NUCLEAR WASTE MANAGEMENT ORGANIZATION

SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Phase 1 Geoscientific Desktop Preliminary Assessment, Lineament Interpretation

TOWNSHIP OF HORNEPAYNE, ONTARIO

APM-REP-06144-0006

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Phase 1 Geoscientific Desktop Preliminary Assessment

Lineament Interpretation
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 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 a successful completion of an initial screening conducted during Step 2 of the site selection process.

The preliminary assessment is a multidisciplinary desktop study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated report (NWMO, 2013). The objective of the desktop geoscientific preliminary assessment is to determine whether the Township of Hornepayne and its periphery, referred to as the “Hornepayne area”, contain general areas that have the potential to meet NWMO’s geoscientific site evaluation factors.

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

- Lineaments were interpreted from multiple, readily-available data sets (aeromagnetic, CDED, SPOT and LandSAT);
- Lineament interpretations were made by documented specialist observers and using a standardized workflow;
- Lineament interpretations were analyzed based on an evaluation of the quality and limitations of the available data sets;
- Interpreted lineaments were separated into three categories (ductile, brittle, dyke) based on their character;
- Lineament interpretations were analyzed using reproducibility tests, particularly the coincidence of lineaments extracted by different observers, coincidence of lineaments extracted from different data sets, relative ages and/or documentation in literature; and
- Final classification of the lineament interpretation was done based on length, and reproducibility.

The distribution of lineaments in the Hornepayne area reflects the bedrock structure, resolution of the data sets used, and the influence of surficial cover. Surficial lineament density, as demonstrated in this assessment, is closely associated with the distribution and thickness of overburden cover that masks the surficial expression of bedrock structures. Surficial lineament density was observed to be highest in the rugged upland area of exposed bedrock located in the western part of the Hornepayne area and lowest in the northern and eastern parts of the Hornepayne area that have increased overburden cover. Lineament density is also influenced by the resolution of the data sets as demonstrated by the comparison of geophysical lineaments interpreted from areas covered by low and high resolution surveys. The highest average lineament densities were observed in the granite-granodiorite intrusions and the foliated to gneissic tonalite suite of the Black-Pic batholith. Comparable but lower average lineament densities were observed in the metasedimentary rocks and the granite-granodiorite intrusions of the Quetico Subprovince.

On the basis of the structural history of the Hornepayne area, a framework was also developed to constrain the relative age relationships of the interpreted lineaments.

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1 INTRODUCTION

In December, 2011, the Township of Hornepayne, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization nine-step site selection process (NWMO 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Hornepayne area for safely hosting a deep geological repository (Step 3).

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1.1 Scope of Work

The scope of work for this assessment includes the completion of a lineament interpretation of remotely-sensed data sets, including surficial (satellite imagery, digital elevation) and geophysical (aeromagnetic) datasets for the Hornepayne area (approximately 4,800 km^2), in northern Ontario (Figure 1). The lineament investigation interprets the location and orientation of possible individual fractures or fracture zones and helps to evaluate their relative timing relationships within the context of the local and regional geological setting. The approach undertaken in this desktop lineament investigation is based on the following:

- Lineaments were mapped from multiple, readily-available data sets that include satellite imagery (Système Pour l'Observation de la Terre - SPOT and Landsat), digital elevation models (DEM, Canadian Digital Elevation Data; CDED), and aeromagnetic geophysical survey data;
- Lineament interpretations from each source data type were made by two documented specialist observers for each data set;
- Lineaments were analyzed based on an evaluation of the quality and limitations of the available data sets, age relationships, reproducibility tests, particularly the coincidence of lineaments extracted by different observers, coincidence of lineaments extracted from different data sets, and/or documentation in literature; and
- Classification was done to indicate the significance of lineaments based on orientation, length, reproducibility and coincidence.

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

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

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

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

- ***Dyke lineaments***: For this preliminary desktop interpretation, any features which were interpreted, on the basis of their distinct character, e.g., scale and composition of fracture in-fill, orientation, geophysical signature and topographic expression, were classified as dykes. Dyke interpretation is largely made using the aeromagnetic data set, 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, should the community be chosen by NWMO and remain interested in continuing with the site selection process.

1.2 Qualifications of the Interpretation Team

The project team employed in the lineament interpretation component of the Phase 1 geoscientific desktop preliminary assessment consisted of qualified experts from Geofirma Engineering Ltd, Ottawa, J.D. Mollard and Associates (2010) Limited, Regina (JDMA), Patterson, Grant & Watson, Toronto (PGW) and Stott Geoconsulting Ltd., Sudbury. Geofirma coordinated the lineament interpretation and completed interpretation of surficial lineaments from satellite and CDED data sets. PGW and Stott Geoconsulting conducted the lineament interpretation on the geophysical data, and JDMA provided interpretation of surficial lineaments.

The following is a brief description of the qualifications and roles of key project team members.

Kenneth Raven, M.Sc., P.Eng. P.Geo. is President of Geofirma Engineering Ltd. He has over 30 years' experience in lineament mapping and structural geological interpretation in Canadian Shield settings, included mapping and interpretation of air photo and airborne geophysical data sets at numerous mine sites, and Atomic Energy of Canada Ltd. research areas investigated as part of the Canadian Nuclear Fuel Waste Management Program. He also completed similar lineament studies at the Chalk River Laboratories in the mid-1990s as part of a siting study for a cavern storage facility for low level radioactive waste. Mr. Raven reviewed Geofirma identification of surficial lineaments and provided overall review of the lineament study including final lineament merging and interpretation.

Dr. Pouran Behnia, Ph.D. of Geofirma Engineering Ltd. is a geologist with more than 14 years of professional and academic GIS experience in remote predictive mapping using multispectral (Landsat, SPOT, ASTER, GeoEye) and hyperspectral data, integrating geo-exploration data for mineral prospect analysis; and landslide susceptibility mapping using knowledge and data driven methods. She has technical expertise with GIS applications, data integration procedures, data management and visualization. Dr. Behnia recently completed a 3-year post-doctoral placement with the Remote Sensing Division of the Geological Survey of Canada and has completed remote predictive mapping of Canada's North using satellite, DEM and geophysical data sets. Dr. Behnia completed identification of surficial lineaments from DEM and satellite imagery data sets.

Sean Sterling, M.Sc., P.Eng., P.Geo. is a senior geoscientist with Geofirma Engineering Ltd. He. has 18 years of specialized experience and expertise in characterization and investigation of fractured bedrock sites including use of Ontario GIS geomapping datasets. He recently provided senior geoscience direction to NMWO on geoscientific characterization of the Bruce nuclear site for hosting a deep geologic repository for low and intermediate level radioactive wastes. Mr. Sterling supervised merging of individual geophysical, DEM and satellite lineament data sets and the final lineament interpretation, as well as development of merging rules and calculation of lineament statistics.

Dru Heagle, Ph.D., P.Geo. is a senior geoscientist with Geofirma Engineering Ltd. He has 16 years of geoscience experience in regional geological/hydrogeological characterization, site characterization and environmental monitoring of the Bruce nuclear site for NWMO, and integrated use of geological, hydrogeological and hydrogeochemical data sets. He has worked as a Research Assistant and Scientist at the Universities of Waterloo and Calgary. Dr. Heagle completed review of this Lineament Interpretation Report.

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

Dr. Jason Cosford, Ph.D., P.Geo. has contributed to a wide range of terrain analysis studies conducted by JDMA, including routing studies (road, rail, pipeline, and transmission line), groundwater exploration, granular resource mapping, and environmental sensitivity analyses. Dr. Cosford provided JDMA interpretation of the surficial lineaments from DEM and satellite imagery data sets.

Dr. James Misener, Ph.D., P.Eng. is President of PGW and a senior geophysicist with 37 years of experience in all aspects of geophysics and geophysics software applications. Dr. Misener founded Geosoft Inc. and led its development of world-leading geosciences software applications until he succeeded Dr. Paterson as President of PGW. He completed interpretation of geophysical lineaments.

Dr. Greg Stott, Ph.D. of Stott Geoconsulting Ltd. has mapped and written extensively on structural/tectonic evolution of the Quetico, Wabigoon, Uchi and Wawa subprovinces of the Superior Province of the Canadian Shield, including interpretation of airborne geophysical surveys. He has over 30 years' experience in structural geological mapping of the Superior Province of the Canadian Shield with the Geological Survey of Canada and with the Ontario Geological Survey. Dr. Stott completed interpretation of geophysical lineaments including ductile lineaments, and also provided text on the structural and geological history of the Hornepayne area.

1.3 Report Organization

Section 2 describes the geological setting of the Hornepayne area, which includes subsections on physical geography, bedrock geology, geological and structural history, Quaternary geology, and land use. Section 3 provides information on the source data and explains the methodology used to identify and assess lineaments. Section 4 presents the findings of the lineament interpretation with a description of lineaments by each data set and a description and classification of integrated lineaments. Section 5 offers a discussion of the findings, specifically the lineament density, reproducibility and coincidence, lineament length, fault and lineament relationships, and relative age relationships. Section 6 is a summary of the report. References and signature page are provided in Sections 7 and 8. Report figures are provided at the end of the report.

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

2 SUMMARY OF PHYSICAL GEOGRAPHY AND GEOLOGY

The Hornepayne area, shown in Figure 1, is underlain by a patchy to continuous cover of glacial soils and the approximately 3.0 to 2.6 billion years old bedrock of the Superior Province of the Canadian Shield – a stable craton that forms the core of the North American continent (Figure 2). The Canadian Shield is an assemblage of Archean-age plates and accreted juvenile arc terranes and sedimentary basins of Proterozoic age that were progressively amalgamated over geologic time scales. Figure 2 shows that there have only been 16 earthquakes, all of magnitude less than 3, recorded within the region surrounding the Hornepayne area since seismic data collection started in 1985.

The Hornepayne area straddles the boundary between the Quetico and Wawa subprovinces of the Superior Province. The Quetico Subprovince has mainly gneissic and migmatized metasedimentary rocks and the Wawa Subprovince is composed primarily of Archean greenstone belts and granitic intrusions, with smaller mafic intrusive rocks locally present. Diabase dykes, largely of Proterozoic age, occur in “swarms” in the entire Superior Province and in the Hornepayne area (Figure 3).

2.1 Physical Geography

A detailed discussion of the physical geography of the Hornepayne area is provided in a separate terrain analysis report (JDMA, 2013) and the following is a summary of that information.

The Hornepayne area is located in the Abitibi Uplands physiographic region, a broadly rolling surface of Canadian Shield bedrock that occupies most of north-central Ontario. Within the Abitibi Uplands, bedrock is typically either exposed at surface or shallowly covered with Quaternary glacial deposits or postglacial organic soils (Thurston, 1991). Figure 4 provides an overview of the surficial geology of the Hornepayne area.

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. Topography in the Hornepayne area is generally rugged with elevation exceeding 480 mASL on the north and west sides of Obakamiga Lake approximately 15 km west of the Township of Hornepayne. Lands further to the north and east are less rugged and lower in elevation (from 220 to 300 mASL) reflecting the continental drainage divide located to the southwest of Hornepayne in the vicinity of Granitehill Lake (Figure 5). Topographic highs generally correspond to bedrock outcrops while topographic lows are generally associated with areas of thicker overburden in bedrock valleys. Bedrock terrain is mapped for roughly 43% of the Hornepayne area (Figure 4). Bedrock terrain includes exposed bedrock and thin, discontinuous drift deposits generally less than one metre thick.

The Hornepayne area contains a large number of lakes of various sizes; there are six lakes larger than 10 km^2, three of which (Nagagami Lake, Obakamiga Lake and Nagagamisis Lake) are larger than 20 km^2, with approximately 8.5% (404 km^2) of the entire area occupied by water bodies (JDMA, 2013). The large lakes are sufficiently large to conceal lineaments up to about ten kilometres in length, and nests of lakes have additional potential to conceal lineaments, especially when the lakes are located in areas where lineaments are obscured by overburden deposits (see also Section 2.4). There is considerable relief between the lakes in most areas.

2.2 Bedrock Geology

The bedrock geology of the Hornepayne area is described in detail in Geofirma (2013) and the following is a summary of that information. Most of the Hornepayne area has only been subject to reconnaissance level bedrock geological mapping (Geofirma, 2013).

The Superior Province has been divided into various subprovinces based on lithology, age, genesis and metamorphism (Thurston, 1991, Stott et al., 2010). The Hornepayne area straddles the boundary of the Quetico and the Wawa subprovinces, with the north half of the Hornepayne area being situated in the Quetico Subprovince (Figure 2). About 150 km to the east, the Quetico and Wawa subprovinces are truncated by the Kapuskasing structural zone that separates these subprovinces from the Abitibi Subprovince (and is sometimes referred to as the Abitibi-Wawa belt).

Figure 3 shows the general bedrock geology and main structural features of the Hornepayne area. The Wawa-Quetico subprovince boundary crosscuts the Hornepayne area and separates the metasedimentary and granitic rocks of the Quetico Subprovince to the north from the Black-Pic batholith of the Wawa Subprovince to the south. Thin slivers of metavolcanic rocks of the Manitouwadge-Hornepayne greenstone belt are mapped within the Black-Pic batholith and along the subprovince boundary. Paleoproterozoic diabase dykes are abundant in the Hornepayne area and include the dominant northwest-trending Matachewan swarm, and the subordinate northeast-trending dykes of Biscotasing and Marathon/Kapuskasing suites.

The initial screening report for the Hornepayne area (Golder, 2011), identified several potentially suitable geologic units within the Hornepayne area. These geologic units include the metasedimentary rocks and granitic-granodioritic intrusions of the Quetico Subprovince, and the Black-Pic batholith of the Wawa Subprovince. These potentially suitable geologic units are shown on Figure 3.

2.2.1 <u>Metasedimentary Rocks of the Quetico Subprovince</u>

Much of the bedrock of the Quetico Subprovince in the northern half of the Hornepayne area is variably exposed and has only been mapped at a reconnaissance level. In the Hornepayne area bedrock in the Quetico Subprovince is dominated by highly metamorphosed and migmatized clastic sedimentary rocks, including also tonalitic gneiss, slivers of mafic metavolcanic rock, granodiorite of uncertain origin, and granitic rocks derived from partial melting of the sedimentary rocks.

The precursor sedimentary rocks were typically composed of turbidite successions derived from the erosion of adjacent volcanic arcs (granite-greenstone terranes) either adjacent to the Quetico Subprovince or conceivably derived from other granite-greenstone terranes hundreds of kilometres away. The deposition of the original sedimentary rocks in the southern Quetico Subprovince 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 thickness of the Quetico Subprovince metasedimentary rocks is estimated to be at least 7.5 km (Percival, 1989), although the thickness is interpreted to decrease along the boundary between the Quetico and Wawa subprovinces, where the metasedimentary rocks are thought to be underlain by rocks of the Wawa Subprovince (Percival, 1989).

2.2.2 Granitic-Granodioritic Intrusions 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), each approximately 7 km by 30 km in size and likely derived from partial melting of the metasedimentary rocks (Percival, 1989; Williams et al.,1991). Similar, though smaller, bodies are mapped approximately 20 km to the east of the Township. No information regarding the thickness of these bodies was found in the available literature. There is some uncertainty whether these bodies are the end point of in situ migmitization of the metasedimentary rocks or true intrusions.

2.2.3 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 (Figure 3; Fenwick, 1967; Stott, 1999). It is mostly composed of well foliated to gneissic granodiorite to tonalite (Milne, 1968), with phases of hornblende-biotite, monzodiorite and pegmatitic granite largely restricted to the margins of the batholith. Within the Hornepayne area, the Black-Pic batholith is described as a gneissic tonalite that locally includes biotite and/or amphibole-bearing tonalite (Williams and Breaks, 1996; Johns and McIlraith, 2003).

