NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

MUNICIPALITY OF WAWA, ONTARIO

APM-REP-06144-0027

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Municipality of Wawa, Ontario

Revision: 0 (Final)

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EXECUTIVE SUMMARY

In December 2011, the Municipality of Wawa, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process, and requested that a preliminary assessment be conducted to assess potential suitability of the Wawa area for safely hosting a deep geological repository (Step 3). This request followed successful completion of an initial screening conducted during Step 2 of the site selection process. The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated preliminary assessment report (NWMO, 2013).

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

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

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

The desktop geoscientific preliminary assessment showed that the Wawa area contains at least three general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. These areas are located within the Wawa Gneiss domain, and the Western batholith.

The geological units hosting the three identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They have sufficient depth and extend over large areas. The bedrock in the three potentially suitable areas is mostly exposed. All three areas have low potential for natural resources, although one of the areas

within the Wawa Gneiss domain lies in close proximity to rocks with known economically exploitable mineral resources (i.e. greenstone belt). The identified potentially suitable areas contain limited surface constraints, and are accessible via recreational roads.

While the three potentially suitable areas appear to have favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The main uncertainties are associated with the presence of major regional faults, the occurrence of numerous dykes, and the low resolution of available geophysical data over most of the Wawa area.

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

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Processing and Interpretation of Geophysical Data, Municipality of Wawa, Ontario (PGW, 2013)

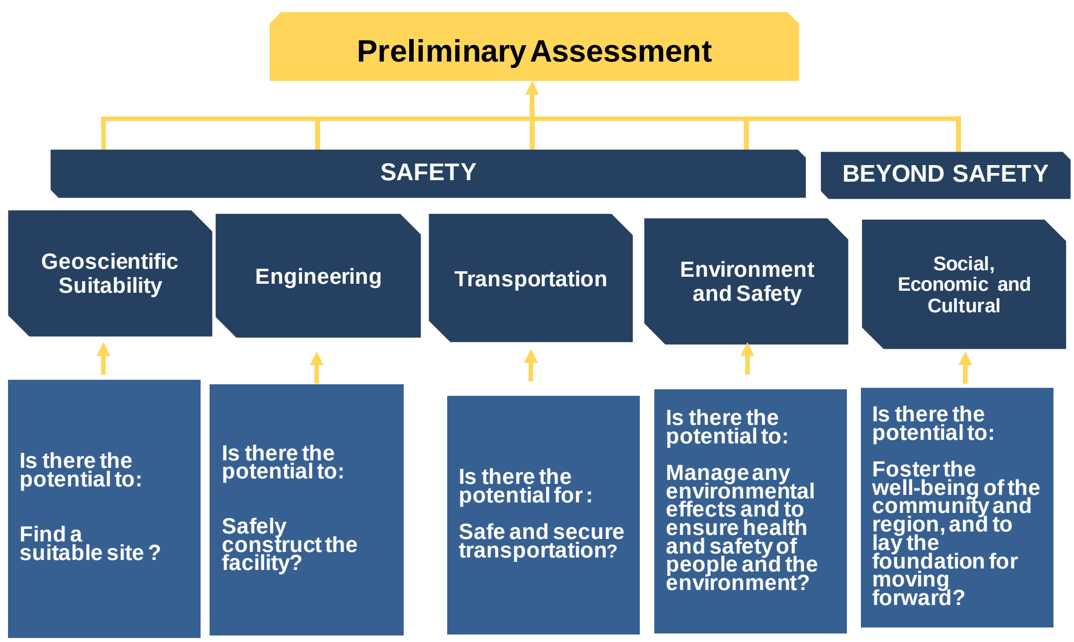
Lineament Interpretation, Municipality of Wawa, Ontario (Geofirma, 2013)

1 INTRODUCTION

1.1 Background

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

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



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

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

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

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

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

1.2 Desktop Geoscientific Preliminary Assessment Approach

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

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

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

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

1.3 Geoscientific Site Evaluation Factors

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

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

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

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

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

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

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

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

1.4 Available Geoscientific Information

Geoscientific information for the Wawa area was obtained from many data sources, including maps, reports, databases and technical papers. The review of existing information identified that there is sufficient geoscientific information available to effectively conduct the Phase 1 desktop geoscientific preliminary assessment studies and to identify general potentially suitable general areas in the Wawa area. Key geoscientific information sources are summarized in this section, with a complete listing provided in Appendix B. Figure 1.2 shows a summary of available geological map coverage and geophysical data surveys for the Wawa area.

1.4.1 DEM, Satellite Imagery and Geophysics

The digital elevation model (DEM) data for the Wawa area is the Canadian Digital Elevation Data (CDED), a 1:50,000 scale, 20 m resolution, elevation model constructed by Natural Resources Canada (NRCan) using provincial data created through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (MNR) (Table 1.1; GeoBase, 2011). The DEM of the Wawa area provided a good quality dataset for identifying topographic lineaments, for quantifying ground slopes and relief, and for assessing regional surface water drainage and likely groundwater flow directions.

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

Dataset	*Product*	*Source*	*Resolution*	*Coverage*	*Acquired*	*Additional Comments*
DEM	Canadian Digital Elevation Data (CDED);1:50,000 scale	Geobase	20 m	Entire Wawa area	1978-1995	Hill-shaded used for mapping
Satellite Imagery	Spot4/5; Orthoimage, multispectral/ panchromatic	Geobase	10 m (panchromatic) 20 m (multispectral)	Entire Wawa area	2005- 2007	Good Coverage
	Landsat-7; Orthoimage, multispectral/ panchromatic	USGS	15 m (panchromatic) 30 m (multispectral)	Entire Wawa area	2000	Good Coverage
Geophysics	Lake Superior	Geological Survey of Canada	1900 m line spacing 305 m sensor height	southwest part of Wawa area	1987	Lowest resolution dataset
	Geological Survey of Canada Regional Magnetic Compilation (Ontario 8 and 17)	Geological Survey of Canada	805m line spacing 305m sensor height	Entire Wawa area	1962, 1963	Low resolution dataset
	Geological Survey of Canada Gravity Data	Geological Survey of Canada	10-15 km/ground surface	Entire Wawa area	1949-1987	Widely-spaced point data
	Geological Survey of Canada Radiometric Data	Geological Survey of Canada	5000 m line spacing 120 m sensor height	Entire Wawa area	1982	Low resolution
	Wawa Survey (GDS1009) Magnetic and Electromagnetic Data	Ontario Geological Survey	200m line spacing 45m Mag sensor Height/ 30m Electromagnetic sensor height	Covers greenstone belts in northern half of Wawa area & northeast corner of Wawa area	1988	Limited usefulness due to greenstone belt coverage

Dataset	*Product*	*Source*	*Resolution*	*Coverage*	*Acquired*	*Additional Comments*
Geophysics	Michipicoten Survey (GDS1010) Magnetic and Electromagnetic Data	Ontario Geological Survey	200m line spacing 30m Mag sensor height/ 30m Electromagnetic sensor height	Covers Michipicoten Greenstone Belt in central part of Wawa area	1980	Limited usefulness due to minimal coverage in Wawa area
	Kapuskasing-Chapleau Survey (GDS1040) Magnetic Data	Ontario Geological Survey/ Geological Survey of Canada	200m line spacing 100m sensor height	Covers small greenstone belt in northeast corner of Wawa area	2001	Limited usefulness due to minimal coverage in Wawa area
	Magpie River-Missinaibi Lake Survey (GDS1237) Magnetic and Electromagnetic Data	Ontario Geological Survey	75m line spacing 40-60 m Mag sensor height / 35-48m Electromagnetic sensor height	Covers small greenstone belt in north central part of Wawa area	2006- 2008	Limited usefulness due to minimal coverage in Wawa area

SPOT-5 satellite imagery for the Wawa area has good resolution (20 m grid size for spectral data and 10 m grid size for panchromatic data). Landsat-7 imagery (30 m grid size for spectral data and 15 m grid size for panchromatic data) was used to augment the SPOT satellite imagery, which significantly improved the quality of the satellite images. Satellite imagery was a high-quality dataset for lineament identification in areas with good bedrock exposure, which occurs throughout the Wawa area. Figure 2.1 shows the Landsat-7 satellite imagery for the Wawa area.

Airborne magnetic, electromagnetic and radiometric data were collected from the Ontario Geological Survey and the Geological Survey of Canada. Low-resolution magnetic data (805 m flight line spacing) obtained from the Geological Survey of Canada (GSC) provide complete coverage of the entire Wawa area (GSC, 2012). Three additional magnetic/electromagnetic surveys (OGS, 2003a; 2003b; 2011b) and one magnetic survey (OGS, 2002; GSC, 2012), with 200 m and 75 m flight line spacing were obtained from the Ontario Geological Survey. These surveys provide higher resolution coverage through much of the northern and central parts of the Wawa area. These surveys focused on exploration in the greenstone belts, while also providing some coverage along the neighbouring margins of the Western, Brulé Bay, and Whitefish Lake batholiths and the Wawa Gneiss domain. Gravity data for the Wawa area was acquired from the GSC and consists of an irregular distribution of 40 gravity stations, comprising roughly a station every 10 to 15 km (GSC, 2012). Radiometric data was acquired from the GSC providing low-resolution (5 km flight line spacing) coverage over the entire Wawa area (GSC, 2012).

1.4.2 Geology

Mapping of the bedrock geology at a 1:15,840 scale is available for parts of the Wawa area, mostly limited to the greenstone belts (Sage, 1982a,b,c,d,e,f), the western portion of the Wawa area including the Western batholith (e.g., Mandziuk and Studemeister, 1981; Massey, 1985), and in the southern portion of the Wawa area (Ayres, 1967). Road cut mapping along Highway 101 from Municipality of

Wawa to Chapleau at a scale of 1 inch:1 mile was carried out by Giblin (1967), but the extent of the mapping is confined primarily to accessible points from the highway.

The entire Wawa area is covered by 1:250,000 scale bedrock geology mapping, which is compiled in two OGS Precambrian Geology Compilation Series Maps (Santaguida, 2001; Johns and McIlraith, 2002). More detailed mapping of portions of the Wawa area is available for Menzies Township, in the northwest part of the Wawa area (Vaillancourt et al, 2003; 2005a,b) and the Western batholith in the western portion of the Wawa area (Reilly, 1991; Reid et al., 1992a,b,c). The greenstone belt mapping was extended to the north by Sage (1994a, b), including an examination of the alteration zones (Sage, 1995).

The Quaternary geology of the Wawa area was mapped at a 1:50,000 scale by Morris (2001a; 2001b) and earlier at 1:100,000 scale as part of the Northern Ontario Engineering Terrain Study (Gartner and McQuay, 1979a,b; McQuay, 1980). The NOEGTS mapping covers the entire Wawa area, while Quaternary mapping at a 1:50,000 scale (Morris, 2001a,b) covers about 50% of the Wawa area, mostly over the central and northeastern portions. Additional mapping at a 1:1,000,000 scale exists for the townships along the southern boundary of the Wawa area (Barnett et al., 1991).

Geological mapping coverage is good for the majority of the Wawa area although the southern part of the Wawa area is mapped at a 1:250,000 scale. Figure 1.2 shows a summary of available geological map coverage and geophysical data surveys for the Wawa area.

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

1.4.3 Hydrogeology and Hydrogeochemistry

Hydrogeologic information for the Wawa area was obtained from the Ontario Ministry of the Environment (MOE, 2012) Water Well Information System (WWIS) database as well as geological (OGS), topographical (MNR) and hydrological maps (MNR, NRCan) of the Wawa area. These data sources contain hydrogeological information on the overburden and shallow bedrock aquifers for portions of the Wawa area where human development has taken place.

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

1.4.4 Natural Resources - Economic Geology

Information regarding the mineral resource potential for the Wawa area has been obtained from a variety of sources including published reports (e.g., Sage et al., 1982c; Delisle, 1991; Heather, 1991; Wilson, 2006), the Assessment File Research Imaging (AFRI) database (MNDM, 2012b), the Abandoned Mines Information System (AMIS) database (MNDM, 2011), the CLAIMaps database (MNDM, 2012a), as well as the Mineral Deposit Inventory (MDI) database (OGS, 2011a). The historical and ongoing mining interest in the Michipicoten and Mishibishu greenstone belts, and the lack of interest in the external granitoid terrane in the Wawa area, is evident from the relative densities of mineral occurrences and active mining claims.

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

1.4.5 Geomechanical Properties

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

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

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

2 PHYSICAL GEOGRAPHY

2.1 Location

The Municipality of Wawa is approximately 420 km^2 in size and is located along the northeast shore of Lake Superior at Michipicoten Bay approximately 227 km north of Sault Ste. Marie, as shown in Figure 1.1. The settlement area of Wawa is situated at the south end of Wawa Lake, approximately 7 km northeast of the Lake Superior shoreline. The Municipality also includes the settlement areas of Michipicoten River Village, and Michipicoten Harbor, both on the shore of Lake Superior. The Municipality of Wawa and its periphery, referred to in this report as the “Wawa area” is 4,274 km^2 in size as shown in Figure 1.1.

The Municipality of Wawa is bordered on the west by the Gros Cap Indian Reserve, on the south by protected areas, and on the east, north and southeast by unorganized territory (Figure 1.1). The closest settlements to the Municipality of Wawa are Hawk Junction 20 km to the northeast, Limer 20 km to the east, and Anjigami, 20 km to the northwest. The settlement area of Wawa is accessed by the Trans-Canada Highway (Highway 17) from the north and south, by Highway 101 from the east, by secondary roads, and by air. The Wawa area is accessible by the CN Railway (formerly the Algoma Central Railway), which connects Sault Ste. Marie in the south to Hearst in the North. Satellite imagery for the Wawa area (Landsat-7, taken in October, 2000) is presented in Figure 2.1. The background image in Figure 2.1 is a colour composite created by assigning a primary colour (red, green and blue) to three of the Landsat multispectral bands. Different materials reflect and absorb solar radiation differently at different wavelengths and therefore have varying intensities within each of the Landsat bands. When combined into a single image, the chosen colour scheme approaches a “natural” representation, where, for example, vegetation appears in shades of green.

2.2 Topography and Landforms

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

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

Elevation within the Wawa area ranges from about 183.2 m at Lake Superior to as much as 607 m within the bordering highlands (Figure 2.2). The settlement area of Wawa is located within the Magpie River valley at approximately 290 mASL elevation. The highest elevations exist in bordering upland areas surrounding the Municipality, typically in association with exposed granitic rocks. Very steep slopes are common in the Wawa area, including near vertical 200 m high cliffs at Old Woman Bay. The most extensive uplands in the northwest and southeast corners of the area are associated with the Western batholith and the Wawa Gneiss domain (Figure 2.2). There is a central low-lying area associated mainly with the valleys of the Magpie and Michipicoten rivers, but also extending south into the low area around Anjigami Lake. These depressions are likely associated with widespread structural weakening. These topographic lows are frequently associated with the organic, alluvial and/or glaciofluvial outwash deposits as shown on Figure 2.3.

The highlands in the northwest, which are largely underlain by the Western batholith, appear to be broken into three north-trending ridges centred on Warpula, Andre, and Bailloquet townships (Figures 1.1 and 2.2). These three ridges have been selected as sites for potential wind farms (JDMA, 2013).

The upland in the southeast part of the Wawa area is underlain by the Wawa Gneiss domain (Figure 2.2). It extends through Roy, Sampson and Pawis townships (Figure 1.1), and it appears to be the most extensive upland in the area. This upland is bounded to the north and south by west-southwest-trending migmatized supracrustal rocks and some metavolcanic belts expressed on the surface as trenches, with the northern belt terminated by the canyon formed along the Agawa River. This highland has also been selected for the potential siting of a wind farm (JDMA, 2013).

The pronounced trenches and troughs bounding the ridges in the central part of the Wawa area give the strongest impression of ridges representing distinct blocks bounded by faults (Figure 2.2). There are four large ridges within the Whitefish Lake batholith, with one centred on each of Lastheels, Fiddler and Debassige townships and one extending through the north part of Isaac Township (Figure 1.1). These ridges have dimensions of about 4 by 8 km with heights of 200 m above the surrounding trenches.

The total change in elevation across the Wawa area is approximately 424 m, and some of the large rock ridges rise 200 m or more from the surrounding trenches. Relief of more than about ten to thirty metres within the Wawa area is expected in virtually all instances to reflect irregularities in the bedrock surface. The greatest relief associated with drift deposits in the Wawa area occurs where meltwater and river erosion has formed terraces as high as 30 m or more composed of deltaic sediments, such as near the mouth of the Magpie River.

Areas of steep slopes form the margins of many of the rugged landforms in the Wawa area, such as ridges and knobs. As steep slopes are often associated with bedrock topography, with some exceptions (e.g., terraces), it is assumed that the presence of steep slopes in this landscape is most likely indicative of bedrock exposure.

The largest areas of highest density of steep slopes are located predominantly along the slopes flanking Lake Superior, near Dog River and Old Woman Bay, with names given to some of the more impressive local features, such as Mountain Ash Hill, Bare Summit, Peat Mountain, and Burlé Hill. Inland, areas of highest density of steep slopes are associated with west-southwest trending steep-walled canyons and escarpments. Examples include a canyon 2 km wide and more than 150 m deep on Dossier Creek in Peterson Township, and one that rises more than 200 m from the Kinniwabi River in the southeast corner of Maness Township (JDMA, 2013).

2.3 Watersheds and Surface Water Features

The Wawa area is located within the Lake Superior drainage basin of the Atlantic Ocean watershed. The overall surface water drainage in the Wawa area is shown on Figure 2.4. Drainage is generally southerly into Lake Superior from the height of land between the Lake Superior drainage basin and that of the Hudson Bay system located approximately 50 km to the northeast (see index map in Figure 2.4).

The main drainage is carried by the Michipicoten River, which flows approximately 110 km from Dog Lake just northeast of the Wawa area into Manitowik Lake, Whitefish Lake, and finally into Lake Superior. Tributaries of the Michipicoten River include the Shikwamka River which drains the east-central part of the Wawa area, the Anjigami River which drains Anjigami Lake and the south-central part of the area, and the Magpie River which drains the north-central part of the Wawa area including the northern half of the Municipality.

The western part of the Wawa area is drained by smaller south-flowing rivers, the largest of which are the Doré River and the Dog River. The south-central part of the Wawa area including Mishewawa Lake is drained by the Old Woman River which discharges to Lake Superior at Old Woman Bay. The Jackpine River drains a large part of the eastern margin of the Wawa area. Its basin is a generally low-relief basin with thicker drift deposits. The southeast part of the Wawa area including Gould Lake is drained by the Agawa River which flows south through the Agawa Canyon prior to discharging into Lake Superior at Agawa Bay, 70 km south of the settlement area of Wawa. The Agawa River drainage basin is very rugged. The Agawa Canyon is structurally controlled by the Agawa Canyon fault.

As part of their terrain analysis, JDMA (2013) carried out a drainage basin analysis in order to confirm and, where possible, partition the most detailed available mapping of watersheds by the MNR. The resulting mapping is shown on Figure 2.4, which includes the divides that delineate the three tertiary-scale watersheds associated with the three main river systems in the Wawa area (Michipicoten-Magpie, Agawa and White rivers), as well as several quaternary-scale watersheds that further compartmentalize surface drainage. The divides or boundaries of the drainage basins in the Wawa area are generally well defined by bedrock ridges.

The Wawa area contains a number of lakes of various sizes (Figure 2.4), four of which are larger than 10 km^2 (Table 2.1 - Lake Superior, Manitowik Lake, Whitefish Lake and Anjigami Lake) and two of which are larger than 20 km^2. Aside from Lake Superior, the largest lakes occupy the major structurally controlled river valleys in the Wawa area. For example, Manitowik Lake, Hawk Lake and Wawa Lake occupy the linear topographic depression formed by the Wawa-Hawk-Manitowik Lake fault, which is associated with the Kapuskasing structural zone (Sage, 1994b). Similarly, Whitefish Lake and Anjigami Lake occupy northeast-trending topographic depressions. There is considerable relief between the lakes in most areas.

Table 2.1 Size of Lakes Larger than 10 km^2 in the Wawa Area

Lake	***Perimeter (km)***	***Area (km^2)***
Lake Superior[1]	140	610
Manitowik Lake	77	24
Whitefish Lake	71	17
Anjigami Lake	43	11

[1]Size within the Wawa area

The remaining lakes tend to be small (less than 1-2 km^2), and many of them are positioned outside of the major river valleys (Figure 2.4). All of the lakes excluding Lake Superior cover only about 7% of the Wawa area.

Some of the lakes are sufficiently large to conceal the surface expression of lineaments up to about ten kilometres in length, and nests of lakes have additional potential to conceal or reveal lineaments, especially when the lakes are located in areas where lineaments are obscured by overburden deposits.

2.4 Land Use and Protected Areas

Figure 2.5 shows a summary of land disposition and ownership within the Wawa area, including known protected areas. Most of the Wawa area is an equal mix of unpatented public Crown land and private lands recognizable on a township basis. The townships along most of the northern boundary of the Wawa area, northeast of Lake Superior Provincial Park and encompassing Hawk and Whitefish lakes are private lands. The Gros Cap Indian Reserve is located immediately west of the Municipality of Wawa. The shorelines of several lakes including Hawk, Manitowik and Whitefish lakes, are non-freehold public lands. Small parcels of private land are found on the shores of several lakes and along highways in unpatented public Crown lands.

2.4.1 Land Use

Land use within the 422 km^2 Municipality of Wawa consists of predominantly unoccupied forest, wetland, lakes and exposed bedrock, as well as some residential, commercial and industrial uses within the 4 km^2 settlement area of Wawa and within the smaller settlement areas of Michipicoten River Village and Michipicoten Harbour. The municipal airport is located about 3.5 km southwest of the settlement area of Wawa.

Land use within the 4,274 km^2 Wawa area outside of the Municipality is predominately parkland, conservation reserve, Indian reserve, private land and unoccupied Crown land consisting of forest, wetland, lakes and exposed bedrock. There are no active mines in the Wawa area.

2.4.2 Parks and Reserves

There are four Ontario provincial parks, two conservation reserves, one recommended conservation reserve, and a forest reserve located in the Wawa area (Figure 1.1). The largest provincial park in the Wawa area is the Lake Superior Provincial Park, which is 1550 km^2 in size, approximately 294 km^2 of which occurs within the Wawa area. The Potholes Provincial Park is located on Highway 101 approximately 40 km west of the settlement area of Wawa, and is 3.47 km^2 in size. The Michipicoten Post Provincial Park occupies 2.89 km^2 of land on the south shore of the Michipicoten River at its outlet into Lake Superior, approximately 7 km southwest of the settlement area of Wawa. The Nimoosh Provincial Park, located approximately 30 km west of the settlement area of Wawa, is approximately 3.5 km^2 in size and contains reaches of the Dog River and Jimmy Kash River.

The 21 km^2 Magpie River Terraces Conservation Reserve is located entirely within the Municipality of Wawa, about 7 km north of the settlement area of Wawa. The South Michipicoten River-Superior Shoreline Conservation Reserve protects approximately 2.22 km^2 of land between the south bank of the Michipicoten River and the northern boundary of Lake Superior Provincial Park, approximately 10 km south of the settlement area of Wawa. The Lake Superior Highlands Conservation Reserve is being recommended, covering an approximate area of 39.5 km^2 about 12-15 km west of the Municipality of Wawa. A 3.90 km^2 forest reserve is located between the south bank of the Michipicoten River and the northern boundary of Lake Superior Provincial Park, straddling Highway 17.

Parks and reserves represent about 12% of the Wawa area.

2.4.3 Heritage Sites

The cultural heritage screening examined known archaeological and historic sites in the Wawa area. Information on archaeological sites in Ontario is provided by the Ontario Ministry of Tourism and Culture, through their Archaeological Sites Database (Ontario Ministry of Tourism and Culture, 2011).

There are 37 registered archaeological sites in the Wawa area, with the majority concentrated within Provincial Parks along the shoreline of Lake Superior, and within the Magpie River Terraces Conservation Reserve.

The Ojibway (Anishinabe) have inhabited the Lake Superior shoreline in the Wawa area for many thousands of years. The Michipicoten Post was an important summer settlement at the confluence of the Michipicoten and Magpie Rivers that was operated between 1821 and 1904 by the Hudson's Bay Company (Douglas, 1995). There are 11 known archaeological sites in this location, including Michipicoten Bay and Harbour. Other Lake Superior shoreline archaeological sites in the Wawa area include 11 in Lake Superior Provincial Park, particularly around Old Woman Bay, and two in Nimoosh Provincial Park. There are four known archaeological sites within and surrounding the Magpie River Terraces Conservation Reserve within the Municipality of Wawa. East of the Municipality of Wawa there five archaeological sites: one on Anjigami Lake, one on the upper reaches of the Michipicoten River, one on Manitowik Lake and two approximately 50 km to the east of the Municipality.

Archaeological potential is established by determining the likelihood that archaeological resources may be present on a subject property. In archaeological potential modelling, a distance to water criterion of 300 m is generally employed for primary water courses, including lakeshores, rivers and large creeks, while a criterion of 200 m is applied to secondary water sources, including swamps and small creeks (Government of Ontario, 1997). The potential for archaeological and historical sites within the Wawa area is considered to be high given the sites already documented, the proximity to the Lake Superior shoreline, and the importance of the area in the historic fur trade.

There are also 30 municipally designated heritage sites, but no National Historic Sites and no Provincial Heritage Trust Sites in the Wawa area (Meridian, 2010; Ontario Heritage Trust, 2012; Parks Canada, 2012).

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

3 GEOLOGY

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

The Wawa area is underlain by the approximately 3.0 to 2.6 billion year old bedrock of the Superior Province of the Canadian Shield – a stable craton created from an assemblage of Archean-age plates, accreted juvenile arc terranes and sedimentary basins of Proterozoic age that were progressively amalgamated over geologic time scales of more than 2 billion years (Figure 3.1). The Canadian Shield forms the stable core of the North American continent.

The Superior Province covers an area of approximately 1,500,000 km^2 stretching from the Ungava region of northern Québec through the northern part of Ontario and the eastern portion of Manitoba, and extending south through to Minnesota and the northeastern part of South Dakota. The Superior Province has been divided into various regionally extensive east-northeast-trending subprovinces based on lithology, age, genesis and metamorphism (e.g., Langford and Morin, 1976; Card and Ciesielski, 1986; Card, 1990) as shown in Figure 3.1. More recently, this division has been revised in terms of lithotectonic terranes and domains (Percival and Easton, 2007; Stott et al., 2010). Terranes are defined as tectonically bounded regions with characteristics distinct from adjacent regions prior to their accretion into the Superior Province, whereas domains refer to lithologically distinct portions within a terrane (Stott et al., 2010). As shown in Figure 3.2, the Wawa area is located in the Wawa-Abitibi Terrane. Although most of the literature reviewed for this assessment uses the older terminology, for the purpose of this report, both terms subprovince and terrane have been retained, choosing one over the other when it is believed to be more appropriate.

The Wawa area is located in the southeastern portion of the Wawa Subprovince: a belt of rocks about 900 km long and 150 km wide, extending from central Minnesota in the United States to the Kapuskasing area in northeastern Ontario. The Wawa Subprovince is bounded on the north by the metasedimentary rocks of the Quetico Subprovince, and to the south by Proterozoic-aged (approximately 1.9 to 1.1 billion- year old) rocks of both the Southern Province and the Mid-continent Rift system. To the east, the Wawa Subprovince is truncated by the Kapuskasing structural zone (Figure 3.2) that separates the Wawa Subprovince from the Abitibi Subprovince (which together form the Wawa-Abitibi terrane).

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 commonly oriented northwest and northeast. Faulting is common in the southeastern part of the Wawa Subprovince, with most faults being oriented northwest and less commonly northeast (McGill and Shrady, 1986; Sage, 1994b).

Figure 3.3 shows the general bedrock geology and main structural features of the southeastern part of the Wawa Subprovince, where the Wawa area is located. The main geological features of the area are groups of rocks known as the Michipicoten, Gamitagama, and Mishibishu greenstone belts, and a group of areally-extensive intrusive rocks termed external granitoid terranes (Williams et al., 1991) that surrounds the greenstone belts.

The greenstone belts are assemblages of supracrustal rocks formed by mafic to felsic volcanic cycles between approximately 2.9 and 2.7 billion years ago, including associated metasedimentary rocks. To the south, between the Michipicoten greenstone belt and the Kapuskasing structural zone, the granitoid terrane is referred to as the Wawa Gneiss domain (Thurston et al., 1977; Moser, 1994) which also contains slivers of supracrustal rocks. The rest of the surrounding granitoid rocks are a mosaic of felsic plutons comprising the Whitefish Lake batholith, the Renabie pluton, the Dubreuilville pluton, and the Western batholith (Card and Poulsen, 1998).

The precise relationship between the external granitoid rocks and greenstone belts is uncertain, although the granitoid intrusions within the greenstone belts and the surrounding granitoid rocks are of similar age (Sage, 1994b). Some of the granitoid intrusions and supracrustal rocks in the external granitoid terrane close to the contact with the greenstone belt are dated as old as approximately 2.9 billion years, but in general the mosaic of granitoid plutons are generally younger than the greenstone belts, and approximately 2.7 billion years (Turek et al., 1990; Turek et al., 1992; Moser, 1994). The plutons are thought to be mid-crustal intrusions developed during or after the formation of the greenstone belts (Percival, 1990).

3.1.2 Geological History

Direct information on the geological and structural history of the Wawa area is limited. The geological and structural history summarized below integrates the results from studies undertaken elsewhere throughout and proximal to the regional area shown in Figure 3.3. It is understood that there are potential problems in regional correlation of specific structural events within a D_x numbering system and in the application of such a system to the local geological history. Nonetheless, this summary represents an initial preliminary interpretation for the Wawa area, which may be modified after site-specific information has been collected, if the community is selected by the NWMO and remains interested in continuing with the site selection process.

The geological and structural history of the Wawa area can be summarized as a tectonic succession of seven deformation events (D_1 to D_7) that occurred between approximately 2.9 and 1.0 billion years ago. Three major episodes of volcanism and sedimentation were recorded in the Michipicoten greenstone belt (Turek et al., 1984; Sage, 1994b) and these episodes were accompanied by emplacement of diatreme breccias and alkali plutons within or marginal to the greenstone belts (e.g., Stott et al., 2002). Plutons and batholiths emplaced synvolcanically were later incorporated into the regional orogenic deformation and associated tectonic uplift. Major folding, refolding and thrusting of the greenstone belt strata were either concurrent with or followed by the aforementioned uplift of the external batholiths. A substantial number of dykes have intruded all rock types in the Wawa area.

The first stage of volcanic activity took place in the Wawa Subprovince at approximately 2.89 to 2.88 billion years ago (Turek et al., 1992), with the deposition of pillowed and massive, basaltic and peridotitic komatiites, which were later overlain by tuffs (Williams, 1991), probably in an oceanic arc to plateau setting (Polat, 2009). Emplacement of the Hawk Lake granitic complex as early as approximately 2.888 billion years ago (Turek et al., 1984) at the eastern margin of the Michipicoten greenstone belt confirms the existence of a common source of coeval plutonism and volcanism of the first cycle.

A second period of tholeiitic volcanism occurred at approximately 2.77 to 2.70 billion years ago, forming much of the greenstone belts in the Wawa Subprovince (Carter, 1988; Williams et al., 1991; Turek et al., 1992; Corfu and Stott, 1998; Polat, 2009; Zaleski et al., 1999). In the Michipicoten greenstone belt, synvolcanic tonalite-trondhjemite-granodiorite occurred in the greenstone rocks between approximately 2.745 and 2.742 billion years ago (Sullivan et al., 1985; Turek et al., 1992), a trondjhemite phase of the Hawk Lake granitic complex at approximately 2.747 billion years ago (Turek et al., 1982), and the Jostle Lake tonalite, either an early phase of the Western batholith or a predecessor igneous intrusion to it, at approximately 2.721 billion years ago.

A third period of tholeiitic to calc-alkalic volcanism and plutonism between approximately 2.701 and 2.694 billion years ago followed in the Wawa Subprovince (Corfu and Stott, 1998; Polat, 2009). This period, or at least towards its end, was marked by the beginning of the collision of the Wawa-Abitibi terrane against the Superior superterrane (Corfu and Stott, 1986; 1998), and the transition from primitive arc tholeiites to calc-alkaline arc magmas may have been caused by thickening of the arc crust as a result of the docking of the Wawa-Abitibi terrane (Kerrich et al., 1999). Volcanism in the Michipicoten greenstone belt was most prominent along its southwestern portion, including synvolcanic to early post-volcanic deposition of the 'Doré conglomerates' as early as approximately 2.698 billion years ago (Corfu and Sage, 1987). Emplacement of the Western batholith, or at least most of it, has also been dated to have occurred during this period, at around 2.698 billion years ago (Turek et al., 1984).

The period until approximately 2.690 to 2.689 billion years ago involved a series of synchronic volcanism, plutonism and sedimentation in the greenstone belts of the Wawa terrane (Corfu and Stott, 1998; Polat, 2009; Zaleski et al., 1999; Davis and Lin, 2003). In the Wawa area, voluminous external granitoid bodies emplaced surrounding the Michipicoten greenstone belt, particularly in the Wawa Gneiss domain (Heather et al., 1995), including emplacement of the Whitefish Lake batholith at approximately 2.694 billion years ago (Turek et al., 1984).

Plutonic activity continued in the Wawa Gneiss domain between approximately 2.689 and 2.680 billion years ago (Heather et al., 1995). Towards the end of this period, a first nappe-style deformation (D_1) is recorded in rocks of the Michipicoten greenstone belt at approximately 2.682 billion years ago. This event was followed by a second deformation event D_2 (Corfu and Sage, 1992) characterized by southward-vergent, northward dipping, refolding and thrust imbrication of major D_1 folds (Arias and Helmstaedt, 1989). The D_2 event is consistent with the continuing northward subduction and collision of the Wawa-Abitibi terrane against the Superior Province in late Archean time, approximately 2.7 to 2.67 billion years ago (e.g. White et al., 2003).

As early as approximately 2.679 billion years ago until approximately 2.674 billion years ago, ultramafic to mafic, heterolitic, diamondiferous diatremes intruded the Michipicoten greenstone belt, followed by lamprophyre dykes (Stott et al., 2002; Vaillancourt et al., 2005a). The dykes, shoshonitic in composition, reflect episodes of crustal extension possibly during the late-stage termination of relative flat subduction of oceanic plateau crust and slab breakoff of the Wawa terrane (Wyman et al., 2006; 2008). This was followed by emplacement of the Dickenson Lake stock approximately 2.677 billion years ago in the Michipicoten greenstone belt, marking the end of the accretion of the Wawa terrane to the Superior Province, as the stock displays a magmatic fabric free of the penetrative effects of the Archean accretion in the Wawa area. Emplacement of this pluton and several other small plutons, including the Maskinonge Lake and Troupe Lake stocks approximately 2.671 billion years ago; the Kabekung Lake possibly approximately 2.670 billion years ago, and Lund Lake approximately 2.662 billion years ago (Turek et al., 1982; Turek et al., 1984; Turek et al., 1992; Sage, 1994b), post-dated the regional D_2 event and marked the end of felsic plutonism activity.

