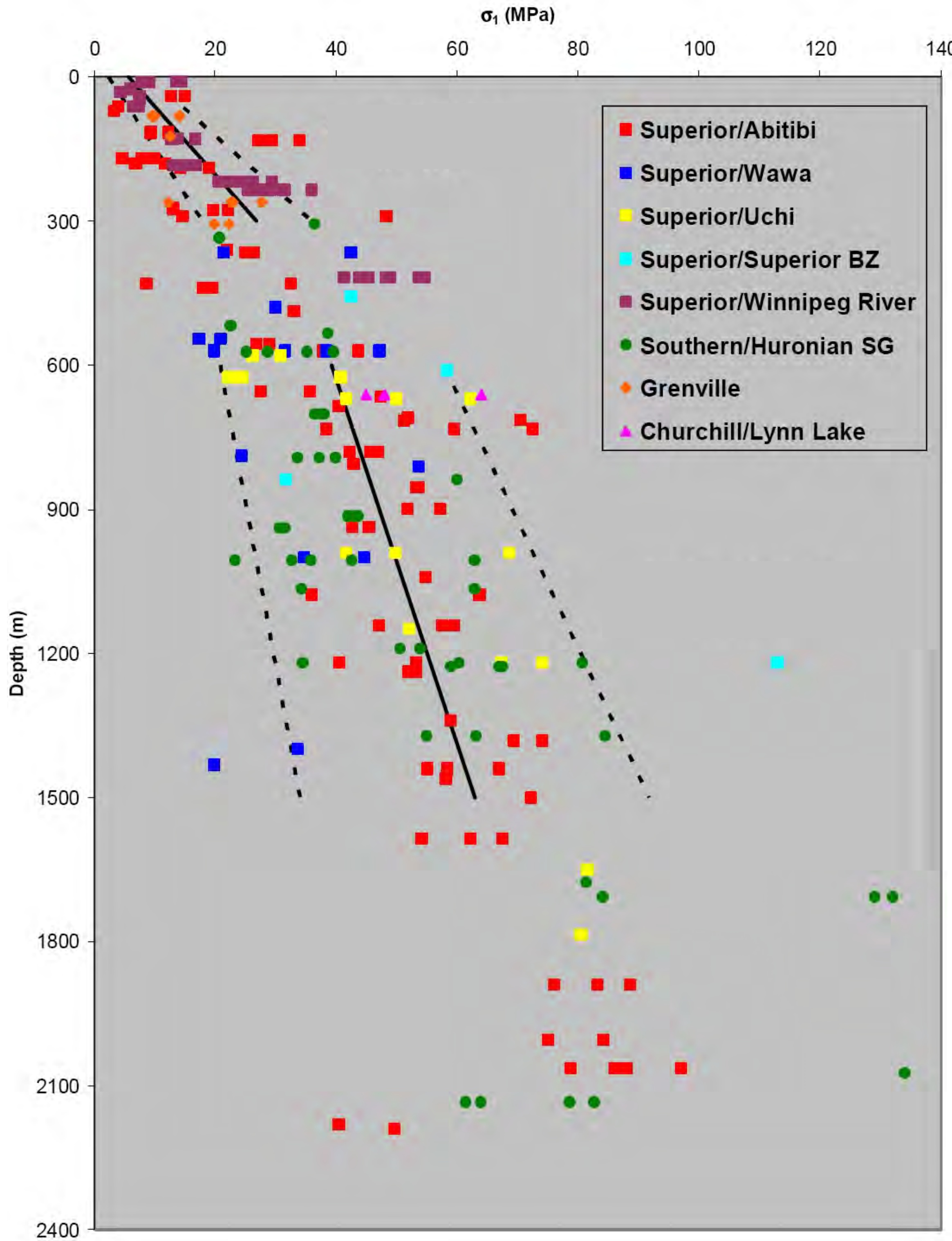
PROJECT No. 10-214-4
NWMO Hornepayne Desktop Geoscientific
Preliminary Assessment of Potential Suitability
TITLE
Groundwater Wells and Diamond
Drill Holes within the Hornepayne Area
FIGURE
4.1
DESIGN: NMP
CAD/GIS: NMP/VMS
CHECK: KGR/SNS
REV: 0
DATE: 07/11/2013
Geofirma
Engineering Ltd
Granite-Granodiorite
QUETICO SUBPROVINCE
Granite-Granodiorite
Metasedimentary Rocks
Hornepayne
Highway 631
Leigh
Black-Pic Batholith
(Gneissic Tonalite)
Granite-Granodiorite
WAWA SUBPROVINCE
Melody Lake
Angela Lake
Nagagamisis Lake
Phillip Lake
Moose Lake
Nagagami Lake
Little Dowsley Lake
Wicksteed Lake
Foch River
Obakamiga River
Marten Lake
Lessard Lake
First Government Lake
Second Government Lake
Moonlight Lake
Mountain Lake
Shekak River
Obakamiga Lake
Hornepayne Lakes
Lascelles Lake
Wilson Lake
Larkin Lake
Granitehill Lake
Mitchell Lake
Cholette Lake
Star Lake
Bone Lake
Kabinakagamisis Lake
Cameron Lake
Kabinakagami Lake
630000 640000 650000 660000 670000 680000 690000 700000
5480000 5470000 5460000 5450000 5440000 5430000
G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure4_1_Groundwater_Wells_R0.mxd