The age of emplacement of the Black-Pic batholith is poorly constrained. The oldest phase of this batholith has been dated at approximately 2.720 billion years old (Jackson et al., 1998), whereas the youngest phase is estimated to be approximately 2.689 billion years old (Zaleski et al., 1999). No information on the thickness of the batholith was found in available literature.

The Black-Pic batholith is interpreted to be a domal structure, with slightly dipping foliations radiating outwards from its 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 by granitic sheets of pegmatite and aplite and are generally more massive (Williams and Breaks, 1989).

Zones of migmatized sedimentary rocks and zones of massive granodiorite to granite exist within the batholith. The contact between these rocks and the tonalitic rocks is relatively gradational with extensive sheeting of the tonalitic unit apparent (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.

2.2.4 Mafic Dykes

Paleoproterozoic diabase dykes are abundant across the Hornepayne area, dominated by the northwest-trending Matachewan swarm that was emplaced approximately 2.45 billion years ago (Heaman, 1997). The northeast-trending dykes comprise two suites: the approximately 2.17 billion year old Biscotasing suite and the approximately 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 density of diabase dykes in this area tends to mask the magnetic signatures of the surrounding Archean bedrock lithologies. A further, more detailed subdivision of the dyke swarms north of 49° 30' was interpreted from aeromagnetic data by Stott and Josey (2009) based on orientation and previous work by Halls and others (Halls et al., 2008; Halls and Davis, 2004; Ernst and Halls, 1983). This dyke mapping was extended southwards for the revised Bedrock Geology of Ontario compilation map (OGS, 2011).

2.2.5 Faults and Shear Zones

The east- west trending Quetico-Wawa subprovince boundary, which cross-cuts the Hornepayne area (Figure 3), is characterized as a major shear zone. Evidence for faulting along the subprovince boundary is generally 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. West of the Hornepayne 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 Quetico-Wawa boundary show little or no evidence of faulting (Williams et al., 1991).

There is one east-trending fault, and numerous northeast- and northwest-trending smaller-scale faults mapped (OGS, 1991) within the Hornepayne area (Figure 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.

2.2.6 Metamorphism

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, 2000; 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 Hornepayne area, 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.

2.3 Geological and Structural 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 area shown in Figure 3, drawing particularly on information from the area around the Township of Manitouwadge, west of the Hornepayne area. It is understood that there are potential problems in applying a regional D_x numbering system into a local geological history. 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 described below can be summarized as a tectonic succession of events following one major episode of volcanism on the northern margin of the Wawa Subprovince, concurrent with and followed by clastic sedimentation and iron formation deposition dominantly within the Quetico Subprovince (Peterson and Zaleski, 1999; Zaleski et al., 1999; Zaleski and Peterson, 2001; Williams and Breaks, 1996).

Synvolcanic plutons are spatially associated with volcanic rocks and subsequently highly metamorphosed and deformed remnants of volcanic and metasedimentary host rocks (Zaleski et al., 1999; Zaleski and Peterson, 2001). Syn-orogenic activity included the exhumation and erosion of the Wawa Subprovince, deposition of sediments into the approximately 2.698 to 2.688 billion year old Quetico basin (Zaleski et al., 1999), and emplacement of the approximately 2.689 billion year old Black-Pic batholith and granitic and gabbroic plutons and stocks (Zaleski et al., 1999). This later emplacement pre-dates and post-dates major collisional folding and refolding during transpressional deformation across the Wawa – Quetico subprovince boundary.

Uplift and cooling of major plutonic bodies was followed by brittle fractures formed during residual late orogenic stress. Three and possibly four Proterozoic diabase dyke swarms intruded this region with the most prominent being the northwest-trending Paleoproterozoic Matachewan dykes (approximately 2.444 billion years ago) and the less frequent northeast-trending dykes of the approximately 2.17 billion year old Biscotasing suite and the approximately 2.11 billion year old Marathon/Kapuskasing suite (Halls et al., 2008; Stott and Josey, 2009). 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.

The relative sequence of Archean faulting across the Hornepayne area (Williams and Breaks, 1989; Peterman and Day, 1989; Percival and Peterman, 1994) indicates that the oldest faults tend to be more ductile and east-trending, 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 belt (Peterson and Zaleski, 1999; Zaleski et al., 1999; and Zaleski and Peterson, 2001). In general, two major penetrative deformation events 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 event either refolds or overprints structures formed during the first event and is responsible for the widespread upright, to moderately inclined and east-plunging, folds defined by the lithologic layering at Manitouwadge, and locally by iron-rich formations folded within the metasedimentary rocks of the Quetico Subprovince.

These large fold structures formed 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 approximately 2.7 to 2.6 billion years ago. This collisional history is reflected in the production of granitic intrusions and injections of partial melts into the sedimentary successions that comprise the Quetico Subprovince, which served as a collisional buffer between more rigid granite-greenstone micro-continents to the north and south. Consequently, the more migmatitic matrix that dominates the Quetico Subprovince forms complex folds and refolds and some of the plutons appear to form metamorphosed, doubly-plunging domical structures (Peterson and Zaleski, 1999; Williams, 1991).

Table 1 provides a simplified summary of the geological history of the Hornepayne area.

Table 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 (approximately 2.695 to 2.677 billion years ago) involving collision of the Wawa-Abitibi micro-continental terrane with terranes to the north. (Percival et al., 2006; Peterson and Zaleski, 1999).
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),

Time Period (billion years ago)	***Geological Event***
ca. 2.687 to 2.680	Regional D_2 deformation coeval with the peak amphibolite facies regional metamorphism, and local granulite facies and partial melting of clastic sedimentary rocks in the Quetico basin.
ca. 2.680	Minimum age of regional D_2 deformation is defined by the 2.68 billion-year-old granite intrusion of the Loken Lake pluton in the Township of Manitouwadge. Maximum age of regional D_3 deformation is defined by folding of the 2.68 billion-year-old Nama Creek pluton, also in Township of Manitouwadge.
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 Quetico metasedimentary migmatites.
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	Regional D_4 deformation defined by antiform folding of the Banana pluton in Township of Manitouwadge and by local interference of D_3 structures preserved locally within the Quetico metasedimentary rocks.
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.

Six main regionally distinguishable deformation episodes (D_1-D_6) for the Manitouwadge area are inferred, based on the regional scale of the deformation, to have also overprinted the bedrock geological units of the Hornepayne area. The following sequence of tectonic deformation (D_x) events is based on detailed structural studies undertaken in the Manitouwadge area (Peterson and Zaleski, 1999; Zaleski et al., 1999; Zaleski and Peterson, 2001; Williams and Breaks, 1996) and is presented here as a general framework to understanding the likely tectonic history of the Hornepayne area.

- 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 Quetico metasedimentary rocks and as a ductile fault at Manitouwadge. S_1 foliations outline D_2 folds.

- D_2 defines the regional schistosity as an axial planar S_2 fabric within amphibolite grade volcanic and sedimentary rocks, migmatitic rocks and differentiated layering in tonalite. S_2 foliations dip 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 Quetico metasedimentary migmatites.

- D_4 local refolding of D_3 structures occurs most typically but very locally preserved within Quetico metasedimentary rocks.

- 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 are 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.

Little information is available for the geological history of Hornepayne area for the period following the onset of development of the Mid-Continent Rift approximately 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 are preserved within the Hudson Bay and Michigan basins. The presence of a small outlier of Paleozoic strata known as the Temiskaming outlier in the New Liskeard area indicates that Paleozoic cover was formerly much more extensive and 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).

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 within the Hornepayne area. The contact between bedrock and the overlying unconsolidated Quaternary sediments represents an unconformity exceeding one billion years.

2.4 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 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. Mapped glacial deposits include morainal (till), glaciofluvial and glaciolacustrine units (Figure 4). The 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, glaciofluvial and glaciolacustrine deposits were laid down in the area east and north of the Township of Hornepayne as shown in Figure 4 (OGS Map 5085 - Gartner and McQuay, 1980a). These deposits combine to almost completely cover the bedrock in this part of the Hornepayne area.

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 in the Hornepayne area was obtained from water well records (JDMA, 2013) and the diamond drillhole database (OGS, 2005) (see Figure 4). Overburden thicknesses within the Hornepayne area typically ranges from 0 to 15 m, with the greatest thickness encountered in a drilled well reported to be 38 m. 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.

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

The impact that the variable distribution of Quaternary sediments has on the results of the lineament interpretation is discussed in Section 5.

2.5 Land Use

Land use within the 4,800 km^2 Hornepayne area outside of the Hornepayne settlement area is predominately Crown land consisting of forest, wetland, lakes and exposed bedrock. There are no active mines in the Hornepayne area. There are linear infrastructure corridors such as roads, railways, and electrical transmission lines however these features do no adversely affect the interpretation of bedrock lineaments.

3 METHODOLOGY

3.1 Source Data Descriptions

The lineament interpretation was conducted using publicly-available surficial (CDED digital elevation models, SPOT and Landsat satellite imagery), and geophysical (aeromagnetic) datasets for the Hornepayne area. Available data were assessed for quality, processed as necessary to improve quality and reviewed before use in the lineament interpretation.

CDED (Figure 5), SPOT-5 (Figure 6) and Landsat-7 datasets were used to identify surficial lineaments expressed in the topography, drainage, and vegetation. The resolution of the Landsat, SPOT and CDED data sets was consistent across the Hornepayne area and provided sufficient detail to allow for the identification of surficial lineaments as short as a few hundred metres in length. The higher resolution of the 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. The geophysical dataset for the Hornepayne area included low-resolution coverage across the entire Hornepayne area as well as smaller regions of increased resolution within the area (Figure 7), principally over the greenstone belts. In all cases, the best resolution data available was used for the lineament interpretation. The aeromagnetic data were valuable in identifying bedrock structures and dykes beneath areas of extensive surficial cover. Table 2 provides a summary of the source datasets used for the lineament interpretation.

3.1.1 Surficial Data

3.1.1.1 Digital Elevation Models (DEMs)

Canadian Digital Elevation Data (Geobase, 2011), 1:50,000 scale, 0.75 arc second (20 m resolution) elevation models served as important data sources for analyzing and interpreting lineaments in the Hornepayne area. Figure 5 shows the CDED dataset enhanced with a hill shade format with a sun angle of 45 degrees from horizon and an orientation (azimuth) of 45 degrees. The digital elevation model (DEM) used for this study was constructed by Natural Resources Canada (NRCan) using provincial data created through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources. The data represented 1:20,000 scale source data acquired through the Ontario Base Mapping (OBM) program, which was a major photogrammetric program conducted across Ontario between 1978 and 1995. Four main OBM data sets were used: OBM contours, OBM spot heights, WRIP stream network, and lake elevations derived using the OBM spot heights and OBM water features. CDED data sets are provided in geographic coordinates, referenced horizontally using North American Datum 1983 (NAD83) and vertically based on the Canadian Geodetic Vertical Datum 1928 (CGVD28). Ground elevations are recorded in metres relative to mean sea level. It was determined that the resolution of the DEM dataset was sufficient to undertake the lineament interpretation.

The files were transferred from geographic coordinates to UTM projection using bilinear resampling, which assigns a value to each output cell based on a weighted average of the four nearest cells in the input raster. Compared with cubic convolution, bilinear resampling can sometimes produce a noticeably smoother surface, whereas cubic convolution can produce a sharper image. However, the differences between the two methods are generally trivial and the selection of bilinear resampling was arbitrary. The projected files were then assembled into a mosaic by JDMA (Figure 5). Table 3 lists the tiles used in the final mosaic.

Table 2 Summary of Source Data Information for the Lineament Interpretation, 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
	Manitouwadge Survey (GDS1205) Magnetics	Ontario Geological Survey	200 m line spacing 45m sensor height	Covers western part of boundary between Wawa Subprovince and Quetico Subprovince	1989	Limited coverage but good quality dataset
	Oba-Kapuskasing Survey (GDS1024) Magnetics	Ontario Geological Survey	200 m line spacing 45m sensor height	Covers southeast corner over greenstone belt bordering on Black-Pic batholith	1986	Limited usefulness due to minimal coverage in Hornepayne area and greenstone belt coverage

Table 3 Summary of 1:50,000 Scale CDED Tiles Used for Lineament Interpretation of the Hornepayne Area

NTS Tiles	*East/West Coverage*	*Ground Resolution (arcsec.)*
42C/14	Both	0.75
42F/01	Both	0.75

For better presentation of linear features, hill-shaded images were created in ArcGIS in four main illuminating azimuths of 45º, 90º, 180º, and 315º (measured clockwise from the north) with the solar incidence angle of 45º from horizon. It was determined that the resolution of the DEM dataset was sufficient to undertake the lineament interpretation with those data. Hill-shaded angles of 45º and 315º were used for the majority of the lineament interpretation. Both hill-shade and slope rasters were useful for mapping lineaments.

3.1.1.2 Satellite Imagery

SPOT imagery, together with Landsat-7 images were used as the satellite data sources for lineament interpretations in the Hornepayne area. Table 4 presents the main specifications of SPOT and Landsat imagery.

Table 4 Summary of SPOT and Landsat Imagery Scenes Used for Lineament Interpretation of the Hornepayne Area

Scene-ID	***Image Centre (Lat/Long)***	***Satellite, Sensor***	***Date of Image***
S5_08415_4925_20060901	49°25', -84°56'	SPOT-5, HRG	September 1, 2006
S5_08456_4925_20060911	48°57', -84°25'	SPOT-5, HRG	September 11, 2006
S5_08509_4857_20060911	48°57', -85°9'	SPOT-5, HRG	September 11, 2006
S5_08426_4857_20070503	49°25', -84°15'	SPOT-5, HRG	May 3, 2007
L71023026_02620020423	48°53', -85°46'	LANDSAT-7, ETM+	April 23, 2002
L71022026_02620020603	48°53', -84°15'	LANDSAT-7, ETM+	July 03, 2002

SPOT multispectral (20 m resolution) and panchromatic (10 m resolution) orthoimagery (Geobase, 2011) were used for identifying surficial lineaments and exposed bedrock within the Hornepayne area. SPOT multispectral data consist of four bands, each recording reflected radiation within a particular spectral range, and each having a radiometric resolution of 8-bits (or a value ranging from 0 to 255). Four SPOT-5 images (scenes) provided complete coverage for the Hornepayne area (Table 4). SPOT 5 images were acquired using the High Resolution Geometric (HRG) sensor. Each image covers a ground area of 60 km by 60 km.

For quality control, NRCan provides images that have a maximum of 5% snow and ice cover, 5% cloud cover and a maximum viewing angle of 15º. NRCan orthorectified the SPOT images using three data sources: 1:50,000 scale Canadian Digital Elevation Data (CDED), National Road Network, and Landsat 7 orthoimagery. The orthoimages are provided in GeoTIFF format, projected using Universal Transverse Mercator (UTM) projection referenced to the North American Datum 1983 (NAD83).

It was determined that the resolution of the SPOT dataset was sufficient to undertake the lineament interpretation. The scenes were processed to create a single panchromatic mosaic (JDMA, 2013). An automated contrast matching technique was applied to the images which minimizes sharp variances in pixel intensity, giving the single image a cohesive appearance. The images were extended beyond the defined boundaries of the Hornepayne area to allow for the mapping of continuous lineaments extending beyond the Hornepayne area. Figure 6 is an example of a false colour composite of the SPOT imagery that was created by assigning a primary colour (red, green and blue) to three of the spectral 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 colour assignment results in a pixel colour that tends to approach a "natural" representation. Image processing and different colour assignments can be used to enhance the presence of different material categories, such as vegetation type, water, soil or man-made features.