East-trending dextral shear zones, formed concurrently with emplacement of the alkalic to calc-alkalic plutons described above, are interpreted as D_3 structures. Later formed brittle north-northwest and northeast-trending faults and fractures, including the Agawa Canyon fault, are interpreted as D_4 structures that developed during a period of crustal cooling. This brittle deformation affects the volcanic greenstone belt rocks as well as the synvolcanic and syn-orogenic plutons. D_5 collectively includes conjugate late brittle faults and fractures trending north-northwest, north-northeast, north-south and east-west, preserved in late tectonic plutons of the Wawa area. These are late cooling structures most typically as local, relatively short fractures. The entire D_3 to D_5 interval of deformation occurred between approximately 2.677 and 2.662 billion years ago. Subsequently, substantial dyke emplacement was initiated in the Wawa area and the region.

Northwest-trending dykes of the Matachewan swarm intruded all other types of rocks from approximately 2.473 to 2.446 billion years ago (Heaman, 1997) as a consequence of a mantle plume centre situated near present-day Sudbury, Ontario. This was followed by intrusion of northeast-trending dykes of the Biscotasing swarm approximately 2.171 to 2.168 billion years ago (Halls and Davis, 2004). Renewed dyke emplacement activity occurred approximately 2.126 to 2.101 billion years ago affecting the Wawa area with the intrusion of the northeast-trending Marathon-Kapuskasing dyke swarm from another mantle plume south of Lake Superior (Halls et al., 2008). With the beginning of the Trans-Hudson Orogeny approximately 1.92 to 1.9 billion years ago (Lucas et al., 1996; Tran, 2001), regional-scale faults were reactivated (D_6) in the Wawa area. Additionally, coeval with the uplift of the Kapuskasing structural zone to the east of the Wawa area approximately 1.9 billion years ago (Percival and West, 1994), block rotation and movement of both northwest-trending and northeast-trending faults occurred in the Wawa area and its vicinity (Halls et al., 1994; Percival and West, 1994; Evans and Halls, 2010).

Most episodes of late movement along faults probably terminated by Keweenawan time, approximately 1.100 billion years ago, during the Mid-continent Rift event along Lake Superior, since northeast-trending dykes of this age (Abitibi swarm) crosscut all major north and northwest-trending faults without displacement (West and Ernst, 1991). Intrusion of the Firesand River carbonatite in rocks of the Michipicoten greenstone belt approximately 1.048 billion years ago (Sage, 1979) probably mark the last relevant Mesoproterozoic episode in the Wawa area before the onset of the Grenville Orogeny (approximately 1.0 to 0.95 billion years ago). Local evidence for a Grenville overprint includes a set of compressional faults that occurs south of the Michipicoten greenstone belt near Cape Gargantua.

Little information is available for the geological history of Wawa area for the period following the Grenville Orogeny and the Mid-continent Rift after approximately 1.0 billion years ago. During the Paleozoic Era, 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 Basin and Michigan Basin. 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. Much of the present surface of the Canadian Shield lies close to an exhumed paleoplain interpreted to be of Ordovician age (Brown et al., 1995). However, no evidence exists that Paleozoic strata were present in the Wawa area (Johnson et al., 1992).

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

A summary of the geological history for the Wawa area and surrounding region is provided in Table 3.1 below.

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

Time Period (billion years ago)	***Geological Event***
ca. 2.89 to 2.88	First cycle of volcanism and coeval emplacement of the Hawk Lake granitic complex along the eastern margin of Michipicoten greenstone belt (Sage, 1994b).
ca. 2.75 to 2.72	Formation of most of the greenstone belts of the Wawa Subprovince (Ketchum et al., 2008). Second cycle of volcanism and synvolcanic plutonism in the Michipicoten greenstone belt (Turek et al., 1992), including Jubilee stock (approximately 2.745 to 2.742 billion years ago) and Jostle Lake tonalite (2.721 billion years ago) emplacement in the Western batholith southwest of the Michipicoten greenstone belt.
ca. 2.701 to 2.694	Onset of the collision of the Wawa-Abitibi terrane against the Superior Superterrane. Third cycle of volcanism and sedimentation in Michipicoten greenstone belt, including deposition of Catfish assemblage between approximately 2.701 and approximately 2.698 billion years ago and deposition in basin in-fill of 'Doré conglomerates' as early as approximately 2.698 billion years ago. Emplacement of external granitoids surrounding greenstone belts, including the Western batholith at approximately 2.698 billion years ago and the Whitefish Lake batholith at approximately 2.694 billion years ago.
ca. 2.682	D_1 nappe-style and D_2 folding and thrusting deformation events. D_2 was characterized by southward-vergent (northward dipping) refolding and thrust imbrication of a major D_1 nappe fold (Corfu and Sage 1992).
ca. 2.679 to 2.674	Crystallization of mafic to ultramafic, heterolithic, diamondiferous diatreme breccias and shoshonitic lamprophyre dykes that intrude Michipicoten greenstone belt (Vaillancourt et al., 2005a; Stott et al., 2002). Lamprophyre dyke emplacement reflects an episode of crustal extension, possibly during late-stage termination of relatively flat subduction of oceanic plateau crust and slab breakoff (Wyman et al., 2006; 2008).
ca. 2.677	Termination of the penetrative effects of Archean orogenies in the Wawa area (end of regional D_2). Emplacement of the Dickenson Lake stock in the Michipicoten greenstone belt approximately 2.677 billion years ago.

Time Period (billion years ago)	***Geological Event***
ca. 2.671 to 2.662	Emplacement of a suite of felsic intrusive stocks, including Maskinonge Lake and Troupe Lake stocks (approximately 2.671 billion years ago) and Lund Lake stock (approximately 2.662 billion years ago) along the northern part of the Michipicoten greenstone belt. These intrusions postdate the penetrative regional D_1 and D_2 deformation events and thereby constrain the dominant record of belt-scale recumbent D_1 nappe folding and D_2 thrust imbrication and refolding (Arias and Helmstaedt, 1989) to between approximately 2.682 and 2.671 billion years ago. East-trending D_3 dextral shear zones are concurrent with or postdate this suite of alkalic to calc-alkalic plutons. Subsequent late tectonic crustal cooling and residual collisional stresses created a generation of D_4 brittle-ductile to brittle faults and brittle fractures of undetermined late orogenic age. The cooling and exhumation of late tectonic plutons produced brittle fractures within the plutons, collectively treated as D_5 features. There is a probable overlap in timing between regional D_4 and D_5 structures. Emplacement of one of the youngest (approximately 2.662 billion years ago) granitic felsic plutons in the Wawa area (Turek et al., 1984).
ca. 2.45	Intrusion of the Matachewan diabase dyke swarm which radiates northwestward from a plume centre near present day Sudbury, Ontario.
ca. 2.17	Intrusion of the northeast-trending Biscotasing quartz tholeiite dyke swarm.
ca. 2.11	Intrusion of the northeast-trending Marathon/Kapuskasing dyke swarm from a plume centre south of Lake Superior (Halls et al., 2008).
ca. 1.92 to 1.9	Brittle (D_6) reactivation of regional-scale faults during the Trans-Hudson Orogeny. Ca. 1.9 billion years ago uplift of the Kapuskasing structural zone was contemporaneous with dextral movements on northeast-trending faults, and sinistral movements on north- to northwest-trending faults, and a twenty three-degree rotation of the western Superior Province relative to the eastern Superior Province (Halls et al., 1994; Percival and West, 1994; Evans and Halls, 2010).
ca. 1.141	Intrusion of the northeast-trending Abitibi dyke swarm extending from the Mid-continent Rift along Lake Superior (e.g., Ernst and Buchan, 1993
ca. 1.1	Keweenawan Mid-continent Rift gabbro and tholeiitic basalt were emplaced south and southwest of Wawa, with local felsic intrusions derived by melting of Archean crust, including emplacement of Firesand River carbonatite approximately 1.048 billion years ago.
ca. 1.0 to 0.95	Late (D_7) north-trending or northwest-trending crustal shortening and reverse fault movement during the Grenville Orogeny (Manson and Halls, 1994).

3.1.3 Regional Structural History

The structural history of the Wawa area and surrounding region has been studied to varying degrees over the years with primary focus on the mineral potential of the greenstone belts and analysis of the tectonically complex Kapuskasing structural zone (e.g., McGill and Shrady, 1986; Arias and Helmstaedt, 1990; McGill, 1992; Moser, 1994). As summarized in Table 3.1, at least 7 episodes of penetrative strain (D_1 to D_7) are understood to have affected the Wawa area. The following sequence of structural deformation (D_x) events characterizes the regional structural history of the Wawa area:

- D_0 primary bedding in sediments and volcanics within the volcanic belts.
- D_1 tectonic deformation produced a regional recumbent nappe-style of folding (F_1) of lithostratigraphic units in the Michipicoten greenstone belt.

- D_2 refolding of the recumbent D_1 nappe structure was followed by thrust faulting with faults and bedding dipping shallowly to steeply towards the northeast. The D_1 and D_2 events are constrained from field relationships to have occurred between approximately 2.682 and approximately 2.671 billion years ago.
- D_3 applies to the east-west-trending and north-northwest-trending dextral shear zones and faults and to the northeast-trending sinistral shear zones and faults during late stage Archean orogenesis in the Wawa area.
- D_4 applies to later brittle faults and fractures trending north-northwest and northeast if present and to the north-south-trending brittle faults including the Agawa Canyon fault. These brittle structures mark a period of crustal cooling under residual stress and affect rocks of the volcanic belts as well as synvolcanic and syn-orogenic plutons.
- D_5 collectively includes conjugate late brittle faults and fractures trending north-northwest, north-northeast, north-south and east-west, preserved in late tectonic plutons of the Wawa area. These are late cooling structures most typically as local, relatively short fractures. Some faults and fractures may have been reactivated during later D_6 Proterozoic events.
- D_6 events are collectively characterized by the development of Proterozoic faults and reactivation of Archean faults. These include faults developed during the Proterozoic uplift of the Kapuskasing structural zone (approximately 1.9 billion years ago) with regional crustal rotation about a vertical axis. This rotation produced, within and bordering the Kapuskasing structural zone, northwest-trending sinistral faults and northeast-trending dextral faults, which are opposite in displacement sense to the general Archean faults of similar orientations. Also included in these D_6 events are possible reactivations of north-south-trending faults by the Keweenawan event (approximately 1.100 billion years ago) during the Mid-continent Rift along and underlying the upper Great Lakes region. These structures are generally undefined and are probably reactivations only. These Proterozoic events could overprint early Proterozoic dyke swarms such as the north-northwest-trending Matachewan swarm (approximately 2.445 to 2.470 billion years ago).
- D_7 involved the activation of reverse faults perpendicular to the extensional axis of the Mid-continent Rift; these faults crosscut Keweenawan bedded units and mark approximately 1.0 billion-year-old north-oriented or northwest-oriented crustal compression during the Grenville Orogeny (Manson and Halls, 1994).

3.1.4 Mapped Regional Structure

Faults are a common feature of the bedrock in the Wawa area (Figure 3.4), with some eleven named and numerous other unnamed faults included in the OGS bedrock geology database. In general, there are three main orientations of mapped faults, trending northwest, north and northeast (McGill and Shrady, 1986; Sage, 1994b; Manson and Halls, 1997). The relative ages of faulting across the Wawa area suggest that the oldest faults (which are largely unmapped) tend to trend east, overprinted by northwest and northeast-trending faults, and followed by late north-trending faults. In relation to the geological history described above, the mapped faults in the area would be considered D_4-D_5 structures that may also include a complex history of re-activation during the D_6 and D_7 events.

Northwest-trending faults include the Trembley, Black Trout Lake, Mildred Lake, Marsden and Treeby faults. The largest of these are the Trembley, Mildred Lake and Marsden faults, which range from 12 to 55 km in length in the Wawa area. These northwest-trending faults are aligned with the Matachewan dyke swarm emplaced approximately 2.45 billion years (Phinney and Halls, 2001), and were likely tectonically active in the late Archean and early Proterozoic eras (Sage, 1994b). Although little is known about the complete tectonic history of these northwest-trending faults, there is some suggestion that some of them (e.g., Mildred Lake fault) may be deep structures that represent the locus of conduits for emplacement of diamondiferous pyroclastic tuff breccias (Archibald, 2008). Observations along a portion of the Trembley fault suggest that it caused major displacement, either sinistral or vertical motion, of greenstone belt rocks in the southwestern part of the Michipicoten greenstone belt (Sears, 1994). In general, sinistral offset is suggested for all northwest-trending faults during uplift of the Kapuskasing structural zone. These sinistral faults are well illustrated by the OGS compilation maps that show displacement of the greenstone belt into separate panels (e.g., Figure 3.3).

Northeast-trending faults include the Wawa Lake, Hawk Lake, Manitowik Lake, Old Woman River, Mishewawa and Firesand River faults (Figure 3.3). The largest of these northeast-trending structures, the combined Wawa Lake, Hawk Lake and Manitowik Lake fault crosses the entire Wawa area and is commonly genetically associated with major dextral offset along the Kapuskasing structural zone (Sage, 1994b). This large fault has also been interpreted as a reactivated structure with an Archean origin to Archean tectonics (Turek et al., 1992; Sage, 1994b). The Firesand River carbonatite was emplaced approximately 1.084 billion years ago (Sage, 1979) in the junction of the Wawa Lake and Hawk Lake faults. The presence of this type of intrusive rock in the Wawa Lake-Hawk Lake fault would imply a deep root for this fault, probably reaching lower crust or upper mantle depth (Sage, 1994b).

The Kapuskasing structural zone (Figure 3.2) is interpreted by Percival and West (1994) as a tilted block which was uplifted during the Paleoproterozoic Era, approximately 1.9 billion years ago (Sage, 1994b; Manson and Halls, 1997). The uplift resulted in exposure of the upper 30 km of the crust, with increasing deeper structural levels below the Michipicoten greenstone belt being exposed to the east. In general, dextral offset is suggested for all northeast-trending faults during uplift of the Kapuskasing structural zone.

North-trending structures include the Agawa Canyon and similarly oriented McEwan Lake faults (Halls and Mound, 1998), and the much shorter Loon Skin Lake fault. The Agawa Canyon fault, sometimes referred to as the McVeigh Creek fault, extends across the Wawa area approximately 10 km to the east of the Municipality of Wawa (Figure 3.3). This fault can be traced many kilometres south of the Michipicoten greenstone belt, and its northerly orientation is uncommon in the area. The fault is considered to be post-Keweenawan in age (i.e. younger than approximately 1.1 billion years), and associated with the Mid-continent Rift (Manson and Halls, 1997). It is generally considered to have a normal, east-side-down movement history (e.g., Renault, 1962). The McEwan Lake fault is a approximately 30 km long, north-trending west-verging thrust fault located approximately 30 km east of the Agawa Canyon fault and south of Hwy 101 in the eastern part of the Wawa area (Figure 3.3). This fault, which is not shown on the current OGS compilation mapping and consequently is not shown on Figures 3.3 and 3.4, is reported to be related to the Kapuskasing structural zone with a vertical displacement of at least 5 km (Halls and Mound, 1998).

As mentioned in Section 3.1.1 and described in Section 3.2.1.5, rocks in the Wawa area host numerous dyke swarms. There is some uncertainty in understanding the extent of damage to the host rock as a result of dyke emplacement. It is well understood, but not easily quantifiable from geophysical data alone, that dyke propagation will induce damage to the host rock within an envelope around the dyke that varies with the size of the intrusion (e.g., Meriaux et al., 1999).

3.1.5 Metamorphism

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

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

In the Archean Superior Province, the relative timing and grade of regional metamorphism corresponds to the type of lithologic composition of the subprovinces (Easton, 2000a; Percival et al., 2006). Granite-greenstone subprovinces contain the oldest, Neoarchean metamorphism of lower greenschist to amphibolite facies in volcano-sedimentary assemblages and synvolcanic to syntectonic plutons. Both metasediment- and associated migmatite-dominated subprovinces, such as the English River and Quetico, and dominantly plutonic and orthogneissic subprovinces, such as the Winnipeg River, 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 and Trans-Hudson Orogen experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through $^{40}Ar/^{39}Ar$ dating to approximately 2.500 billion years ago, the significance 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, located east of the Wawa area, is an approximately 1.9 billion years old thrust structure that uplifts a westward-tilted Archean crust and juxtaposes greenschist facies rocks exhumed from <10km depth on its west site near Wawa against granulite facies rocks on its east side that have been exhumed from approximately 30 km depth (Percival and West, 1994). Approximately 1.0 billion year ago, far-field reactivation of faults by compression from the Grenville Orogeny produced a sub-greenschist metamorphic overprint along pre-existing faults in the vicinity of Lake Nipigon and near Lake Superior (Manson and Halls, 1994).

The greenstone belt rocks of the Wawa area have been metamorphosed to the greenschist grade of regional metamorphism, with an aureole of contact metamorphism of amphibolite grade at the margins of large internal and external plutons (Ayres, 1969; Easton, 2000a). Relative to smaller greenstone belts (e.g., Hemlo) the grade of metamorphism in the Michipicoten greenstone belt is low. Within the Wawa Gneiss domain, the grade of metamorphism increases eastward toward the Kapuskasing structural zone, reflecting exposure of progressively deeper structural level (Easton, 2000a). Like all other rocks in the Wawa area, the diabase dykes have been affected by greenschist grade regional metamorphism. They usually display well-developed chilled margins, related to emplacement, and aureoles of contact metamorphism.

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 approximately 950 million years ago.

3.1.6 Erosion

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

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

3.2 Local Bedrock and Quaternary Geology

Information on local bedrock geology for the Wawa area was obtained from the various published reports for the area, geological maps (Section 1.5.1), and the geophysical interpretation of the area conducted as part of this desktop preliminary assessment (PGW, 2013). Findings from the geophysical, terrain analysis and lineament studies carried out as part of the preliminary assessment of the Wawa area (Geofirma, 2013; JDMA, 2013; PGW, 2013) are integrated in this report to provide insight on the lithological variability, structures and extent of the overburden cover for each of the main geological units in the Wawa area, including the potentially suitable units identified in the initial screening report (Geofirma, 2011). The potentially suitable geological units in the Wawa area comprise the Western batholith, the Whitefish Lake batholith, the Brulé Bay batholith, and the Wawa Gneiss domain.

The majority of the Wawa area is covered by low-resolution aeromagnetic data (flight line spacing of 805 m), while small portions of the central and northern Wawa area are covered by four higher resolution (flight line spacing of 75 to 200 m) surveys (PGW, 2013).

3.2.1 Bedrock Geology

The regional and local bedrock geology of the Wawa area is shown on Figures 3.3 and 3.4, respectively, while a conceptual geological cross section through the Wawa area is given in Figure 3.5. The total magnetic field and the first vertical derivative of the residual magnetic field over the Wawa area are shown on Figures 3.6 and 3.7, respectively. The regional Bouguer gravity data is shown on Figure 3.8.

The geology of the Wawa area is dominated by large granitic to granodioritic intrusions and associated foliated to gneissic tonalitic units, including the Western, Whitefish Lake, and Brulé Bay batholiths, and the Wawa Gneiss domain, as well as a number of smaller felsic to mafic plutons and stocks. These Neoarchean intrusions were emplaced into the older Michipicoten, Gamitagama and Mishibishu greenstone belts. A description of the main batholiths, the Wawa Gneiss domain and the greenstone belts in the Wawa area is provided in the following subsections.

3.2.1.1 Western Batholith

The Western batholith is approximately 7-27 km wide by 50 km long and is located in the northwestern corner of the Wawa area (Figure 3.3). The lithological composition of the Western batholith is based largely on mapping by Mandziuk (1981) and Reid et al. (1992a,b,c), respectively, covering different sections of the batholith and adjacent greenstone belts. Mapping carried out by Reid et al. (1992a, b) extensively covered the western portion of the batholith, comprising the Franchere, Warpula, Legarde, and Levesque townships, as well as slivers of the Bostwick, Andre, Macaskill, and St. Germain townships (Figures 3.4 and 1.2). Mapping of the northwestern arm of the Michipicoten greenstone belt, in the Iron Lake area, carried out by Reilly (1991) complements Reid et al. (1992b) mapping in the northern half of the Legarde township (Figure 1.2). Mapping carried out by Mandziuk (1981) in the eastern portion of the Western batholith covered the Andre and Bailloquet townships. This mapping is complemented by mapping of Vaillancourt et al. (2005b) who covered a small portion of the batholith that extends into the southwestern corner of the Menzies township. Santaguida (2001) created a compilation map both of smaller scale and using various sources other than those mentioned above.

Reid et al. (1992a, b) mapped two main lithological types in the central-west half of the Western batholith. The first lithological type consists of massive to foliated, biotite and hornblende-biotite tonalite to granodiorite, which is gneissic in localized areas. The second rock type is massive to foliated, biotite and biotite-hornblende granodiorite to quartz-monzonite, and minor monzo-granite. A third, but less common rock type observed by Reid et al. (1992a, b) in the mapped area consists of foliated to gneissic, leucocratic, biotite and hornblende biotite quartz-diorite to tonalite, with minor gneissic hornblende quartz-diorite to diorite. In the northern part of the Lagarde township, the two main lithologies described by Reid et al. (1992a, b) somewhat differ from the foliated to gneissic, medium-grained, equigranular to plagioclase-phyric, granodiorite to quartz diorite, with local facies of granite, reported by Reilly (1991) for this area.

Mandziuk (1981) described two main lithological types in his mapped area, which he termed ‘diatexitic gneiss suite’ and ’massive granitic suite’. Their respective spatial distribution coincides relatively well with the two townships mapped. Mandziuk (1981) suggested that these two suites formed from two separate episodes of migmatization, posing a syn- to post-tectonic diapiric origin for the late granitic suite which hosts the early gneissic suite as enclaves in it. Transition between both suites is gradual and usually accompanied by gneissosity, establishing a broad compositional continuum between both suites. The older ‘diatexitic gneiss suite’, mostly present in the Andre township, is described as granodiorite and trondhjemite (albite-rich tonalite) gneiss and porphyroclastic biotite-hornblende leucogneiss. These rocks display relict migmatitic structures with no indication of dislocation, bretiation, rotation or complex folding. A foliated trondhjemite at the left side of the Trembley fault, which highly resembles Mandziuk’s gneissic suite, was dated by Turek et al. (1984) as approximately 2.698 billion years old. Mandziuk’s gneissic suite seem to extend to the Doré Lake area, where Massey (1985) mapped coarse-grained, equigranular, strongly foliated granodiorite with supracrustal xenoliths, suggesting an igneous origin for the foliation.

The younger ‘massive granitic suite’ was described by Mandziuk (1981) as massive to weakly foliated, often porphyritic, biotite-hornblende trondhjemite, biotite quartz-monzonite, granodiorite, and granite. Mandziuk (1981) granitic suite seems to extend to the north of Bailloquet township, where a massive to homogeneous body, granodiorite to granite in composition mapped by Vaillancourt et al. (2003; 2005b) in the adjacently northern Menzies township reasonably matches Mandziuk’s granitic suite. Vaillancourt et al. (2003; 2005b) also indicated the existence of a complex heterolitic breccia intrusion bounding the western side of the former body, which they interpreted to be a border facies of an intrusion located west and south of the Menzies township. The breccia is medium- to coarse-grained, with a dioritic matrix and includes accessory hornblende and biotite, mainly dioritic to tonalitic, and partly gneissic. A direct lithological correlation of this breccia with either of Mandziuk (1981) suites is unclear.

Three main suites were considered in Santaguida (2001) compilation map. The most southerly suite is massive to foliated granodiorite to tonalite suite, enveloped northward by a gneissic to foliated tonalite to granodiorite suite with minor supracrustal inclusions. The northernmost and easternmost suite is a massive to foliated granodiorite to granite suite. In general, the plutonic subdivisions shown on Santaguida (2001) are not well supported by the mapping of Reid et al. (1992a, b); conversely, Santaguida (2001) division agrees reasonably well with the lithologies and fabrics reported by Mandziuk (1981). An interpreted subdivision of plutonic components is given in the shapefile database as a set of sharp contact polygons. However, the reliability of this interpretation is limited and requires ground follow-up to more confidently define the main components of the batholith.

Gowest Amalgamated Resources Ltd. (2008) advanced seven drillholes up to depths between 292 and 453 m in a drill program carried out in the Molybdenite Lake area (Figure 3.4). Quartz biotite gneiss with lesser quartz monzonite and granodiorite, and scattered inclusion of mafic xenoliths was reported to be the dominant lithology found in all drillholes. Diabase dykes and migmatized mafic metavolcanic rocks were also encountered at depth. These rock types agree well with rock types observed in the surface.

Consistent 65 to 85 degrees northward and northeastward dips of the planar preferred alignment of minerals (foliation to gneissosity) occur across the breadth of the batholith (Reid et al., 1992a,b,c; Vaillancourt et al., 2005b), excepting for those areas affected by high migmatization. The foliation is also consistent with the bedding-parallel deformation fabric in the Mishibishu Lake greenstone belt and the Michipicoten greenstone belt. Strong to intense strain fabric dominates the northern rim of the Mishibishu greenstone belt against the Western batholith, with the Mishibishu Lake deformation zone (shear zone) tracing along the northern rim of the belt within 2 to 3 km from the batholith. Although Reilly (1991) observed consistent westward plunges of mineral and stretching lineations in the Iron Lake area within the Michipicoten greenstone belt, lineations appear to trend mostly down-dip toward the north where observed within the foliation planes of both the batholith and adjacent greenstone belts (Reid et al., 1992a,b; Vaillancourt et al., 2005b). The relationship between deformation in both greenstone belts and the batholithic complex is unclear but the consistent northward dip of foliation and down-dip direction of lineation across this batholith and adjacent greenstone belts suggests a regional scale deformation event that overprints these suites of rocks.

Reilly (1991) reported a transition of rafted inclusions, mafic intrusions and migmatitic textures along the granite-greenstone contacts in the north and northwestern margin of the Western batholith. In addition, there is evidence of an aureole of contact strain and metamorphism imposed by the batholith on the adjacent greenstone rocks up to 1 km wide (Reilly, 1991). The complexity of transition along the boundary suggests that the contact is marked not only by shearing, but sheet-like intrusions of granitic magma into the adjacent amphibolitic basalt with local rafted inclusions of amphibolite and felsic dykes injected from the adjacent phase of the batholith. Similar migmatitic transitions were observed by Reid et al. (1992c) along the contacts between the Western batholith and the Mishibishu greenstone belt. The transitional zones are up to 750 m wide and characterized by narrow sills and stringers of granitic neosome penetrating up to 5 km into greenstone rocks.

The geophysical interpretation of the Western batholith completed as part of the desktop preliminary assessment (PGW, 2013) allows for reinterpretation of the nature and position of the contacts of the batholith based on the higher resolution magnetic surveys completed in the bordering greenstone belts (Figures 3.6 and 3.7). The magnetic results within the Western batholith show a predominantly low background response with increased variability associated with localized high magnitude anomalies. This variability may correspond to the distribution of mapped bedrock lithologies in the batholith, although interpretation of their lithological contacts is difficult. Some mafic to intermediate metavolcanics and mafic-ultramafic rocks are mapped towards the south end of the Western batholith, and the magnetic variability within the batholith could also reflect the presence of these rocks on a larger extent. The granodiorite to granite units predominantly show a lower magnetic response within the batholith, and tend to increase gradually towards the contact zones adjacent to the greenstone belts and the gneissic tonalites. This geological contact against the gneissic tonalites appears as a broadly defined high magnetic zone, and may reflect an increased presence of magnetic mineral content associated with alteration along the contact. The southern portion of the Western batholith is largely underlain by the foliated tonalite suite that exhibits an indistinct gradient contact with the gneissic tonalite to the north. This unit is slightly more magnetic than the gneissic tonalite and tends to show more coherent magnetic foliation.

The geophysical interpretation shows a greatly reduced density of dykes in the Western batholith compared to the greenstones and intrusive rocks to the east (PGW, 2013). There is an abundance of faults evident from the aeromagnetic data across the Western batholith based on aeromagnetic discontinuities and linear aeromagnetic troughs. However, the lower resolution of the aeromagnetic data across the Western batholith greatly limits the geophysical survey as a satisfactory tool for identifying faults, especially in the granitoid regions.

No information on the thickness of the Western batholith is available, though as part of the regional granitoid terrane, they may be expected to exceed several kilometres in thickness (Szewcyk and West, 1976; Percival, 1990; Percival et al., 2012). There is a pronounced gravity low over most of the central part of the Western batholith (Figure 3.8) that correlates with the mapped and interpreted granodiorite-granite and tonalite suite complex. The sparse gravity data coverage also reflects the “pinch-out” of the gneissic tonalite suite towards the western edge of the map (PGW, 2013).

3.2.1.2 Wawa Gneiss Domain

The Wawa Gneiss domain was mapped and described by Moser (1994 and references therein) in a region just east of the Wawa area. It has been estimated to be 10 to 15 km thick (Jackson and Sutcliffe, 1990; Percival, 1990; Moser, 1994) as shown on the conceptual geological cross section (Figure 3.5). The gneiss domain is a multi-phase intrusive complex dominantly composed of tonalite to granodiorite gneiss and foliated tonalite (gneissic tonalite suite - unit 11 in Figure 3.4) but within the Wawa area it has not been mapped in sufficient detail to allow for a full understanding of its compositional characteristics. The tonalitic gneiss phase has been estimated to be approximately 2.71 billion years old (Jackson and Sutcliffe, 1990; Moser, 1994), with an older 2.743 billion years old phase of diorite to tonalite recognized along the western margin of the domain within the Wawa area (Sage, 1994b).

A portion of the Wawa Gneiss domain bounding the northern portion of the Gamitagama greenstone belt is of trondhjemitic composition, massive to foliated, and its contaminated margin is in sharp vertical contact against the greenstone rocks (Krogh and Turek, 1982). A migmatitic domain is found for at least three kilometres adjacent to the eastern boundary of the Michipicoten greenstone belt and Hawk Lake toward the southeast of the Firesand River carbonatite (Sage, 1979; see also mylonites in Sage, 1982d, Map 2442). In this portion of the gneiss domain four phases have been observed. The oldest recognizable phase is medium- to coarse-grained quartz diorite and trondhjemite to tonalite, which has well developed schistosity and contains many xenoliths and blocks of metavolcanic and metaigneous rocks. Evidence of similar comparable ages, within adjacent granitoid terrains, to volcanic assemblages reflects the widespread presence of synvolcanic magmatic chambers preserved within external batholiths of relatively older metamorphosed tonalite to quartz diorite. The oldest phase is intruded by quartz diorite or tonalite of similar fabric, and both phases are intruded by dykes of schistose trondhjemite. The youngest phase consists of massive and equigranular small bodies of aplite, pegmatite and granodiorite. In the area adjacent to the Marsden-Agawa Canyon fault, toward which the southeast-most lobe of the Michipicoten greenstone belt extends, Massey (1985) described the Wawa Gneiss domain as usually composed of equigranular, medium- to coarse-grained tonalite and granodiorite, but diorite, quartz diorite and granite could also be found. Foliation is moderately to strongly developed. Epidote is commonly found in all lithologies in the Anjigami Lake area.

East of the Wawa area and the Budd Lake fault (~Hwy 651), the gneisses are northwest-trending and curvi-planar (Bursnall et al., 1994). West of the Budd Lake fault, the foliation trend in the gneisses is west to southwest (Moser, 1994).

Reconnaissance mapping by Card (1979; 1982) shows the presence of large, younger, and more massive to foliated granodiorite batholithic bodies, like the Whitefish Lake batholith, which intrude the tonalite gneiss in the Wawa Gneiss domain. These late tectonic intrusions resemble the very large late tectonic granitic batholiths in the Ignace area and across the Berens River region to northwest of Pickle Lake in northwestern Ontario. They are most likely tabular or pancake-shaped owing to their large horizontal width relative to known depths of the Earth's crust. There has been very little mapping done on the Wawa Gneiss domain and related Whitefish Lake and Brulé Bay batholiths. Williams et al. (1991) noted that reconnaissance mapping by Card (1979; 1982) attempted to subdivide the granitoid complexes into older tonalitic bodies and younger granodiorite to granite intrusions. The Whitefish batholith and Brulé Bay batholith, as outlined by Johns and McIlraith (2002), are derived from the east-central sheet, Bedrock Geology of Ontario Map 2543 (OGS, 1991). The Bedrock Geology of Ontario Map 2543 bases the batholiths on Card's (1979, 1982) account who conducted regional reconnaissance roadside outcrop visits. Hence, the general subdivisions of the granitoid regions in the Wawa Gneiss domain and enclosed batholiths are largely based on reconnaissance mapping.

The geophysical interpretation completed as part of this desktop preliminary assessment (PGW, 2013) shows that magnetic responses over the Wawa Gneiss domain (i.e. gneissic tonalite suite) are quite subdued, with a slightly lower background response compared to the neighbouring Brulé Bay and Whitefish Lake batholiths (Figures 3.6 and 3.7). The geophysical interpretation subdivides the Wawa Gneiss domain by identifying contacts between the gneissic tonalite suite and the granodiorite-granite. The northern border between the Wawa Gneiss domain and the Michipicoten greenstone belt, exhibit a sharp magnetic gradient reflecting the geological contact. Within the gneissic tonalite suite, the magnitude of the north-northwest to northwest-trending dyke magnetic response appears to be more subdued compared to throughout the granodiorite-granite, possibly indicating a slightly higher magnetic response for the gneissic tonalite suite making the magnetic contrast with the dykes less apparent. The dykes also appear to transect the central migmatite unit that crosses the Wawa Gneiss domain, which possesses a somewhat weaker regional background response compared to the surrounding intrusive units.

The north-northwest-trending dykes stand out in the geophysical interpretation and the density of dykes west of the Agawa Canyon fault is greatly reduced compared to the remainder of the domain. Some east-northeast-striking foliation is also evident, mainly in the central and eastern portions of the domain (Figure 3.7). The Wawa Gneiss domain correlates with regional gravity lows (Figure 3.8) which cannot be distinguished from those over the Whitefish Lake and Brulé Bay batholiths. The granite-granodiorite located south of the northern migmatite unit in the area south of Hwy 101 and surrounding Shakashi Lake correlates with a somewhat higher gravity response, indicating a relatively thin intrusion.