LEGEND
Township of Hornepayne
Highway
Local Road
Railway
Water Area, Permanent
Watercourse, Permanent
Watercourse, Intermittent
Mapped Geological Fault
Mapped Dyke
Subprovince Boundary
Iron Formation
Active Mining Claims
Discretionary Occurrence
Occurrence
Bedrock Geology
13 Granite-granodiorite, massive to foliated
11 Granite-granodiorite, muscovite/biotite bearing
10 Foliated tonalite suite
9 Gneissic tonalite suite
5 Metasedimentary rocks
2 Mafic volcanic rocks
SCALE 1:250,000
0 2.5 5 10 15 20
Kilometres
PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Claims: Ministry of Northern Mines and Development June 2012
Geology: Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
Mineral Inventory: Mineral Deposit Inventory, 2011
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ©Queens Printer 2011
PROJECT No. 10-214-4
NWMO Hornepayne Desktop Geoscientific
Preliminary Assessment of Potential Suitability
TITLE
Mineral Showings and Dispositions
of the Hornepayne Area
FIGURE
5.1
DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0
DATE: 07/11/2013
Geofirma Engineering Ltd
N
QUETICO SUBPROVINCE
WAWA SUBPROVINCE
Granite-Granodiorite
Metasedimentary Rocks
Black-Pic Batholith
(Gneissic Tonalite)
Highway 631
Hornepayne
Leigh
Melody Lake
Angela Lake
Phillip Lake
Nagagamisis Lake
Moose Lake
Nagagami Lake
Little Dowsley Lake
Wicksteed Lake
Marten Lake
Lessard Lake
First Government Lake
Second Government Lake
Moonlight Lake
Mountain Lake
Obakamiga Lake
Hornepayne Lakes
Shekak River
Wilson Lake
Lascelles Lake
Larkin Lake
Granitehill Lake
Mitchell Lake
Cholette Lake
Star Lake
Bone Lake
Kabinakagamisis Lake
Cameron Lake
Kabinakagami Lake
Foch River
Obakamiga River
Graphite
Cu
Peat
Fe, U
Cu, Ni
S, Pyrite
630000 640000 650000 660000 670000 680000 690000 700000
5430000 5440000 5450000 5460000 5470000 5480000
G:\Data\Project\Hornepayne\10-214-4_Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure5_1_Mineral_Showings_Dispositions_R0.mxd



Maximum Horizonal In Situ Stresses Measured in the Canadian Shield

Data Source:Report No: 06819-REP-01300-10107-R00; P.K. Kaiser, S. Maloney, 2005.