Two Landsat Enhanced Thematic Mapper Plus (ETM+) images acquired in 2002 (Table 4) were used in concert with the SPOT imagery. The Landsat ETM+ is a sensor carried onboard the Landsat-7 satellite, managed by NASA and has acquired images of the Earth nearly continuously since July 1999, with a 16-day repeat cycle. Landsat ETM+ image data consist of eight spectral bands, with a spatial resolution of 30 m for bands 1 to 5 and band 7. The resolution of panchromatic band is 15 m (Table 2) and the radiometric resolution of all bands is 8-bits. The approximate scene size is 170 km north-south by 183 km east-west. Landsat data in spite of having lower spatial resolution compared to SPOT data, because of having higher spectral resolution proved to be very useful for bedrock and structural mapping. The Landsat orthorectified image was downloaded from USGS Global Visualization Viewer (http://glovis.usgs.gov) in GeoTIFF format.

The original Landsat images were processed using PCI Geomatica image processing software. Contrast enhancement was applied on the images to obtain better discrimination between various lithological and structural features. To do this, areas covered with water and ice were first masked on images. Threshold values on Landsat band-1 and band-4 were used to remove ice and water from the images, respectively. The radiometric ranges obtained for the water- and ice-free images were then used to enhance the original images by applying a linear contrast stretching.

3.1.2 Geophysical Data

The geophysical dataset incorporates aeromagnetic, gravity and radiometric data available across the entire Hornepayne area, and some limited electromagnetic data, however only aeromagnetic data was extensively used for the lineament interpretation. Table 5 provides a summary of the acquisition parameters for each aeromagnetic dataset used. The magnetic data located within the Hornepayne area were processed using several common geophysical techniques in order to enhance the magnetic response to assist with the interpretation of geophysical lineaments. The enhanced magnetic grids used in the lineament interpretation include the first and second vertical derivatives, and the tilt angle filter grids. These enhanced grids were processed and imaged using the Geosoft Oasis montaj software package. Acquisition parameters, processing methods and enhanced grids associated with the geophysical datasets used in the lineament interpretation are discussed in detail in PGW (2013). Three additional magnetic grids using a combination of gradient and amplitude equalization filters were prepared using the Encom (Pitney Bowes) Profile Analyst software package in order to highlight the edges of magnetic sources. The combination of all of the enhanced magnetic grids provide much improved resolution of subtle magnetic fabrics and boundaries in areas that appear featureless in the total magnetic field. Figure 7 shows a compilation of the first vertical derivative of total field (reduced to pole) of each of these aeromagnetic datasets.

As shown in Figure 7, the quality of geophysical data varied significantly across the Hornepayne area, as a function of the flight line spacing, the flying height and the age of the survey. The integrity of the higher quality data was maintained throughout and the poorest resolution data was only used where higher resolution data were unavailable. It was determined that overall the quality of the data was sufficient to perform the lineament interpretation at the scale of the Hornepayne area.

Table 5 Summary of Geophysical Survey Acquisition Parameters for Lineament Interpretation of the Hornepayne Area

Survey	***Flight Line Spacing (m)***	***Grid Cell Size (m)***	***Sensor Height (m)***
GSC regional compilation	805	200	305
Manitouwadge (Blocks G and I)	200	50	45-60
Oba-Kapuskasing	200	40	45

The majority of the Hornepayne area is covered by low-resolution aeromagnetic data published by the Geological Survey of Canada (GSC) and downloaded from their Geoscience Data Repository for Geophysical and Geochemical Data (GSC, 2012). These data were acquired at a flight line spacing of 805 m and a sensor height at 305 m.

Two higher resolution magnetic surveys, published by the Ontario Geological Survey (OGS), were available for use in the lineament interpretation. These surveys include the Manitouwadge survey (OGS, 2002) that covers the greenstone belts and surrounding rocks near the Wawa-Quetico subprovince boundary in the western quarter of the Hornepayne area with a flight line spacing of 200 m and a sensor height of 45 to 60 m, and the Oba-Kapuskasing survey (OGS, 2003) that covers a small (35 km^2) southeast corner of the Hornepayne area with a fight line spacing of 200 m and a sensor height of 45 m. These surveys were all focused on the greenstone belts, and provide only marginal coverage of intrusive rocks in the Hornepayne area.

3.2 Lineament Interpretation Workflow

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

The interpretation guidelines for brittle and dyke lineaments used in the subsequent analysis involved three steps:

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

Each identified lineament feature was classified in an attribute table in ArcGIS. The description of the attribute fields used is included in Table 6. Fields 1 to 9 are populated during the first step. Fields 10 and 11 are populated during the second step. Fields 12 to 19 are populated in the third and final step.

Table 6 Summary of Attribute Table Fields Populated for the Lineament Interpretation

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

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

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

A detailed description of the three workflow steps, as well as the way each associated attribute field is populated for each interpreted brittle or dyke lineament is provided below. In addition, the ductile geophysical lineament interpretation (Figure 11) was made using the aeromagnetic geophysical survey data by an automated picking routine with confirmation by a single documented specialist observer.

3.2.1 Step 1: Lineament Identification and Certainty Level

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

The geophysical data set also allowed the interpreter to assess the feature type of the lineaments. The brittle geophysical lineaments were interpreted as linear fractures that exhibit magnetic signals that are lower than the surrounding bedrock. Where clear offsets can be determined, the brittle fractures can be further characterized as faults, and attributed accordingly. In Hornepayne, the presence of dyke lineaments were characterized as linear traces in which the magnetic signal of the feature were higher than the surrounding bedrock. The ductile lineaments were traced as curvi-linear features using the geophysical data representing the internal fabric of the rock units.

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

3.2.2 Step 2: Reproducibility Assessment 1 (RA_1)

The two individual GIS lineament maps from each dataset were then integrated to provide a single interpretation for the DEM (Figure 8), Landsat/SPOT (Figure 9) and aeromagnetic (Figure10) data that included the results of the first stage reproducibility assessment (RA_1). Reproducibility is judged based on the coincidence, or lack thereof, of interpreted lineaments within an assigned buffer zone. For example, if a lineament was identified by both interpreters within an overlapping buffer zone, then it was deemed coincident.

An initial buffer zone width (Buffer_RA_1) of 200 m was selected to evaluate coincidence. For many of the lineaments, coincidence could be demonstrated with a smaller buffer width, and in these cases a buffer width of either 100 m or 50 m, depending on the maximum offset, was entered in the attribute field. Where coincident interpreted lineaments were identified, the one line that appeared to best represent the surficial or geophysical expression of the feature (based on the judgment of the integrator) was retained and assigned attributes. In some instances, where deemed appropriate, either an existing line was edited or a new line was drawn as part of the merging process to best capture the expression of the lineament. This single feature was then assigned a reproducibility value of two (RA_1 = 2), recording the identification of the feature by two interpreters. Where a lineament was identified by only one of the interpreters, it received a buffer zone width of zero (Buffer_RA1 = 0) and a reproducibility value of one (RA_1 = 1) in the attribute table.

3.2.3 Step 3: Reproducibility Assessment (RA_2)

In step 3, the three dataset-specific interpretations were integrated into a single map following a similar reproducibility assessment (RA_2) procedure. In this second assessment, reproducibility is based on the coincidence, or lack thereof, of interpreted lineaments between different individual data sets within an assigned buffer zone (Buffer_RA_2). Coincident lineaments were assigned a Buffer_RA_2 value of 200 m, 100 m, or 50 m, depending on the maximum distance between individual lineaments. Where coincident lineaments were identified, one of the existing lines was selected or edited to represent that feature; and in some cases, where appropriate, a new line was drawn that best captured the merger of individual lineaments, in a process similar to the integration of RA_1 lineaments.

The merged lineaments were then assigned a reproducibility (coincidence) value (RA_2) of two or three, depending on whether the feature was identified in any two or all three of the assessed data sets. That is, for coincident lineaments, a single integrated feature, attributed accordingly, is carried forward into the final mapped interpretation. If a lineament was identified in only one data set, and thus not a coincident lineament, it received a reproducibility value of one (RA_2 = 1) in the attribute table. The data sets within which each feature have been identified is indicated in the appropriate attribute table field (Geophys, DEM, Landsat/SPOT).

4 FINDINGS

4.1 Description of Lineaments by Data Set

4.1.1 Surficial Datasets (CDED and Landsat/SPOT)

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

A total of 770 lineaments comprise the dataset of merged lineaments identified by the two interpreters from the CDED digital elevation data (Figure 8). These lineaments range in length from 460 m to 60.1 km, with an arithmetic mean length of 6.7 km and a median length of 4.6 km. The most notable features of the CDED lineament orientations when plotted on a rose diagram of normalized lineament length (Figure 8 inset) are the dominant east- and north-northeast-trend with a subordinate northwest trend. The north-northeast- and east-trending CDED lineaments show a wider range of orientation variability (about 30º) compared to the northwest set of lineaments which primarily occur over a narrower 10º-20º azimuth range. Certainty values of 3, 2 and 1 were assigned to 185 (24%), 328 (43%) and 257 (33%) of the CDED lineaments, respectively. The RA_1 reproducibility assessment shows reproducibility between the two pickers for 280 of the CDED lineaments (36%, RA_1 = 2) and a lack of reproducibility for 490 of the CDED lineaments (64%, RA_1 = 1). The lack of reproducibility is likely due to the fact that the two pickers selected slightly different numbers of CDED lineaments (600 vs 437) and the indistinct nature of some features in the available datasets.

The Landsat/SPOT lineament dataset compiled from the merger of lineaments identified by the two interpreters yielded a total of 1,071 lineaments (Figure 9). The length of the Landsat/SPOT lineaments ranges from 230 m to 50.3 km, with an arithmetic mean length of 4.5 km and a median length of 3.1 km. When the azimuths of the lineaments are plotted on a rose diagram of normalized lineament length (Figure 9 inset), there are similar orientation trends and strengths compared to those evident in the CDED dataset. The most prominent orientation is north-northeast to northeast and this trend is comparably defined in the satellite imagery and the CDED dataset. Secondary lineament trends from the satellite imagery include an east-trend and a northwest-trend, again similar in character to those defined by the CDED dataset. Twenty percent (20%) of the Landsat/SPOT lineaments, a total of 216, were assigned a certainty value of 3. Certainty values of 2 and 1 were assigned to 496 (46%) and 359 (34%) of the satellite lineaments, respectively. The reproducibility assessment shows reproducibility for 308 (29%) of the satellite lineaments (RA_1 = 2), and a lack of reproducibility for 763 (71%) of the satellite lineaments (RA_1 = 1). The lack of reproducibility is likely due to the fact that the two pickers selected slightly different numbers of satellite lineaments (734 vs 633), the indistinct nature of some of features in the available datasets, and the reliance on different satellite images (Landsat/SPOT vs SPOT) by the two pickers.

Orientation data for the CDED lineaments appear to be comparable to those for the Landsat/SPOT lineaments, with possible qualification that the dominant north-northeast-trending lineament set identified in the CDED dataset has a somewhat broader orientation range extending from north-northeast to northeast. Both lineament interpretations are affected by the Quaternary cover in the northern and eastern parts of the Hornepayne area. Generally, lineaments identified in CDED and Landsat/SPOT datasets are comparable, with 39% more lineaments identified in the satellite imagery than the CDED dataset. This increased occurrence reflects the increased resolution of the satellite imagery over the CDED dataset.

4.1.2 Geophysical Data

The airborne geophysical data interpretation was able to distinguish between features that could be interpreted as brittle or dyke lineaments (Figure 10) and ductile lineaments (Figure 11). Aeromagnetic features interpreted to reflect ductile lineaments have been mapped separately and are shown on Figure 11. Such features are useful in identifying the stratigraphy and structure within the greenstone belts and within the metasedimentary rocks and gneissic and foliated intrusive rocks of the Hornepayne area, particularly in the vicinity of the subprovince boundary. Figure 11 shows an increased occurrence of ductile lineaments in the metasedimentary rocks of the Quetico Subprovince and the gneissic and foliated tonalite suites of the Black-Pic batholith. The ductile structure in these rocks is predominately oriented east, parallel to the subprovince boundary in the vicinity of the boundary, swinging to northeast in the southwestern corner of the Hornepayne area in the Black-Pic batholith. In this report, the ductile lineaments are shown to provide context to our understanding of the tectonic history of the Hornepayne area, but were not included in the statistical analysis undertaken with the dataset. Therefore, the following discussion relates only to those lineaments interpreted as brittle fracture and dyke lineaments.

A total of 479 lineaments comprise the data set of merged brittle and dyke lineaments identified by the two interpreters from the geophysical data (Figure 10). Of the 479 lineaments, 89 are interpreted as fractures, while 390 are interpreted as dykes (Figure 10). The length of the geophysical fracture lineaments ranged from 2.4 km up to 77.9 km, with an arithmetic mean length of 14.6 km and a median length of 11.8 km. Azimuth data of normalized lineament length (Figure 10 inset) for the geophysical lineaments interpreted as fractures exhibit three distinct trends: east, north-northeast and northwest. The strongest of these geophysical fracture sets is the east-trending set and this strength reflects the strong structural influence of the subprovince boundary on local bedrock fracturing and structure. The length of the geophysical dyke lineaments ranged from 126 m up to 121.4 km, with an arithmetic mean length of 8.5 km and a median length of 3.2 km. The 390 lineaments identified as dykes, which includes smaller mapped segments of the same dyke, belong primarily to the northwest-trending suite of Matachewan dykes (Figure 10 inset). A second minor set of dykes oriented northeast is related to the Biscotasing and Marathon/Kapuskasing swarms. The occurrence of dykes 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.

Twenty-nine (33%) of the geophysical fractures were assigned the highest level of certainty of 3, while 33 (37%) and 27 (30%) of the fractures were given certainty values of 2 and 1, respectively. A total of 165 (42%) of the dykes identified from geophysical data were assigned a certainty value of 3, while 174 (45%) of the dykes were given certainty values of 2 and 51 (13%) were given values of 1. The reproducibility assessment identified coincidence for 4 fractures (5%) (RA_1 = 2) and a lack of coincidence for 85 of the interpreted fractures (95%) (RA_1 = 1). The reproducibility assessment identified reproducibility for 126 of the interpreted dykes (32%) (RA_1 = 2) and a lack of reproducibility for 264 of the interpreted dykes (68%) (RA_1 = 1). The low reproducibility results for both geophysical fractures and dykes reflects the indistinct nature of some of features in the available datasets, and the higher level of subjective interpretation necessary to select geophysical lineaments with low-resolution aeromagnetic data compared to the surficial datasets.

4.2 Description and Classification of Integrated Lineament Coincidence (RA_2)

The integrated lineament data set produced by determining the coincidence of all lineaments interpreted from the CDED data, Landsat/SPOT imagery, and geophysical data is presented on Figures 12 and 13. Figure 12 displays the lineament classification based on the coincidence values determined by Reproducibility Assessment (RA_2) including a normalized lineament length rose diagram of the entire dataset as an inset. Figure 13 displays the lineament classification based on length of interpreted lineaments, and includes the same normalized lineament length rose diagram as an inset. The merged lineaments were classified by length using four length bins: >10 km, 5-10 km, 1-5 km and <1 km. These length bins were defined based on an analysis of the lineament length frequency distributions for the Hornepayne area.

The final merged lineament data set contains a total of 1,868 lineaments comprising 1,478 fractures and 390 dykes that range in length from 126 m to 121.4 km. The arithmetic mean length of these lineaments is 6.4 km and the median length is 3.6 km. Lineaments in the >10km and 5-10 km length bins represent 17% and 20% of the final merged lineaments, respectively, while lineaments in the 1-5 km and <1 km length bins represent 55% and 8% of the final merged lineaments, respectively. Orientation data for the final merged lineament data set (inset of Figures 12 and 13) exhibit a fairly uniform distribution of three prominent trends. The normalized lineament length rose diagram for all final merged lineaments clearly shows the presence of three main lineament orientations; a dominant northwest-trending set, and two weaker sets oriented northeast and east. The northwest trending lineament set includes fractures and Matachewan dykes. The northeast-trending set also comprises fractures and dykes of the Biscotasing and Marathon/Kapuskasing swarms. The east-trending lineament set principally comprises fractures that are subparallel to the subprovince boundary.