The combined results of the review of available geoscientific information and the geophysical interpretation (PGW, 2013) completed in the current assessment indicate that the Wawa Gneiss domain is dominantly composed of tonalite to granodiorite gneiss and foliated tonalite but within the Wawa area it has not been adequately characterized or mapped to provide full insight of its compositional characteristics.

3.2.1.3 Whitefish Lake and Brulé Bay Batholiths

The Whitefish Lake batholith is a massive granodiorite to granite intrusion within the Wawa Gneiss domain, making up much of the central portion of the Wawa area (Williams et al., 1991), as shown in Figure 3.4. South of the extension of the Michipicoten greenstone belt which bisects the batholith, the batholith has previously been referred to as the Brulé Bay batholith (McCrank et al., 1981). The Whitefish Lake-Brulé Bay batholiths cover an approximate elongated area with northeast and southwest axes of approximately 62 km by 15 km, respectively. No specific information was found on the thickness of these two granitic bodies, though as part of the regional granitoid terrane, they may be expected to exceed several kilometres in thickness (Percival, 1990). The massive granodiorite to granite intrusion has been dated at approximately 2.694 billion years old (Turek et al., 1984). Massey (1985) mapped the southwestern portion of the Whitefish Lake-Brulé Bay batholiths in reference to their margins, distant up to about some 2.5 kilometres from the contact with the Michipicoten greenstone belt. Notwithstanding that his description may not apply toward the core of the batholiths, Massey (1985) described granodiorite and tonalite as the dominant lithologies, with less appearance of microgranodiorite, granite, diorite, quartz monzonite, quartz monzodiorite, and aplite and pegmatite. At the margin zone with the greenstone rocks, which can exceed 1.5 kilometres, granodiorite becomes volumetrically more important displaying metavolcanic enclaves of varied sizes. Diorite to granodiorite displays a weak to moderate foliation and in some parts, a gneissic fabric, while texture is generally equigranular with minor porphyritic facies. Leaving from the marginal zones toward the core of the batholiths, more massive granodiorite and granite are found. Massey (1985) posed a magmatic origin for the foliation in the granodiorite, acknowledging that a tectonic component may have enhanced its development.

The results of the review of available geoscientific information completed in the current assessment show that there is some indication from previous mapping showing migmatitic layering and inclusions of amphibolite within the tonalitic gneisses of the outer margins of the Whitefish Lake and Brulé Bay batholiths. There is also some broad indication of an area of higher magnetic susceptibility centred on previously mapped, evidently late-tectonic Whitefish Lake batholith comprising granodiorite. To a lesser extent this is evident also in the vicinity of the Brulé Bay batholith. The interpreted subdivision of internal phases of these batholiths is given in the available mapping as a set of sharp contacts. However, the reliability of this interpretation is limited and requires ground follow-up to more confidently define the main components of the batholiths.

The geophysical interpretation of the Whitefish Lake and Brulé Bay batholiths completed in the current assessment (PGW, 2013) shows a lower resolution of aeromagnetic imagery within these batholiths relative to the greenstone belts (Figure 3.6 and 3.7). This lower resolution data greatly limit the value of the aeromagnetic images for identification of distribution of lithology and batholith contacts. Evidence of the geological contacts of the intrusive units is almost nonexistent in the magnetic data, with the exception of the contact with the Michipicoten greenstone belt, which is typically well-defined and correlates well with the bedrock geology map.

The contacts between the granite-granodiorite of the Whitefish Lake-Brulé Bay batholiths and the gneissic tonalite suite of the Wawa Gneiss domain are marked by subtle disruptions of the dyke magnetic signatures. The density of dykes observed within the Brulé Bay batholith is greatly reduced compared to the remainder of the intrusive units. Similar dyke density is observed within the central migmatite unit that crosses the Whitefish Lake batholith, which possesses a somewhat weaker magnetic background response compared to the surrounding intrusive units.

Dykes observed on the lower resolution magnetic data across the Whitefish Lake batholith, and to a lesser degree the Brulé Bay batholith, appear as broad linear anomalies (roughly 1 km wide) that extend over larger distances (tens of kilometres). Where these anomalies are traced into the higher resolution magnetic data they can typically be reinterpreted as multiple dykes, with greatly reduced anomaly widths. It is apparent that these dykes occur in much greater numbers in the eastern part of the Wawa area, where in the higher resolution magnetic data spacing between adjacent dykes, is on the order of a few hundred metres. Faults are less reliably apparent across these batholiths, owing to the intense overprinting of the aeromagnetic data by the patchwork of Matachewan dykes and northeast-trending Kapuskasing dykes.

Although the gravity data are sparsely distributed throughout the Wawa area, they exhibit a regional-scale gravity low that corresponds to the location of the Whitefish Lake batholith, and to a lesser extent the Brulé Bay batholith. For the most part the gravity lows coincide with the granodiorite to granite units mapped east of the Agawa Canyon fault. Along the southern boundary of the Whitefish Lake batholith the gravity response shows a gradual increase associated with the location of the migmatite and granodiorite-granite intrusion near Kinniwabi and Shakashi Lakes. This slightly higher gravity response may reflect thinning of the batholith or an increase in rock density likely associated with the adjacent migmatite unit. The gravity low response generally extends, becoming more prominent, further south into portions of the gneissic tonalite suite.

Within the Whitefish Lake batholith, the radioelement response is dominated by potassium associated with the granodiorite-granite unit. Along the western boundary of the batholith the radioelement response becomes slightly elevated in uranium, which may correspond to the boundary between the batholith and the nearby Michipicoten greenstone belt.

3.2.1.4 Greenstone Belts

The greenstone belts in the Wawa area were not considered as potentially suitable for hosting a deep geological repository in the initial screening due to their composition, structural complexity and resource potential (Geofirma, 2011). However, they are described here for completeness and context.

There are three greenstone belts within the Wawa area: the Michipicoten, Gamitagama and Mishibishu greenstone belts (Figure 3.4). These greenstone belts are supracrustal assemblages formed by mafic to felsic volcanic cycles between approximately 2.9 and approximately 2.7 billion years ago. The regional geology, structural setting and economics of the Michipicoten, Mishibishu and Gamitagama greenstone belts are well summarized by Williams et al. (1991). The Michipicoten greenstone belt is a structurally and stratigraphically complex of volcanic, sedimentary and intrusive rocks, metamorphosed to greenschist facies and localized amphibolite facies (Williams et al., 1991; Sage, 1994b).

Significant developments subsequent to the summary of Williams et al. (1991) are additional age determinations (e.g., Turek et al., 1992; Vaillancourt et al., 2005a); geological mapping by Vaillancourt et al. (2005b) in the Menzies Township area; papers summarizing research on the Kapuskasing structural zone (e.g., Halls et al., 1994; Moser, 1994; and Percival and West, 1994); and papers describing a comparatively unique Archean suite of diamondiferous lamprophyres and related diatreme breccias in the Menzies and Musquash townships (e.g., Wyman et al., 2006 and references therein), which provide interpretive constraints on the orogenic evolution of the Wawa region modelled in a shallowly dipping plate subduction setting. The Michipicoten greenstone belt is the largest of the greenstone belts in the Wawa area and is further described below.

The Michipicoten greenstone belt has been subdivided into three cycles (tectonic assemblages) of bimodal mafic to felsic volcanism that erupted episodically at approximately 2.888 billion years ago (Hawk assemblage), approximately 2.750 to 2.736 billion years ago (Wawa assemblage), and approximately 2.7 billion years ago (Catfish assemblage) (Turek et al., 1982; 1984; Ayer et al., 2003; Vaillancourt et al., 2004). Preservation of the oldest cycle is limited to a small area in the vicinity of Hawk Lake on the eastern margin of the Wawa belt along with a subvolcanic intrusion. The other two cycles are interleaved and folded across the width of the belt. An imprecisely-dated episode of diamondiferous lamprophyric dykes and related multiple diatreme breccia emplacements occurred at approximately 2.674 billion years ago (Stott et al., 2002; Ayer et al., 2003). Clastic sedimentation followed as evidenced from the presence of diamonds and other gems deposited in polymictic conglomerate (Kopylova et al., 2011). The main period of regional shortening deformation and batholithic uplift overlapped sedimentation and continued to affect the late diatreme breccias. The late tectonic Dickenson Lake stock (Figure 3.4) intruded the Michipicoten greenstone belt in Knicely township north of the Wawa area near Highway 17 and is approximately coeval at approximately 2.677 billion years (Turek et al., 1990) with the diamondiferous breccias and lamprophyre dykes (Stott et al., 2002).

The general structural framework of the Michipicoten greenstone belt as a fold and thrust belt was summarized by Arias and Helmstaedt (1990). Foliation and bedding in the Michipicoten Belt are typically closely parallel and dip shallowly to moderately to the northeast and more steeply north to northeastward in the north half of the belt. Mineral lineations are generally down-dip (Vaillancourt et al., 2005b) to moderately west- to northwest-plunging (e.g., Heather and Arias, 1992). This final structural framework is a product of refolded nappe-like regional folding of the volcanic-sedimentary stratigraphy, which has been subsequently back-thrusted (dipping northeastwards) producing a complex interleaved package of tectonic assemblages.

3.2.1.5 Mafic Dykes

There are two main sets of diabase dykes that intrude all rock types in the Wawa area (Figure 3.4), as well as a volumetrically minor and younger third set. The first set consists of the dominant northwest-trending and subvertically dipping dykes of the Matachewan Swarm (Bates and Halls, 1991; West and Ernst, 1991; Phinney and Halls, 2001). The Matachewan dykes were emplaced between approximately 2.473 and 2.446 billion years ago in the area between Lake Superior and James Bay, with subvertical dip and north-northwest to northwest strike, reaching up to 40 m in width (Phinney and

Halls, 2001). The second set consists of subvertical northeast-trending diabase dykes of the Abitibi and Biscotasing swarms. Emplacement of these dykes has been related to the Kapuskasing structural zone uplift (Halls and Davis, 2004; Ernst and Halls, 1983; 1984), while some of them are also considered to be related to the approximately 2.126 to 2.101 billion year old Marathon swarm (Halls et al., 2008). Both northwest- and northeast-trending sets of dykes are compositionally indistinguishable.

Sage (1994b) and Vaillancourt et al. (2003) also reported a younger set of dykes in the Wawa area identical to the older ones, which occupy the same system of fractures, with northwest and northeast trends, and of presumed Proterozoic age. At least some of the northeast-trending dykes are of Keweenawan age, approximately 1.142 billion year old (Massey, 1985; Vaillancourt et al., 2003), coincident with the Mid-continent Rift and opening of a small, linear ocean basin that underlies Lake Superior.

3.2.2 Quaternary Geology

Overburden deposits within the Wawa area were originally mapped as part of the Northern Ontario Engineering Terrain Study (NOEGTS), a program undertaken between 1977 and 1980. These studies divided the landscape into a set of distinct terrain units within which the engineering characteristics are broadly predictable. In many areas of northern Ontario, including the Wawa area, maps produced from these programs currently represent the best level of detail available for surficial geology mapping and descriptions of terrain conditions (JDMA, 2013). Major landforms mapped by the NOEGTS program are shown on Figure 2.3 after Gartner and McQuay (1979a, b) and McQuay (1980).

Subsequent to the NOEGTS mapping, the Ontario Geological Survey completed surficial geological mapping at more detailed 1:50,000 scale over the northeast part of the Wawa area (Morris, 2001a, b).

Most of the Wawa area has exposed bedrock or bedrock-drift complex, and Quaternary deposits are limited and predominantly located in bedrock controlled valleys. Bedrock terrain (Figure 2.3) including exposed bedrock and discontinuous drift deposits generally less than one metre thick, cover about 75% of Wawa land area. The Quaternary cover in the Wawa area mostly comprises different types of glacial deposits that accumulated with the progressive retreat of the ice sheet during the end of the Wisconsinan glaciations (Figure 2.3; JDMA, 2013). This period of glaciation began approximately 115,000 years ago and peaked about 21,000 years before present, at which time the glacial ice front extended south of Ontario into what is now Ohio and Indiana (Barnett et al., 1991).

All Quaternary deposits within the Wawa area were deposited during the Late Wisconsin by the Labrador sector of the Laurentide Ice Sheet. Bedrock striae indicate that there were two prominent ice flow directions (JDMA, 2013). The oldest and most pervasive ice flow was south to southwest (159° - 240°). A later, weaker ice flow was to the southwest and west (220° - 290°). The younger set of striae was formed during the latter stages of glaciation as the ice sheet began to thin and bedrock topography began to influence the direction of ice flow.

During ice retreat, ice-contact stratified drift was deposited as recessional moraine, eskers and dead ice topography, leaving a thin (less than 1 m thick) till veneer that drapes the bedrock surface. This till veneer, when present, is the uppermost deposit across most of the Wawa area. Glaciofluvial outwash was deposited primarily within bedrock-controlled valleys directly from the ice margin or from wasting ice detached from the ice sheet. Also during retreat, the ice sheet was fronted by glacial meltwaters associated with the Lake Superior basin or by glacial meltwater impounded by the ice sheet and topographically higher ground. Glaciolacustrine materials were deposited in these waters, filling the deeper bedrock valleys.

Information on the thickness of Quaternary deposits within the Wawa area is largely derived from terrain evaluation (JDMA, 2013). Measured thicknesses are limited to a small number of water well records (MOE, 2012) for rural residential properties and to diamond drill holes (OGS, 2005) concentrated in the greenstone belts (Figure 2.3). A detailed accounting of recorded depths to bedrock in the Wawa area is provided by JDMA (2013), and depths generally range from 0 to 15 m, although greater thicknesses have been recorded in a few locations. Overburden thicknesses of up to 130 m exist in bedrock valleys. Materials encountered during drilling include thick sequences of clay, sand, and gravel.

The results of the terrain analysis study (JDMA, 2013) show that all of the potentially suitable geologic units in the Wawa area have limited overburden cover. The percentages of surficial area in each potentially suitable geological unit mapped as bedrock and bedrock drift complex are 85% for the Western batholith, 76% for the Whitefish Lake batholith, 66% for the Brulé Bay batholith and 72% for the Wawa Gneiss domain.

3.2.3 <u>Lineament Investigation</u>

A lineament investigation was conducted for the Wawa area using multiple datasets that included satellite imagery (Landsat/SPOT), digital elevation model data (CDED) and geophysical (aeromagnetic) survey data (Geofirma, 2013). The lineament investigation identified three categories of interpreted features (ductile lineaments, brittle lineaments and dyke lineaments) in the Wawa area, and evaluated their relative timing relationships within the context of the local and regional geological setting. A detailed analysis of interpreted lineaments is provided by Geofirma (2013) and key aspects of the lineament investigation are summarized in this section.

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

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

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

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

The desktop interpretation of remotely-sensed datasets necessarily includes a component of uncertainty as a result of data quality, scale of Wawa area, expert judgement, and to a certain extent, the quality of the pre-existing knowledge of the bedrock geology of the Wawa 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 selected by the NWMO and remain interested in continuing with the site selection process.

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

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

The Landsat/SPOT and CDED datasets (Figures 2.1 and 2.2, respectively) were used to identify surficial lineaments expressed in the topography, drainage and vegetation. The Landsat/SPOT dataset has a uniform resolution of 10 m (panchromatic) and 20 m (multispectral) over the entire Wawa area (JDMA, 2013, Geofirma, 2013). The CDED dataset is at a 1:50,000 scale, with a uniform 20 m resolution over the entire Wawa area (JDMA, 2013). The resolution of the Landsat/SPOT and CDED datasets allowed for the identification of surficial lineaments as short as a few hundred metres in length and provided sufficient detail to reveal surficial structural patterns (Geofirma, 2013). Aeromagnetic datasets (Figures 3.6 and 3.7) were used to identify linear geophysical anomalies indicative of bedrock structures. Regional low resolution data (at 805 m line spacing) is available for the entire Wawa area (Figure 1.2). High resolution data (at 75 and 200 m line spacing) is available for the greenstone belts of the Wawa area and the periphery of batholiths and the Wawa Gneiss domain. The high resolution geophysical coverage allowed for the identification of geophysical lineaments on the order of 500 m or longer in length, while the regional geophysical coverage limited the resolution of geophysical lineaments to features on the order of 2 km or longer in length.

Figure 3.9 shows the combined surficial lineaments (Landsat/SPOT and CDED) using the results from RA_1, without any filtering of overlapping features. The Landsat/SPOT dataset yielded a total of 1,114 surficial lineaments, ranging from 260 m to 97.4 km in length, with an arithmetic mean length of 5.4 km, while the CDED dataset yielded a total of 927 lineaments, ranging from 590 m to 111 km long, with an arithmetic mean length of 6.5 km. The results shown in Figure 3.9 depict the results binned into four length categories (< 1 km, 1 – 5 km, 5 – 10 km, > 10 km). Based on the thin and limited overburden cover, mapped satellite and CDED lineaments are considered a fair representation of surficial bedrock lineaments in the Wawa area. Both the Landsat/SPOT and CDED datasets offered advantages to characterize the surficial lineaments. The higher resolution of the Landsat/SPOT imagery allowed for finer structures to be identified that were not resolved by the CDED data; but, the CDED data often revealed subtle trends masked by the surficial cover captured in the Landsat/SPOT imagery. Both satellite and CDED datasets identified the same length-weighted lineament trends of northeast, north-northwest and east.

The aeromagnetic dataset yielded a total of 789 lineaments (Figure 3.10), 441 interpreted as fractures (brittle faults) and 348 interpreted as dykes. The results shown in Figure 3.10 depict the results from the RA_1 analysis for both geophysical fractures and dykes, binned into four length categories (< 1 km, 1 – 5 km, 5 – 10 km, > 10 km). The length of the geophysical fracture lineaments ranged from 950 m to 65.6 km, with an arithmetic mean length of 12.7 km. The length of the geophysical dyke lineaments ranged from 200 m to 38.6 km, with an arithmetic mean length of 4.8 km. The density and distribution of geophysical lineaments is influenced by the resolution of the aeromagnetic coverage, which is greater in the greenstone belts than in the intrusive rocks. The length-weighted lineament trends for the geophysical lineaments interpreted as fractures exhibit trends to north-northwest, northeast, east and north.

The 348 lineaments identified as dykes (Figure 3.10), which includes smaller segments of the same dyke, belong primarily to the northwest to north-northwest trending suite of Matachewan dykes. A second minor set of dykes oriented northeast is interpreted to be related to the Abitibi and Biscotasing swarms. There is an apparent spatial variation in the distribution of these dykes with an increased occurrence of the north-northwest trending Matachewan dykes in the eastern half of the Wawa area (i.e., within the Wawa Gneiss domain and Whitefish Lake batholith). The Brulé Bay batholith and the Western batholith appear to a have lower occurrence of dykes than the eastern half of the Wawa area. The resolution of the aeromagnetic datasets is the same for both of these areas, suggesting the difference may be related to actual differences in geological structures.

Aeromagnetic features interpreted as ductile lineaments have been mapped separately and are shown on Figure 3.11. Such features are useful in identifying the stratigraphy and structure within the greenstone belts and to a lesser extent in the gneissic and foliated intrusive rocks of the Wawa area. The degree of deformation within the greenstone belts and the “wrapping” of the greenstone stratigraphy around the younger intrusive units is apparent in Figure 3.11. Figure 3.11 also shows an increased occurrence of ductile lineaments in the foliated and gneissic tonalite suites of Western batholith relative to the Whitefish Lake-Brulé Bay batholiths and Wawa Gneiss domain. It should be noted that the density of these ductile lineaments is also influenced by the resolution of the geophysical coverage.

The geophysical lineament data has advantages over surficial lineament data in that it is minimally affected by overburden cover, which may partially or completely mask surficial lineaments. Importantly, aeromagnetic data allows interpretation of lineaments from the surface to potentially great depths. However, the low reproducibility results (RA_1) for both geophysical fractures (6%) and dykes (32%) between geophysical interpreters indicates the indistinct nature of some of features in the available datasets, and the higher level of expert judgement necessary to select geophysical lineaments with low-resolution aeromagnetic data compared to surficial datasets.

Figure 3.12 shows the distribution of merged surficial and geophysical lineaments interpreted for the Wawa area (RA_2 compilation), classified by length and presented in four length categories (< 1 km, 1 – 5 km, 5 – 10 km, > 10 km) for each of the brittle and dyke lineament categories. The merged lineament dataset yielded a total of 2,079 lineaments, ranging from 200 m to 111 km in length, with an arithmetic mean length of 7.1 km. There were three dominant lineament trends observed in the merged lineament dataset based on length-weighted frequency, they are northeast, north-northwest and east. The north-northwest trending lineament set includes fractures and Matachewan dykes. The northeast and east lineament sets are comprised mainly of fractures. Lineament orientation trends for the potentially suitable geologic units in the Wawa area (i.e., Western batholith, Whitefish Lake batholith, Brulé Bay batholith and Wawa Gneiss domain) are presented on Figure 3.13 and further discussed in the geologic unit specific sub-sections below.

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

- Longer lineaments generally have a higher certainty and reproducibility.
- There is a much greater coincidence between surficial lineaments (29% of the total merged fracture lineaments are interpreted from both CDED and SPOT) than between geophysical lineaments and surficial lineaments (6% of the total merged fracture lineaments are observed in geophysical data and at least one of the surficial data sets), presumably due to the fact that surficial lineaments interpreted from CDED and Landsat/SPOT are expressions of the same bedrock feature.
- The low coincidence between surficial and geophysical lineaments is presumably due to a variety of factors. For example, the structures identified in the aeromagnetic data may not have a surface expression; surficial features may not extend to great depth; structural features may not possess a magnetic susceptibility contrast with the host rock; surface expressions of lineaments may be masked by the presence of infilling or overburden; and the geometry of the feature (e.g., dipping versus vertical). These factors are further constrained by the resolution of the differing datasets. At 805 m flight line spacing, small features or features in the aeromagnetic dataset oriented at a low angle to the flight lines may not be recognizable.
- Given the lack of both overburden cover and high resolution aeromagnetic data over all of intrusive geologic units of potential suitability (i.e., Western batholith, Whitefish Lake and Brulé Bay batholiths, and the Wawa Gneiss domain), the mapped lineaments provide a common basis for the identification of differences in lineament density between potentially suitable geologic units.

Figures 3.14 to 3.17 were produced in order to provide some insight into the influence of lineament length on the distribution of lineament density across the Wawa area. This set of figures shows the progressive filtering (removing) of lineaments corresponding to the same length bins used above (< 1km, 1 – 5 km, 5 – 10 km, > 10 km), and with the remaining lineaments plotted on top of the density gradient. In other words, Figure 3.14 includes all lineaments shown in Figure 3.12 and with a background showing the same information as a density gradient map (in km/km^2). Figure 3.15 filters out the < 1 km long lineaments and so the underlying density gradient map represents only those lineaments 1 km in length or greater. The same is done, in a step-wise manner, for Figures 3.16 (filtering all lineaments < 5 km) and for Figure 3.17 (filtering all lineaments < 10 km). The density plots with lineament lengths filtered are presented to allow one to more clearly see the longer lineaments. In general, these figures show that filtering out the shorter lineaments greatly increases the spacing (reduces density) between lineaments, including those areas having exposed bedrock and higher resolution aeromagnetic surveys, which includes all of the potentially suitable geologic units in the Wawa area. For example, comparison of Figures 3.14 and 3.17 shows that the western, north-central and south-central parts of the Western batholith, the northern part of the Whitefish Lake batholith, the east-central part and southeastern corner of the Wawa Gneiss domain, and the area of the Wawa Gneiss domain west of the Agawa Canyon fault all contain relatively few lineaments that are longer than 10 km, leaving larger volumes of rock between interpreted long lineaments.

Figure 3.18 shows the combined datasets (i.e., mapped OGS regional faults, brittle lineaments, dykes and ductile features) which helps provide a structural understanding of the Wawa area. Because of the large number of brittle fractures and dykes, it is difficult to see the coincidence of interpreted lineaments and OGS mapped faults in the Wawa area, as illustrated on Figure 3.4. As discussed in the lineament interpretation report (Geofirma, 2013), the main known, named faults and their approximate orientation in the Wawa area include the following:

- Manotowik Lake fault, Hawk Lake fault, Wawa Lake fault, Magpie River fault, Firesand River fault, Mishewawa Lake fault and Old Woman River fault – northeast-trending;
- Trembley fault, Black Trout Lake fault, Mildred Lake fault, Marsden fault and Treeby Lake fault – north-northwest-trending; and
- Agawa Canyon fault – north-trending.

All of the known, named faults listed above are associated with specific mapped lineaments and, with the exception of the late Agawa Canyon and McEwan Lake faults, the trend of these faults correspond with the major lineament trends (northeast and north-northwest) described above. The north-trending Agawa Canyon and McEwan Lake faults are late, large-scale structures that do not have extensive parallel features in the Wawa area. The east-trending set of lineaments evident from satellite and geophysical datasets do not correspond with known, named faulting in the Wawa area. Based on prevalence of east-trending ductile lineaments (Figures 3.11 and 3.18), the east-trending lineament set may be reflective of ductile deformation as well as brittle deformation events.

Review of Figures 3.9, 3.10, 3.12 and 3.14 to 3.17 shows that overall lineament density as defined by the presence of final merged interpreted fractures and dykes is generally relatively high in all of the potentially suitable intrusive units. These figures show that dyke lineament densities are highest in the Whitefish Lake batholith and Wawa Gneiss domain, and lowest in the Brulé Bay and Western batholiths. This spatial pattern of higher dyke lineament density in the eastern parts of the Wawa area is related to proximity to Kapuskasing structural zone located 30 to 40 km east of the Wawa area. These lineament densities are interpreted to be independent of overburden cover and aeromagnetic data resolution, as similar mapped bedrock exposure and aeromagnetic data resolution is available for all potentially suitable geological units in the Wawa area.

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

Another aspect of uncertainty associated with the high density of diabase dykes observed/interpreted in the Wawa 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 Wawa area (e.g., Figure 10 of the Lineament Interpretation report; Geofirma, 2013), suggests that underlying structure in the host rock may be under identified in these areas of increased dyke density.

The following subsections describe the characteristics of the interpreted lineaments for each of the main intrusive bodies in the area, as well as an interpretation of the relative age of the lineaments identified in the Wawa area.

3.2.3.1 Western Batholith

A total of 442 lineaments consisting of 396 fractures and 46 dykes were mapped over the 631 km^2 area of the Western batholith in the Wawa area (Figures 3.12 and 3.13). Many of the long interpreted lineaments extend beyond the batholith into the adjoining metavolcanic rocks of the Michipicoten and Mishibishu Lake greenstone belts. Comparison of Figure 3.9 (surficial lineaments) and Figure 3.10 (geophysical lineaments) shows that density of surficial lineaments in the Western batholith is greater than the density of geophysical lineaments due to a greater number of identified surficial lineaments, and that there are fewer shorter length geophysical lineaments. This may be due to the relatively high resolution SPOT/CDED datasets available, which allow for the identification of a higher number of surficial lineaments compared to geophysical lineaments, whose interpretation is limited by the low resolution aeromagnetic data available. Both the interpreted surficial lineaments (Figure 3.9) and geophysical lineaments (Figure 3.10) show similar trends with dominant northeast, east-west and north-northwest orientations observed for the Western batholith (Figure 3.13).

Mapped fracture lineaments in the Western batholith coincided with all OGS mapped faults, including the Trembley fault and Black Trout Lake fault, as shown on Figure 3.4. North-northwest- and northeast-trending dykes are also present throughout the Western batholith (Figure 3.10).

Based on Figure 3.14, the north-central and south-central parts of the Western batholith have lower apparent total lineament densities than the rest of the batholith.

3.2.3.2 Whitefish Lake Batholith

A total of 369 lineaments consisting of 315 fractures and 54 dykes were mapped over the 548 km^2 area of the Whitefish Lake batholith in the Wawa area (Figures 3.12 and 3.13). Many of the long interpreted lineaments extend beyond the batholith into the adjoining metavolcanic rocks of the Michipicoten greenstone belt, the Wawa Gneiss domain and the Brulé Bay batholith. Comparison of Figure 3.9 (surficial lineaments) and Figure 3.10 (geophysical lineaments) shows that density of surficial lineaments in the Whitefish Lake batholith is greater than the density of geophysical lineaments due to a greater number of identified surficial lineaments, and that there are fewer shorter length geophysical lineaments. Both the interpreted surficial lineaments (Figure 3.9) and interpreted geophysical fracture lineaments (Figure 3.10) show similar trends with dominant northeast to east-northeast, north-northwest, east and minor north orientations observed (Figure 3.13). Interpreted geophysical dyke lineaments show a dominant north-northwest trend with a subordinate set trending northeast.

Interpreted fracture lineaments in the Whitefish Lake batholith coincided with all OGS mapped faults, including the Agawa Canyon fault, as shown on Figure 3.4. Dominant north-northwest trending dykes and a subordinate set of northeast-trending dykes are also present throughout the Whitefish Lake batholith (Figure 3.10). The density of dykes in the greenstone belt to the northeast of the Whitefish Lake batholith is much higher than in the Whitefish Lake batholith due to the high resolution aeromagnetic surveys available over the greenstone belt. As the dykes are pervasive in all geologic units in the Wawa area, a higher density of dykes is expected for the Whitefish Lake batholith than indicated on Figure 3.10, if higher resolution aeromagnetic data were available.

Given that both the relative extent of bedrock exposure and the resolution of the available aeromagnetic data is similar across the batholiths, based on Figure 3.14, the northern part of the Whitefish Lake batholith near Outline Bay, and the central portion of the batholith near Whitefish Lake have lower apparent total lineament densities.

3.2.3.3 Brulé Bay Batholith

A total of 200 lineaments consisting of 188 fractures and 12 dykes were interpreted over the 254 km^2 area of the Brulé Bay batholith in the Wawa area (Figure 3.12). Most of the long interpreted lineaments extend beyond this small batholith into the adjoining metavolcanic rocks of the Michipicoten and Gamitagama greenstone belts, the Wawa Gneiss domain and the Whitefish Lake batholith. Comparison of Figure 3.9 (surficial lineaments) and Figure 3.10 (geophysical lineaments) shows that density of surficial lineaments in the Brulé Bay batholith is greater than the density of geophysical lineaments due to a greater number of identified surficial lineaments, and that there are fewer shorter length geophysical lineaments. Both the interpreted surficial lineaments (Figure 3.9) and geophysical fracture lineaments (Figure 3.10) show similar trends with dominant northwest, east, northeast and north orientations observed (Figure 3.13). A minor set of widely-spaced north-northwest- and northeast-trending dykes were also interpreted in Brulé Bay batholith (Figure 3.10).

Interpreted fracture lineaments in the Brulé Bay batholith coincided with all OGS mapped faults, including the Old Woman River fault, the Trembley fault, the Treeby Lake fault and the Mishewawa Lake fault, as shown on Figure 3.4. A minor set of widely-spaced north-northwest- and northeast-trending dykes are also present in Brulé Bay batholith (Figure 3.10). There is moderate coincidence of the interpreted dyke lineaments and OGS mapped dykes in the Brulé Bay batholith.

The densities of fractures and dykes of the Brulé Bay batholith are the highest and lowest, respectively, of the potentially suitable geologic units in the Wawa area. Based on Figure 3.14 the Brulé Bay batholith has fairly uniformly high apparent total lineament densities.

3.2.3.4 Wawa Gneiss Domain

A total of 761 lineaments consisting of 639 fractures and 122 dykes were interpreted over the 1,205 km^2 area of the Wawa Gneiss domain in the Wawa area (Figure 3.12). Many of the long interpreted lineaments extend into the adjoining metavolcanic rocks of the Michipicoten and Gamitagama greenstone belts, into the Whitefish Lake-Brulé Bay batholiths, and beyond the Wawa area. Comparison of Figure 3.9 (surficial lineaments) and Figure 3.10 (geophysical lineaments) shows that density of surficial lineaments in the Wawa Gneiss domain is greater than the density of geophysical lineaments due to a greater number of identified surficial lineaments, and that there are fewer shorter length geophysical lineaments.

Both the interpreted surficial lineaments (Figure 3.9) and geophysical fracture lineaments (Figure 3.10) show similar trends with dominant north-northwest, northeast to east-northeast and east orientations observed (Figure 3.13). A notable difference in orientations of surficial and geophysical fracture lineaments is the interpretation of a set of long north-trending fractures identified from the low-resolution aeromagnetic data. Interpreted dyke lineaments show a dominant orientation of north-northwest-trending dykes and a subordinate set of northeast-trending dykes are also present throughout the Wawa Gneiss domain (Figure 3.10).

Interpreted fracture lineaments in the Wawa Gneiss domain coincided with all OGS mapped faults, including the Manitowik Lake fault and the Agawa Canyon fault, as shown on Figure 3.4. Dominant north-northwest-trending dykes and a subordinate set of northeast-trending dykes are also present throughout the Wawa Gneiss domain (Figure 3.10). Similar to the Whitefish Lake batholith, the density of dykes in the adjoining greenstone belt to the north of the Wawa Gneiss domain is much higher than in the Wawa Gneiss domain likely due to the high resolution of available aeromagnetic surveys of the greenstone belt compared to the Wawa Gneiss domain. As the dykes are pervasive in all geologic units, if higher resolution geophysical data were available, a higher density of dykes may be expected for the Wawa Gneiss domain than indicated on Figure 3.10.

Based on Figure 3.14, the east-central part and the southeastern corner of the Wawa Gneiss domain and the area of the Wawa Gneiss domain west of the Agawa Canyon fault have lower apparent total lineament densities.

3.2.3.5 Relative Age Relationships of Lineaments

The relative ages of mapped faulting across the Wawa area suggest that the oldest faults tend to trend east, overprinted by north-northwest- and northeast-trending faults, followed by late north-trending faults. In the Wawa area, the most prominent faults are related to the northeast-trending dextral displacement across the Kapuskasing structural zone and associated north-northwest-trending sinistral faults. These sinistral faults are well illustrated by the OGS compilation maps (Johns and McIlraith, 2002; Santaguida, 2001) that show displacement of the greenstone belt into separate panels (Figure 3.4). The aeromagnetic data confirm this pattern (e.g., Figure 3.6 and 3.7; PGW, 2013). The most prominent dextral fault in the area is the Wawa-Hawk-Manitowik fault (or Manitowik fault) just west of the Whitefish Lake batholith. This fault is a major component in the westernmost dextral movement of the Kapuskasing structural zone.

Most episodes of late movement along faults in the Wawa area probably terminated by Keweenawan time, approximately 1.100 billion years ago, during the emplacement of the Mid-continent Rift along Lake Superior. This relationship is suggested by the observation that the northeast-trending dykes of this age (Abitibi swarm) crosscut all major north and northwest-trending faults without displacement (West and Ernst, 1991). Local evidence of a set of faults occurs south of the Michipicoten greenstone belt near Cape Gargantua that is probably related to late compression during the Grenville Orogeny.