Maximum Horizontal In Situ Stresses Typically Encountered in Crystalline Rock of the Canadian Shield **NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability**		Prepared by: NMP/ADG Reviewed by: KGR/SNS Date: 04/09/2013
FIGURE 6.1	Doc. No.:10-214-3_Hornepayne_Figure6_1_Maximum_Horizontal_In_Situ_Stresses.cdr	

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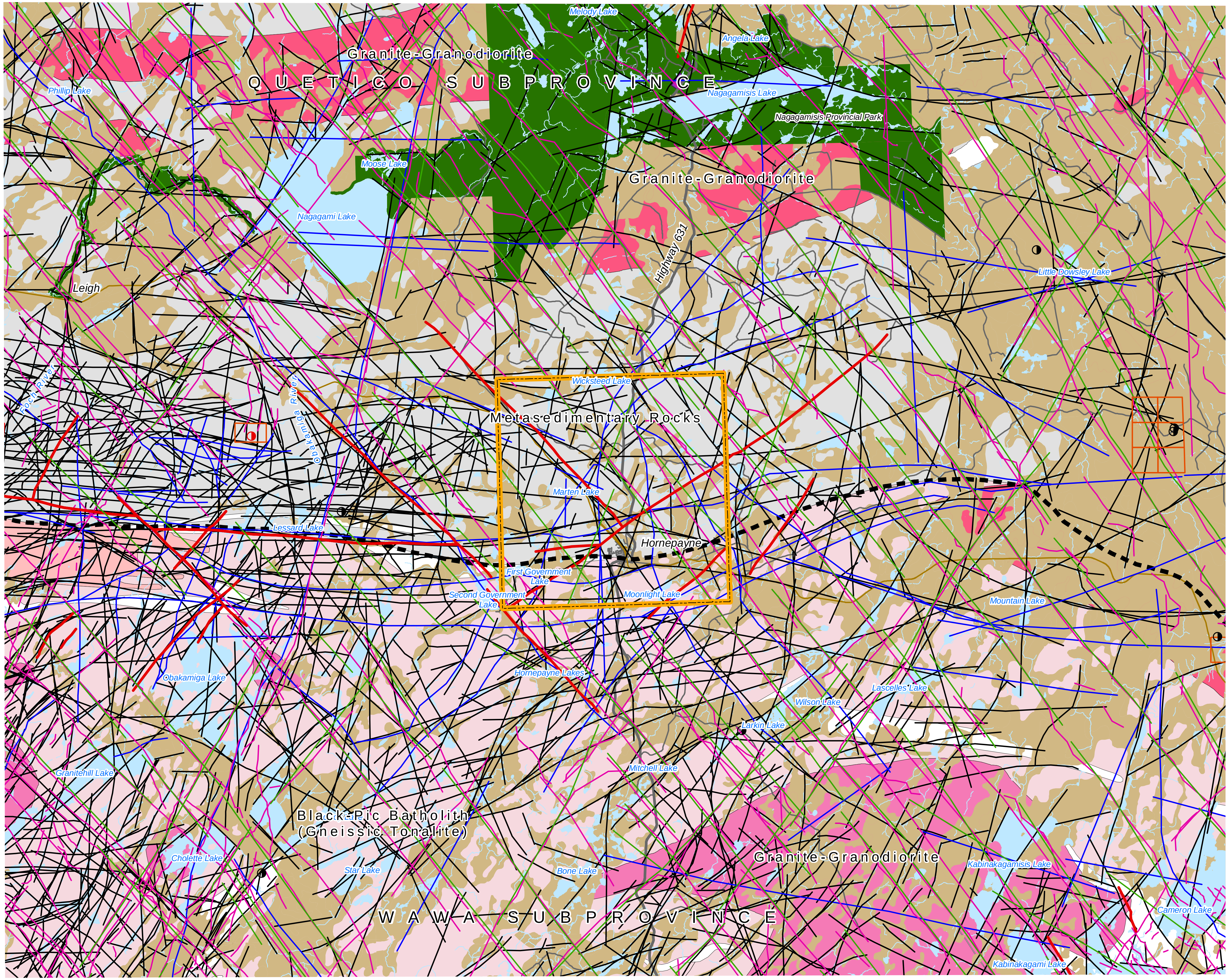