Results from RA_2 for the final merged lineament data set (Figure 12) shows that potential RA_2 scores of 2 and 3 are only available for the 1,478 identified fractures. As interpreted dykes are only identified from aeromagnetic data and often do not appear to exhibit a distinct surficial expression that is recognized in either the satellite imagery or the CDED data, almost all of the interpreted dykes have RA_2 scores of 1. The results of RA_2 show that 21 lineaments (1%) were identified and coincident on all three data sets (RA_2 = 3), and 348 lineaments (19%) were coincident with a lineament from one other data set (RA_2 = 2). A total of 1,499 lineaments (80% of 1868 lineaments) lacked a coincident lineament from the other data sets (RA_2 = 1). There is much greater coincidence between surficial fracture lineaments (interpreted from CDED and satellite imagery) than between the geophysical fracture lineaments and either of the surficial data sets. However, about 34% of the final merged geophysical fracture lineaments (27 out of 79) were coincident with a mapped surficial lineament, primarily due to the small number (and likely more obvious) geophysical lineaments identified.

The low RA_2 scores for the geophysical fracture and dyke lineaments and the low RA_1 for the geophysical fracture and dyke lineaments are likely reflective of the inherent difficulty in interpreting low-resolution aeromagnetic data as exists for much of the Hornepayne area.

4.3 Description of Lineaments of Potentially Suitable Geologic Units in the Hornepayne Area

As described in Section 2.2, the bedrock geology of the Hornepayne area is dominated by metasedimentary rocks and foliated/gneissic tonalite which are intruded by massive to foliated granite-granodiorite and gneissic bodies. These metasedimentary and intrusive rocks, which are considered potentially suitable geologic units, include the metasedimentary rocks of the Quetico Subprovince, granite and granodiorite intrusions of the Quetico Subprovince, foliated and gneissic tonalite suites of the Black-Pic batholith and massive to foliated granite-granodiorite of the Black-Pic batholith. The following discussion describes the dominant interpreted lineament orientations and characteristics for each of these four bedrock geologic units (Figure 14). 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.

There were 836 lineaments identified over an area of approximately 1,934 km^2 of the metasedimentary rocks of the Quetico Subprovince. These lineaments consist of 662 fractures and 174 dykes. Azimuth data of normalized lineament length for all of the lineaments from metasedimentary rocks of the Quetico Subprovince, exhibit a dominant northwest-trend and subordinate trends of east and north-northeast (Figure 14). Mapped fracture lineaments in the metasedimentary rocks of the Quetico Subprovince identified 8 of the 9 mapped faults shown on Figure 14. The northeast-trending fault mapped by the OGS extending from the settlement area of Hornepayne was not identified in the lineament interpretation. Both Matachewan and Biscotasing-Marathon/Kapuskasing dykes cross the metasedimentary rocks of the Quetico Subprovince. The majority of these OGS mapped dykes were identified in the lineament interpretation.

The muscovite/biotite bearing granite-granodiorite intrusions of the Quetico Subprovince include the two elongated bodies in the northern part of the Hornepayne area and two smaller similar mapped geologic units in the eastern part of the Hornepayne area in the Quetico and Wawa subprovinces closer to the subprovince boundary. These intrusive bodies cover about 743 km^2 of the Hornepayne area. A total of 300 lineaments consisting of 218 fractures and 82 dykes, were mapped over the muscovite/biotite bearing granite-granodiorite intrusions. The rose diagram of normalized lineament length for lineaments from these rocks again shows a dominant northwest trend and subordinate trends of east and north-northeast (Figure 14). Mapped fracture lineaments in muscovite/biotite-bearing granite-granodiorite intrusions identified part of the only mapped fault in these rocks in the north central part of the Hornepayne area that extends north-northeast from the Hornepayne area (Figure 14). 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 presence of overburden cover of these rocks.

There were 857 lineaments consisting of 700 fractures and 157 dykes, identified over an area of approximately 1,654 km^2 of the foliated and gneissic tonalite suites of the Black-Pic batholith. Lineament orientation data for these rocks on a rose diagram of normalized lineament length indicate the same lineament trends as above: a dominant northwest trend, and two subordinate trends of northeast and east (Figure 14). Mapped fracture lineaments in the massive to foliated and gneissic tonalite suites of the Black-Pic batholith identified 9 of 11 mapped faults shown on Figure 14. 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 interpretation. 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 interpretation.

The massive to foliated granite-granodiorite of the Black-Pic batholith occurs principally in the southeastern part of the Hornepayne area (approximately 331 km^2 in size), where 243 lineaments were identified. These lineaments consist of 180 fractures and 63 dykes. The rose diagram of normalized lineament lengths from this granite-granodiorite unit shows a dominant northwest trend and a subordinate north-northeast trend (Figure 14). The east-trending lineament set evident in the other geologic units is not as clearly defined 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. Mapped fracture lineaments in the massive to foliated granite-granodiorite of Black-Pic batholith identified both of the short mapped faults found in the southeast corner of the Hornepayne area (Figure 3). 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 lineament interpretation.

5 DISCUSSION

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

5.1 Lineament Density

Lineament density across the Hornepayne area (see Figures 12 and 13) differs markedly due to variable extents of overburden cover (Figure 4) and resolution of the aeromagnetic surveys (Figure 10). The highest lineament densities are observed in the western part of the Hornepayne area in the areas north and south of the subprovince boundary where high resolution geophysical surveys and limited overburden cover occur. The lowest lineament densities are observed in the areas of increased overburden cover in the northern and eastern parts of the Hornepayne area, that also have low-resolution aeromagnetic surveys.

Consequently, consideration of the distribution and thickness of overburden cover and the resolution of airborne geophysical surveys within the Hornepayne area is essential for interpreting the results of the lineament assessment, particularly for interpreting information on length and density of surficial lineaments. Thick drift deposits are able to mask the surface expression of lineaments. In areas of thick and extensive overburden, major structures could exist completely undetectable in the Landsat/SPOT and CDED data, particularly if these areas also contain large lakes. The interpretation of geophysical lineaments, on the other hand, is less affected by surficial cover. The variability of the density of geophysical lineaments in the Hornepayne area is influenced by the resolution of the available magnetic data (Figure 10), more than the presence or absence of overburden cover. High-resolution aeromagnetic data are available in the Hornepayne area only for the western portion of the area near the subprovince boundary (i.e. parts of the Quetico metasedimentary rocks and Black-Pic batholith) and for a small area of mafic volcanic rocks in the extreme southeast corner of the Hornepayne area (Figure 10).

Of the 1,868 lineaments mapped from CDED, Landsat/SPOT and geophysical data, about 80% are derived from surficial data sources of CDED and Landsat/SPOT data, the remainder are from aeromagnetic surveys. Overall increased aeromagnetic lineament density, particularly for dykes, might be anticipated in the event that higher resolution airborne geophysical data were available for more of the Hornepayne area.

Review of Figures 8, 9, 10, 12 and 13 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.

The dyke lineament densities are relatively uniform in three of the four potentially suitable geologic units, with slightly higher dyke lineament densities observed for the Black-Pic granite-granodiorite.

The lineament densities for potentially suitable geologic units should be interpreted with caution, recognizing that the observed densities are influenced by the amount of overburden cover, the resolution of the aeromagnetic surveys and the proximity to the subprovince boundary, and that the variability of lineament density within potentially suitable geologic units is greater than the variability between geologic units. For example, the low lineament densities noted for the Quetico granite-granodiorite intrusive rocks, reflect in order of decreasing importance, the amount of overburden cover, the distance from the subprovince boundary and the low resolution of the airborne geophysical surveys.

In addition, the high density of observed and interpreted diabase dykes 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), suggests that underlying structure in the host rock, reflected by brittle lineament density, may be under identified in these areas of increased dyke density.

5.2 Lineament Reproducibility and Coincidence

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

The findings from the reproducibility assessment RA_1 indicate that approximately 33% of surficial lineaments (29% for Landsat/SPOT; 36% for CDED) were identified by both interpreters (see Figures 8 and 9). Importantly, longer lineaments with higher certainty values were identified more often by both interpreters. However, the reproducibility assessment of the geophysical lineaments shows that only 130 (27%) of the total number of fracture and dyke lineaments (479) were identified by both interpreters (Figure 10). As with the surficial lineaments, longer geophysical lineaments with higher certainty values were also recognized more often by both interpreters (RA_1=2).

Coincidence between features identified in the various datasets was evaluated in the second Reproducibility Assessment (RA_2). As would be expected, the surficial lineaments interpreted from CDED and Landsat/SPOT show the highest coincidence at about 26% (361 out of 1410 merged surficial fracture lineaments were coincident between CDED and satellite) which corresponds to 24% of total fracture lineaments that were coincident between CDED and satellite (361 out of 1478). This is in part explained by the fact that lineaments interpreted from the satellite imagery and the digital elevation data represent surficial expressions of the same bedrock feature. In contrast, about 34% (27 out of 79) of the interpreted geophysical fractures were coincident with surficial fractures, which corresponds to 2% (27 out of 1478) of the total lineament dataset (fractures) that shows coincidence. This low coincidence between surficial and geophysical lineaments is not unexpected, and may be the result of various factors, such as: deep structures that are identified in geophysics may not have a surface expression; surficial features may not extend to great depth; structural features may not possess a magnetic susceptibility contrast with the host rock; surface expressions of lineaments may be masked by the presence of overburden; and/or the geometry of the feature (e.g. dipping versus vertical). All these may be further constrained by the resolution of the datasets. Regardless of the degree of coincidence, the observed overlap in dominant lineament orientation between all datasets (i.e., northwest, east and north-northeast to northeast - see insets on Figures 8, 9 and 10) suggests that all datasets are identifying the same regional sets of structures.

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

5.3 Lineament Length

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

As described in Section 4.2, lineaments in the >10km and 5-10 km length bins represent 17% and 20% of the final merged lineaments, respectively, while lineaments in the 1-5 km and <1 km length bins represent 55% and 8% of the final merged lineaments, respectively. Longer interpreted lineaments generally have higher certainty, reproducibility and coincidence values. Although the existence of interpreted lineaments would need to be confirmed through field observations, certainty and reproducibility values provide a preliminary indication that the longer features identified are related to bedrock structures.

Figure 12 shows the interpreted lineaments classified by lineament length. Four lineament length bins (0-1 km, 1-5 km, 5-10 km, > 10 km) were used for this analysis and a length-weighted frequency rose diagram indicates the dominant lineament orientations (inset of Figure 12). Three prominent lineament orientation sets (northwest, northeast, and east), can be clearly recognized in the length-weighted dataset, with the northwest-trending set, primarily comprising the suite of Matachewan dykes and parallel fractures, being dominant.

5.4 Fault and Lineament Relationships

As discussed above in Section 5.1, there are 1,868 interpreted lineaments in the Hornepayne area that broadly follow three trends: a dominant northwest trend and subordinate northeast and east trends. There are no named OGS mapped faults in the Hornepayne area, but there are 19 unnamed OGS mapped faults as shown on Figures 3 and 14. These 19 unnamed faults have three orientations; northwest, northeast and east, parallel to the same trends identified in the lineament interpretation.

As discussed in part in Section 4.3, 16 of the 19 mapped faults are associated with specific interpreted lineaments. The three mapped OGS faults that were not identified in the lineament interpretation are all northeast-trending features located within and near the Township of Hornepayne.

Whether there is a relationship between the regional stress field and known mapped faults and observed lineament orientations is difficult to determine.

The principal horizontal neotectonic stress orientation in central North America is generally oriented approximately east-northeasterly (63º ± 28º; Zoback, 1992), although anomalous stress orientations have also been reported in the mid-continent that include a 90º change in azimuth of the maximum compressive stress axis (Brown et al., 1995) and a north-south maximum horizontal compressive stress (Haimson, 1990). Local variations, and other potential complicating factors involved in characterizing crustal stresses, including, the effect of shear stress by mantle flow at the base of the lithosphere (Bokelmann, 2002; Bokelmann and Silver, 2000), the degree of coupling between the North American plate and the underlying mantle (Forte et al., 2010), the effects of crustal depression and Holocene rebound, and the influence of the thick lithospheric mantle root under the Canadian Shield, make it premature to correlate the regional neotectonic stress orientation with the orientation of interpreted lineaments at the desktop stage.

5.5 Relative Age Relationships

The structural history of the Manitouwadge area was presented in Section 2.3 as a likely general framework for understanding the history of the Hornepayne area. In brief summary, six main regionally distinguishable deformation episodes (D_1-D_6) for the Manitouwadge area are inferred, based on the regional scale of the deformation, to have also overprinted the bedrock geological units of the Hornepayne area. D_1-D_2 developed gneissic foliation, folds, deformation fabric and other ductile structure between approximately 2.696 and approximately 2.680 billion years ago in the older metasedimentary and gneissic rocks. D_3 events developed east- and northwest-trending dextral shear zones and faults and northeast-trending sinistral shear zones and faults during late stage Archean orogenesis. D_4 produced local refolding of D_3 structures mostly within the Quetico metasedimentary rocks. D_5 collectively includes conjugate late brittle faults and fractures trending northwest, northeast and north that correspond to cooling of the crust under residual late orogenic stress. D_3 to D_5 events occurred between approximately 2.680 and approximately 2.671 billion years ago. D_6 collectively includes activation of Proterozoic faults, emplacement of mafic dykes (see below) and reactivated Archean faults associated with far-distant collision between the Trans-Hudson Orogen and the Superior Province, and uplift of the Kapuskasing structural zone to the east between approximately 1.947 and approximately 1.1 billion years ago.

Paleoproterozoic diabase dykes are abundant across the Hornepayne area, dominated by the northwest-trending Matachewan swarm emplaced approximately 2.45 billion years ago, and the subordinate northeast-trending dykes of the approximately 2.17 billion year old Biscotasing suite and the approximately 2.11 billion year old Marathon/Kapuskasing suite.

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 reactivated, and mafic dykes that were emplaced, during the Proterozoic Era. Evidence for east-trending fault activity 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.

Most episodes of late movement along faults in the Hornepayne area probably terminated by Keweenawan time, approximately 1.100 billion years ago, during the emplacement of the Mid-Continent Rift along Lake Superior, since northeast-trending dykes of this age (Abitibi swarm) crosscut all major north- and northwest-trending faults without displacement in the region south and southeast of the Hornepayne area (West and Ernst, 1991).

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 been re-activated under brittle conditions. 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- approximately 2.680 billion year old D_1-D_2 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 (since approximately 2.680 billion years ago).

6 SUMMARY

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

The distribution of lineaments in the Hornepayne area reflects the bedrock structure, resolution of the data sets used, and the influence of surficial cover. Surface lineament density, as demonstrated in this interpretation, is closely associated with the distribution and thickness of overburden cover that masks the surficial expression of bedrock structures. Lineament density was observed to be highest in the rugged upland area of exposed bedrock located in the western part of the Hornepayne area, and lowest in the northern and eastern parts of the Hornepayne area that have increased overburden cover. Lineament density is also influenced by the resolution of the data sets as demonstrated by the comparison of aeromagnetic lineaments interpreted from low and high resolution surveys.

The results of the final merged lineament mapping show that the variability in observed lineament densities is greater within potentially suitable geologic units due to the above noted factors than between geologic units. The highest average lineament densities were observed in granite-granodiorite and foliated to gneissic tonalite suite of the Black-Pic batholith. Comparable but lower average lineament densities were observed in the metasedimentary rocks and the granite-granodiorite intrusions of the Quetico Subprovince.

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

The orientations observed for the combined set of lineaments from all sources (except ductile stratigraphic horizon and foliation-related features) include prominent northwest, northeast and east trends. It may be possible, with further detailed investigation, to assign the formation of the identified lineaments to distinct deformation events. However, it is difficult at the desktop stage to provide any further constraint on the timing of lineament development beyond denoting all identified brittle and dyke lineaments as composite D_3-D_6 structures that were formed during a protracted period of time post-dating ca. 2.680 billion years ago.