At the desktop stage of preliminary assessment, it is still uncertain whether or not each interpreted lineament is in fact an actual brittle geological feature, or whether or not it has significant expression at depth. Nor are the three dimensional orientations of such features discernible at the desktop stage, and shallow dipping features cannot be reliably differentiated from steeply dipping features. Given the issues of low available aeromagnetic data resolution, it is difficult at the desktop stage of the preliminary assessment of potential suitability to assign temporal relationships with any degree of confidence to the identified lineaments. The only distinction that can be made is between older ductile and younger brittle features, albeit with the caveat that many of the 'ductile' lineaments may have developed under brittle conditions and have simply re-activated the pre-existing ductile fabric. Therefore, a tentative preliminary interpretation of the lineament dataset is that the identified ductile (i.e. stratigraphic and foliation-related) lineaments originated largely as pre- 2.671 billion year old features while the brittle lineaments (including dyke lineaments) may be considered to be composite D_3-D_7 structures that were formed during a protracted period of time (since approximately 2.671 billion years ago).

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

The Wawa area lies in the Superior Province of the Canadian Shield, where large parts have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). Hayek et al. (2011) indicated that the Superior Province has experienced a number of low magnitude shallow seismic events. However, there have not been any recorded earthquakes in the Wawa area over the period 1982-2012. Figure 3.19 presents the location of earthquakes with a magnitude 3 or greater that are known to have occurred in Canada from 1627 until 2010 and Figure 3.20 shows the locations and magnitudes of earthquakes recorded in the National Earthquake Database (NEDB) for the period between 1985 and May 2012, in the region surrounding the Wawa area. These two figures show that there have not been any recorded earthquakes in the Wawa area over these periods and that no seismic events of magnitude greater than 6 are recorded within 400 km of the Wawa area. The closest recorded earthquake was a 2.2 Nuttli Magnitude event recorded in January 2011, approximately 87 km northwest of the settlement area of Wawa.

In summary, available literature and recorded seismic events up to December 2012 indicate that the Wawa area is located within a region of low seismicity: the tectonically stable central craton portion of the Superior Province of the Canadian Shield.

3.3.2 Neotectonic Activity

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

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

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

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

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

Under the appropriate conditions, glaciolacustrine deposits may preserve neotectonic features indicative of paleo-seismic activity (JDMA, 2013). Existence of such features can be used to extend the seismic record for a region well into the past. Figure 2.3 shows areas of limited glaciolacustrine deposits in the Wawa area primarily along the north shore of Lake Superior. JDMA (2013) also notes that several glaciolacustrine deposits are located on the Whitefish Lake and Brulé Bay batholiths and the Wawa Gneiss domain, with the largest deposits found in the southeast and northeast corners of the Wawa area.

4 HYDROGEOLOGY AND HYDROGEOCHEMISTRY

4.1 Groundwater Use

Information concerning groundwater use in the Wawa area was obtained principally from the Ontario Ministry of the Environment Water Well Information System (WWIS) database (MOE, 2012). The locations of known water wells are shown in Figure 4.1. The WWIS database contains a total of 71 water well records for the Wawa area. Of these there are 41 records which provided useful information on lithology, well yield, and static water level, as indicated in Table 4.1 below. The MOE water well records show that groundwater use in the Wawa area is limited and restricted to a small number of domestic/residential uses. Water wells in the Wawa area obtain water from the overburden and shallow bedrock. There are no municipal groundwater takings in the Wawa area. The Municipality of Wawa obtains its municipal water supply from Wawa Lake.

Table 4.1 Water Well Record Summary for the Wawa Area

Water Well Type	*Number of Wells*	*Total Well Depth (m)*	*Static Water Level (mBGS)*	*Tested Well Yield (L/min)*	*Depth to Top of Bedrock (mBGS)*
Overburden	31	3.3-101	0.9-28	4-227	Not Applicable
Bedrock	10	38-117	1-113	4-68	0-86

4.2 Overburden Aquifers

There are 31 water well records in the Wawa area that can be confidently assigned to overburden aquifers. These wells are all completed in overburden materials within the bedrock valleys of the Magpie, Michipicoten and Doré rivers, as they approach Lake Superior and range in depth from 3.3 to 101 m deep. The well yields for these wells range from 4 to 227 L/min, with the range being explained by the diversity of materials encountered during drilling: from clay to gravel. These well yields reflect the purpose of the wells (private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from overburden aquifers. The static water levels in the overburden wells range from less than 1 m to 28 mBGS, with the largest depth-to-water being associated with thick deposits of coarse grained materials.

The review of the water well information indicates that competent overburden aquifers exist where thick overburden deposits occur, and within bedrock valleys particularly in proximity to Lake Superior (Morris, 2001a; 2001b). It is notable that overburden is thin to non-existent over much of the Wawa area.

4.3 Bedrock Aquifers

No information was found on deep groundwater conditions in the Wawa area at a typical repository depth of approximately 500 m below ground surface (mBGS). In the Wawa area there are 10 well records that can be confidently assigned to the shallow bedrock aquifer, ranging in depth from 38 to 117 m. Measured pumping rates in these wells are variable and range from 4 to 68 L/min, with an average yield of 36 L/min. These values reflect the purpose of the wells (private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from the aquifers.

Long-term groundwater yield in fractured bedrock will depend on the number and size of fractures, their connectivity, transmissivity, storage and on the recharge properties of the fracture network in the larger regional aquifer.

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

4.4 Regional Groundwater Flow

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

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

On a regional scale, shallow (i.e. within approximately the upper 100 m of overburden and fractured bedrock) groundwater flow across the Wawa area can be expected to mimic surface water flow systems, with groundwater divides coinciding with drainage divides and discharge occurring into topographic lows. Steep slopes and the general absence of thick overburden deposits in the areas mapped as bedrock terrain in the Wawa area will promote surface runoff and minimize groundwater recharge. Where permeable deposits cover the bedrock, recharge areas will occur within highlands and along local positively expressed topographic features forming drainage divides such as ridges and local uplands. Thicker drift deposits are present in the valleys and trench bottoms, and these deposits are expected to represent the most significant local discharge zones in the bedrock terrain. Groundwater discharge in these areas occurs into creeks, rivers, lakes and wetlands. Gartner and McQuay (1979a, b) and McQuay (1980) as part of NOEGTS work indicate that bedrock terrain in the Wawa area is generally well drained, and that bedrock-controlled lineaments in this terrain are expressed as linear depressions that often contain water and reworked glacial-fluvial deposits of sand and gravel. High relief areas can have higher hydraulic gradients that may impact the depth extent of shallow flow systems. Site-specific, subsurface characteristics such as hydraulic conductivity and groundwater density variations, will also influence flow system geometry.

Bedrock aquifers within the bedrock terrain are likely shallow with recharge occurring through discontinuities such as joints and fractures. Gartner and McQuay (1979a, b) and McQuay (1980) suggest that groundwater occurs in fractures and along fault zones in the bedrock terrain, but this terrain unit is considered to have only poor to fair potential for potable municipal groundwater supplies. These authors also suggest that a large proportion of the groundwater in the bedrock terrain is confined to fractures in the upper 45 to 60 m of bedrock, with permeability varying from impermeable to highly permeable, depending on the spacing, depth and aperture of discontinuities in the bedrock. Many of the drainage courses (e.g., Magpie, Michipicoten and Dore Rivers) follow eroded zones of weakness in the underlying bedrock.

There is little known about the hydrogeologic properties of the deep bedrock in the Wawa area, as no deep boreholes have been advanced for this purpose. Experience from other areas in the Canadian Shield has shown that active groundwater flow in bedrock is generally confined to shallow fractured localized systems, and is dependent on the secondary permeability associated with the fracture networks (Singer and Cheng, 2002; Trainer, 1988). For example, in Manitoba's Lac du Bonnet batholith, groundwater movement is largely controlled by a fractured zone down to about 200 m depth (Everitt et al., 1996). The low topographic relief of the Canadian Shield tends to result in low hydraulic gradients for groundwater movement in the shallow active region (McMurry et al., 2003). In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan range from approximately 10^{-15} to 10^{-10} m/s (Stevenson et al. 1996; Ophori and Chan, 1996). Data reported by Raven et al. (1985) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} to less than 10^{-12} m/s below a depth of 400 to 500 m. While deeper into the bedrock, fracture frequency tends to decline, and eventually, the movement of ions is diffusion dominated, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion limited conditions.

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

There is no site-specific information on the hydraulic characteristics of the dykes interpreted for the Wawa area. Information from mines in the Canadian Shield (Raven and Gale, 1986), and other geological settings shows that dykes may act as either pathways or barriers for groundwater flow in a host rock. Their hydraulic characteristics depend on a wide range of factors that include their frequency and location within the host rock, their orientation with respect to the direction of groundwater flow, their mineralogical composition, degree of alteration and their potential association with brittle deformation structures (e.g., Ryan et al., 2007; Svensson and Rhén, 2010; Gupta et al., 2012; Holland, 2012).

Regional groundwater flow in the Wawa area was assessed using surface water elevations, surface drainage directions and ground surface elevations based on the expectation that the regional groundwater table will be a subdued reflection of topography. Because of the large amount of exposed bedrock in the Wawa area the groundwater table for most of the area will be present within the bedrock, likely within several metres of ground surface. Exceptions to this assumption will occur within the overburden-infilled bedrock valleys of the major rivers as they approach the regional groundwater discharge location of Lake Superior. In these areas of thick permeable overburden the groundwater table is present within the overburden and the overburden will act as a local discharge area for bedrock groundwater.

Based on the available topographic and drainage information, groundwater in the Wawa area is conceptualized as being recharged in the bordering highlands of the northern and eastern parts of the Wawa area with flow predominantly southward and westward via local discharge to lakes and river valleys to the regional discharge location of Lake Superior. These estimates of regional groundwater flow conditions in the bedrock will be locally affected by the presence of faults and major structural and lithological discontinuities that have hydraulic properties different from that of the bulk bedrock. The exact nature of deep groundwater flow systems in the Wawa area will need to be evaluated at later stages of the assessment, through the collection of site-specific information.

4.5 Hydrogeochemistry

No information on groundwater geochemistry at repository depth was found for the Wawa area. Existing literature, however, has shown that groundwater within the Canadian Shield can be subdivided into two main hydrogeochemical regimes: a shallow, generally fresh water flow system that extends to a depth of about 150 m, and a deep, saline water flow system (Gascoyne, 2004; Singer and Cheng, 2002).

Groundwater geochemistry at depth in the Canadian Shield is controlled more by geological structure and rock mass hydraulic conductivities, than by bedrock lithology. Consequently, insight into the hydrogeochemistry of potentially suitable geologic units in the Wawa area at proposed repository depths can be gained at this desktop stage from looking at detailed studies completed elsewhere in the Canadian Shield in generally similar structural and lithologic settings.

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

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

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

5 NATURAL RESOURCES - ECONOMIC GEOLOGY

The current version of the OGS Mineral Deposit Inventory (OGS, 2011a) was used to identify mineral occurrences in this report.

The mining claims database (MNDM, 2012a) is updated regularly by MNDM. The version used in this report was obtained on June 26, 2012. Another data source used in this report is the Abandoned Mines Information System or AMIS (MNDM, 2011), which contains data on the abandoned mines and inactive mines for the Province of Ontario, including the Wawa area.

5.1 Petroleum Resources

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

5.2 Metallic Mineral Resources

There are currently no operating mines in the Wawa area. However, iron and gold production and exploration activities in the area date back to the 1890's. Iron was extracted for over 100 years at three mine sites within the Michipicoten greenstone belt (Sault Ste. Marie Public Library, 2008): the Helen, MacLeod, and Sir James Dunn mines just north of the settlement area of Wawa. Other past producing iron and gold mines within the Michipicoten greenstone belt in the Wawa area include the Lucy, Ruth, and Josephine mines west and northwest of Hawk Junction (Figure 5.1). Similarly, gold was in the past produced and is currently being explored for in both the Michipicoten and Mishibishu greenstone belts. Past gold producing mines within the Wawa area include the Grace-Darwin, Jubilee, Minto, Parkhill and Surlaga mines, which are part of the "Michipicoten Camp" located in the Municipality of Wawa (Figure 5.1).

In comparison to the greenstone belts, metallic mineral exploration activities within the granitic bodies of the Wawa area (e.g., Wawa Gneiss domain, Western, Whitefish and Brulé Bay batholiths) has been limited to non-existent. A limited number of mineral occurrences have been recorded in the Whitefish Lake and Western batholiths, and in the Wawa Gneiss domain. However, the economical viability of such occurrences has not been proven to date.

Figure 5.1 shows the areas of active exploration interest based on active mining claims and known mineral occurrences identified in the Mineral Deposit Inventory - 2011 (OGS, 2011a). The historical and ongoing interest in the Michipicoten and Mishibishu greenstone belts, and the lack of interest in the external granitoid terrane, is evident from the relative densities of mineral occurrences and active mining claims.

Metallic mineralization occurrences in the Wawa area include: iron, copper-zinc, molybdenum, gold, silver, and hematite. Despite the range of mineral occurrences, only gold and iron have been mined in the Wawa area according to the Mineral Deposits Inventory (OGS, 2011a).

5.2.1 Iron

Deposits of iron formation are common in the Michipicoten greenstone belt. Iron formation occurs as hematite and siderite, and resulted from chemical sedimentation during quiescent periods during the three cycles of volcanism that occurred between 2.9 and 2.7 billion years ago.

Iron was in the past produced within the Michipicoten greenstone belt from a number of mines, which collectively produced over 140 million tonnes of iron ore. Although these mines are not currently active, iron ore reserves remain and the MNDM estimates that approximately 44 million tonnes of iron ore still exist in Michipicoten greenstone belt (MNDM, 2010). Dianor Resources Inc. announced in 2011 that it would undertake a preliminary review of the iron ore potential of its Leadbetter (diamond) property which includes the Lucy Iron Range (Dianor, 2011) and Canada Iron Inc. holds the iron rights to the Josephine Mine (Canada Iron Inc., 2011).

5.2.2 Base Metals

Greenstone belts in the Wawa area have the appropriate geological conditions to potentially host massive sulphide deposits. Also, mineral occurrences of copper, zinc, lead, tungsten, niobium and nickel have been identified within the Michipicoten greenstone belt (Figure 5.1). However, exploration for these types of deposits in the Wawa area has not yielded any successful results to date.

There is an active mining claim over an identified occurrence of molybdenum within the Western batholith, west of the Michipicoten greenstone belt (see Figure 5.1). At this location the molybdenum occurs in association with a fault and a zone of quartz veins. There are also two occurrences of tungsten (as wolframite) in the Wawa area, one of which is in the Western batholith on the shore of Lake Superior. The economic viability of these occurrences has not been proven.

5.2.3 Gold

As described earlier, gold was produced in the past at the Michipicoten Camp in the Michipicoten greenstone belt. Gold mineralization in the Michipicoten Camp occurs within the margins and hornsfelded supracrustal rocks enveloping the Hawk Lake Granitic Complex and the Jubilee stock (Sage, 1994b). Here the gold occurs primarily in shear zones (Delisle, 1991). Gold mineralization is also present along the eastern margin of the Wawa Gneiss domain, and occurs in veins within marginal zones in close contact with the metavolcanics (Studemeister, 1985; Heather and Arias, 1987). For example, the Renabie Gold Mine produced gold from within the Wawa Gneiss domain, adjacent to the eastern end of the Michipicoten greenstone belt, approximately 80 km northeast of the settlement area of Wawa.

Although at present there are no active gold mines in the Wawa area, gold exploration continues in the region. The mining claims in the vicinity of the Jubilee stock, southeast of the settlement area of Wawa, are predominantly held by the Citadel Gold Mines Inc., and there has been a historical resource estimate of 525,000 ounces of gold (Delta Uranium Inc., 2009). The closest operating gold mines are the Island Gold mine located approximately 40 km northeast of Wawa on the northern margins of the Michipicoten greenstone belt, and the Eagle River Mine located approximately 50 km west of the settlement area of Wawa in the Mishibishu greenstone belt.

In summary, gold mineralization occurs predominantly within the greenstone belts and along sheared margins of some intrusive rocks. There are no economic occurrences of gold and there have been no gold mining activities in the main bodies of the granitoid terrane surrounding the Michipicoten greenstone belt in the Wawa area.

5.2.4 Uranium

The Firesand River Carbonatite complex, located approximately 10 km east of settlement area of Wawa in the Michipicoten greenstone belt, was identified in an inventory of Ontario’s uranium and thorium deposits (Robertson and Gould, 1983), and is known to contain low concentrations of uranium and thorium (Wilson, 1990). Radioactive carbonate-rich dykes occur in numerous road cuts along Highway 101 but they appear too small to be of economic interest (Sage et al., 1982c).

The radiometric survey summarized as part of the initial screening (Geofirma, 2011) indicates radioactivity predominantly, but not uniformly, within the external granitoid terrane (e.g., the Whitefish Lake batholith). However, no economic deposits of uranium have been identified in the Wawa area. The closest known economic uranium mineralization is approximately 100 km to the south, in the Montreal River area.

5.2.5 Rare Earth Metals

According to Wilson (1990) potential for rare earth metals exists in the Wawa area. Pegmatites within the granitoid terrane external to the greenstone belts (i.e., Wawa Gneiss domain and Western, Whitefish Lake and Brulé Bay batholiths) and the Firesand River Carbonatite complex in the Michipicoten greenstone belt, have been identified as targets for rare earth element exploration. However, there is no record of past or current mining activities for rare metals in the Wawa area, and no occurrences have been recorded.

5.3 Non-Metallic Mineral Resources

5.3.1 Sand, Stone and Gravel

Sand and gravel resources are coincident with the glaciofluvial outwash deposits as mapped on Figure 2.3 and sand and gravel extraction currently occurs from a pit near the mouth of the Michipicoten River (Figure 5.1). Such extraction is limited to unconsolidated overburden deposits at shallow depth.

Superior Aggregates holds a license for below water table extraction of trap rock in the Michipicoten Harbour area, on Lake Superior at the west end of Michipicoten Bay (The Sault Star, 2011). Other aggregate quarries are likely present within the Wawa area.

According to Wilson (1990), the potential for an economically viable building stone industry in the Wawa area is poor to fair, with the internal plutons of the Michipicoten greenstone belt being the best sites for quarry development. Granitic bodies such as the Western, Whitefish Lake and Brulé Bay batholiths, while having potentially suitable rock, were considered too difficult to access (i.e., too remote) to make them economically viable.

5.3.2 Diamonds

In 1991, industrial grade diamonds were discovered in the Michipicoten River. In 1995, gem quality diamonds were found in a bedrock occurrence on the Trans-Canada Highway, approximately 20 km north of the settlement area of Wawa. Since then, more than 50 occurrences of diamondiferous bedrock have been reported in an area of approximately 30 km^2 in size, centred approximately 20 km north of the settlement area of Wawa within the Michipicoten greenstone belt (Figure 5.1) (Wilson, 2006). These occurrences are hosted within the approximately 2.6-2.7 billion year old calc-alkaline lamprophyres and volcano-clastic breccias, formed contemporaneously with the metavolcanic rock of the greenstone belt (Kopylova et al., 2010), and are unusual in that they are not associated with kimberlites (Wilson, 2006). A second set of occurrences approximately 12 km northeast of the settlement area of Wawa (in the vicinity of the Lucy iron range) is hosted in metasedimentary conglomerate, although the primary volcanic rock of the conglomerate diamonds may be a kimberlite (Kopylova et al., 2010).

Active exploration for diamonds in the Wawa area is currently ongoing (Wilson, 2006). A joint venture between Spider Resources and KWG Resources Inc. is exploring the breccia-hosted diamonds north of the Municipality, while Dianor Resources Inc. is is exploring the conglomerate-hosted Leadbetter diamond project (Dianor, 2011). Dianor (2011) estimates 566 million tonnes of diamond-bearing conglomerate. The economic viability of these two diamond deposits has not been proven to date.

In 1997, two kimberlite intrusions (possibly associated with a narrow subvertical dyke striking north-northwest) were discovered in the eastern part of the Whitefish Lake batholith, approximately 5 km east of the northern tip of Whitefish Lake (Kaminsky et al., 2002). The economic viability of these kimberlite diamond deposits has yet to be proven.

5.3.3 Industrial Minerals

No industrial mineral deposits have been identified within the Wawa area (Figure 5.1). According to Wilson (1990), there is minimal potential for the development of industrial mineral deposits at 1990 market prices. Wilson (1990) described eleven known occurrences of minor importance in the Wawa area (Figure 5.1).

5.4 Abandoned Mine Sites

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

The abandoned or inactive mines primarily fall within the greenstone belts, although there are two abandoned/inactive mines in the Western Batholith that occur within the molybdenum mine claim area. The database information on these two mines indicates they were trenches (MNDM, 2011).

6 GEOMECHANICAL PROPERTIES

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

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

6.1 Intact Rock Properties

No information on intact rock properties is available for the Wawa area. Intact rock properties tabulated in Table 6.1 are based on laboratory testing of rock core specimens from boreholes. The table also includes basic rock properties such as density, porosity, uniaxial compressive strength and tensile strength for use in engineering design and structural analyses. These parameters feed into the rock mass classification schemes, and *in-situ* stress determination.

Data on intact rock strengths and elastic properties of gneissic rocks including paragneisses and orthogneisses are available from studies completed at the Chalk River Laboratories. Based on data reported by Annor et al. (1979) and Larocque and Annor (1985) uniaxial compressive strengths of 100-200 MPa, tangent elastic moduli of 80-100 GPa and Poisson's ratio of 0.2-0.3 may be expected for metasedimentary rocks and gneisses. These reported ranges of geomechanical properties may be representative of metasedimentary and foliated/gneissic rocks in the Wawa area.

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

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

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

NA = Not Available

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

6.2 Rock Mass Properties

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

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

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

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

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

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

6.3 *In-situ* Stresses

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

No site-specific information is available regarding the *in-situ* stress conditions in potentially suitable geologic units in the Wawa area, although there have been *in-situ* stress measurements made a underground mines in the greenstone belts in the Wawa area as well as in the Wawa Subprovince outside of the Wawa area (Figure 6.1). The nearest *in-situ* stress measurements were taken in metavolcanic rocks at depths of 360 to 810 mBGS at the MacLeod Mine located just north of the settlement area of Wawa (Arjang and Herget, 1997). The reported maximum principal stress data available from 11 sets of tests ranged from 17.4 to 53.7 MPa with an average value of 32 MPa. The maximum principal stress was subhorizontal and oriented from the north-northwest to east-northeast (Kaiser and Maloney, 2005). The minimum principal stress was vertical. The intermediate principal stress was also subhorizontal and comparable in magnitude to the maximum principal stress, suggesting a predominantly horizontally isotropic stress regime. Herget (1973) noted that some of the measured directions of maximum compressive stresses aligned with directions of maximum compression (north-northwest) deduced from kinematic analysis of slaty cleavage, transverse faults and fracture slickensides. A maximum principal stress direction of east-northeast is similar to that indicated by the World Stress Map (Zoback, 1992).

The observation that the stress state is neither constant nor linear (Maloney et al., 2006) suggests that variability should be expected in the Canadian Shield. Based on the available stress measurement data (Figure 6.1), Maloney et al. (2006) developed a conceptual model that describes the variable stress state in the upper 1,500 m of the Canadian Shield. The conceptual model identifies a shallow stress released zone from surface to a depth of 250 m, a transition zone from 250 to 600 m and an undisturbed stress zone below 600 m. The undisturbed stress zone can be expected to be representative of far-field boundary stress conditions whereas stresses within the shallow zone tend to be lower as they have been disturbed through exhumation and influenced by local structural weaknesses such as faults (Maloney et al., 2006).

Typical repository depths of approximately 500 m fall within the transition zone, where the maximum principal stress may range from approximately 20 to 50 MPa (Figure 6.1). The dataset presented by Maloney et al. (2006) indicate an average northeast orientation for the maximum horizontal stress, which is consistent with the World Stress Map, although anomalous stress orientations have been identified in northwest Ontario including a 90° change in azimuth of the maximum compressive stress axis which was identified in the near surface of the Whiteshell area of Manitoba (Brown et al., 1995). In addition, a roughly north orientation of maximum horizontal compressive stress was found for the Sioux Falls Quartzite in South Dakota (Haimson, 1990), as well as in the Wawa Subprovince near Marathon, Ontario (David Bell Mine) (Kaiser and Maloney, 2005).

Local stress relief features such as faults and shear zones can be expected to locally affect stress regime. For example, thrust faults at AECL's URL in the Lac du Bonnet Batholith were shown to be boundaries between significant changes in the magnitude and orientation of the principal stresses. Above a major thrust fault, located at depth of 270 m, the magnitude was close to the average value for the Canadian Shield and the orientation of the maximum horizontal stress was consistent with the average predicted by the World Stress Map (i.e., southwest) (Zoback, 1992). Below the same thrust fault, the stress magnitudes are much higher than the average data for the Canadian Shield, and the maximum principal stress rotates approximately 90° to a northwest orientation (Martino et al., 1997). This orientation is consistent with the data presented by Herget (1980) for the area which indicates maximum compression clustered in the northeast and northwest for the Canadian Shield.

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

6.4 Thermal Conductivity

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

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

Table 6.2 Thermal Conductivity Values for Granite, Granodiorite and Tonalite

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

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

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

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

7 POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE WAWA AREA

7.1 Approach

The objective of the Phase 1 desktop geoscientific preliminary assessment is to assess whether the Wawa area has the potential to contain general areas that are suitable for hosting a deep geological repository. At this stage of the assessment, the intent is to assess whether there are areas within the Wawa area that have the potential to satisfy the geoscientific evaluation factors and safety functions outlined in the site selection process document (NWMO, 2010). The location and extent of general potentially suitable areas would be refined during the second phase of the preliminary assessment through more detailed assessments and field evaluations.

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

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

- ***Geological Setting:*** Areas of unfavourable geology identified during the initial screening (Geofirma, 2011) were not considered. Such areas include rocks of the Michipicoten, Gamitagama, and Mishibishu greenstone belts. These units were considered not suitable due to their lithological heterogeneity, structural complexity and potential for mineral resources. Potentially suitable geological units in the Wawa area include the Western batholith, and the Wawa Gneiss domain, including the Whitefish Lake/Brulé Bay batholith. The geological setting associated with each general potentially suitable area identified is further discussed in Section 7.2.

- ***Structural Geology:*** Faults are a common feature of the bedrock in the Wawa area, with numerous mapped faults extending for tens of kilometres (Figure 3.4). Some of these faults are interpreted as being associated with the Kapuskasing Structural Zone; other faults, such as the Agawa Canyon fault, are associated with the Mid-continent Rift (Section 3.1.4). Areas within or immediately adjacent to large mapped faults (e.g., Agawa Canyon fault) and shear zones were considered unfavourable. The thickness of potentially suitable units was also considered when identifying potentially suitable areas. The Wawa Gneiss domain is estimated to be 10 to 15 kilometres thick and the Western and Whitefish Lake/Brulé Bay batholiths are expected to exceed several kilometres in thickness based on their regional extent. These thicknesses are sufficient for the purpose of developing a repository.

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

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

- ***Protected Areas:*** All provincial parks and conservation reserves, including the recommended Lake Superior Highlands Conservation Reserve (Section 2.4), were excluded from consideration in the selection of general potentially suitable areas. The largest protected areas in the Wawa area include the Lake Superior Provincial Park (294 km^2) covering part of the Brulé Bay batholith and the Wawa Gneiss domain, and the Magpie River Terraces Conservation Reserve (21 km^2) within the Michipicoten greenstone belt. The recommended Lake Superior Highlands Conservation Reserve covers part of the southern portion of the Western batholith. Other smaller protected areas in the Wawa area include the Nimoosh Provincial Park, which overlies a portion of the Western batholith and Potholes Provincial Park, which covers part of Wawa Gneiss domain (Figure 2.1).

- ***Natural Resources:*** The potential for natural resources in the Wawa area is shown on Figure 5.1. Areas with known potential for exploitable natural resources were excluded from further consideration. These include the rocks of the Mishibishu, Michipicoten, and Gamitagama greenstone belts. The mineral potential of the Western batholith, the Wawa Gneiss domain and the Whitefish Lake/Brulé Bay batholiths is considered to below. At this stage of the assessment, areas of active mining claims located in geologic environments judged to have low mineral resource potential were not systematically excluded.

- ***Surface Constraints:*** Areas of obvious topographic constraints (e.g., density of steep slopes), large water bodies (wetlands, lakes), and accessibility were considered for the identification of general potentially suitable areas. While areas with such constraints were not explicitly excluded at this stage of the assessment, they are considered less preferable, all other factors being equal. Lake cover in the Wawa area is generally uniform, with most lakes being less than 10 km^2 in extent. Larger water bodies, such as Whitefish Lake and Anjigami Lake cover parts of the Whitefish Lake/Brulé Bay batholith. Topography is generally rugged in the Wawa area, where very steep slopes are common (Figure 2.2). The majority of the Wawa area is accessible via Highway 17 and Highway 101, and a number of existing logging roads, with the exception of some portions of the northern area of the Western batholith and northern parts of the Whitefish Lake/Brulé Bay batholith (Figures 1.1 and 3.4).

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the above key geoscientific characteristics revealed that the Wawa area contains general areas where there is a potential to find suitable sites for hosting a deep geological repository. These general areas are located within the Western and Whitefish Lake batholiths, and in the Wawa Gneiss Domain. Figure 7.1 shows features illustrating some of the key characteristics and constraints used to identify general potentially suitable areas, including: bedrock geology; protected areas; areas of thick overburden cover; surficial and geophysical lineaments, existing road network, the potential for natural resources and mining claims. Zoomed-in views of the Western batholith and the Wawa Gneiss domain, including the Whitefish Lake/Brulé Bay batholith, are shown on Figures 7.2 and 7.3. The legend of each figure includes a 2 km by 3 km box to illustrate the approximate extent of suitable rock that would be needed to host a repository.

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

7.2.1 Western Batholith

As discussed in Section 3.2.1.1, the Western batholith is a large (631 km^2 within the Wawa area), multi-phase intrusion that is mostly composed of tonalite, and massive granitic rocks (Figure 3.4). The gneissic tonalite phase of the Western batholith is estimated to be 2.698 billion years old (Turek et al., 1984). While the thickness of the Western batholith is not known, it is expected to exceed several kilometres in thickness (Percival, 1990). Three long mapped faults crosscut the Western batholith: the northwest-trending Black Trout Lake and Trembley faults, and an unnamed northeast-trending fault. There are also numerous northwest- and northeast-trending dykes mapped within the Western batholith in the Wawa area (Figure 3.4).

Within the Wawa area, the Western batholith has low potential for natural resources; extensive bedrock exposure and is mostly free of surface constraints (i.e., topography and large bodies of water). The Nimoosh Provincial Park and the recommended Lake Superior Highlands Conservation Reserve cover only a small portion of the Western batholith (Figure 7.2). Therefore, the differentiating factors for selecting potentially suitable areas within the Western batholith were considered to be geology, lineament density, and structural geology.

The general potentially suitable area identified within the Western batholith is located in the northeastern portion of the intrusion, between the Trembley fault and the Jimmy Kash River, and north of Molybdenite Lake (Figure 7.2). This area lies within an area of lower lineament density relative to other parts of the Wawa area (Figure 3.14). Figure 3.10 shows that geophysical lineaments in the potentially suitable area are mostly interpreted as fracture lineaments longer than 5 km, with only a small number of lineaments interpreted as dykes. The spacing between these long geophysical lineaments varies from less than 1 to about 3 km. It is anticipated that the density of geophysical lineaments in this area to be higher, as interpreted lineaments are based on low resolution data. Figure 3.9 shows the surficial lineament density to be generally high throughout most of the Western batholith, likely due to the extensive bedrock exposure, which makes surficial lineaments readily mappable. The interpreted spacing between interpreted surficial lineaments longer than 5 km in the identified general area ranges from less than 1 to about 2.5 kilometres.

Interpreted geophysical and surficial lineaments in the potentially suitable area within the Western batholith (Figures 3.9; 3.10; and 7.2) suggest that there is some potential to find suitable rock volumes between long lineaments. This would need to be further assessed during subsequent stages of the site evaluation process, as the structural characteristics of the Wawa area are fairly complex due to its close proximity to the Kapuskasing structural zone and the Mid-continent Rift (Section 3.1.4).

The distribution of lineament density as a function of lineament length over the Western batholith is shown on Figures 3.14 to 3.17 for all lineaments and lengths greater than 1 km, 5 km and 10 km, respectively. As expected, the density of lineaments progressively decreases in the Western batholith as shorter lineaments are filtered out (Figures 3.14 to 3.17).

Although the density of dykes seems to be lower over the Western batholith compared to the remainder of the Wawa area, there still remain some uncertainties regarding the distribution, density and structural impact of the dykes in the Wawa area. The main uncertainties are related to: the potential for smaller scale dykes to be present between interpreted dykes; the potential underestimation of geophysical lineaments due to the predominance and masking effect of the dyke signal in the geophysical dataset; and the potential for damage that may have been caused to the host rock during dyke emplacement.

The potentially suitable area in the Western batholith comprises predominantly private land (Figure 2.5), and is free of active mining claims as shown on Figures 5.1 and 7.2. Although the area does not contain any protected areas, Nimoosh Provincial Park lies in close proximity to the southwest (Figure 7.2). Access to the identified potentially suitable area in the Western batholith is limited via the existing road network. The area is of moderate relief, and contains a generally low percentage of lake/wetland cover.

7.2.2 Wawa Gneiss Domain

As discussed in Section 3.2.1.2, the Wawa Gneiss domain is a vast intrusive complex that comprises multiple phases of variable composition, age and deformation and extends for 1,205 km^2 within the Wawa area. In the Wawa area the Wawa Gneiss domain is predominantly composed of approximately 2.71 billion years old tonalitic gneiss and younger massive granitic rocks (Figure 3.4; Jackson and Sutcliffe, 1990; Moser, 1994). Migmatized rocks (i.e. rocks that underwent partial melting) are also mapped in the Wawa Gneiss domain (Figure 3.4), reflecting the high degree of metamorphism that affected these rocks. The thickness of the Wawa Gneiss domain has been estimated to be approximately 10 to 15 km (Jackson and Sutcliffe, 1990; Percival, 1990; Moser, 1994)

The distinct granitic Whitefish Lake/Brulé Bay batholith is within the Wawa Gneiss domain and makes up most of the central portion of the Wawa area (Figures 3.4 and 7.1). This approximately 2.694 billion years old batholith covers an approximate elongated area of 62 km by 15 km and is expected to exceed several kilometres in thickness (Percival, 1990). The long north-trending Agawa Canyon Fault crosscuts the Wawa Gneiss domain in the Wawa area, bisecting the intrusion. There are also numerous northwest- and northeast-trending dykes mapped within the Wawa Gneiss domain (Figures 3.4 and 7.3).