Melody Lake
Angela Lake
Granite-Granodiorite
QUETICO SUBPROVINCE
Phillip Lake
Nagagamisis Lake
Nagagamisis Provincial Park
Moose Lake
Granite-Granodiorite
Nagagami Lake
Highway 631
Little Dowsley Lake
Leigh
Wicksteed Lake
Metasedimentary Rocks
Obakamiga River
Marten Lake
Lessard Lake
Hornepayne
First Government Lake
Second Government Lake
Moonlight Lake
Mountain Lake
Hornepayne Lakes
Obakamiga Lake
Lascelles Lake
Wilson Lake
Larkin Lake
Mitchell Lake
Granitehill Lake
Black-Pic Batholith
(Gneissic Tonalite)
Granite-Granodiorite
Cholette Lake
Star Lake
Bone Lake
Kabinakagamisis Lake
Cameron Lake
WAWA SUBPROVINCE
Kabinakagami Lake

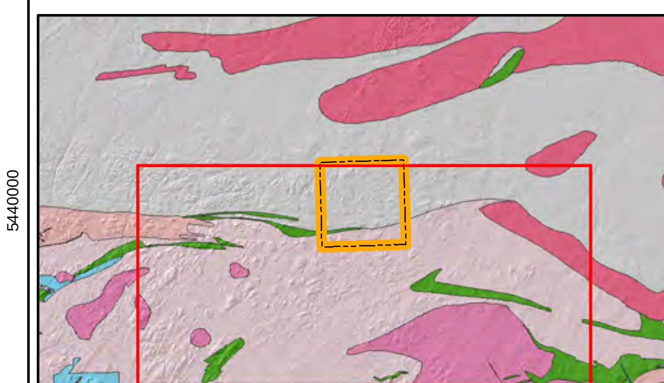
LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Subprovince Boundary
- Active Mining Claims
- Areas with Overburden Cover
- Unfavourable Geology
  - * see figure 3.4 for legend of Favourable Geology
- Discretionary Occurrence
- Occurrence
- Mapped Geological Fault
- Mapped Dyke

Brittle Lineament

- Geophysical Dyke
- Geophysical Fracture
- Surficial Fracture

Approximate Size of Repository Footprint
3 km
2 km



SCALE 1:250,000

0 2 4 8 12 16
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Claims: Ministry of Northern Mines and Development June 26, 2012
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott, 2013
Geology: MRD126_REV1-Bedrock Geology of Ontario, 2011
Mineral Inventory: Mineral Deposit Inventory, 2011
Surficial Geology: NOEGTS-OGS MRD-160 (scale 1:100,000)
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Key Geoscientific Characteristics of the Black-Pic Batholith in the Hornepayne Area