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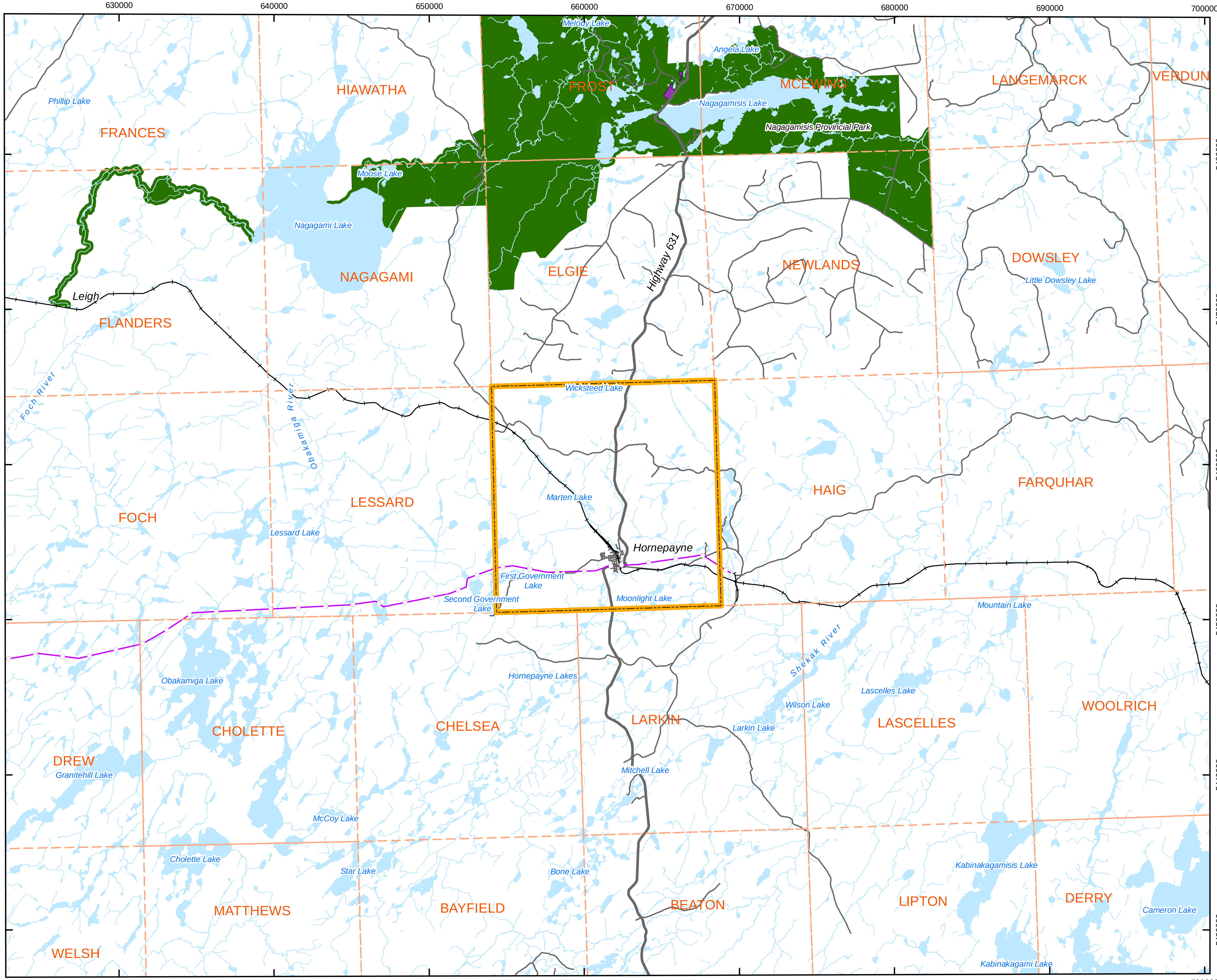
8 REPORT SIGNATURE PAGE

Respectfully submitted,

Geofirma Engineering Ltd.

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

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



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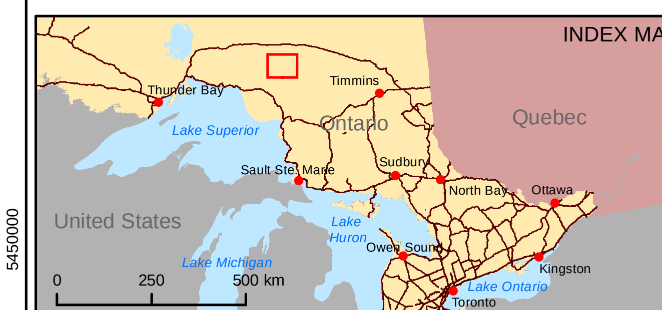
LEGEND
- Township of Hornepayne
- Geographic Township
- Forest Reserve
- Provincial Park
- Highway
- Local Road
- Railway
- Utility Line
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent



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Kilometres

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Road: LIO MNR Road Segment
Township: LIO Geographic Township Improved
Utility: LIO Utility Line
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
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NORTH

PROJECT No. 10-214-4
NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report

TITLE
Township of Hornepayne
and Surrounding Area

FIGURE
1

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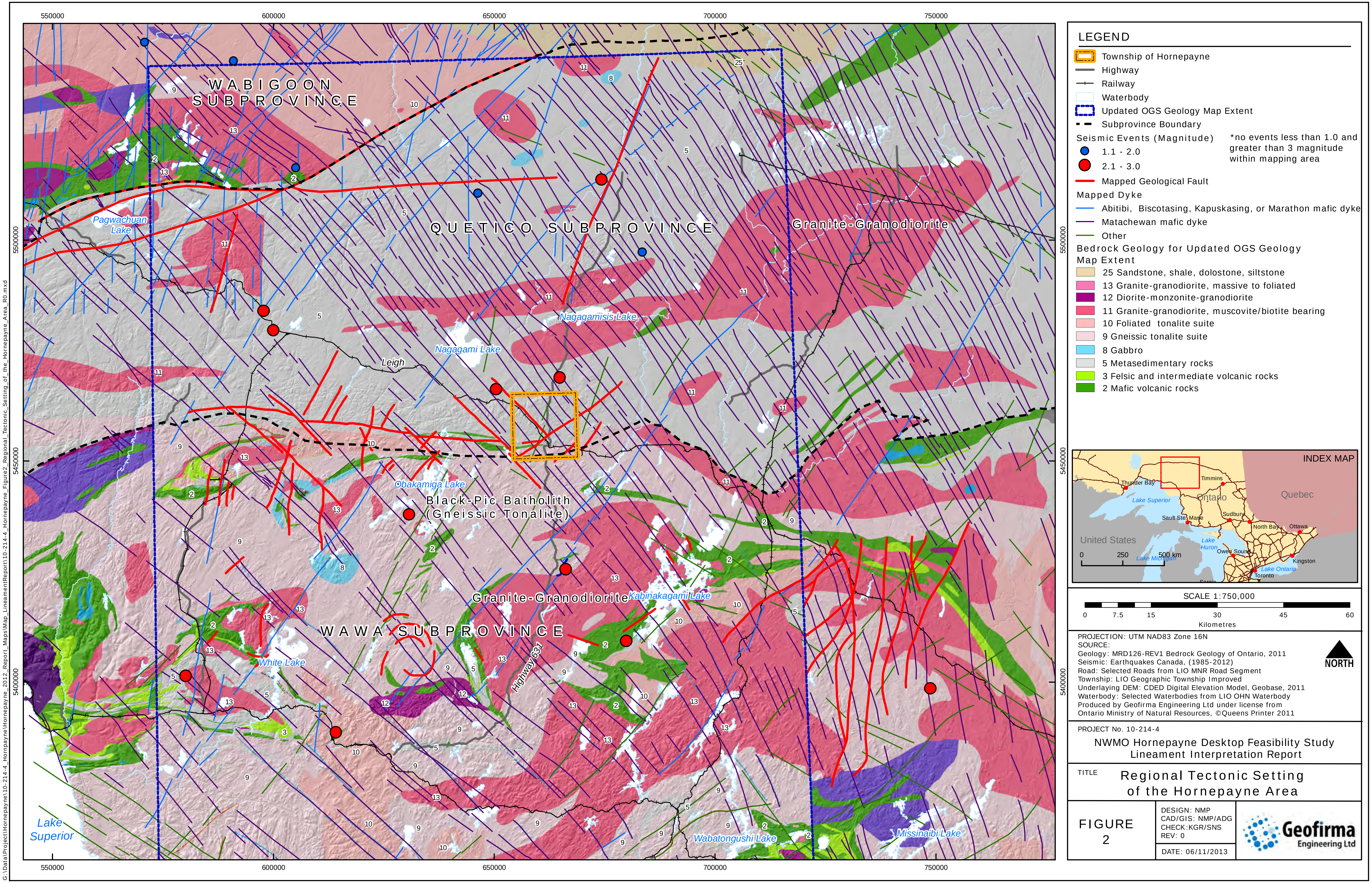
CAD/GIS: NMP
CHECK: KGR/SNS
REV: 0

DATE: 06/11/2013

Geofirma Engineering Ltd



LEGEND
Township of Hornepayne
Highway
Railway
Waterbody
Updated OGS Geology Map Extent
Subprovince Boundary
Seismic Events (Magnitude)
1.1 - 2.0
2.1 - 3.0
*no events less than 1.0 and greater than 3 magnitude within mapping area
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
WABIGOON SUBPROVINCE
QUETICO SUBPROVINCE
WAWA SUBPROVINCE
Granite-Granodiorite
Black-Pic Batholith (Gneissic Tonalite)
Pagwachuan Lake
Nagagamisis Lake
Nagagami Lake
Leigh
Obakamiga Lake
Kabinakagami Lake
White Lake
Highway 631
Lake Superior
Wabatongushi Lake
Missinaibi Lake
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
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Seismic: Earthquakes Canada, (1985-2012)
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
Underlying DEM: CDED Digital Elevation Model, Geobase, 2011
Waterbody: Selected Waterbodies from LIO OHN Waterbody
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011
NORTH
PROJECT No. 10-214-4
NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report
TITLE
Regional Tectonic Setting of the Hornepayne Area
FIGURE 2
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK:KGR/SNS
REV: 0
DATE: 06/11/2013
Geofirma Engineering Ltd
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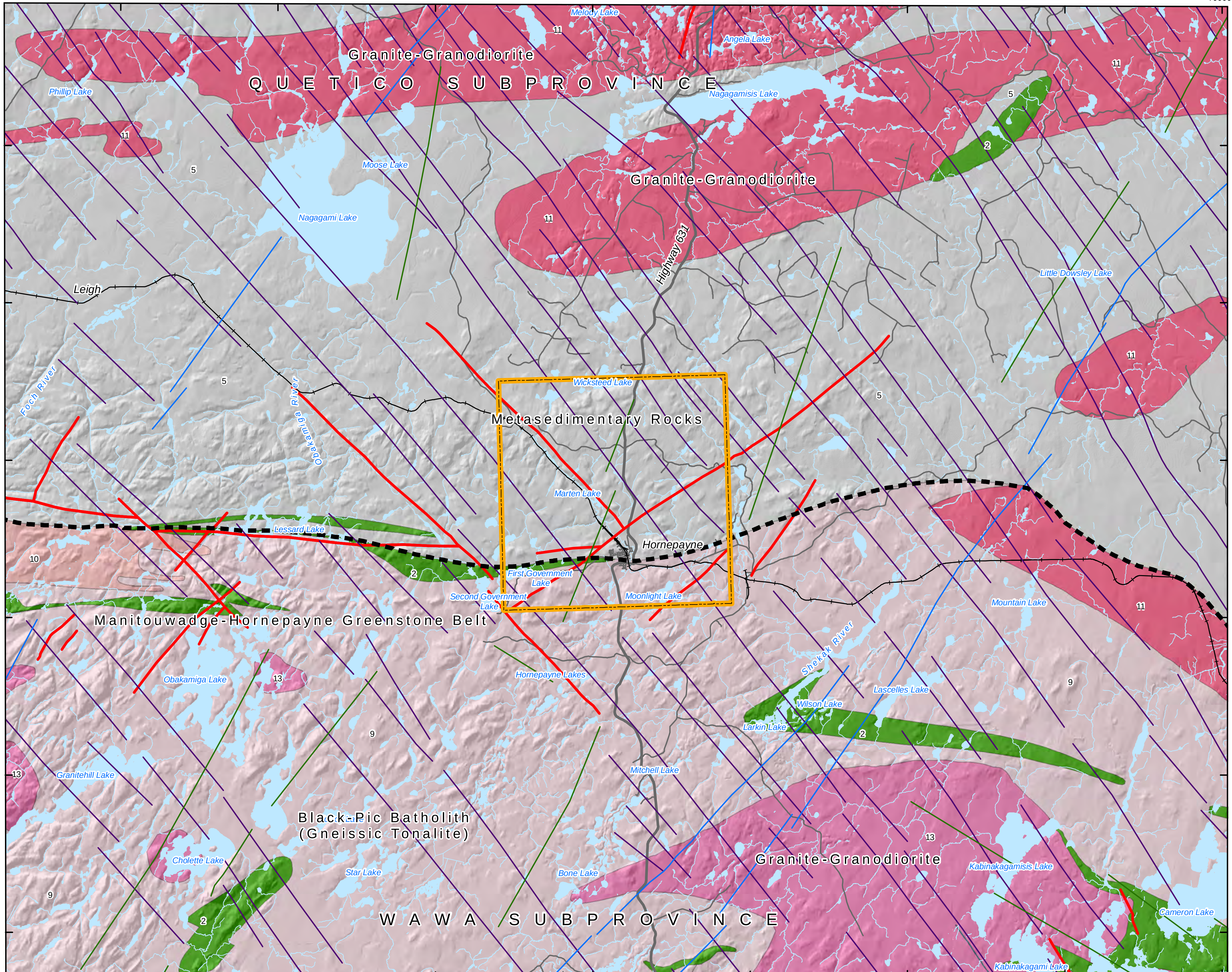


LEGEND

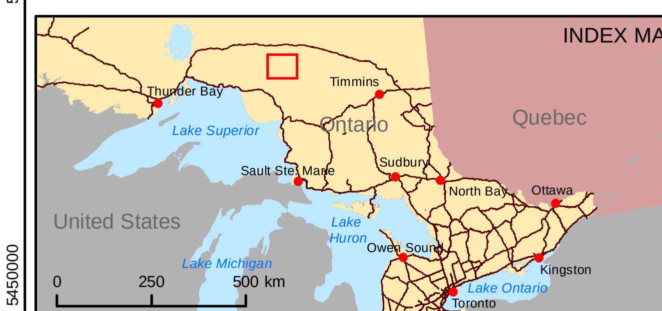
Township of Hornepayne
Highway
Local Road
Railway
Water Area, Permanent
Watercourse, Permanent
Watercourse, Intermittent
Subprovince Boundary
Mapped Geological Fault

Mapped Dyke

Abitibi, Biscotasing, Kapuskasing, or Marathon mafic dike
Matachewan mafic dike
Other

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



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Kilometres

NORTH

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Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report