The Wawa Gneiss domain and Whitefish Lake/Brulé Bay batholith have extensive bedrock exposure, generally a low potential for natural resources and are free of significant surface constraints (i.e., topography and large water bodies). The largest protected area over these units is the Lake Superior Provincial Park, which covers part of the western portion of the Wawa Gneiss domain (Figure 7.3). Therefore, the differentiating factors for selecting potentially suitable areas were considered to be mostly lineament density and structural geology.

Two general potentially suitable areas were identified in the Wawa Gneiss domain. The first area is located west of the Agawa Canyon fault, south of Anjigami Lake, and north of the Lake Superior Provincial Park. The second potentially suitable area is in the eastern part of the Whitefish Lake/Brulé Bay batholith, to the east of the Agawa Canyon fault, between Whitefish Lake and the northeastern margin of the intrusion (Figure 7.3). Both of these general areas lie fairly close to the Agawa Canyon fault, and it is uncertain to what extent this long structure affects their potential suitability.

The two potentially suitable areas within the Wawa Gneiss domain were identified to capture areas with lower lineament density. As shown in Figure 3.10, the spacing of geophysical lineaments ranges from 1 to about 4 km in the area within the Whitefish Lake/Brulé Bay batholith, and from less than 1 to about 2 km in the area west of the Agawa Canyon fault. The area within the Whitefish Lake/Brulé Bay batholith contains numerous mapped and interpreted dykes (Figures 3.10 and 7.3). No dykes were interpreted in the other area. As discussed above in Section 7.2.1, density of geophysical lineaments is expected to be higher given the low resolution of available geophysical data.

Figure 3.9 shows the surficial lineament density to be generally moderate to high throughout the Wawa Gneiss domain. The interpreted spacing between surficial lineaments longer than 5 kilometres in the two identified potentially suitable areas ranges from less than 1 to about 3 km.

As noted above for the Western batholith, while there is some potential to find suitable rock volumes between long lineaments in the identified areas, the uncertainties related to presence of dykes and the proximity of the Wawa area to the Kapuskasing structural zone and the Mid-continent Rift would need to be further assessed.

The distribution of lineament density as a function of lineament length over the Wawa Gneiss domain is shown on Figures 3.14 to 3.17 for all lineaments and lengths greater than 1 km, 5 km and 10 km, respectively. As expected the figures show that, in general, the density of lineaments progressively decreases as shorter lineaments are filtered out.

The two general potentially suitable areas identified in the Wawa Gneiss domain comprise mostly private land (Figure 2.5), and do not contain any protected areas (Figure 7.3). Mineral resource potential is considered low throughout both areas, with no active mining claims recorded (Figures 5.1 and 7.3). The area in the Whitefish Lake batholith lies in close proximity to rocks with potential for mineral resources (i.e. greenstone belt), and contains two documented kimberlite occurrences. However, the economic potential of these occurrences has not been proven. Access is limited to recreational/collector roads that either run through or nearby the general areas.

Topographic relief in the general areas of the Wawa Gneiss domain is moderate (Figure 2.2). Drainage is good throughout the areas, with total lake/wetland cover being generally low, although part of the Whitefish Lake covers a portion of the general area in the Whitefish Lake batholith.

In summary, the three general potentially suitable areas within the Western batholith and Wawa Gneiss domain were identified based mostly on geology, lineament density and structural geology. Bedrock geology in all three areas has low potential for economically exploitable natural resources, good bedrock exposure and lower lineament density. The areas are also outside of protected areas and are accessible to some extent via the existing road network. Inherent uncertainties remain in relation to the proximity to major regional faults, the occurrence of numerous dykes, and the low resolution of available geophysical data over the three identified potentially suitable areas.

7.2.3 Other Areas

No general potentially suitable areas were identified within the Brulé Bay batholith. Lineament density in the Brulé Bay batholith is moderate to high, and more than 60% of the intrusion is encompassed by Lake Superior Provincial Park (Figure 7.3). While a small potentially suitable area is found east of the park, the proximity to such a large protected area is a concern for site access and site characterization activities.

An area in the southern portion of the Western batholith was identified with relatively low lineament density (Figures 3.14 to 3.17). However, a conservation reserve is planned for a large portion of that area (JDMA, 2013). An additional region of low interpreted lineament density was also identified within the Wawa Gneiss domain in the southeast corner of the Wawa area (Figures 3.14 to 3.17). However, the region is considered less favorable because it hosts a large mass of migmatized rocks (Figure 3.4) with documented iron formations and mineral occurrences (Figures 5.1 and 7.3).

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

7.2.4 Summary of Geoscientific Characteristics of the General Potentially Suitable Areas

Table 7.1 provides a summary of the key geoscientific characteristics of the three identified general potentially suitable areas in the Wawa area.

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

Geoscientific Descriptive Characteristic	***General Potentially Suitable Areas***		
	Wawa Gneiss Domain	***Whitefish Lake/Brulé Bay Batholith***	***Western Batholith***
Rock Type	Gneissic tonalite	Massive granodiorite to granite	Massive granodiorite to granite, and gneissic tonalite
Age	ca. 2.71 billion years	ca. 2.694 billion years	ca. 2.698 billion years
Inferred host rock thickness	10 to15 km	several km	several km
Extent of geologic unit in the Wawa area	1,205 km^2	548 km^2	631 km^2

Geoscientific Descriptive Characteristic	***General Potentially Suitable Areas***		
	Wawa Gneiss Domain	***Whitefish Lake/Brulé Bay Batholith***	***Western Batholith***
Relative proximity to mapped structures (faults, shear zones, subprovince boundaries, etc.)	Agawa Canyon Fault - 6 km Kapuskasing (McEwan Fault) – 36 km Old Woman Fault – 15 km Wawa Lake fault – 26 km E-NE Fault west of Wawa area – 66 km	Agawa Canyon Fault – 12 km Kapuskasing (McEwan Fault) – 30 km Old Woman Fault – 27 km Wawa Lake fault – 7 km E-NE Fault west of Wawa area – 61 km	Agawa Canyon Fault – 37 km Kapuskasing (McEwan Fault) – 80 km Old Woman Fault – 36 km Wawa Lake fault - 25 E-NE Fault west of Wawa area – 15 km
Structure: faults, foliation, dykes, joints	Moderate to high apparent surface lineament density Low to high apparent geophysical lineament density	Moderate to high apparent surface lineament density Low to high apparent geophysical lineament density	High apparent surface lineament density Low to high apparent geophysical lineament density
Aeromagnetic characteristics and resolution	Moderately noisy, low resolution	Moderately noisy, low resolution	Moderately noisy, low resolution
Terrain: topography, vegetation	Low to moderate relief, sparsely forested	Moderate to high relief, sparsely forested	Moderate relief, sparsely forested
Access	Good access to north via recreation road	Access via collector road within 1-2 km at south	Limited Access - highway 10km (northeast) and recreation road 7.5 km (northwest)
Resource Potential	Low	Low	Low
Overburden cover	~14%	~2%	~9%
Drainage	Generally good (12% surface water)	Generally good (13% surface water)	Generally good (8% surface water)

7.3 Evaluation of the General Potentially Suitable Areas in the Wawa area

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

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

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

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

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

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

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

An evaluation of the three general potentially suitable areas in the Wawa area in the Western batholith, and the Wawa Gneiss domain and Whitefish Lake batholith is provided in the following subsections.

7.3.1 Safe Containment and Isolation of Used Nuclear Fuel

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

This requires that:

- The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events;

- The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities;

- The hydrogeological regime within the host rock should exhibit low groundwater velocities;

- The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multiple-barrier system;

- The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement; and

- The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation function of the repository.

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

As discussed in Section 3 and summarized in Table 7.1, review of available information as part of this preliminary assessment indicates that the estimated thicknesses of the Wawa Gneiss domain is of at least 10 km, and that of the Whitefish Lake and Western batholiths is expected to be in the order of several kilometres (Section 7.2). Therefore, the rock in the three general potentially suitable areas identified within these geologic units is likely to extend well below typical repository depths (approximately 500 m), which would contribute to the isolation of the repository from human activities and natural surface events.

Analysis of interpreted lineament spacing, including dykes, indicates that the three identified general areas in the Wawa area have a relatively lower density of lineaments and some potential to contain structurally bounded competent rock volumes of sufficient size to host a deep geological repository. The classification of lineament density as a function of lineament length shows that the variable density and spacing of shorter brittle lineaments is influenced by data resolution, and to a lesser extent the amount of exposed bedrock. By classifying the lineaments according to length, this local bias is somewhat reduced and the spacing between lineaments increases as shorter lineaments are filtered out. Longer lineaments are more likely to extend to greater depth than shorter lineaments. All three areas identified lie fairly close to mapped long faults (e.g. Trembley fault, Agawa Canyon fault). The extent to which these long structures would affect potential suitability of the three general areas would need to be further assessed.

As discussed in Section 4.4, there is limited information on the hydrogeologic properties of the deep bedrock in the Wawa area. It is therefore not possible at this stage of the evaluation to predict the nature of the groundwater regime at repository depth in the three identified general areas. The potential for groundwater movement at repository depth is, in part, controlled by the fracture frequency, the degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of mineral infilling. Available information for other granitic intrusions (plutons and batholiths) within the Canadian Shield, indicates that active groundwater flow within structurally bounded blocks tends to be generally limited to shallow fracture systems, typically less than 300 m. At greater depths, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). However, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion-limited conditions. Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan range from approximately 10^{-15} m/s to 10^{-10} m/s (Ophori and Chan, 1996; Stevenson et al., 1996). Data reported by Raven et al. (1985) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400-500 m.

Also, experience from other areas in the Canadian Shield indicates that ancient faults, similar to those in the Wawa area, have been subjected to extensive periods of rock-water interaction resulting in the long-term deposition of infilling materials that contribute to sealing and a much reduced potential for groundwater flow at depth. Site-specific conditions that can influence the nature of deep groundwater flow systems in the Wawa area would need to be investigated at later stages of the site evaluation process through site characterization activities that include drilling and testing of deep boreholes.

Numerous dykes have been mapped and interpreted in the Wawa area, as it lies within a region of dyke swarms. Information from mines in the Canadian Shield (Raven and Gale, 1986), and other geological settings shows that dykes may act as either pathways or barriers for groundwater flow in a host rock. Their hydraulic characteristics depend on a wide range of factors that include their frequency and location within the host rock, their orientation with respect to the direction of groundwater flow, their mineralogical composition, degree of alteration and their potential association with brittle deformation structures (e.g., Ryan et al., 2007; Svensson and Rhén, 2010; Gupta et al., 2012; Holland, 2012), including both pre-existing structures and those developed as a result of dyke emplacement.

Information on other geoscientific characteristics relevant to the containment and isolation function of a deep geological repository, such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, the thermal and geomechanical properties of the rock is limited for the Wawa area. The review of available information from other locations with similar geological settings, did not reveal any obvious conditions that would suggest unfavourable mineralogical or hydrogeochemical characteristics for the granitic plutonic rocks characterizing the three general potentially suitable areas identified within the Wawa area (Sections 4 and 7.2). In the Wawa area, there is an additional uncertainty related to the potential impact of dykes on the thermal conductivity of the surrounding host rocks. Site specific mineralogical and hydrogeochemical characteristics, including pH, Eh and salinity, would need to be assessed during subsequent site evaluation stages.

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

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

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

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

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

- The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation function of the repository;

- The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository; and

- The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.

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

The Wawa area is located in the Superior Province of the Canadian Shield, where large portions of land have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). There have not been any recorded earthquakes in the Wawa area (Section 3.3) over the period 1627 to 2012 and no seismic events of magnitude greater than 6 are recorded within 400 km of the Wawa area. As discussed in Sections 3.1 and 3.2, faults have been identified in the Wawa area including the regional Agawa Canyon fault. However, there is no evidence to suggest these faults have been tectonically active within the past billion years.

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

Land in the Wawa area is still experiencing isostatic rebound following the end of the Wisconsinan glaciation (Section 3.3.2). Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella et al., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1-2 mm/yr) south of the Great Lakes. Lake level records (Mainville and Craymer, 2005) indicate that present day rebound rates in the Wawa area should be well below 10 mm/yr, likely between 2 and 4 mm/yr. There is no site-specific information on erosion rates for the Wawa area. However, as discussed in Section 3.1.6, the erosion rates from wind, water and past glaciations on the Canadian Shield are reported to be low.

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

7.3.3 Safe Construction, Operation and Closure of the Repository

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

This requires that:

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

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

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

The three general potentially suitable areas are situated in areas having extensive outcrop exposure (Figures 2.3 and 7.1). At this stage of the site evaluation process it is not possible to accurately determine the exact thickness of the overburden deposits in these areas due to the low resolution of available data. However it is anticipated that overburden cover is not a limiting factor in any of the identified general areas.

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

7.3.4 Isolation of Used Fuel from Future Human Activities

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

This requires that:

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

The mineral potential in the Wawa area (Section 5) is limited to the greenstone belts and no known economic mineralization has been identified to date within the Western batholith or the Wawa Gneiss domain in the Wawa area. The economic mineral potential is considered low within these geologic units.

The review of available information did not identify any groundwater resources at repository depth for the Wawa area. As discussed in Section 4, the MOE Water Well Information System (WWIS) database (MOE, 2012) shows that all water wells known in the Wawa area obtain water from overburden or shallow bedrock sources ranging from 5 to 117 m. Experience from other areas in the Canadian Shield has shown that active groundwater flow in crystalline rocks is generally confined to shallow fractured localized systems (Singer and Cheng, 2002). The MOE WWIS indicates that no potable water supply wells are known to exploit aquifers at typical repository depths in the Wawa area or anywhere else in northern Ontario. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits potential yield, even if suitable water quality were to be found.

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

7.3.5 Amenability to Site Characterization and Data Interpretation Activities

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

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

As described in Section 3, the bedrock geology of the Wawa Gneiss domain, Western batholith and Whitefish Lake batholith is mapped as relatively homogeneous massive granodiorite-granite and gneissic tonalite, geology that is not expected to be difficult to characterize. At this stage of the assessment, it is uncertain if multiple intrusive phases exist within the three identified areas. Such uncertainties, however, are not expected to greatly affect site characterization.

Interpreted lineaments represent the observable two-dimensional expression of three-dimensional features. The ability to detect and map such lineaments is influenced by topography, the character of the lineaments (e.g., their width, orientation, age, etc.), and the underlying resolution of the data used for the mapping. Interpreted surficial and geophysical dyke lineaments in the Wawa area exhibit well defined orientations (i.e., northwest, and northeast), which is beneficial for site characterization and interpretation activities. The degree of structural complexity associated to the orientation of lineament features in three dimensions will need to be further assessed through detailed site investigations in future phases of the site selection process.

The identification and field mapping of structures is strongly influenced by the extent and thickness of overburden cover and the presence of large water bodies. The Wawa area does not contain extensive deposits of overburden or large lakes that would potentially conceal geological structures. The identified general areas mostly comprise exposed bedrock which would facilitate surface bedrock mapping. Two of the three identified general potentially suitable areas in the Wawa area are accessible using exiting recreational road networks, while access to the general area in the Western batholith via the existing road network is limited.

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

8 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

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

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

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

The desktop geoscientific preliminary assessment showed that the Wawa area contains at least three general areas that have the potential to satisfy NWMO’s geoscientific site evaluation factors. These general areas are located within the Wawa Gneiss domain, and the Western batholith.

The geological units hosting the three identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They have sufficient depth and extend over large areas. The bedrock in the three potentially suitable areas is mostly exposed. All three areas have low potential for natural resources, although one of the areas within the Wawa Gneiss domain lies in close proximity to rocks with known economically exploitable mineral resources (i.e. greenstone belt). The identified potentially suitable areas contain limited surface constraints, and are accessible via recreational roads.

While the three potentially suitable areas appear to have favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The main uncertainties are associated with the presence of major regional faults, the occurrence of numerous dykes, and the low resolution of available geophysical data over most of the Wawa area.

Interpreted lineaments suggest that the three identified general areas may contain sufficient rock volumes that are favourable for hosting a deep geological repository. However, the structural characteristics of the Wawa area are fairly complex due to its close proximity to the Kapuskasing structural zone to the east and the Mid-continent Rift to the southwest. The Wawa area includes a number of long mapped faults in the vicinity of the three identified potentially suitable areas. Also, the Wawa area contains numerous dykes as it lies within major regional dyke swarms. The low resolution of geophysical data available for the Wawa area and the occurrence of numerous dykes could be masking the presence of both smaller scale dykes and fractures not readily identifiable from available data.

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

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10 REPORT SIGNATURE PAGE

Respectfully submitted,

Geofirma Engineering Ltd.

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Senior Geoscientist

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

APPENDIX A

Geoscientific Factors

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

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

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

APPENDIX B

Geoscientific Data Sources

Table B.1 Summary of Geological Mapping Sources for the Wawa Area

Database	***Description***	***Scale (Regional/ Local)***	***Used? (Yes/ No)***
AFRI	The AFRI database contains the technical results from all exploration work carried out in Ontario. Data includes location, property ownership, type of work done, commodities sought for each assessment file and a link to a pdf version of each file. Spatial data is collected for each file in the form of polygons indicating property outlines.	Regional	Yes
AMIS (Abandoned Mines Information System Database)	AMIS is a database containing information on all known abandoned and inactive mine sites within the province of Ontario. There are currently 5,700 known abandoned mine sites scattered throughout the Province, which contain more than 16,400 mine features.	Regional	Yes
Bedrock Geology (MRD 126-Revision 1)	Bedrock Geology contains information about the solid rock underlying the Province of Ontario at a compilation scale of 1:250,000. Data includes: bedrock units, major faults, dike swarms, iron formations, kimberlites and interpretation of the Precambrian bedrock geology underlying the Hudson Bay and James Bay lowlands Phanerozoic cover.	Regional	Yes
CLAIMaps	CLAIMaps contains active claims, alienations and dispositions. Data includes: links to further land tenure information.	Regional	Yes
Diabase Dykes (MRD 241)	Stott, G.M. and S.D. Josey, 2009. Post-Archean mafic (diabase) dikes and other intrusions of northwestern Ontario, north of latitude 49°30′; Ontario Geological Survey	Regional	Yes
Drillholes	Drillholes contains information on surface and underground drilling done as outlined by assessment files. Data includes: company name, company hole number, township and a link to the full drillhole record on Geology Ontario.	Regional	Yes
Earthquakes Canada (NEDB)	Geological Survey of Canada Earthquake Search (On-line Bulletin): http://www.earthquakescanada.nrcan.gc.ca/index- eng.php	Regional	Yes
Mineral Deposits Inventory (MDI)	The 2011 database contains an overview of mineral occurrences in the province of Ontario. The data includes the occurrence type (mineral or discretionary), primary and secondary commodity, deposit name and a link to the full record on Geology Ontario.	Regional	Yes
Geochemistry (MRD 242)	Stone, D. 2010. Geochemical analyses of rocks, minerals and soil in the central Wabigoon Subprovince area, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 242.	Regional	Yes
Geochronology (MRD 75)	Geochronology Data for Ontario; Ontario Geological Survey. The compilation covers all isotopic ages greater than 10 Ma for Ontario, and adjacent areas of Manitoba, Michigan, Minnesota, New York and Quebec.	Regional	No (redundant)
Geochronology (MRD 275)	Buse, S., D. Stone, D. Lewis, D. Davis and M.A. Hamilton, 2010. U/Pb Geochronology Results for the Atikokan Mineral Development Initiative	Regional	Yes
Geotechnical Boreholes	Geotechnical Boreholes contains records of boreholes constructed during geotechnical investigations. Data includes: information on the Geological Stratum identified down each hole as well as the hole depth.	Regional	Yes

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

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

Product	*Source*	*Type*	*Line Spacing/ Sensor Height*	*Coverage*	*Date*	*Additional Comments*
Lake Superior	GSC	Fixed wing magnetic	1900m/305m	Covers southwest part of Wawa area	1987	Recorded digitally, levelled to a nationwide magnetic datum.
Ontario #8	GSC	Fixed wing magnetic	805m/305m	Covers northwest part of Wawa area	1962	Recorded on analog charts, navigation and flightpath based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum.
Ontario #17	GSC	Fixed wing magnetic	805m/305m	Covers central and east parts of Wawa area	1963	Recorded on analog charts, navigation and flightpath based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum.
GSC Gravity Coverage	GSC	Ground Gravity Measurements	10-15km/ surface	Entire Wawa area	1949-87	Bouguer gravity field, first vertical derivative, horizontal gradient and the isostatic residual gravity field were extracted from the GSC gravity compilation. Station locations were extracted from the point data.
GSC Radiometric Coverage	GSC	Fixed wing radiometric data	5000m/120m	Entire Wawa area (onshore)	1982	Grids of potassium, equivalent uranium, equivalent thorium, natural air absorbed dose rate, and ratios of eU/K, eTh/K and eU/eTh were extracted from the GSC's nationwide radiometric compilation.
Wawa Survey (GDS1009)	OGS	Helicopter magnetic, FDEM (Dighem III 3-frequency)	200m/ 45m	Focused on the greenstone belts in the northern part of the area, and also covers some metasediments	1988	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic coverage, and provides electromagnetic coverage. The data were reprocessed in 2003, which improved the quality.
Michipicoten Survey (GDS1010)	OGS	Helicopter magnetic, FDEM (HEM-802 2-frequency)	200m/47m	Focused on the Michipicoten Greenstone Belt in the central part of the area	1980	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic coverage, and provides electromagnetic coverage. The data were reprocessed in 2003, which improved the quality.
Magpie River-Missinaibi Lake Survey (GDS1237)	OGS	Helicopter magnetic, TDEM (VTEM)	75m/35-40m	Focused on the greenstone belts in the northeastern part of the area	2006/ 2008	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic coverage, and provides electromagnetic coverage. Its closer line spacing and EM system focused on bedrock sources also provides superior data to Wawa survey (GDS1009), and superior magnetic data to the Kapuskasing-Chapleau survey (GDS1040). The data were reprocessed in 2011, which improved the quality.
Kapuskasing-Chapleau Survey (GDS1040)	OGS	Fixed wing magnetic	200m/100m	Covers northeast part of the area	2001	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic coverage.

Table B.3 Summary of Geoscientific Databases for the Wawa Area

Map Product	*Title*	*Author*	*Source*	*Scale*	*Date*	*Coverage*	*Additional Comments*
ARM11A	Geological Map of the Michipicoten Iron Range	A.P. Coleman A.B. Willmott	OMNDM	1:31680	1902	Partial	Low-res mapping of the Greenstone Belt
ARM36A	Michipicoten area, District of Algoma, Ontario	T.L. Gledhill	OMNDM	1:47520	1927	Partial	Low-res mapping of the Greenstone Belt
ARM36B	Goudreau-Lochalsh area, District of Algoma, Ontario	T.L. Gledhill W.H. Collins E. Thomson	OMNDM	1:63360	1927	Partial	Low-res mapping of the Greenstone Belt
ARM40E	Goudreau gold area, District of Algoma, Ontario	E.S. Moore	OMNDM	1:31680	1931	Partial	Low-res mapping of the Greenstone Belt
ARM49G	Goudreau-Lochalsh area, District of Algoma, Ontario	E.L. Bruce	OMNDM	1:31680	1940	Partial	Low-res mapping of the Greenstone Belt
M1946-02	Township 47 [Riggs Township], District of Algoma, Ontario	E.L. Bruce	OMNDM	1:31680	1946	Partial	Low-res mapping of the Greenstone Belt
M1946-05	Helen iron range, Township 29, ranges 23 and 24 [McMurray and Chabanel townships]	E.S. Moore H.S. Armstrong	OMNDM	1:4800	1946	Partial	Low-res mapping of the Greenstone Belt
M1946-06	Lucy iron range, townships 28 and 29, Range 24 [Esquega and Chabanel townships]	E.S. Moore H.S. Armstrong	OMNDM	1:9600	1946	Partial	Low-res mapping of the Greenstone Belt
M1946-07	Ruth iron range, Township 28, Range 24 [Esquega Township]	E.S. Moore H.S. Armstrong	OMNDM	1:9600	1946	Partial	Low-res mapping of the Greenstone Belt
M1946-08	Josephine-Bartlett iron range, Township 28, Range 25 [Corbiere Township], District of Algoma, Ontario	E.S. Moore H.S. Armstrong	OMNDM	1:9600	1946	Partial	Low-res mapping of the Greenstone Belt
M2139	Township 31 and 30, Range 20, Algoman District	L.D. Ayres	OMNDM	1:31680	1967	Partial	Low-res mapping of SW part of Wawa area

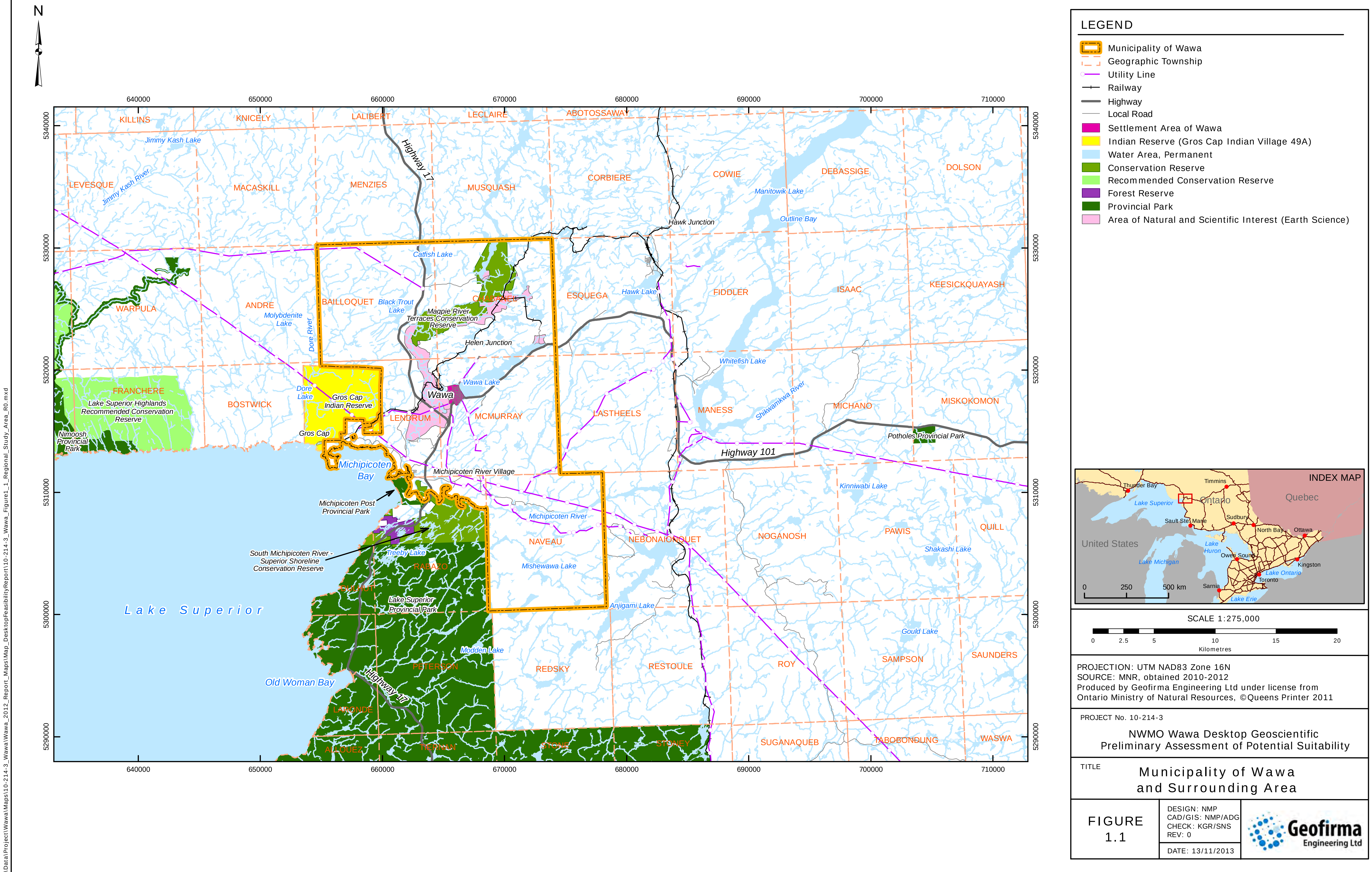
Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
M2333	University River, NTS 41N/14 + 42C/SW,Algoma and Thunder Bay Districts	G. Bennett P.C. Thurston	OMNDM	1:63360	1976	Partial	Low-res mapping of NW part of Wawa area
M2353	Riggs and West townships, NTS 42C/8, Algoma District	P. Srivastava G. Bennett F. Elmhirst M.D. Andrews	OMNDM	1:31680	1977	Partial	Low-res mapping of NE part of Wawa area
M2483	Matchinameigus Lake, Algoma District	M.J. Downes	OMNDM	1:31680	1983	Partial	Low-res mapping of NE part of Wawa area
M2543	Bedrock Geology of Ontario East Central Sheet	Ontario Geological Survey	OMNDM	1:1000000	1991	Full	Digital data release MRD-126 Revision 1 described in Table 3 below
M2555	Quaternary Geology of Ontario East-Central Sheet	P.J. Barnett A.P. Henry D. Babuin	OMNDM	1:1000000		Full	Digital data release MRD-126 Revision 1 described in Table 3 below
M2573	Quaternary Geology, Franz-Manitowik Lake-Kinniwabi Lake Area	T.F. Morris	OMNDM	1:50000	2001	Partial	Detailed mapping of eastern portion of Wawa area
M2574	Quaternary Geology, Hawk Junction-Michipicoten River Area	T.F. Morris	OMNDM	1:50000	2001	Partial	Detailed mapping of central portion of Wawa area
M2666	Precambrian Geology Compilation Series - White River Sheet	F. Santaguida	OMNDM	1:250000	2001	Partial	Compilation mapping of northern part of the Wawa area
M2669	Precambrian Geology Compilation Series - Michipicoten Sheet	G.W. Johns S.J. McIlraith	OMNDM	1:250000	2002	Partial	Compilation mapping of western part of the Wawa area
OFR5532	Geology of the Mishewawa Lake Area, District of Algoma	N.W.D. Massey	OMNDM	1:15,840	1985	Partial	Early geological mapping of the area around the Wawa townsite
OFR5783	Geology of the Iron Lake Area	B.A. Reilly	OMNDM	1:15,840	1991	Partial	Early geological mapping of the northwest part of the Wawa area

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
P0174	Township 31, Range 20 [Allouez Township], District of Algoma	L.D. Ayers	OMNDM	1:15840	1963	Partial	Detailed mapping of the western part of the Wawa area. Some structural information
P0175	Township 30, Range 20 [Tiernan Township], District of Algoma	L.D. Ayers	OMNDM	1:15840	1963	Partial	Detailed mapping of the northern part of the Wawa area. Some structural information
P0423	Highway 101, Chapleau to Wawa, districts of Sudbury and Algoma	P.E. Giblin	OMNDM	1:63360	1967	Partial	Low resolution roadside mapping along Highway 101
P0507	Operation Pukaskwa, University River sheet, districts of Thunder Bay and Algoma	G. Bennett P.C. Thurston J.F. Giguere	OMNDM	1:63360	1969	Partial	Detailed mapping of part of the western part of the Wawa area. Some structural information
P0828	Geological series, McMurray Township and parts of surrounding townships	R.J. Rupert	OMNDM	1:15840	1975	Partial	Detailed mapping of the central part of the Wawa area. Some structural information and time relationships
P2302	Geological series, Matchinameigus Lake area (west half), District of Algoma	M.J. Downes J. Owen	OMNDM	1:15840	1979	Partial	Detailed mapping of the NE part of the Wawa area. Some structural information
P2303	Geological series, Matchinameigus Lake area (east half), District of Algoma	M.J. Downes J. Owen	OMNDM	1:15840	1979	Partial	Detailed mapping of the NE part of the Wawa area. Some structural information
P2406	Precambrian geology of the Molybdenite Lake area covering parts of Andre and Bailloquet townships	Z.L. Mandziuk P.A. Studemeister	OMNDM	1:15840	1981	Partial	Detailed mapping of the western part of the Wawa area. Some structural information

Map Product	***Title***	***Author***	***Source***	***Scale***	***Date***	***Coverage***	***Additional Comments***
P2439	Precambrian geology of Chabanel Township, Algoma District	R. P. Sage Z. Rebic S. Abercrombie K. Neale D.W. MacMillan D. England T. Calvert	OMNDM	1:15840	1982	Partial	Detailed mapping of the central part of the Wawa area. Some structural information
P2440	Precambrian geology of Esquega Township, Wawa area, Algoma District	R. P. Sage Z. Rebic S. Abercrombie K. Neale D.W. MacMillan D. England T. Calvert	OMNDM	1:15840	1982	Partial	Detailed mapping of the central part of the Wawa area. Some structural information
P2441	Geological series, Precambrian geology of McMurray Township, Wawa area, Algoma District	R.P Sage E. Sawitzky J. Turner P. Leeselleur E. Sagle	OMNDM	1:15840	1982	Partial	Detailed mapping of the central part of the Wawa area. Some structural information
P2442	Geological series, Precambrian geology of Lastheels Township, Wawa area, Algoma District	R.P Sage E. Sawitzky J. Turner P. Leeselleur E. Sagle	OMNDM	1:15840	1982	Partial	Detailed mapping of the central part of the Wawa area. Some structural information
P2568	Precambrian geology of Musquash Township, Algoma District	R.P Sage D. England T. Calvert G. Oudkerk R. Worona K. Koscinsko	OMNDM	1:15840	1982	Partial	Detailed mapping of the central part of the Wawa area. Some structural information
P2607	Geological series, Precambrian geology, Corbiere Township, Algoma District	R.P Sage T. Calvert R. Epstein D. England K. Koscinsko R. Worona G. Oudkerk J. Inasi M.B. Lockwood D. Thomas	OMNDM	1:15840	1984	Partial	Detailed mapping of the central part of the Wawa area. Some structural information
P2681	Geological series, Precambrian geology, Lendrum Township and parts of Gros Cap I.R. 49	N.W.D. Massey E. Jennings	OMNDM	1:15840	1983	Partial	Detailed mapping of the central part of the Wawa area. Some structural information