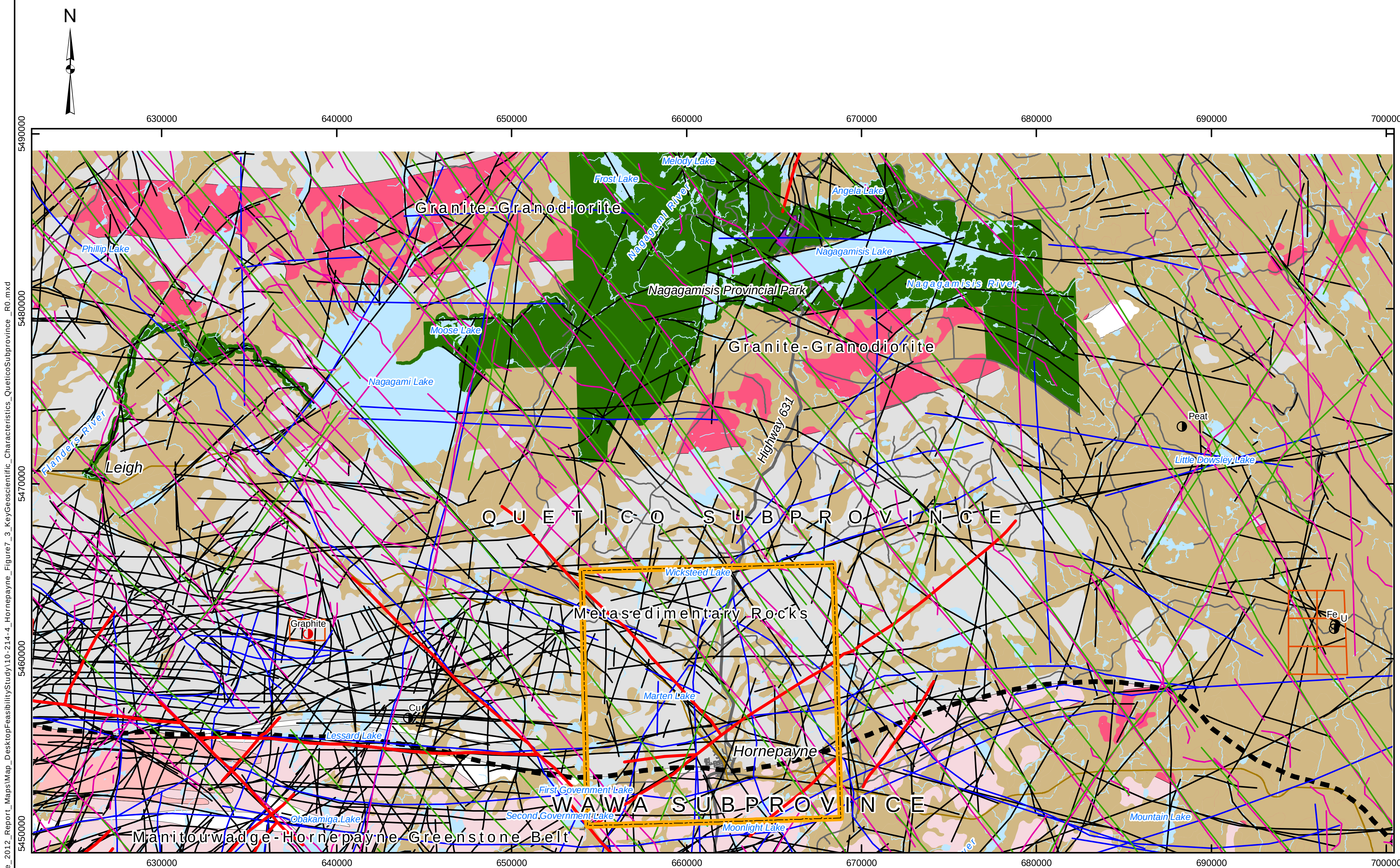
FIGURE 7.2

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 07/11/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornpayne\Hornepayne_2012_Report_Maps\Map_DesktopFeasibilityStudy\10-214-4_Hornepayne_Figure7_2_KeyGeoscientific_Characteristics_BlackPicBatholith_R0.mxd



LEGEND

- Township of Hornepayne
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Subprovince Boundary
- Active Mining Claims
- Areas with Overburden Cover
- Unfavourable Geology
- * see figure 3.4 for legend of Favourable Geology
- Discretionary Occurrence
- Occurrence
- Mapped Geological Fault
- Mapped Dyke

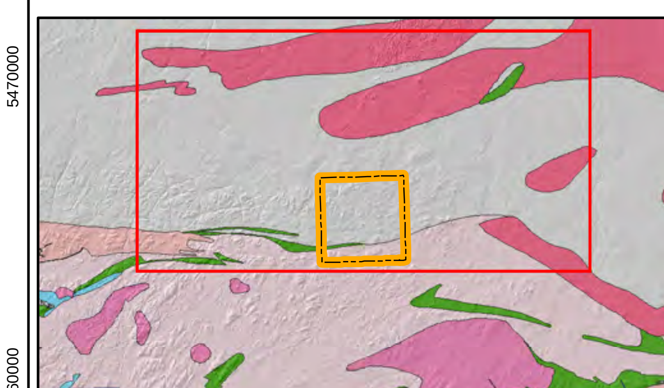
Brittle Lineament

- Geophysical Dyke
- Geophysical Fracture
- Surficial Fracture

Approximate Size of Repository Footprint

3 km

2 km



SCALE 1:250,000

0 2 4 8 12 16

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Claims: Ministry of Northern Mines and Development June 26, 2012
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott, 2013Geology: MRD126_REV1-Bedrock Geology of Ontario, 2011
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Key Geoscientific Characteristics of the Quetico Subprovince in the Hornepayne Area

FIGURE 7.3

DESIGN: NMP
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 07/11/2013

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