TITLE

Bedrock Geology
of the Hornepayne Area

FIGURE
3

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

DATE: 06/11/2013

Geofirma Engineering Ltd

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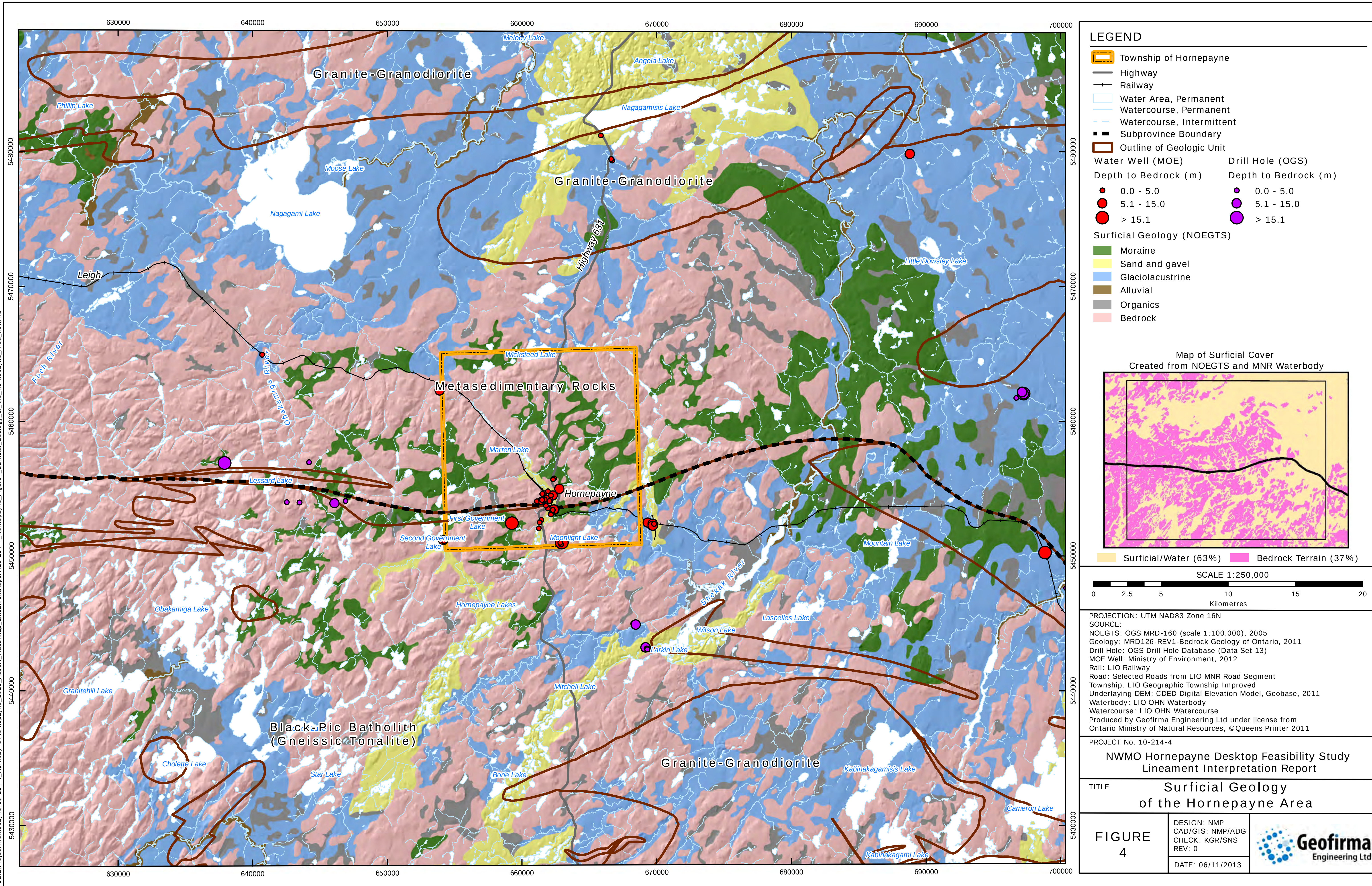

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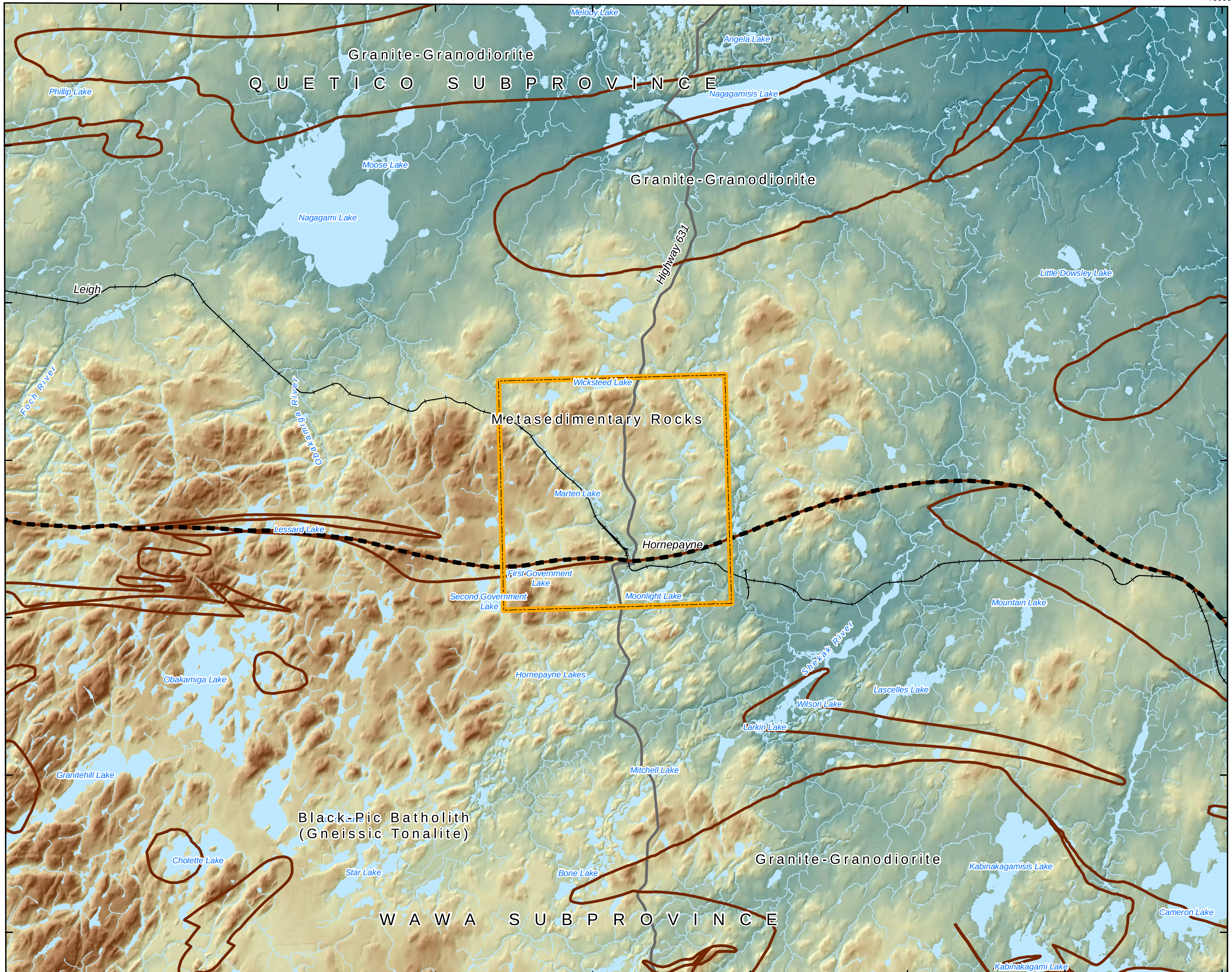

LEGEND

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

Elevation (mASL)

483

333

263

SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

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SOURCE:
Topography: CDED Digital Elevation Model, Geobase, 2011
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
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NORTH

PROJECT No. 10-214-4

NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report

TITLE

CDED Digital Elevation Model
of the Hornepayne Area

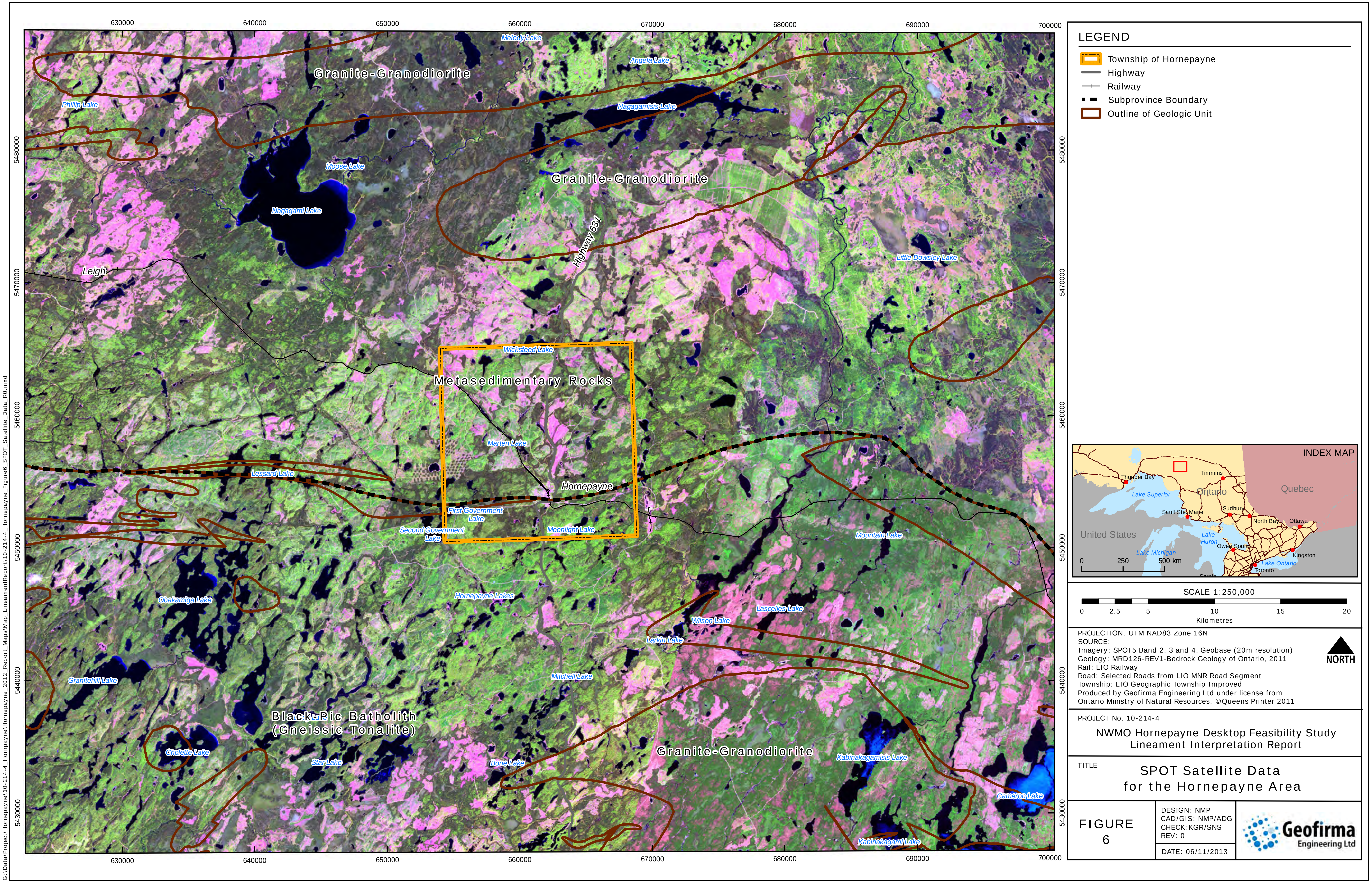
FIGURE
5

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

DATE: 06/11/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornpayne\Hornepayne_2012_Report_Maps\Map_LineamentReport\10-214-4_Hornepayne_Figure5_CDED_Digital_Elevation_Model_R0.mxd


630000
640000
650000
660000
670000
680000
690000
700000
5480000
5470000
5460000
5450000
5440000
5430000
Granite-Granodiorite
Granite-Granodiorite
Metasedimentary Rocks
Black-Pic Batholith (Gneissic Tonalite)
Granite-Granodiorite
Melody Lake
Angela Lake
Phillip Lake
Nagagamisis Lake
Moose Lake
Nagagami Lake
Highway 631
Leigh
Little Dowsley Lake
Wicksteed Lake
Marten Lake
Lessard Lake
Hornepayne
First Government Lake
Second Government Lake
Moonlight Lake
Mountain Lake
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
LEGEND
Township of Hornepayne
Highway
Railway
Subprovince Boundary
Outline of Geologic Unit
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:
Imagery: SPOT5 Band 2, 3 and 4, Geobase (20m resolution)
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ©Queens Printer 2011
NORTH
PROJECT No. 10-214-4
NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report
TITLE
SPOT Satellite Data
for the Hornepayne Area
FIGURE
6
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK:KGR/SNS
REV: 0
DATE: 06/11/2013
Geofirma Engineering Ltd
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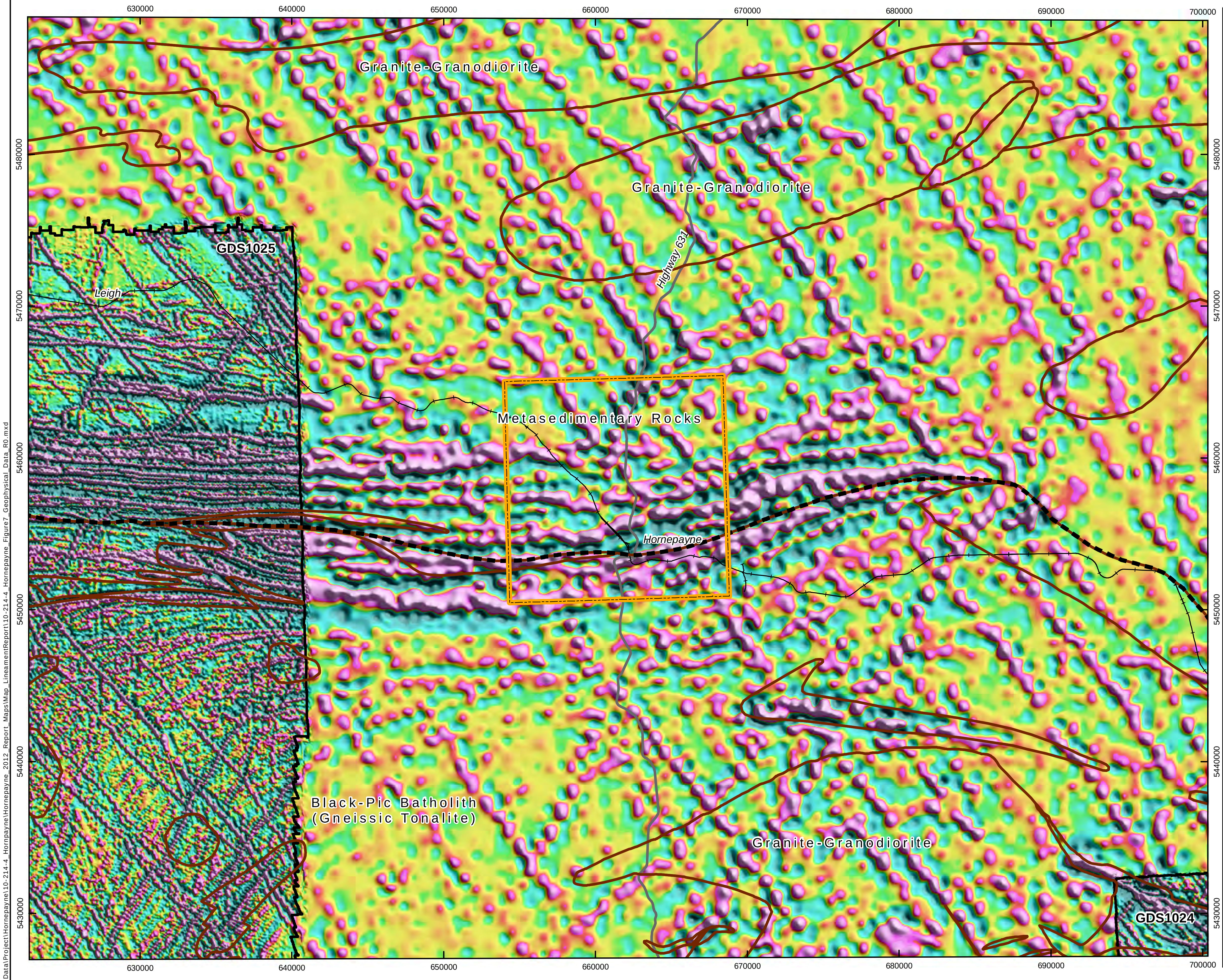