Map Product	***Title***	***Author***	***Source***	***Scale***	***Date***	***Coverage***	***Additional Comments***
P2682	Geological series, Precambrian geology, Rabazo Township, Algoma District	N.W.D. Massey S. Navratil	OMNDM	1:15840	1983	Partial	Detailed mapping of the central part of the Wawa area. Some structural information
P2683	Geological series, Precambrian geology, Naveau Township, Algoma District	N.W.D. Massey S. Navratil E.A. Jennings	OMNDM	1:15840	1983	Partial	Detailed mapping of the central part of the Wawa area. Some structural information
P2684	Geological series, Precambrian geology, Nebonaionquet Township, Algoma District	N.W.D. Massey E.A. Jennings	OMNDM	1:15840	1983	Partial	Detailed mapping of the central part of the Wawa area. Some structural information
P2970	Precambrian geology, Mishibishu Lake area, northeastern section, districts of Thunder Bay and Algoma	R.P. Bowen J. Logothetis K.B. Heather	OMNDM	1:15840	1986	Partial	Detailed mapping of the western part of the Wawa area. Some structural information
P2972	Precambrian Geology Mishibishu Lake Area	R.P. Bowen J. Logothetis K.B. Heather	OMNDM	1:15840	1986	Partial	Detailed mapping of the western part of the Wawa area. Some structural information
P3148	Generalized Precambrian geology, Mishibishu Lake area	R.G. Reid R.P. Bowen K.B. Heather J. Logothetis B.A. Reilly	OMNDM	1:50000	1992	Partial	Detailed mapping of the western part of the Wawa area. Some structural information
P3152	Precambrian geology, Mishibishu Lake area, Mishibishu Lake sheet	R.G. Reid R.P. Bowen K.B. Heather J. Logothetis B.A. Reilly	OMNDM	1:15840	1992	Partial	Detailed mapping of part of the western part of the Wawa area. Some structural information
P3153	Precambrian geology, Mishibishu Lake area, Jostle Lake sheet	R.G. Reid R.P. Bowen K.B. Heather J. Logothetis B.A. Reilly	OMNDM	1:15840	1992	Partial	Detailed mapping of part of the western part of the Wawa area. Some structural information

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
P3156	Precambrian geology, Mishibishu Lake area, Point Isacor sheet	R.G. Reid R.P. Bowen K.B. Heather J. Logothetis B.A. Reilly	OMNDM	1:15840	1992	Partial	Detailed mapping of part of the western part of the Wawa area. Some structural information
P3157	Precambrian geology, Mishibishu Lake area, Dog Harbour sheet	R.G. Reid R.P. Bowen K.B. Heather J. Logothetis B.A. Reilly	OMNDM	1:15840	1992	Partial	Detailed mapping of part of the western part of the Wawa area. Some structural information
P3184	Marginal notes, Mishibishu Lake area	R.G. Reid R.P. Bowen K.B. Heather J. Logothetis B.A. Reilly	OMNDM	Various	1992	Partial	Mapping notes for specific localities in the Mishibishu Lake area
P3303	Precambrian Geology, Michipicoten Greenstone Belt, Central Portion	R.P. Sage	OMNDM	1:50000	1994	Partial	Detailed mapping of the central part of the Wawa area with mapped structures.
P3304	Bedrock Geochemical Sample Location Map, Michipicoten Greenstone Belt, Central Portion	R.P. Sage	OMNDM	1:50000	1994	Partial	Detailed geochemical mapping of lake bottom sediments for the central part of the Wawa area.
P3322	Alteration Zones of the Central Portion of the Michipicoten Greenstone Belt	R.P. Sage	OMNDM	1:50000	1995	Partial	Detailed mapping of the central part of the Wawa area with mapped structures.
P3366	Precambrian geology, Menzies Township	C. Vaillancourt G.R. Dessureau S.M. Zubowski	OMNDM	1:20000	2005	Partial	Detailed mapping of part of the western part of the Wawa area with structural information. Mapping included in MRD-151



PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Municipality of Wawa and Surrounding Area

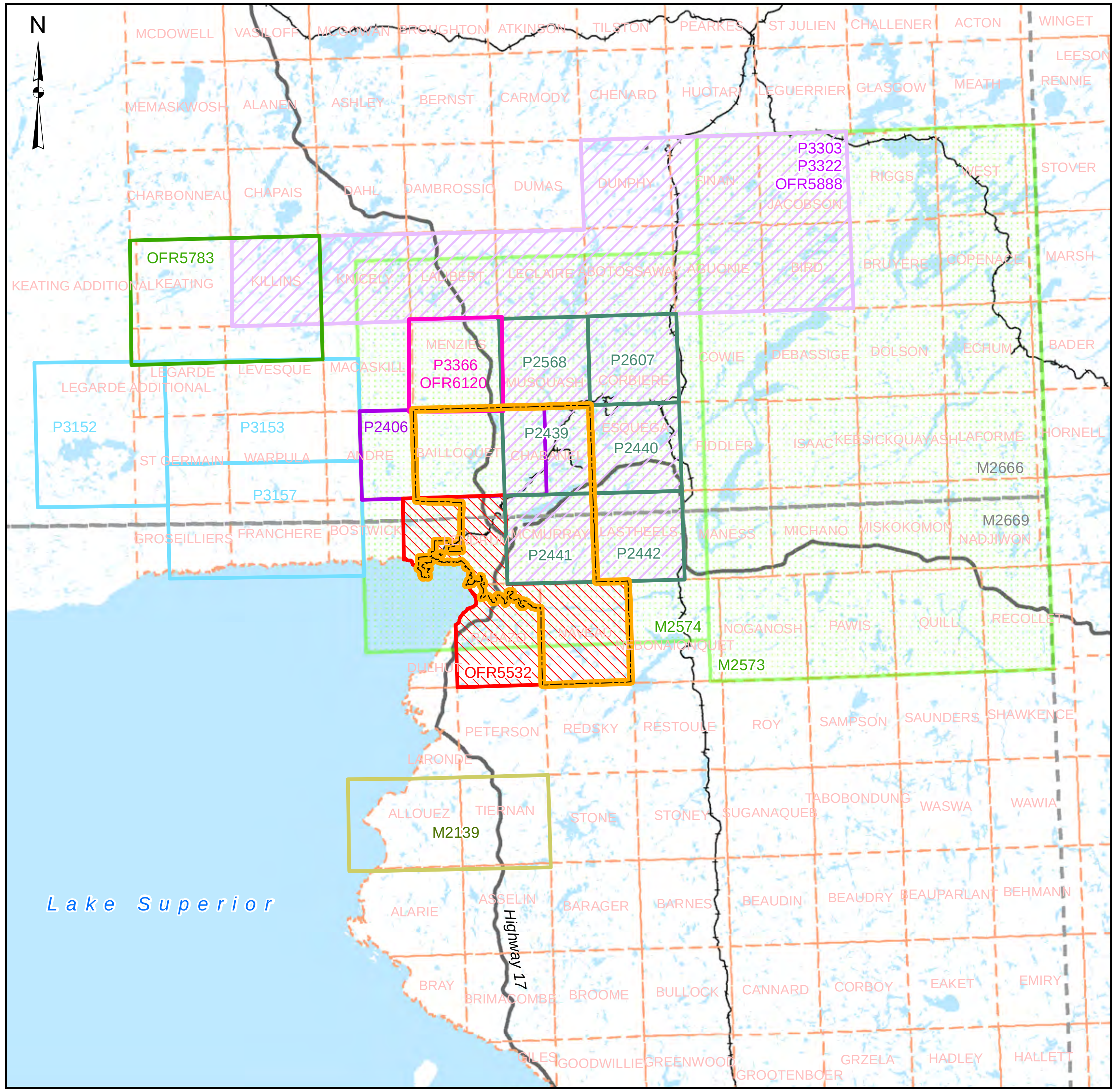
FIGURE 1.1

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

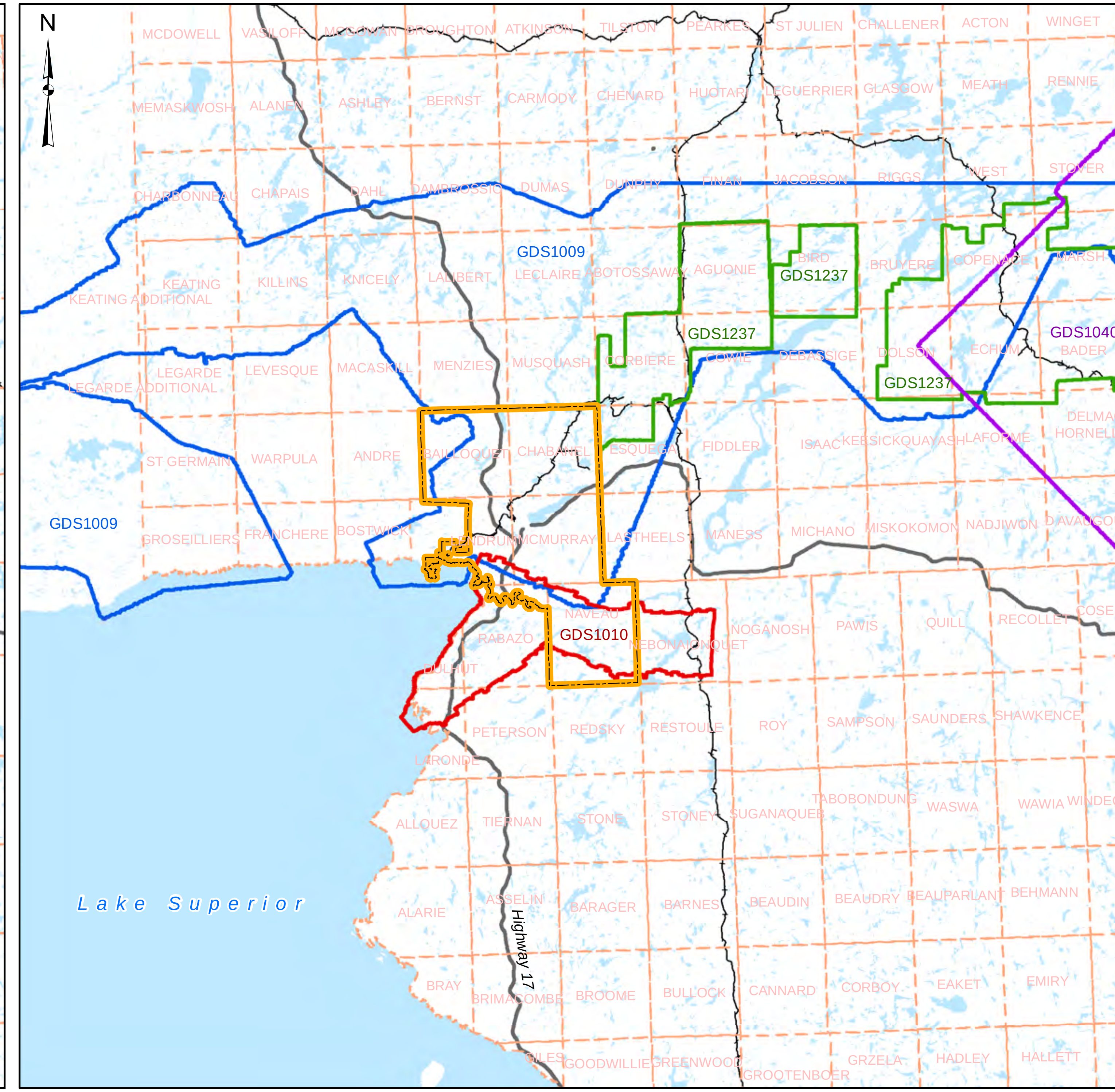
DATE: 13/11/2013

Geofirma Engineering Ltd

Geology Mapping Coverage



Geophysics Mapping Coverage



LEGEND

- Municipality of Wawa
- Geographic Township
- Highway
- Railway
- Water Area, Permanent

Detailed Geology Extent

- Ayres, 1967 (M2139)
- Mandziuk & Studemeister, 1981 (P2406)
- Massey, 1985 (OFR5532)
- Morris, 2001 a,b (M2573, M2574)
- Reilly, 1991 (OFR5783)
- Vaillancourt et al, 2003 (OFR6120), 2005 b (P3366)
- Reid et al, 1992 a,b,c (P3157, P3153, P3152)
- Sage, 1982 a,b,c,d,e,f (P2439, P2440, P2441, P2442, P2568, P2607)
- Sage, 1994 a,b (P3303, OFR5888); 1995 (P3322)
- Santaguida, 2001 (M2666), Johns & McIlraith, 2002 (M2669)

Full Geology Coverage

OGS Quaternary Geology of Ontario (Barnett et al, 1991)
OGS Bedrock Geology of Ontario 2011 (MRD 126)
OGS Northern Ontario Engineering Geology Terrain Study (Gartner & McQuay, 1979 a,b; McQuay, 1980)

Full Geophysics Coverage

GSC Gravity 1949-1987
GSC Radiometric 1982
GSC Magnetic 1962, 1987

SCALE 1:600,000

0 5 10 20 30 40
Kilometres

Geophysical Survey Extent

- Michipicoten Area (GDS1010)
- Kapuskasing-Chapleau (GDS1040)
- Magpie River-Missinaibi Lake Area (GDS1237)
- Wawa Area (GDS1009)

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

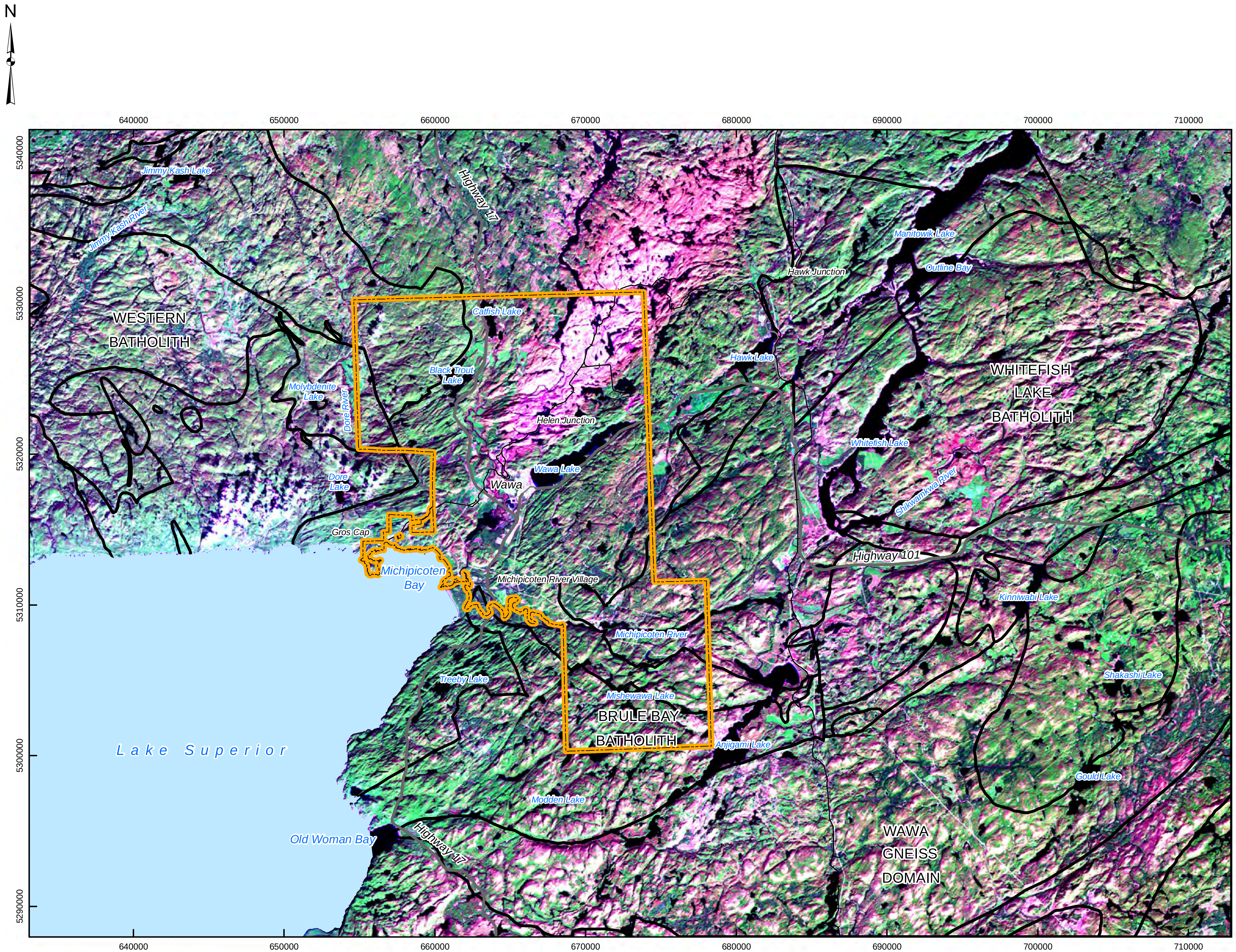
PROJECT No. 10-214-3
NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE
Geoscience Mapping and Geophysical Coverage of the Wawa Area

FIGURE 1.2

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 11/8/2013

Geofirma Engineering Ltd



LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Outline of Geologic Unit

Landsat

- Red: Band 7
- Green: Band 4
- Blue: Band 2

INDEX MAP

SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Imagery: Landsat 7, USGS
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Produced by Geofirma Engineering Ltd under license from Ontario Ministry of Natural Resources, ©Queens Printer 2011

PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Satellite Imagery of the Wawa Area

FIGURE 2.1

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 11/7/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure2_1_Landsat_Satellite_Imagery_R0.mxd

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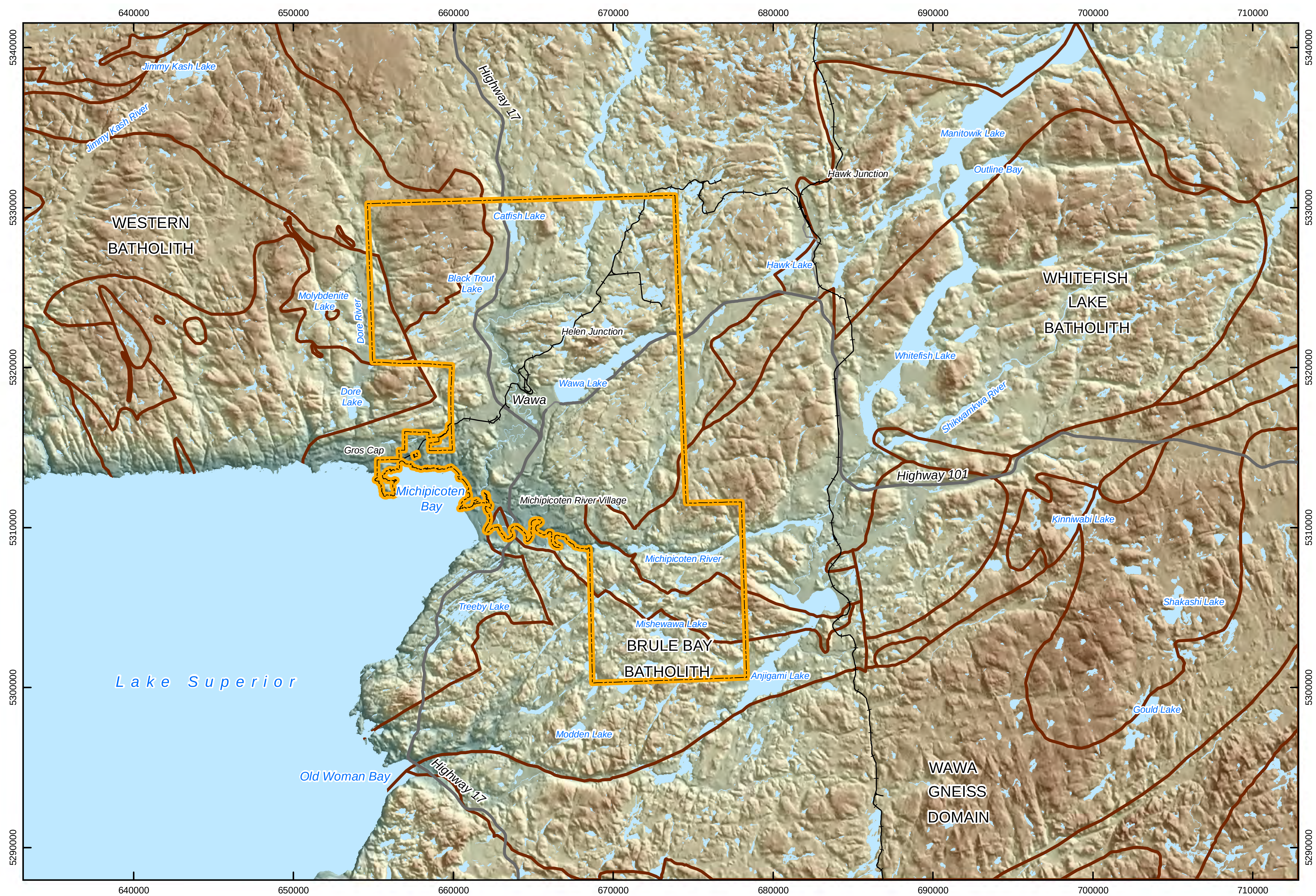
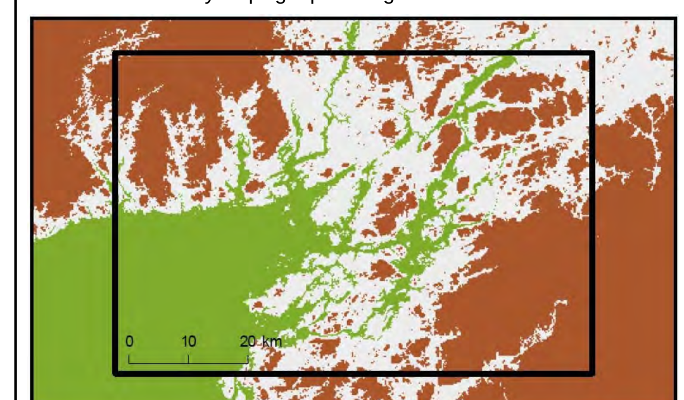


LEGEND

Municipality of Wawa
Highway
Local Road
Railway
Water Area, Permanent
Outline of Geologic Unit

Elevation (mASL)
610
356
185

Key Topographic Highs and Lows



Elevation (mASL)
185 - 320
321 - 410
411 - 650

SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

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

PROJECT No. 10-214-3
NWMO Wawa Desktop Geoscientific
Preliminary Assessment of Potential Suitability

TITLE
Elevation and Major Topographic
Features of the Wawa Area

FIGURE
2.2

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

DATE: 11/7/2013

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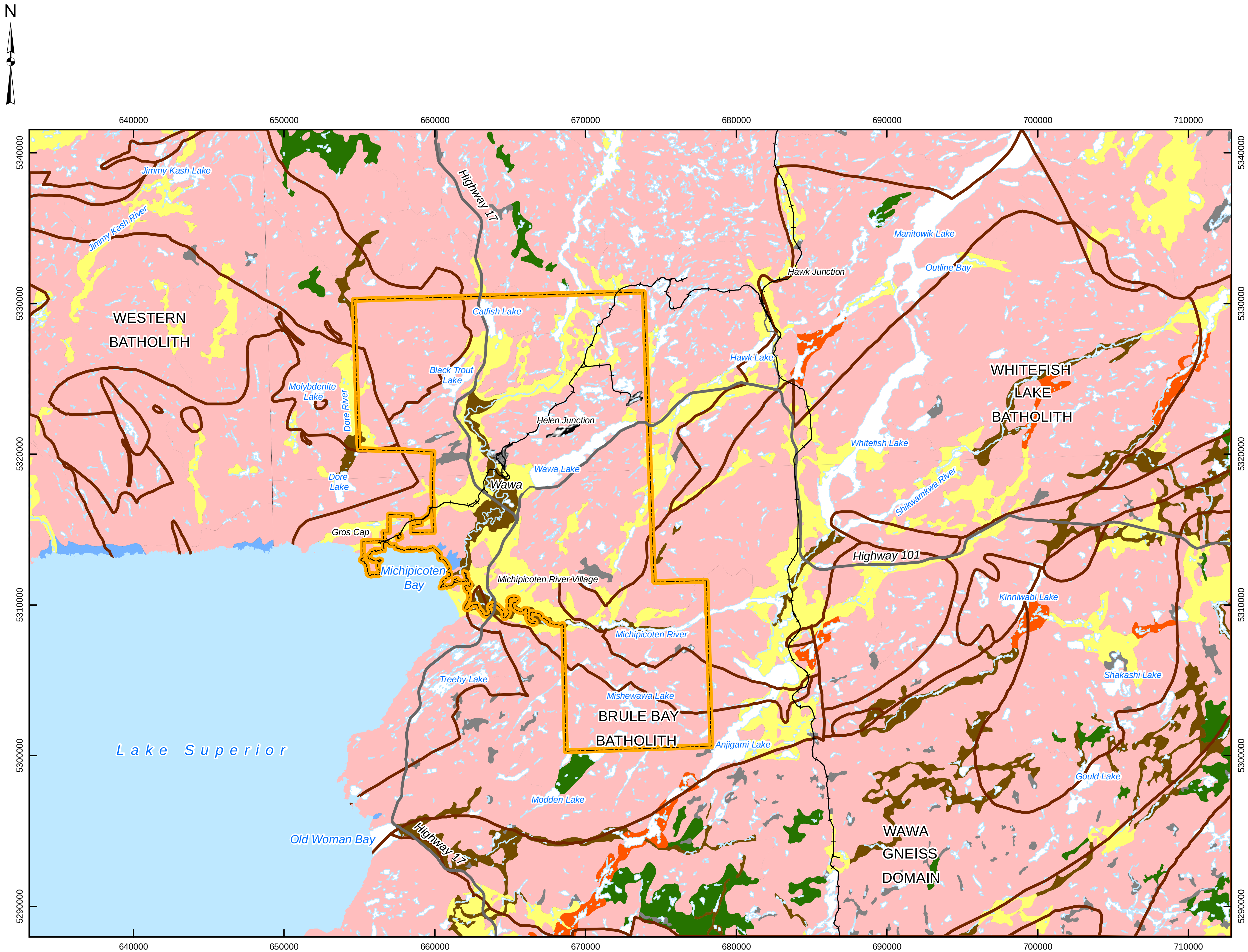
Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure2_2_Elevation_and_Major_Topographic_Features_R0.mxd



LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Outline of Geologic Unit

Surficial Geology (NOEGTS)

- Modern alluvial
- Glaciofluvial esker
- Bedrock
- Ground moraine
- Glaciofluvial outwash
- Glaciolacustrine
- Organic

Map of Surficial Cover
Created from NOEGTS and MNR Waterbody

- Surficial/Water/Wetland (34%)
- Bedrock Terrain (66%)

SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 20010-2012
NOEGTS: OGS MRD-160 (scale 1:100,000)
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Produced by Geofirma Engineering Ltd under license from
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific
Preliminary Assessment of Potential Suitability

TITLE

Terrain Features of the Wawa Area

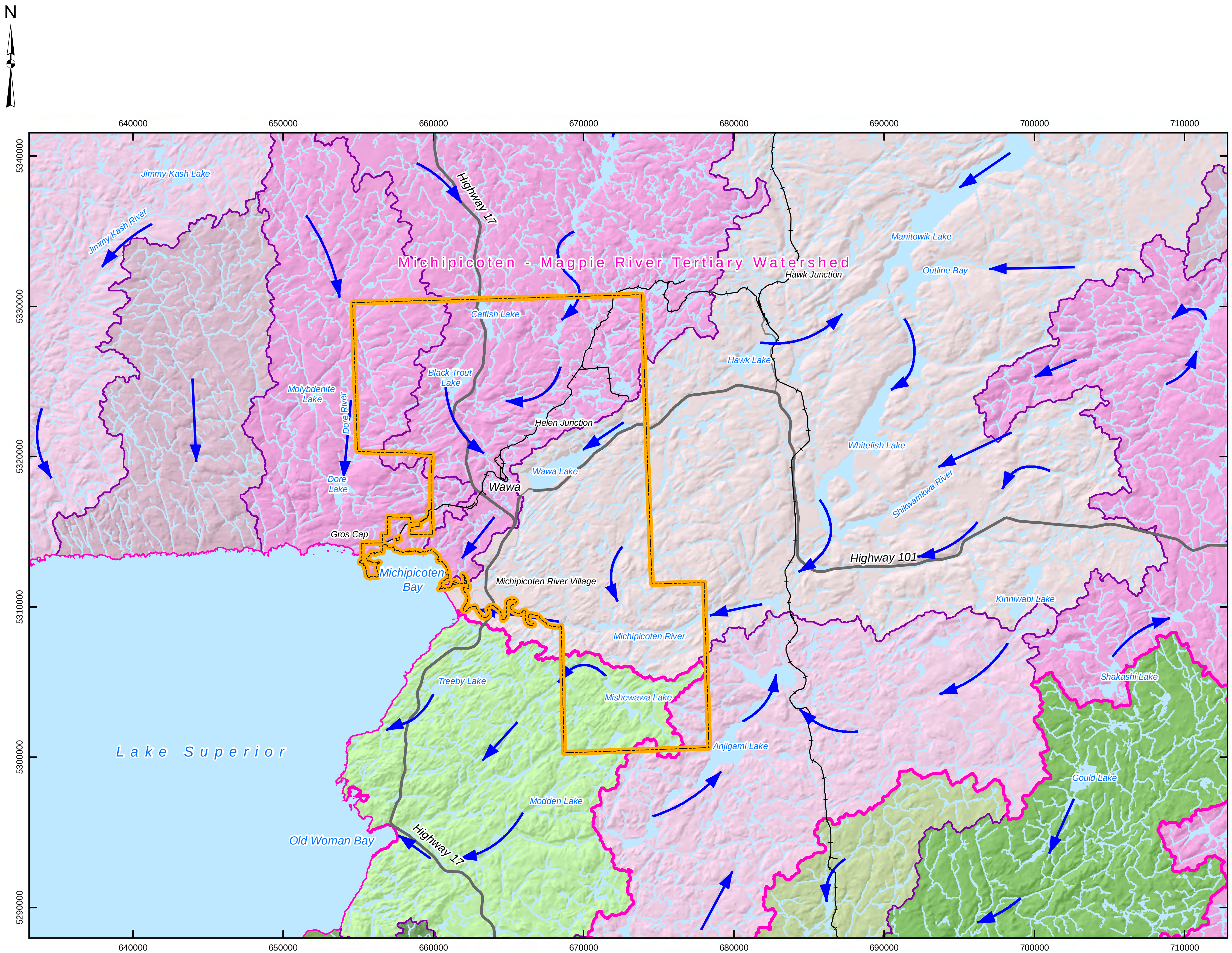
FIGURE
2.3

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

DATE: 11/8/2013

Geofirma
Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure2_3_Terrain_Features_of_the_Wawa_Area_R0.mxd



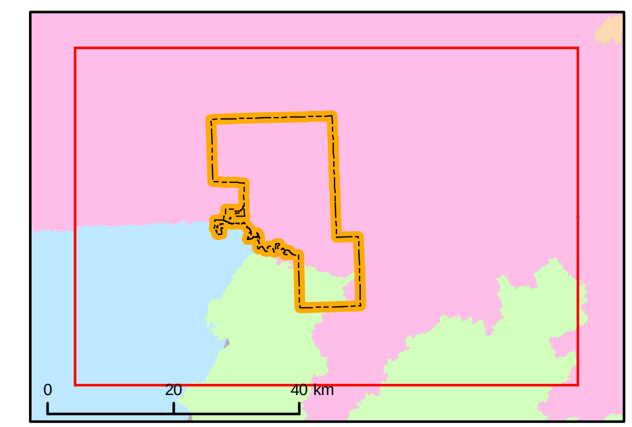
G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure2_4_Drainage_Features_of_the_Wawa_Area_R0.mxd

LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Surface Water Flow Direction
- Tertiary Watershed Boundary

Quaternary Watershed Boundary
- MNR/JDMA
- JDMA
- MNR

Map of Tertiary Watersheds



- Municipality of Wawa

Tertiary Watersheds
- Agawa sub-sub basin
- Michipicoten - Magpie sub-sub basin

SCALE 1:275,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2009-2012
Quaternary Watershed: MNR, JDMA, 2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Underlying DEM: CDED Digital Elevation Model, Geobase, 2011
Produced by Geofirma Engineering Ltd under license from
Ontario Ministry of Natural Resources, ©Queens Printer 2011

PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific
Preliminary Assessment of Potential Suitability

TITLE

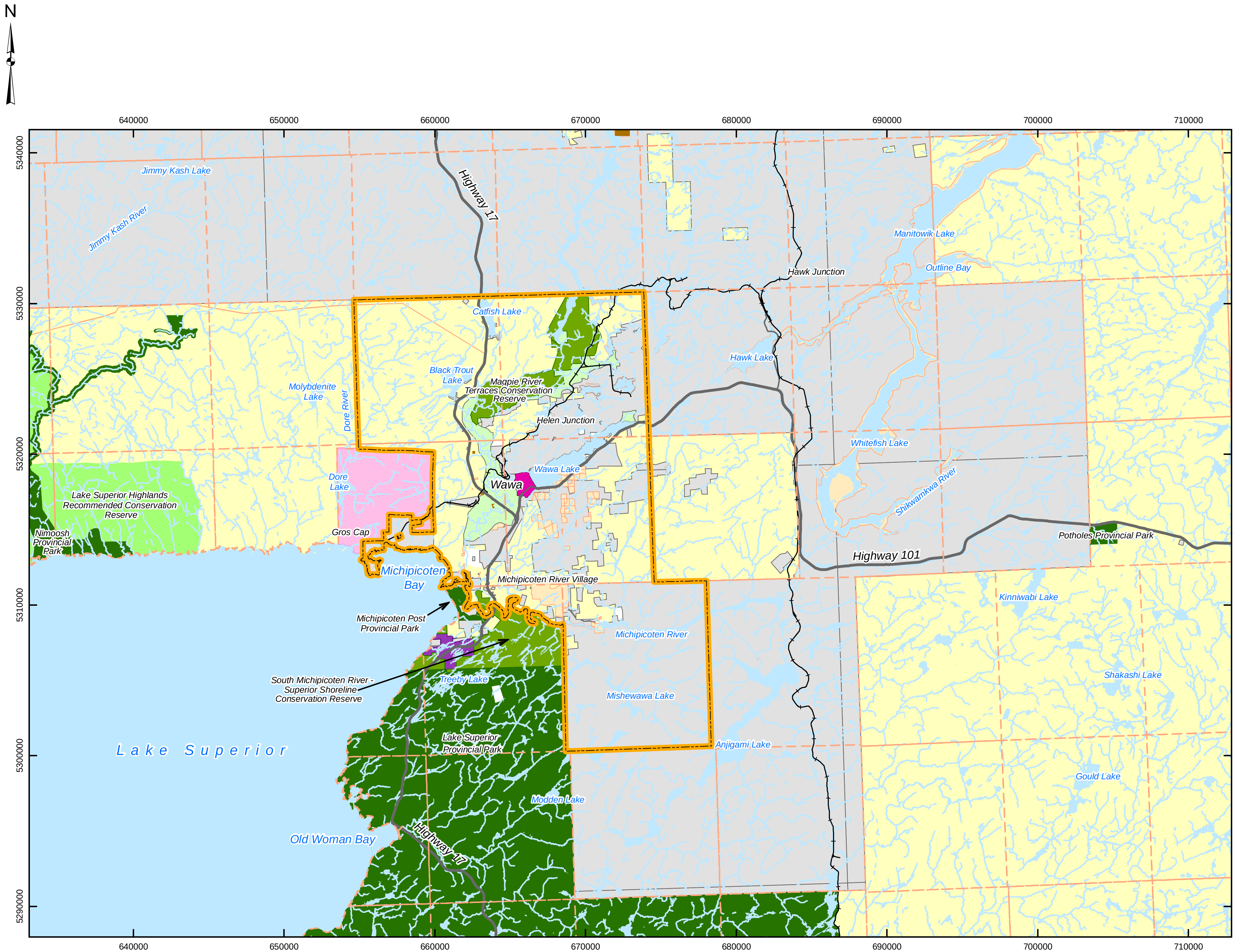
Drainage Features of the Wawa Area

FIGURE 2.4

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

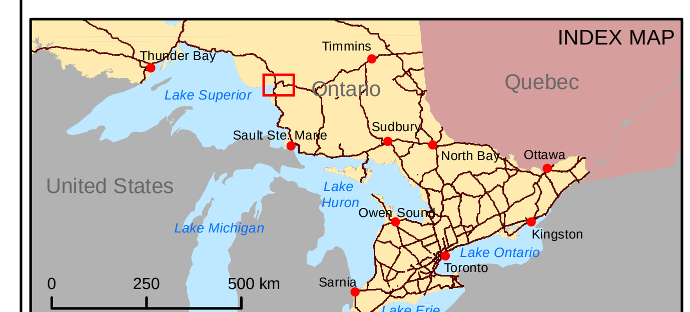
DATE: 11/11/2013

Geofirma Engineering Ltd



LEGEND

- Municipality of Wawa
- Settlement Area of Wawa
- Geographic Township
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Watercourse, Permanent
- Watercourse, Intermittent
- Conservation Reserve
- Recommended Conservation Reserve
- Forest Reserve
- Provincial Park
- Area of Natural and Scientific Interest (Earth Science)
- Crown Leased Land
- Crown Land - Non-Freehold Dispositions Public
- Crown Land - Unpatented Public Land
- Federal Land - Indian Reserve
- Private Land



SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012, NWMO
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE Land Disposition and Ownership within the Wawa Area

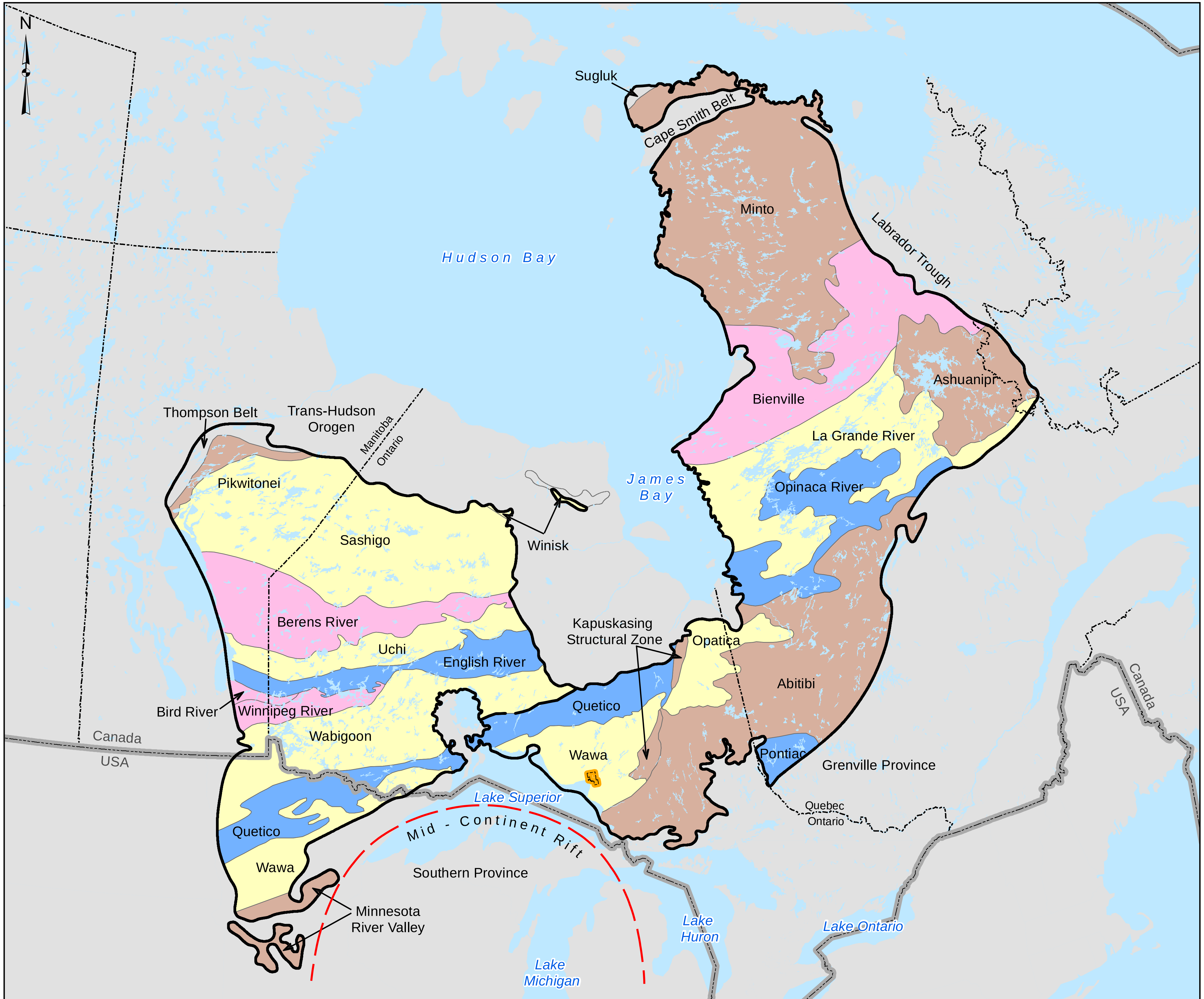
FIGURE 2.5

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

DATE: 13/11/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure2_5_Land_Disposition_Ownership_R0.mxd

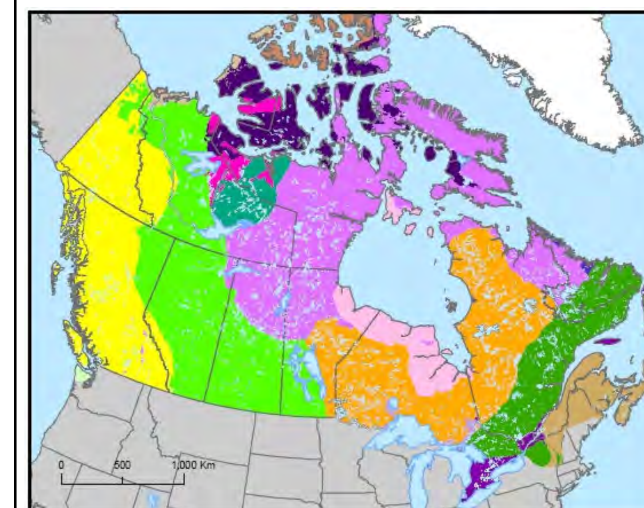


LEGEND

- Municipality of Wawa
- Provincial Boundary
- International Boundary
- Limit of Exposed Archean Rock

Superior Province (Archean)

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



Geological Regions of Canada

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

SCALE 1:9,500,000

0 75 150 300 450 600
Kilometres

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

PROJECT No. 10-214-3
NWMO Wawa Desktop Geoscientific
Preliminary Assessment of Potential Suitability

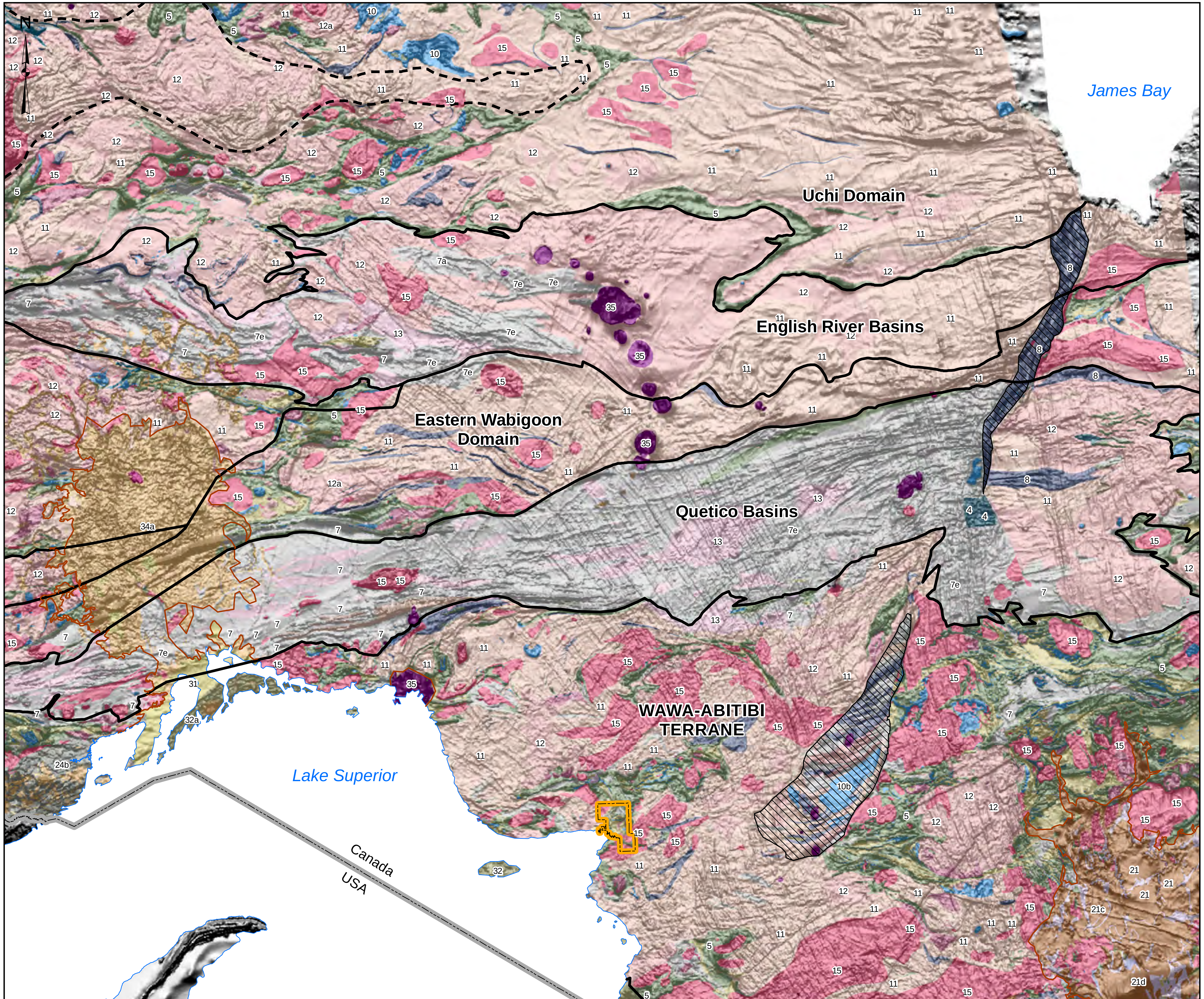
TITLE Subdivision of the Superior Province of the Canadian Shield

FIGURE 3.1

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 8/18/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_1_Subdivision_of_the_Superior_Province_CanadianShield_R0.mxd



LEGEND

- Municipality of Wawa
- Kapuskasing Structural Zone
- Proterozoic Embayment
- Terrane Boundary
- Domain Boundary

Bedrock Geology

- 56 Sandstone, shale, dolostone, siltstone
- 55 Shale, limestone, dolostone, siltstone
- 49 Mafic to ultramafic plutonic rocks
- 38 Carbonate-alkalic intrusive suite (450 to 600 Ma)
- 36 Jacobsville Gp.; Oronto Gp
- 35 Carbonatite-alkalic intrusive suite (1.0 to 1.2 Ga)
- 34 Mafic and related intrusive rocks (Keweenawan age)
- 32 Osler Gp., Maminse Point Fm., Michipicoten Island Fm
- 31 Sibley Gp.
- 30 Felsic intrusive rocks
- 29 Sudbury Igneous Complex (1850 Ma), norite, gabbro, granophyre
- 28 Whitewater Gp.
- 27 Carbonatite-alkalic intrusive suite (ca. 1.9 Ga)
- 24 Sedimentary Rocks (Animikie Group): wacke, shale, iron formation, limestone, minor volcanic rocks, conglomerate, taconite, aldal chert, carbonate rocks, argillite-tuff
- 23 Mafic and related intrusive rocks
- 21 Cobalt Gp.: siltstone,argillite, sandstone, conglomerate
- 20 Quirke Lake Gp.: sandstone, siltstone, conglomerate, limestone, dolostone
- 19 Hough Lake Gp.: siltstone, wacke, argillite, quartz-feldspar sandstone, conglomerate, sandstone
- 17 Mafic and ultramafic intrusive rocks
- 16 Hornblendite - nepheline syenite suite
- 15 Massive granodiorite to granite
- 14-Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- 4 Mafic to ultramafic metavolcanic rocks
- 3 Mafic metavolcanic and metasedimentary rocks
- 2 Felsic to intermediate metavolcanic rocks

SCALE 1:2,500,000

0 20 40 80 120 160

Kilometres

PROJECTION: UTM NAD83 Zone16N
SOURCE: NRC, Terrane: Stott, G., M.T. Corkery, J.A. Percival, M. Simard, J. Goutier 2010. A Revised Terrane Subdivision for the Superior Province; Ontario Geological Survey (MRD-278)
Geophysical underlay: Ontario #7, GSC, 800 m line spacing
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Terrane Subdivision of the Central Superior Province

FIGURE 3.2

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

DATE: 11/7/2013

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G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_2_Terrane_Subdivision_of_the_Central_Superior_Province_R0.mxd

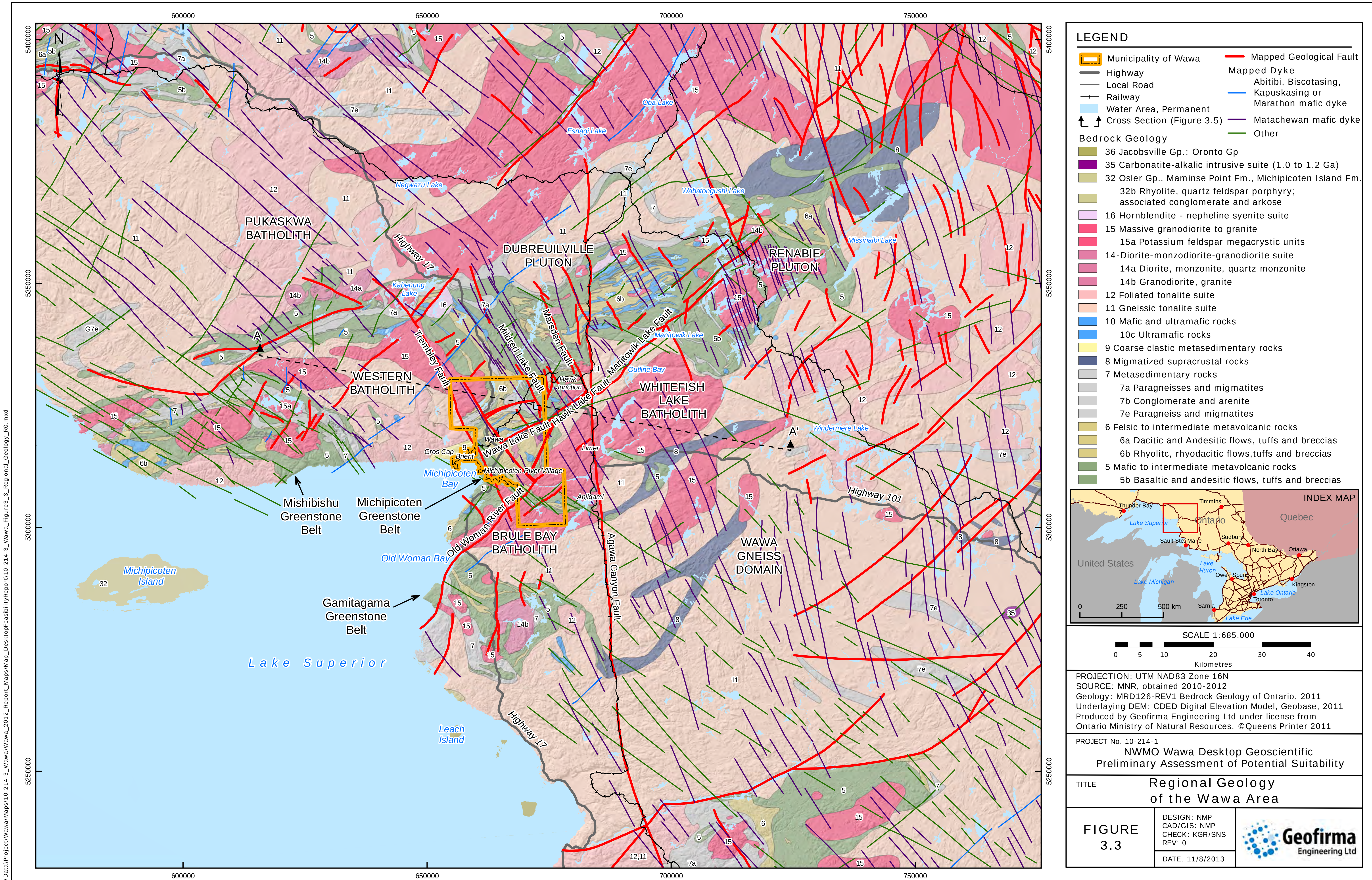
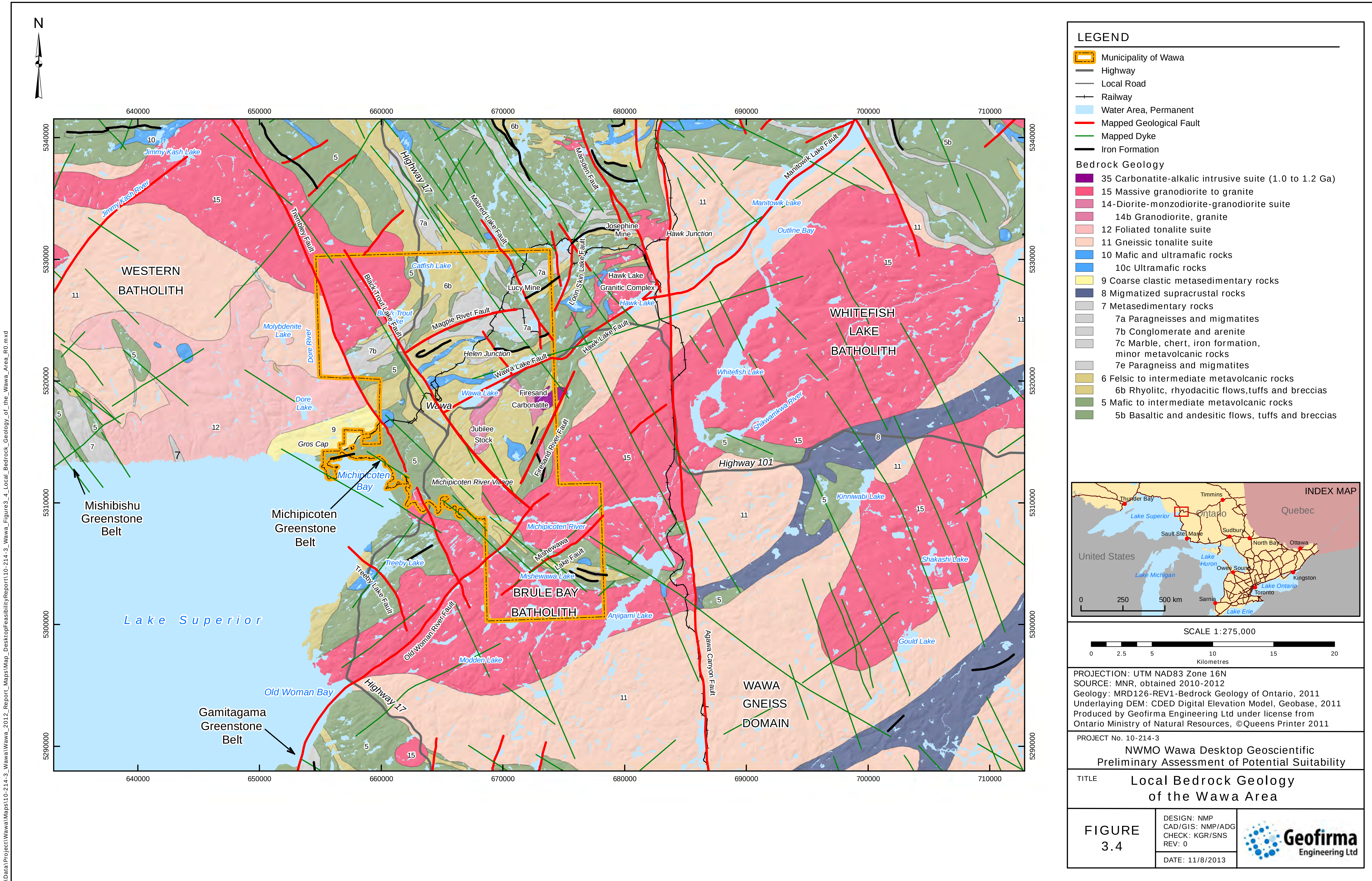


FIGURE 3.3 Regional Geology of the Wawa Area



N
WESTERN BATHOLITH
WHITEFISH LAKE BATHOLITH
BRULE BAY BATHOLITH
WAWA GNEISS DOMAIN
Mishibishu Greenstone Belt
Michipicoten Greenstone Belt
Gamitagama Greenstone Belt
Lake Superior
Wawa
Michipicoten Bay
Old Woman Bay
Gros Cap
Highway 17
Highway 101
Hawk Junction
Michipicoten River Village
Firesand Carbonatite
Jubilee Stock
Helen Junction
Lucy Mine
Josephine Mine
Hawk Lake Granitic Complex
Black Trout Lake Fault
Magpie River Fault
Wawa Lake Fault
Hawk Lake Fault
Firesand River Fault
Mishewawa Lake Fault
Treeby Lake Fault
Old Woman River Fault
Agawa Canyon Fault
Manitowik Lake Fault
Tremblay Fault
Mildred Lake Fault
Marsden Fault
Loon Skin Lake Fault
Jimmy Kash Lake
Jimmy Kash River
Catfish Lake
Molybdenite Lake
Dore River
Dore Lake
Wawa Lake
Hawk Lake
Manitowik Lake
Outline Bay
Whitefish Lake
Shikwamkwa River
Kinniwabi Lake
Shakashi Lake
Gould Lake
Anjigami Lake
Mishewawa Lake
Michipicoten River
Treeby Lake
Modden Lake
LEGEND
Municipality of Wawa
Highway
Local Road
Railway
Water Area, Permanent
Mapped Geological Fault
Mapped Dyke
Iron Formation
Bedrock Geology
35 Carbonatite-alkalic intrusive suite (1.0 to 1.2 Ga)
15 Massive granodiorite to granite
14-Diorite-monzodiorite-granodiorite suite
14b Granodiorite, granite
12 Foliated tonalite suite
11 Gneissic tonalite suite
10 Mafic and ultramafic rocks
10c Ultramafic rocks
9 Coarse clastic metasedimentary rocks
8 Migmatized supracrustal rocks
7 Metasedimentary rocks
7a Paragneisses and migmatites
7b Conglomerate and arenite
7c Marble, chert, iron formation, minor metavolcanic rocks
7e Paragneiss and migmatites
6 Felsic to intermediate metavolcanic rocks
6b Rhyolitic, rhyodacitic flows,tuffs and breccias
5 Mafic to intermediate metavolcanic rocks
5b Basaltic and andesitic flows, tuffs and breccias
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
Sarnia
Lake Erie
0 250 500 km
SCALE 1:275,000
0 2.5 5 10 15 20
Kilometres
PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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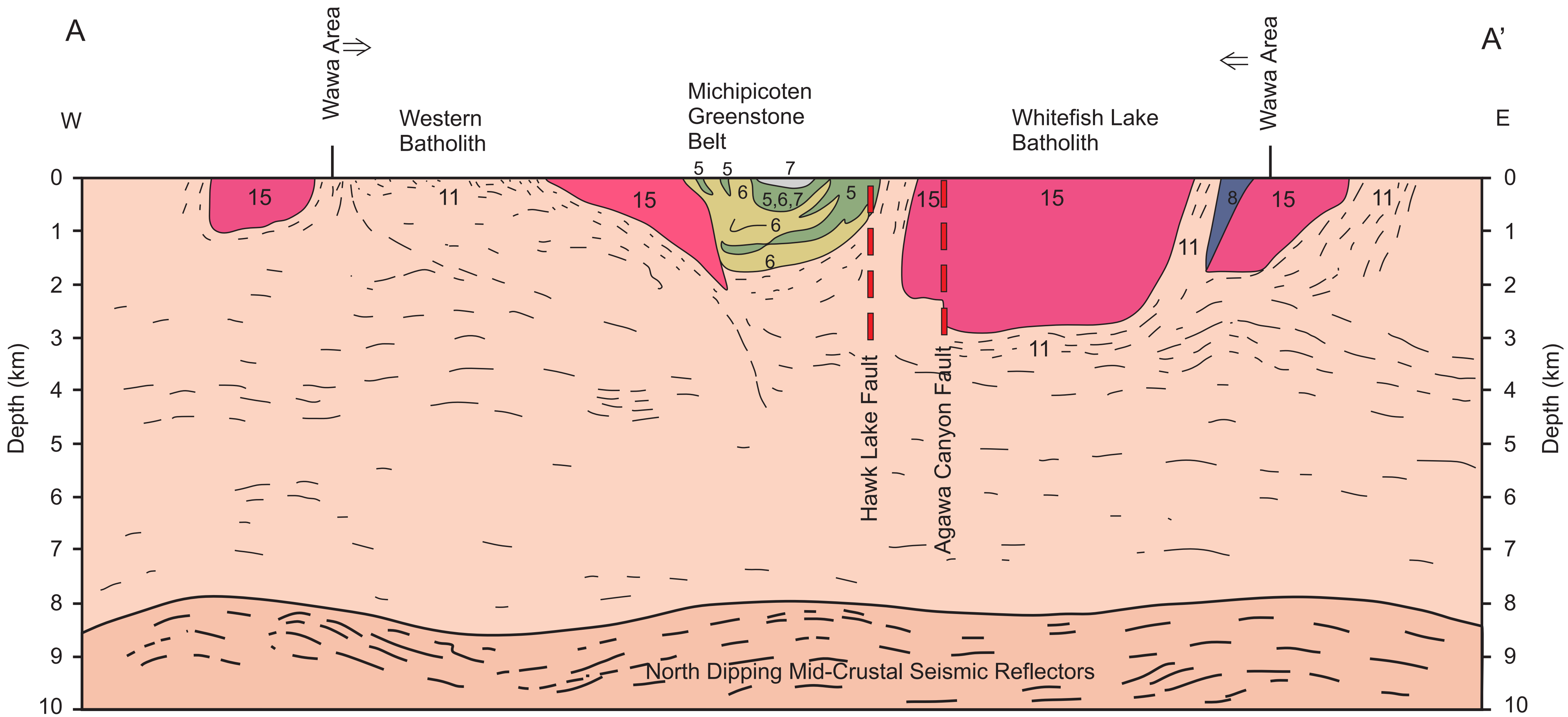
PROJECT No. 10-214-3
NWMO Wawa Desktop Geoscientific
Preliminary Assessment of Potential Suitability
TITLE
Local Bedrock Geology
of the Wawa Area
FIGURE
3.4
DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 11/8/2013
Geofirma Engineering Ltd
G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_4_Local_Bedrock_Geology_of_the_Wawa_Area_R0.mxd

CONCEPTUAL CROSS SECTION ACROSS
WESTERN BATHOLITH-MICHIPICOTEN BELT - WHITEFISH LAKE BATHOLITH

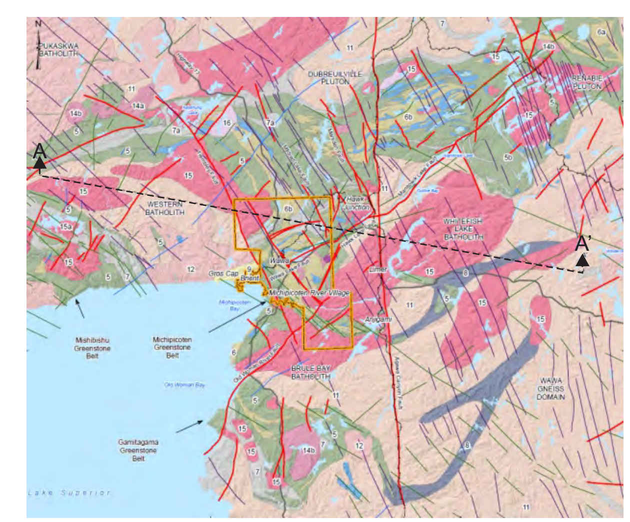


0 10 20 30 km

Vertical Exaggeration = 4.5x

LEGEND

- 15 Massive granodiorite to granite
- 11 Gneissic tonalite suite
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
- 6 Felsic to intermediate metavolcanic rocks
- 5 Mafic to intermediate metavolcanic rocks
- Foliation and seismic reflectors
- Fault



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

Conceptual Geologic Cross Section - Wawa Area NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability		Prepared by: ADG Reviewed by: KGR
FIGURE 3.5	Doc. No.:10-214-3_Wawa_Fig3_5_Cross_Section_R0	Date: Aug 20, 2013

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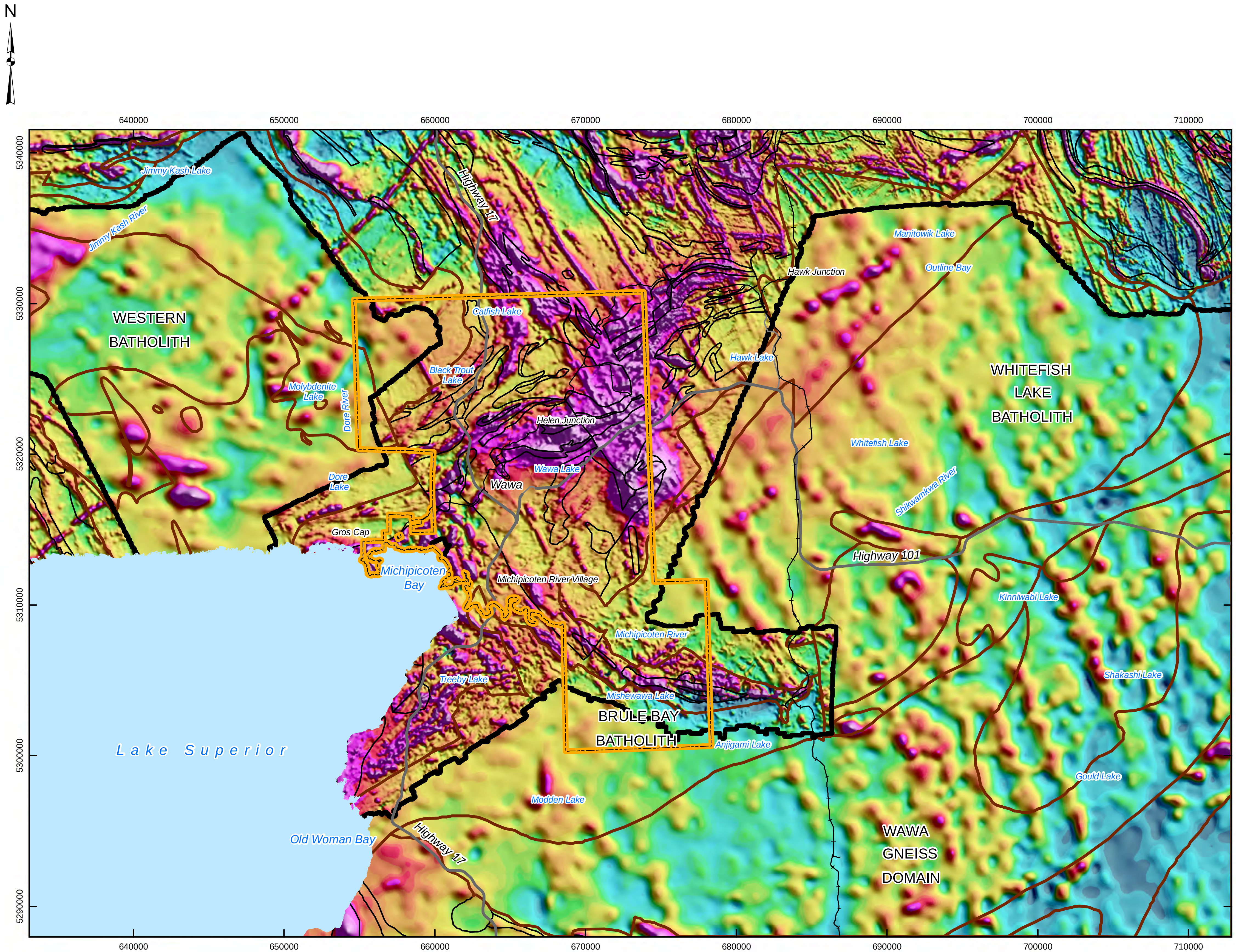


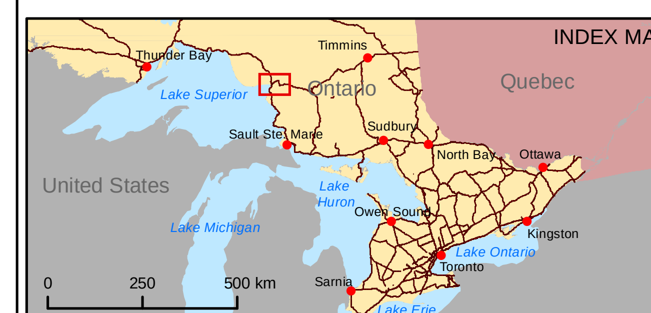
LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Geological Contact
- Outline of Geologic Unit
- Higher Resolution Geophysical Surveys

Residual Total MagneticField (nT)