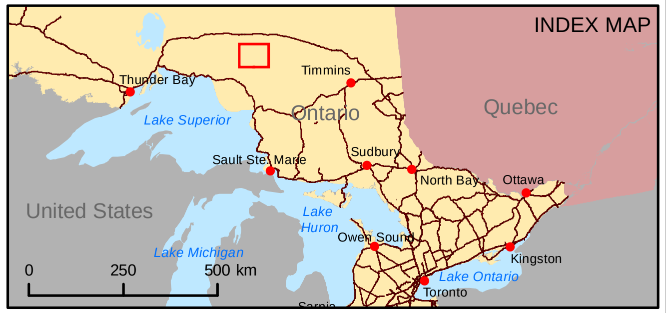
LEGEND

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

MAG

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

NORTH

PROJECTION: UTM NAD83 Zone 16N
SOURCE:
Aeromagnetic: Pole Reduced Magnetic Field: PGW (2012)
Geophysical Surveys Outline: PGW (2012)
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
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NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report

TITLE

First Vertical Derivative of the Pole-Reduced Magnetic Field of the Hornepayne Area

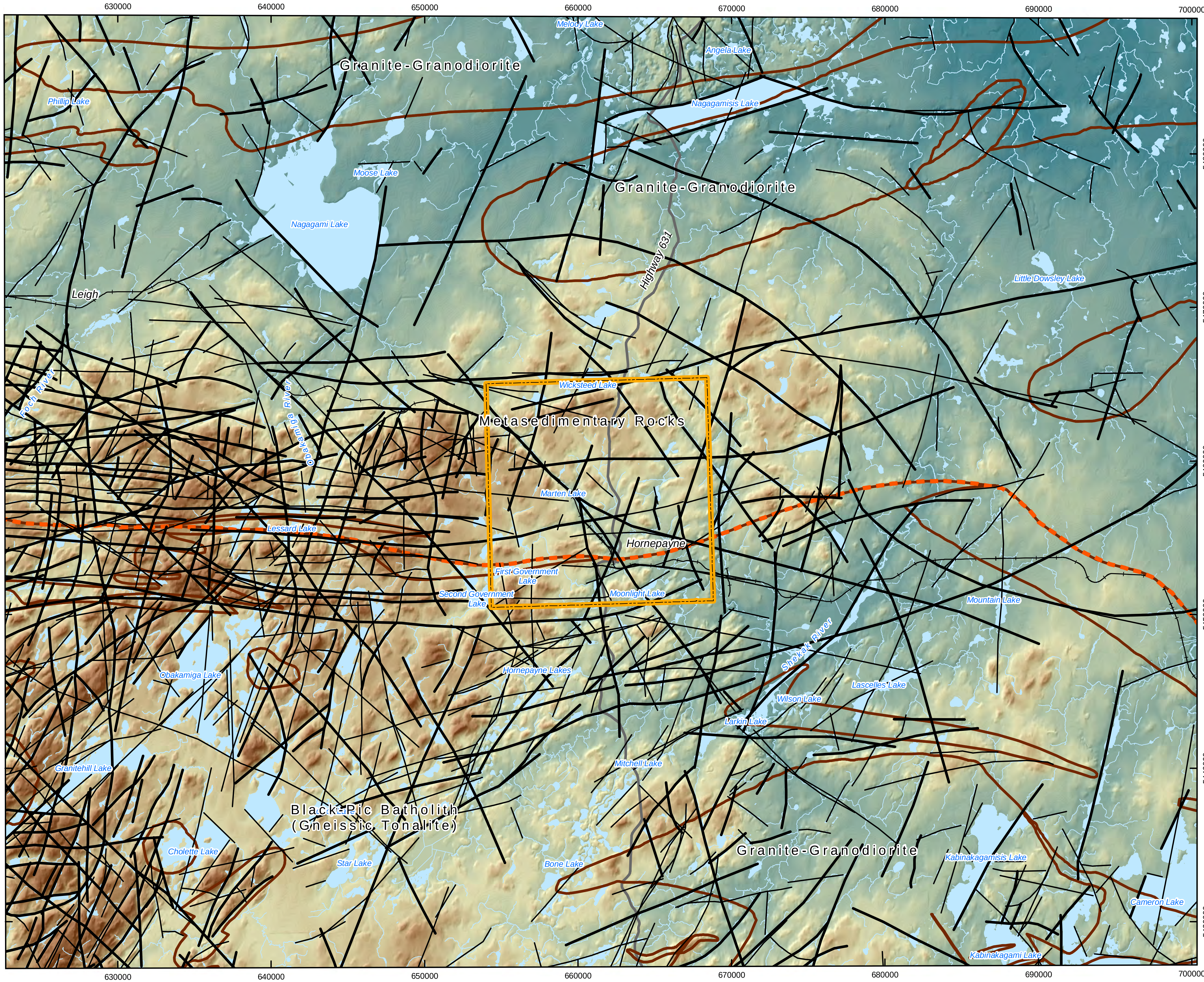
FIGURE 7

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

DATE: 06/11/2013

Geofirma Engineering Ltd

G:\Data\Project\Hornepayne\10-214-4_Hornpayne\Hornepayne_2012_Report_Maps\Map_LineamentReport\10-214-4_Hornepayne_Figure7_Geophysical_Data_R0.mxd



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LEGEND

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

CDED Lineament Reproducibility (RA_1)

- Fracture (RA_1 = 1)
- Fracture (RA_1 = 2)

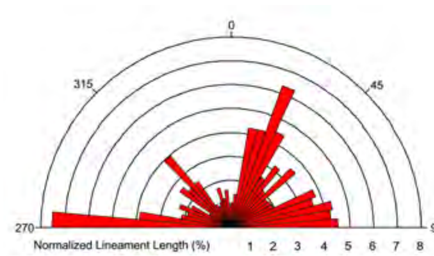
Elevation (mASL)

483

333

263

Hornepayne CDED Data -
Normalized Lineament Length in 5 Degree Azimuth Bins



SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE:
Topography: CDED Digital Elevation Model, Geobase, 2011
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Fractures: Geofirma Engineering, JDMA
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
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PROJECT No. 10-214-4

NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report

TITLE

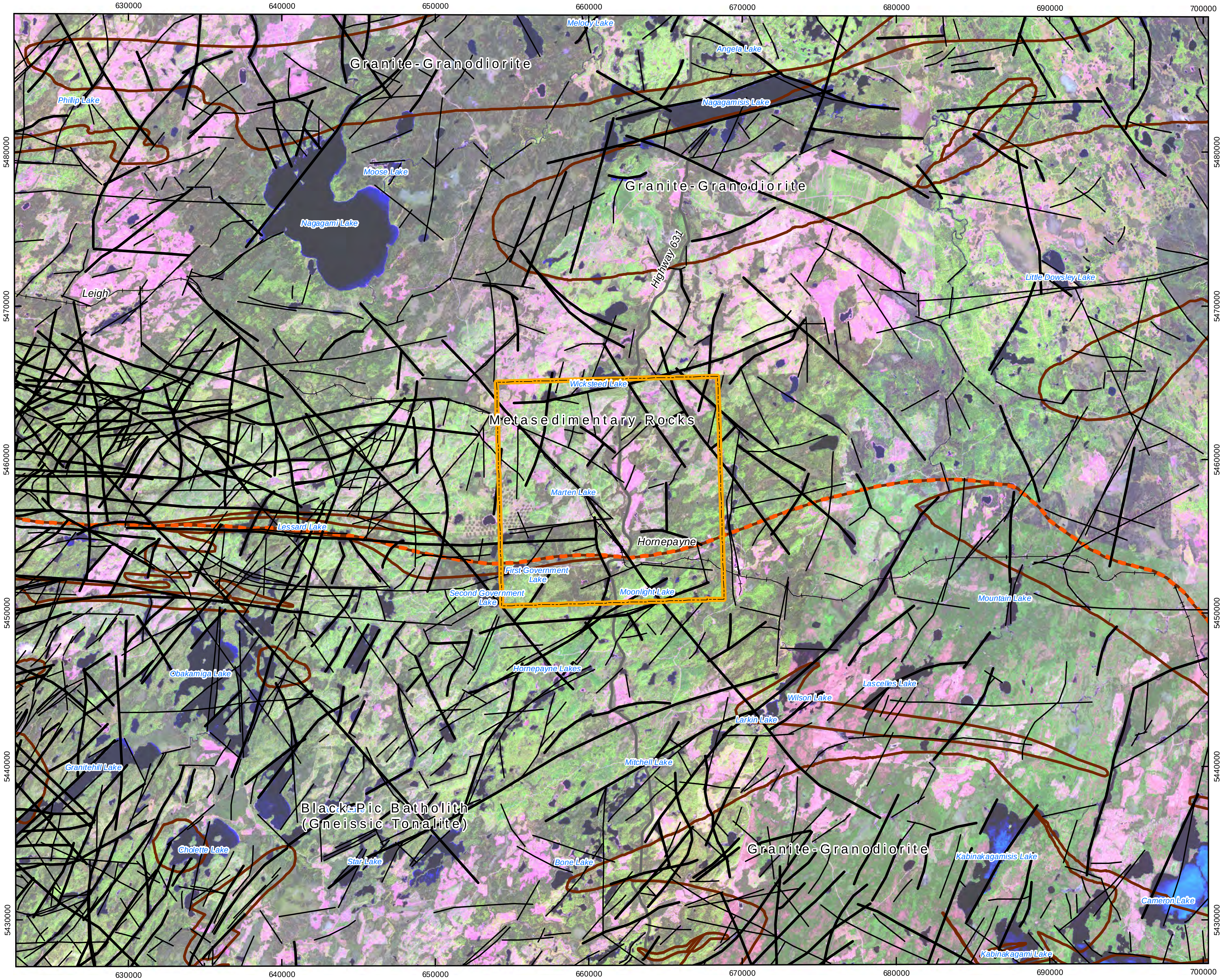
CDED Reproducibility
Assessment (RA_1)

FIGURE
8

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

DATE: 06/11/2013

Geofirma Engineering Ltd



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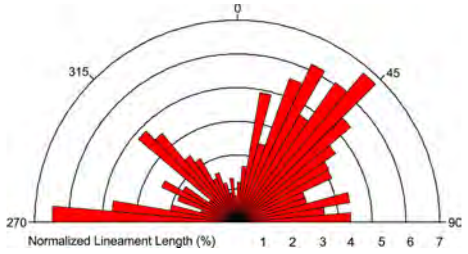
LEGEND

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

Landsat/SPOT Lineament Reproducibility (RA_1)

- Fracture (RA_1 = 1)
- Fracture (RA_1 = 2)

Hornepayne SPOT Data -
Normalized Lineament Length in 5 degree Azimuth Bins



SCALE 1:250,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE:
Imagery: SPOT5 Band 2, 3 and 4, Geobase (20m resolution)
Fractures: Geofirma Engineering, JDMA
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
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PROJECT No. 10-214-4

NWMO Wawa Desktop Feasibility Study
Lineament Interpretation Report

TITLE

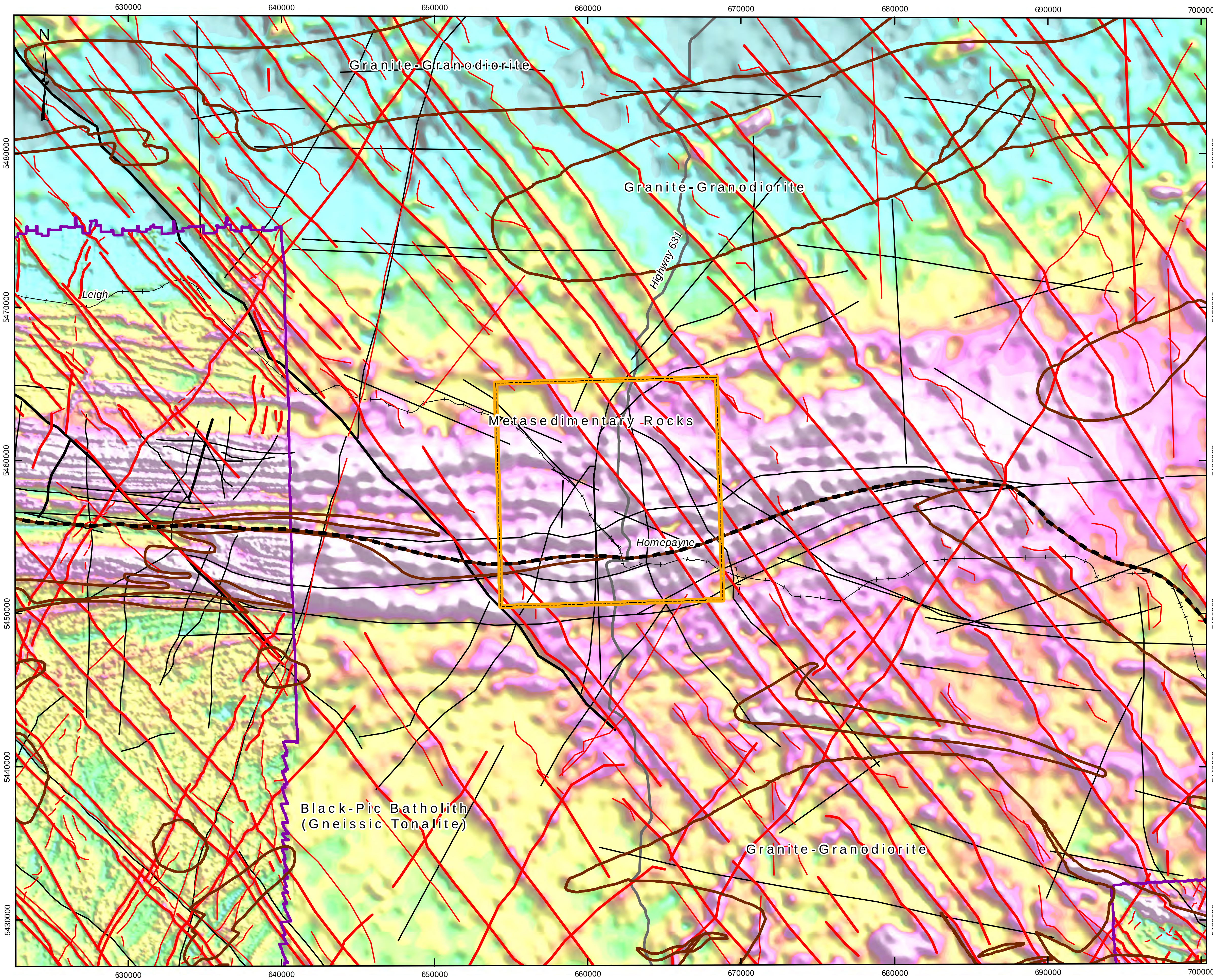
Landsat/SPOT Reproducibility
Assessment (RA_1)

FIGURE
9

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

DATE: 13/08/2013

Geofirma
Engineering Ltd



LEGEND

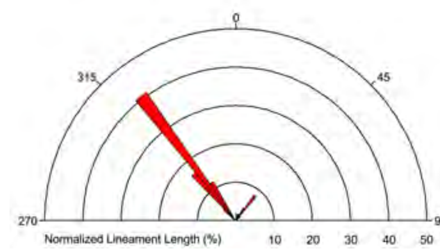
- Township of Hornepayne
- Highway
- Railway
- Subprovince Boundary
- Outline of Geologic Unit
- Higher Resolution Geophysical Surveys

Aeromagnetic Lineament Reproducibility (RA_1)

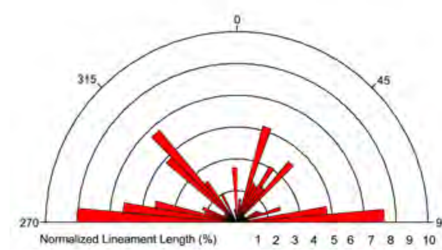
- Fracture (RA_1 = 1)
- Fracture (RA_1 = 2)
- Dyke (RA_1 = 1)
- Dyke (RA_1 = 2)

Magnetic - See Figure 7 for magnetic legend

Hornepayne Geophysical Dykes -
Normalized Lineament Length in 5 Degree Azimuth Bins



Hornepayne Geophysical Fractures -
Normalized Lineament Length in 5 Degree Azimuth Bins



SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE:
Aeromagnetic Reduced Magnetic Field: PGW (2012)
Dykes and Faults: PGW, Greg Stott
Geophysical Surveys Outline: PGW (2012)
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
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NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report

TITLE Aeromagnetic Reproducibility Assessment (RA_1)

FIGURE 10

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

DATE: 13/08/2013

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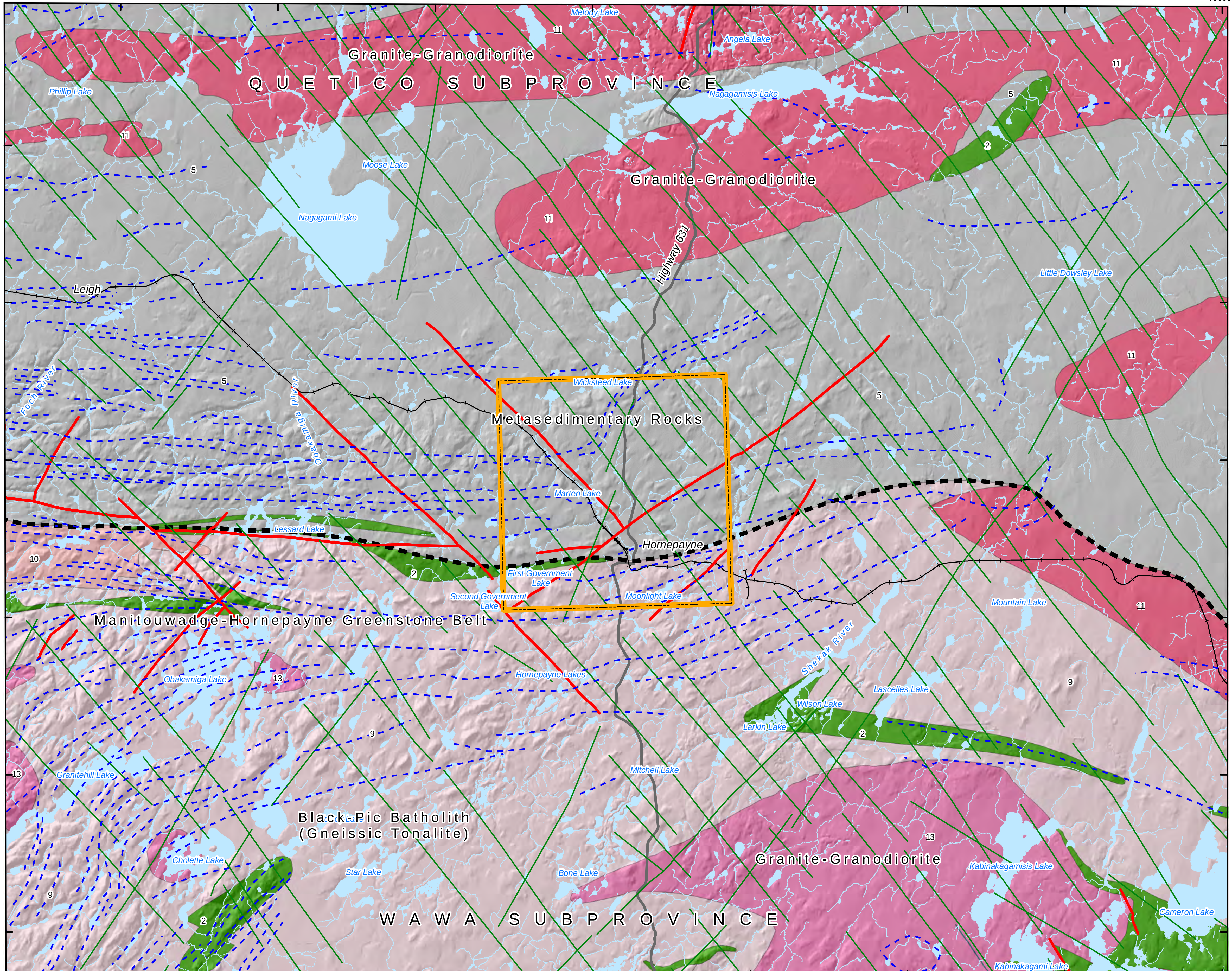
G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_LineamentReport\10-214-4_Hornepayne_Figure10_Aeromagnetic_Reproducibility_Assessment_R0.mxd



LEGEND

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

SCALE 1:250,000

0 2.5 5 10 15 20

Kilometres

NORTH

PROJECTION: UTM NAD83 Zone 16N
SOURCE:
Geology: MRD126_REV1-Bedrock Geology of Ontario, 2011
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
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NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report

TITLE

Ductile Lineaments
of the Hornepayne Area

FIGURE
11

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

DATE: 11/7/2013

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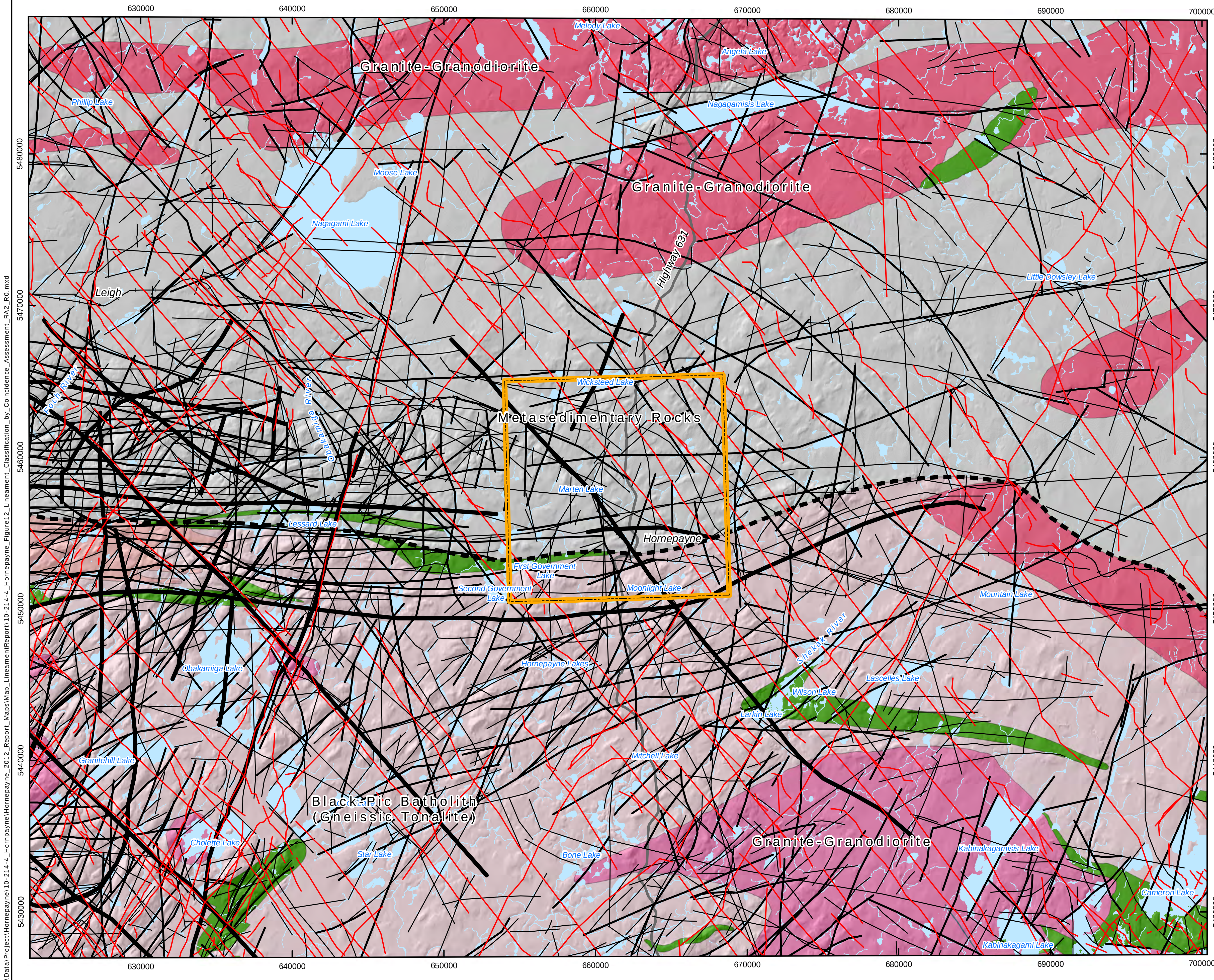
G:\Data\Project\Hornepayne\10-214-4_Hornepayne\Hornepayne_2012_Report_Maps\Map_Lineament\Report\10-214-4_Hornepayne_Figure11_Ductile_Features_of_the_Hornepayne_Area_R0.mxd



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LEGEND

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

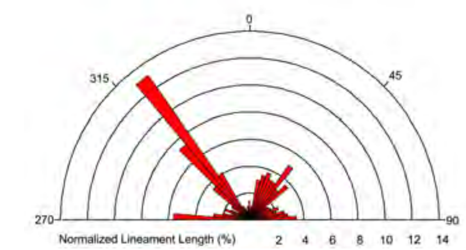
Lineament Reproducibility (RA_2)

- Fracture (RA_2 = 1)
- Fracture (RA_2 = 2)
- Fracture (RA_2 = 3)
- Dyke (RA_2 = 1) *no dyke with RA_2 > 1

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 All Data -
Normalized Lineament Length in 5 Degree Azimuth Bins



Total Lineaments = 1,868

SCALE 1:250,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE:
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Township: LIO Geographic Township Improved
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
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NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report

TITLE Lineament Classification by Reproducibility Assessment (RA_2)

FIGURE 12

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

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LEGEND

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

Fracture (length)

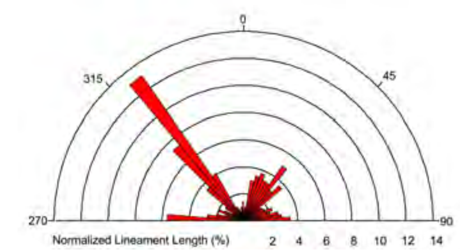
- 0 - 1 km
- 1 - 5 km
- 5 - 10 km
- 10+ km

Dyke (length)

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

Bedrock Geology - see Figure 3 for geology legend

Hornepayne All Data -
Normalized Lineament Length in 5 Degree Azimuth Bins



Total Lineaments = 1,868

SCALE 1:250,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE:
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
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Lineament Interpretation Report

TITLE

Lineament Classification by Length

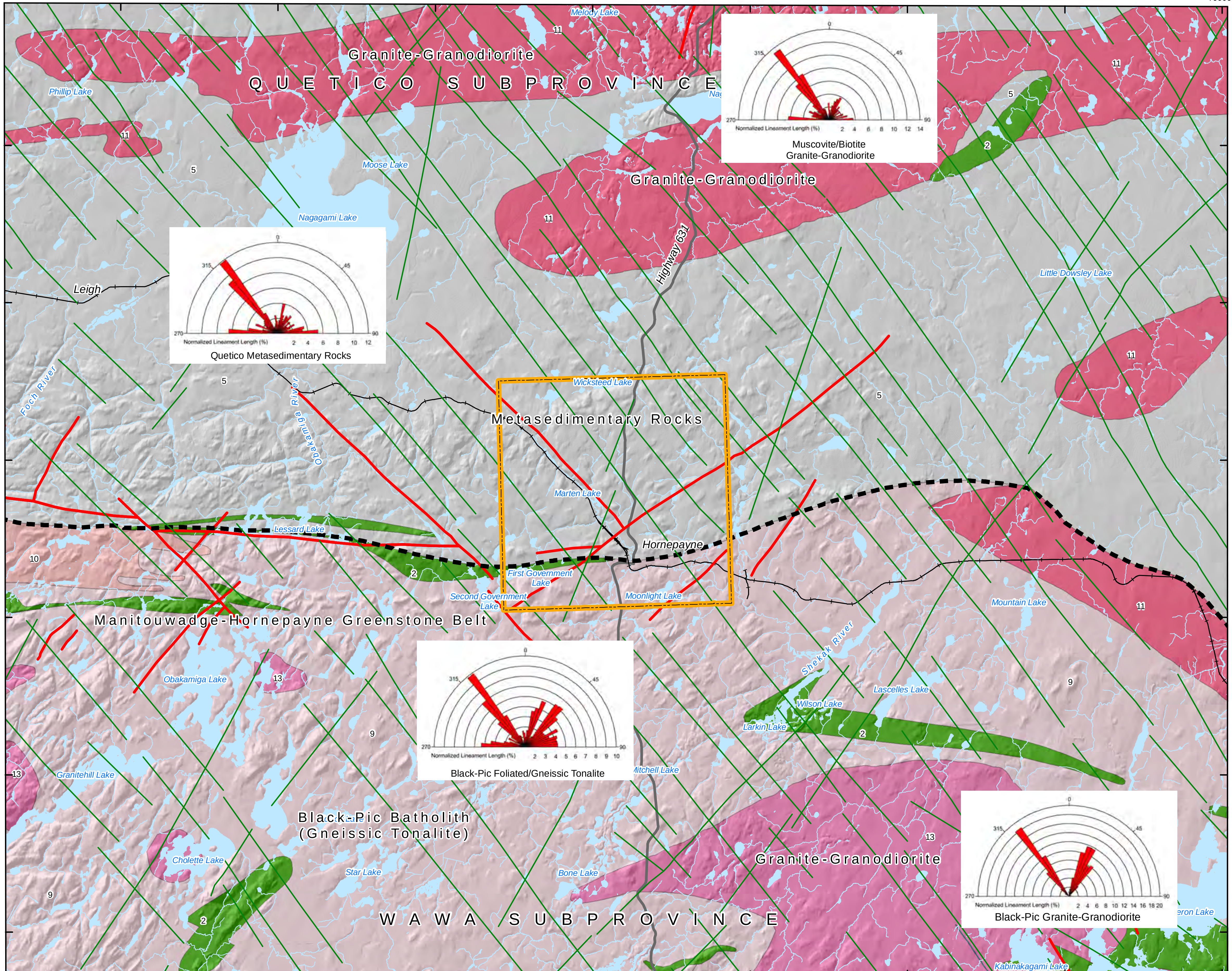
FIGURE 13

DESIGN: NMP
CAD/GIS: NMP/ADG
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_LineamentReport\10-214-4_Hornepayne_Figure13_Lineament_Classification_by_Length_R0.mxd



LEGEND

- Township of Hornepayne
- Highway
- 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

PROJECTION: UTM NAD83 Zone 16N
SOURCE:
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Rail: LIO Railway
Road: Selected Roads from LIO MNR Road Segment
Township: LIO Geographic Township Improved
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
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NWMO Hornepayne Desktop Feasibility Study
Lineament Interpretation Report

TITLE

Lineament Orientations of Potentially Suitable Geologic Units in the Hornepayne Area

FIGURE 14

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

DATE: 06/11/2013

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