440, 280, 200, 140, 100, 80, 60, 40, 20, 0, -20, -40, -60, -80, -100, -120, -140, -160, -180, -200, -240, -260, -280, -300, -320

RTP
(nT)



SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Airborne Geophysics: MAG, PGW, 2013
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
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PROJECT No. 10-214-3
NWMO Wawa Desktop Geoscientific
Preliminary Assessment of Potential Suitability

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

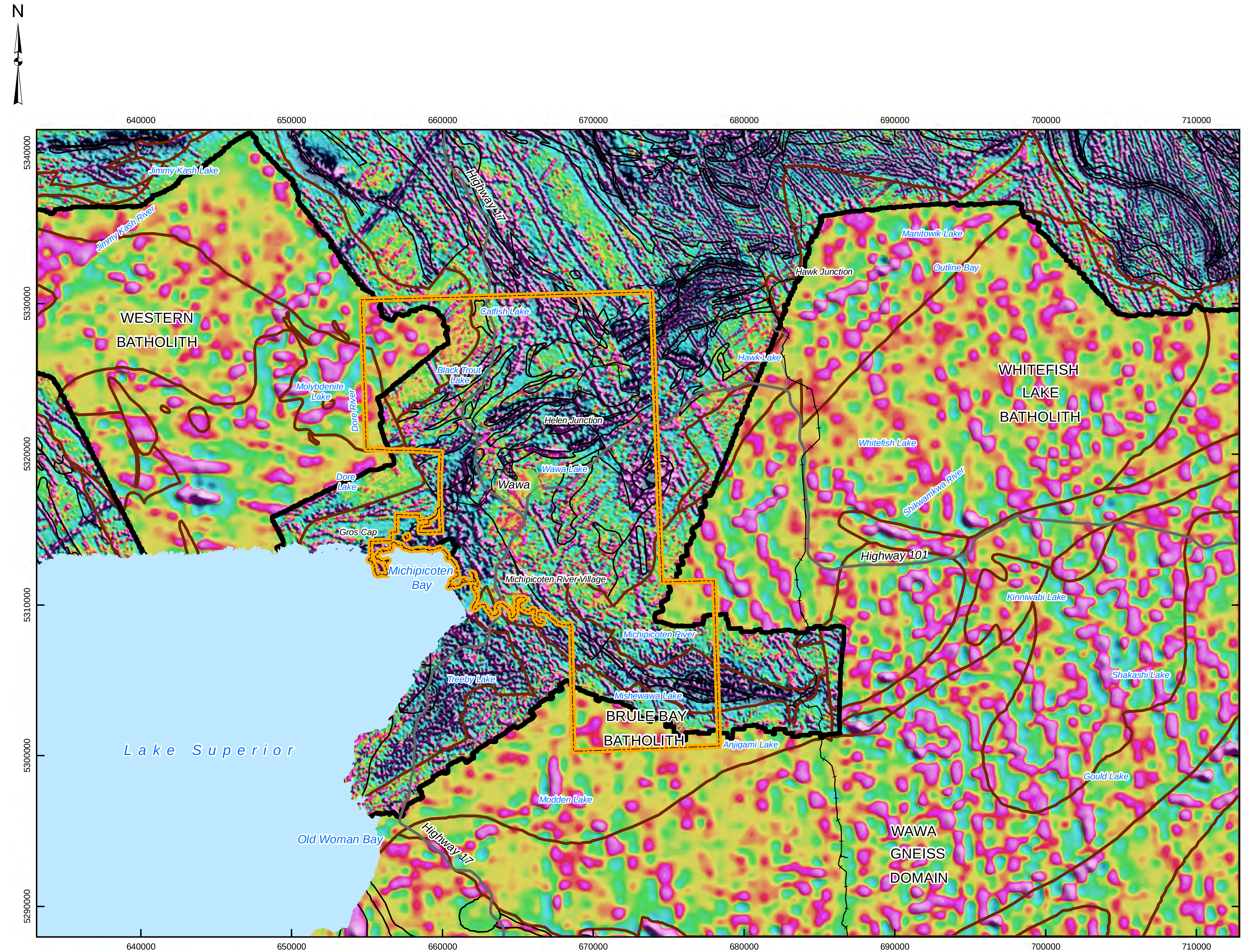
FIGURE
3.6

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

DATE: 11/8/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_6_Total_Magnetic_Field_R0.mxd



G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_7_First_Vertical_Derivative_Magnetic_Field_R0.mxd

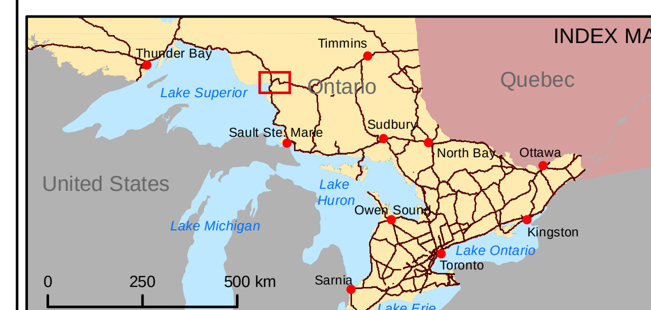
LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Geological Contact
- Outline of Geologic Unit
- Higher Resolution Geophysical Surveys

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

1.155, 0.525, 0.300, 0.190, 0.130, 0.085, 0.060, 0.040, 0.020, 0.005, 0.000, -0.010, -0.015, -0.025, -0.035, -0.050, -0.065, -0.080, -0.100, -0.120, -0.150, -0.180, -0.220, -0.275, -0.355, -0.475, -0.675, -1.115

1VD of RTP (nT/m)



SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Airborne Geophysics: MAG (First Vertical Derivative), PGW, 2013
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

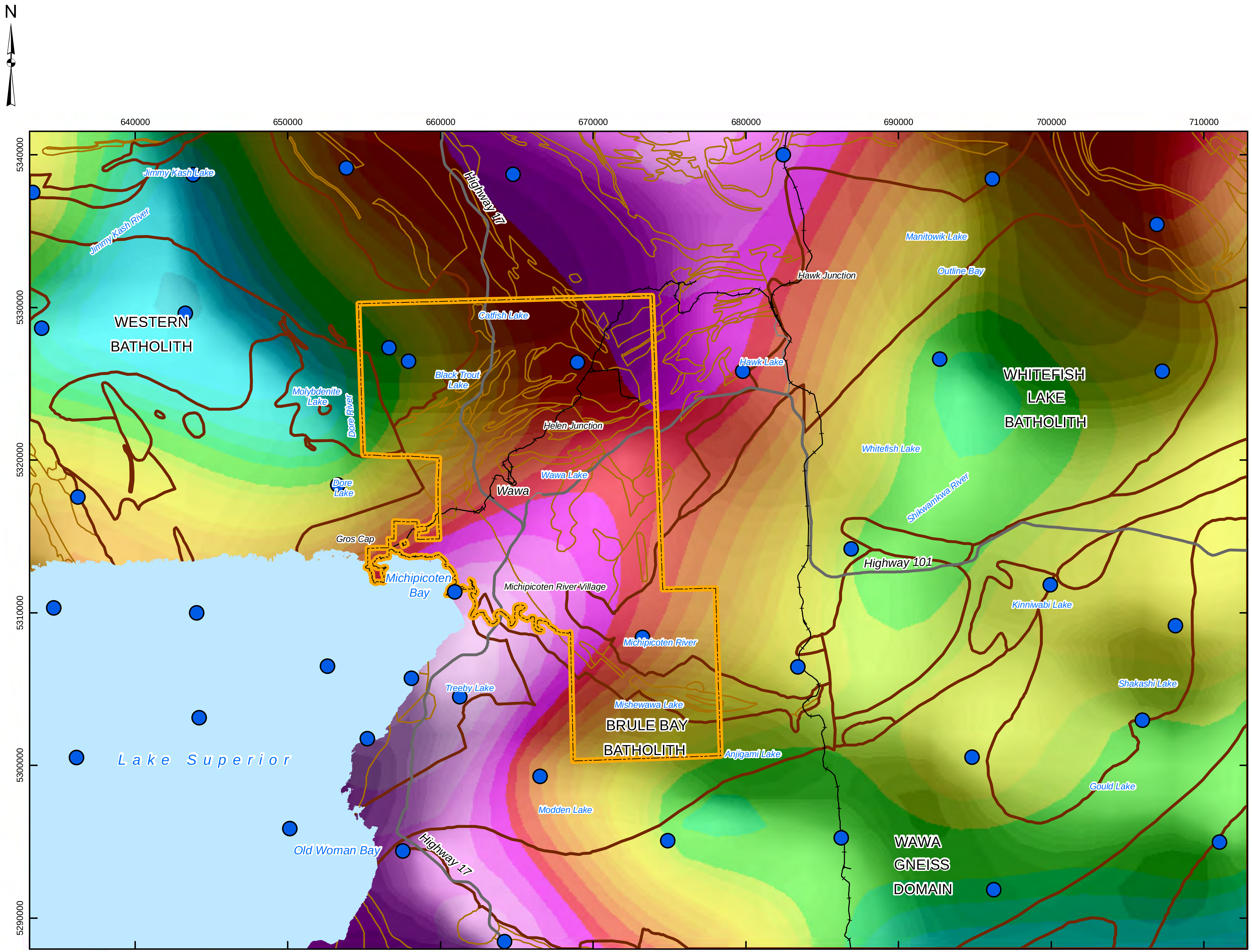
First Vertical Derivative (Reduced to Pole) of the Magnetic Field of the Wawa Area

FIGURE 3.7

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

DATE: 11/8/2013

Geofirma Engineering Ltd



LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Geological Contact
- Outline of Geologic Unit
- Gravity Station

Bouguer Gravity (mGal)

-27, -31, -34, -37, -40, -42, -45, -47, -49, -51, -52, -54, -55, -56, -57, -58, -59, -60, -62, -63, -64, -65, -66, -68, -69, -71

Bouguer Gravity (mGal)

SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Airborne Geophysics: Bouguer Gravity. PGW, 2013
Geology: MRD126-REV1 Bedrock Geology of Ontario, 2011
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PROJECT No. 10-214-3
NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE
Bouguer Gravity of the Wawa Area

FIGURE 3.8

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

DATE: 8/18/2013

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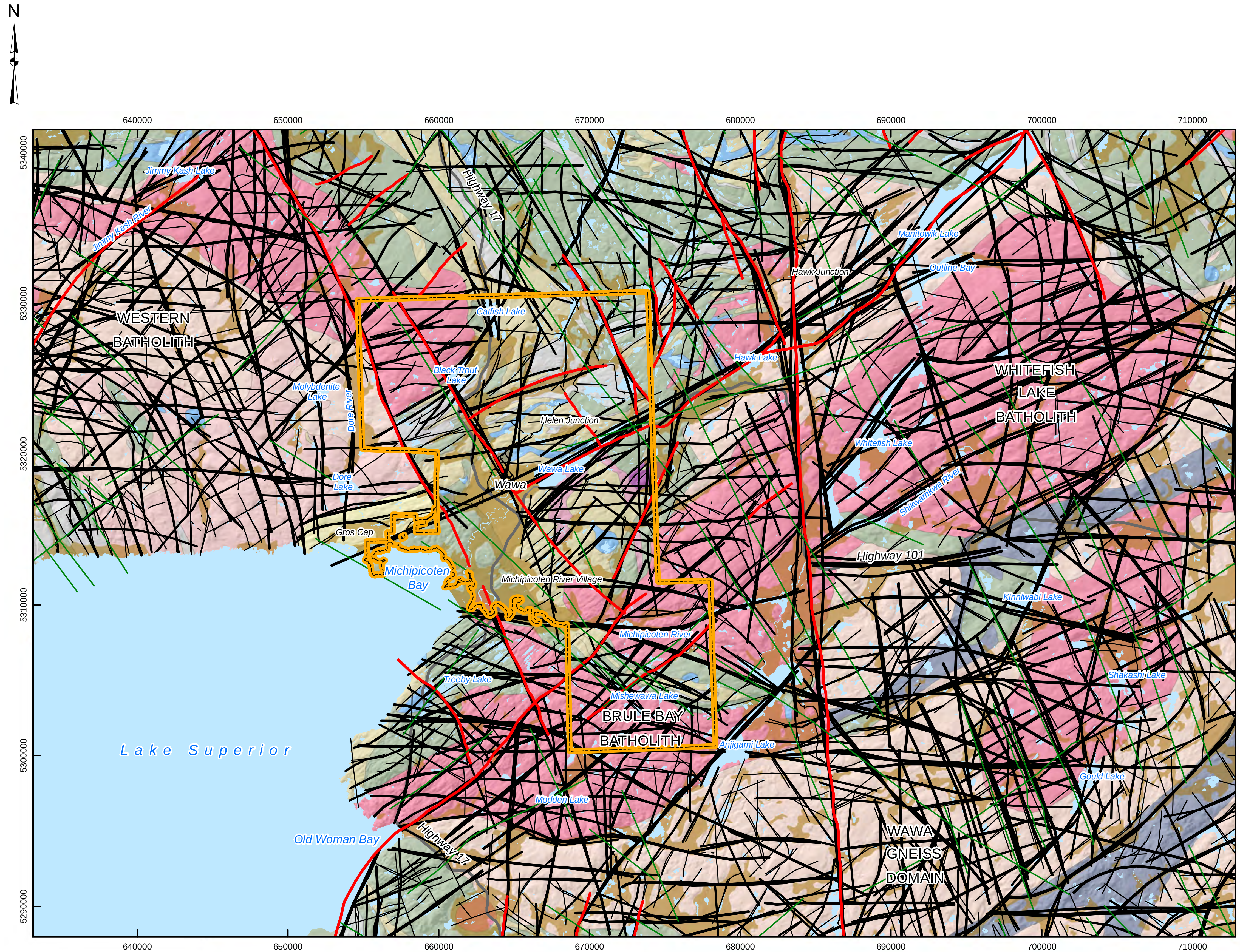
G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_8_Bouguer_Gravity_R0.mxd



LEGEND

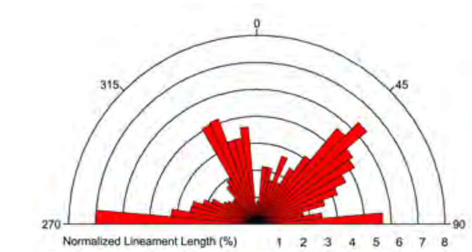
- Municipality of Wawa
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Areas with Overburden Cover
- Mapped Geological Fault
- Mapped Dyke

Surficial Lineament (CDED and SPOT)

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

Bedrock Geology - see Figure 3.4 for geology legend

Wawa Surficial Lineaments -
Normalized Length in 5 Degree Azimuth Bins



SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

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

PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific
Preliminary Assessment of Potential Suitability

TITLE

Surficial Lineaments of the Wawa Area

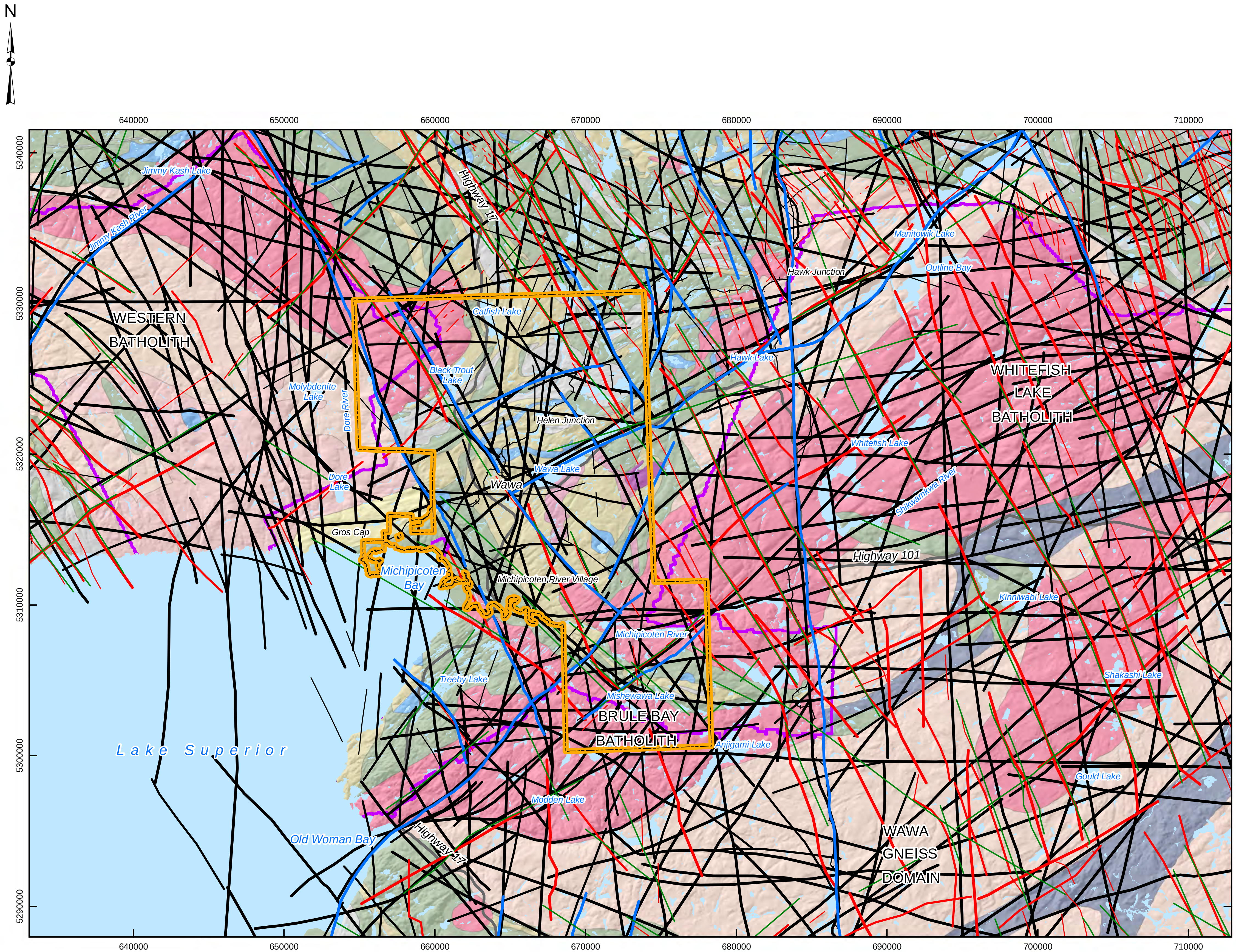
FIGURE
3.9

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

DATE: 11/8/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_9_Surficial_Lineaments_R0.mxd



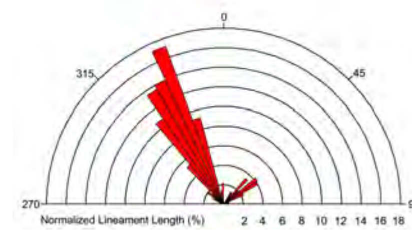
LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Mapped Geological Fault
- Mapped Dyke
- Higher Resolution Geophysical Surveys

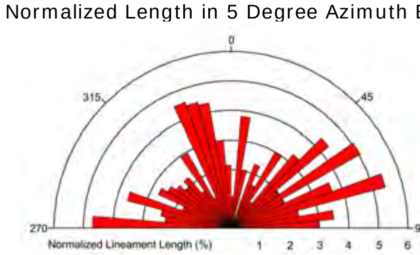
Fracture (length)	Dyke (length)
< 1 km	< 1 km
1 - 5 km	1 - 5 km
5 - 10 km	5 - 10 km
> 10 km	> 10 km

Bedrock Geology - see Figure 3.4 for geology legend

Wawa Geophysical Dykes -
Normalized Length in 5 Degree Azimuth Bins



Wawa Geophysical Fractures -
Normalized Length in 5 Degree Azimuth Bins



SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific
Preliminary Assessment of Potential Suitability

TITLE

Geophysical Lineaments
of the Wawa Area

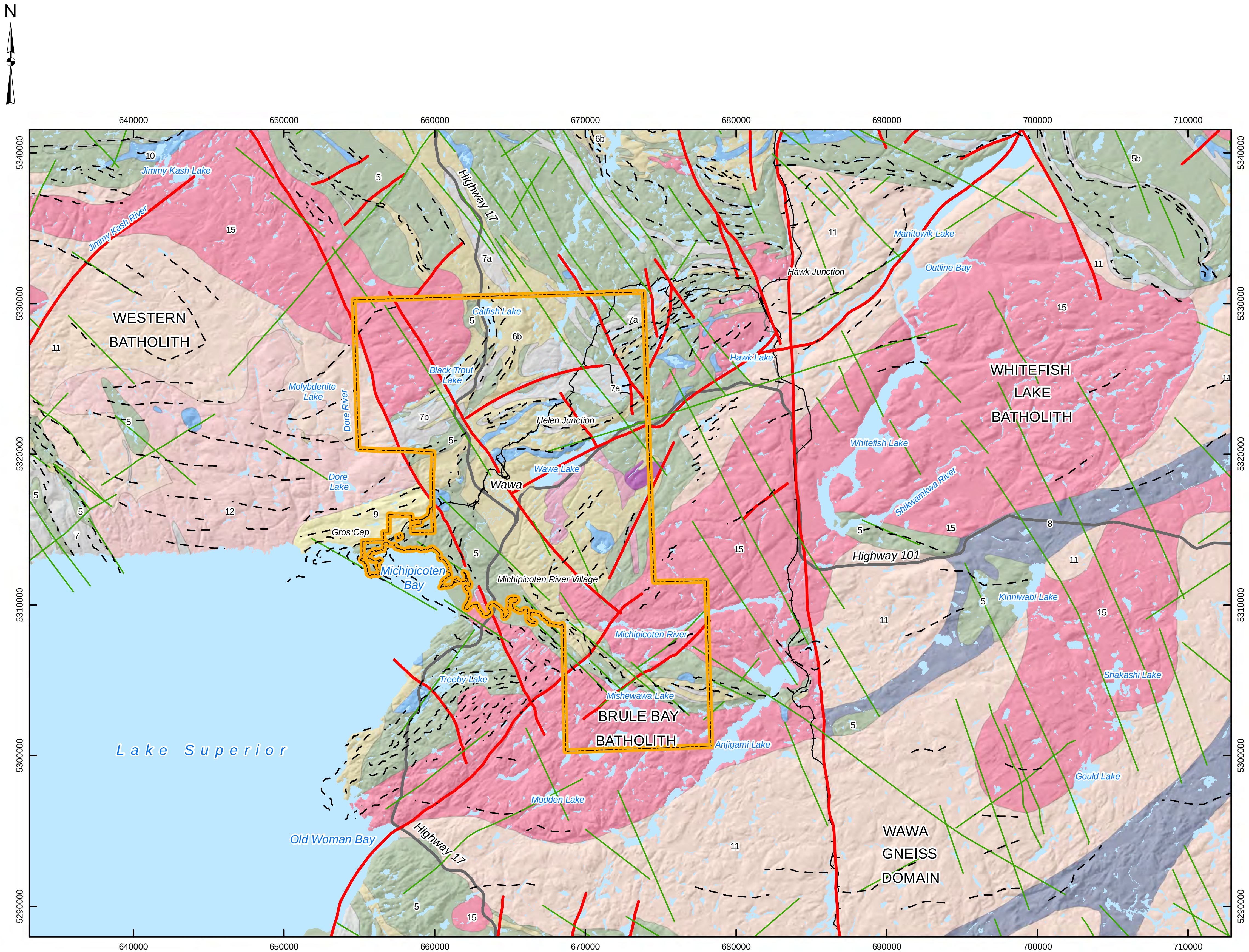
FIGURE
3.10

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

DATE: 11/8/2013

Geofirma
Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_10_Geophysical_Lineaments_R0.mxd



LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Mapped Geological Fault
- Mapped Dyke
- Ductile Lineament

Bedrock Geology

- 36 Jacobsville Gp.; Oronto Gp
- 35 Carbonatite-alkalic intrusive suite (1.0 to 1.2 Ga)
- 32 Osler Gp., Maminse Point Fm., Michipicoten Island Fm.
  - 32b Rhyolite, quartz feldspar porphyry; associated conglomerate and arkose
- 16 Hornblendite - nepheline syenite suite
- 15 Massive granodiorite to granite
  - 15a Potassium feldspar megacrystic units
- 14-Diorite-monzodiorite-granodiorite suite
  - 14a Diorite, monzonite, quartz monzonite
  - 14b Granodiorite, granite
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
  - 10c Ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
  - 7a Paragneisses and migmatites
  - 7b Conglomerate and arenite
  - 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
  - 6a Dacitic and Andesitic flows, tuffs and breccias
  - 6b Rhyolitc, rhyodacitic flows,tuffs and breccias
- 5 Mafic to intermediate metavolcanic rocks
  - 5b Basaltic and andesitic flows, tuffs and breccias

SCALE 1:275,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Ductiles: Greg Stott
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Ductile Lineaments of the Wawa Area

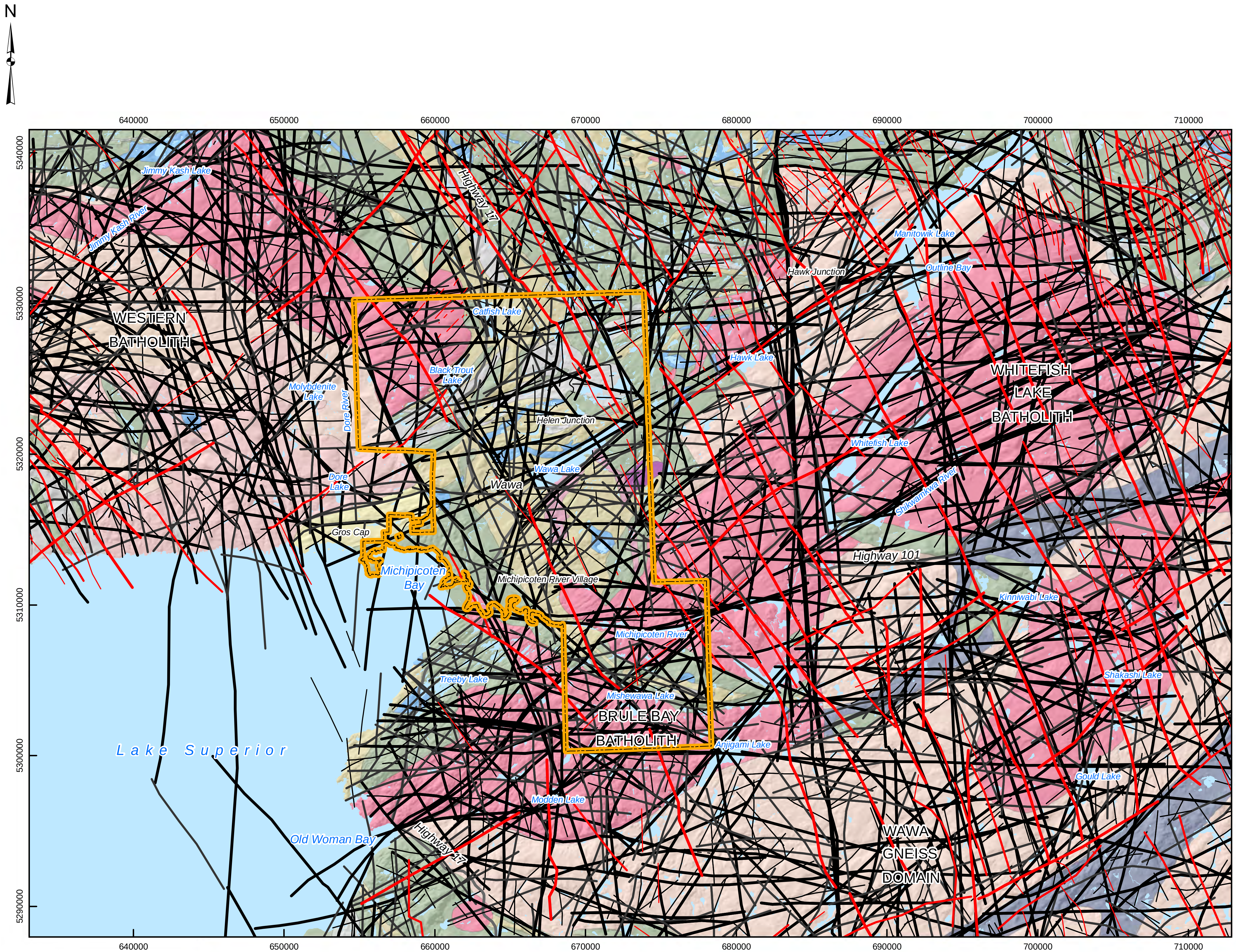
FIGURE 3.11

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

DATE: 11/8/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_Desktop\FeasibilityReport\10-214-3_Wawa_Figure3_11_Ductile_Features_of_the_Wawa_Area_R0.mxd



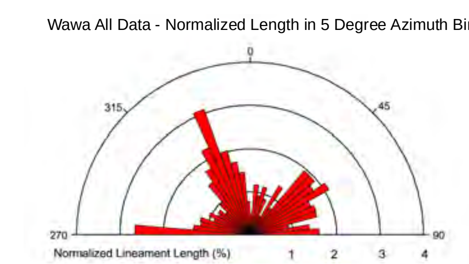
LEGEND

Municipality of Wawa
Highway
Local Road
Railway
Water Area, Permanent

Surficial and Geophysical Fracture (length)
< 1 km
1 - 5 km
5 - 10 km
> 10 km

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

Bedrock Geology - see Figure 3.4 for geology legend



SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-3
NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE
Merged Lineaments of the Wawa Area

FIGURE 3.12

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 11/8/2013

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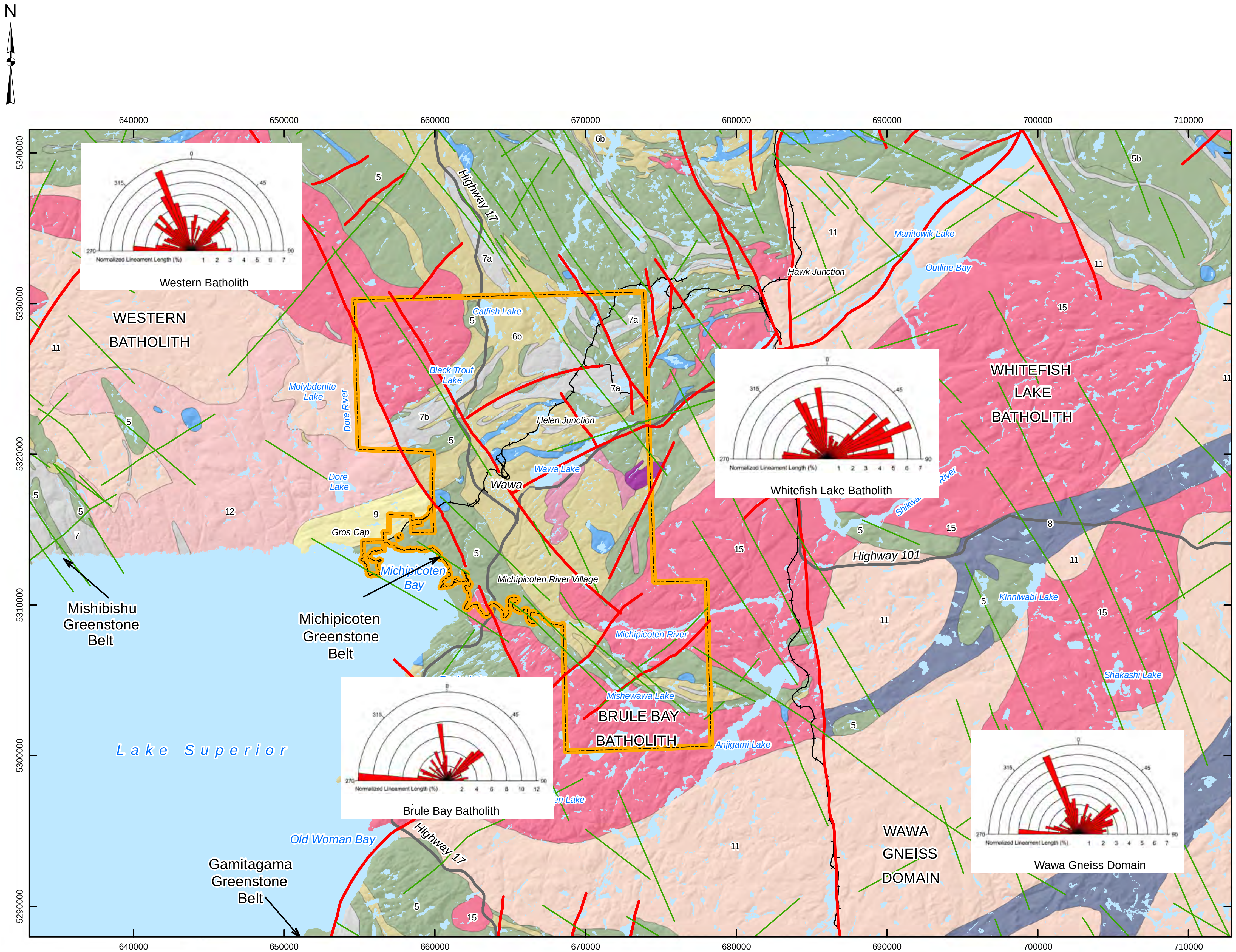
G:\Data\Project\Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_12_Merged_Lineaments_Classification_by_Length_R0.mxd



LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Mapped Geological Fault
- Mapped Dyke

Bedrock Geology

- 36 Jacobsville Gp.; Oronto Gp
- 35 Carbonatite-alkalic intrusive suite (1.0 to 1.2 Ga)
- 32 Osler Gp., Maminse Point Fm., Michipicoten Island Fm.
  - 32b Rhyolite, quartz feldspar porphyry; associated conglomerate and arkose
- 16 Hornblendite - nepheline syenite suite
- 15 Massive granodiorite to granite
  - 15a Potassium feldspar megacrystic units
- 14-Diorite-monzodiorite-granodiorite suite
  - 14a Diorite, monzonite, quartz monzonite
  - 14b Granodiorite, granite
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
  - 10c Ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
  - 7a Paragneisses and migmatites
  - 7b Conglomerate and arenite
  - 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
  - 6a Dacitic and Andesitic flows, tuffs and breccias
  - 6b Rhyolitic, rhyodacitic flows,tuffs and breccias
- 5 Mafic to intermediate metavolcanic rocks
  - 5b Basaltic and andesitic flows, tuffs and breccias

SCALE 1:275,000

0 2.5 5 10 15 20 Kilometres

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

TITLE

Lineament Orientations of Potentially Suitable Geologic Units of the Wawa Area

FIGURE 3.13

DESIGN: NMP
CAD/GIS: VMS/NMP
CHECK: KGR/SNS
REV: 0
DATE: 13/11/2013

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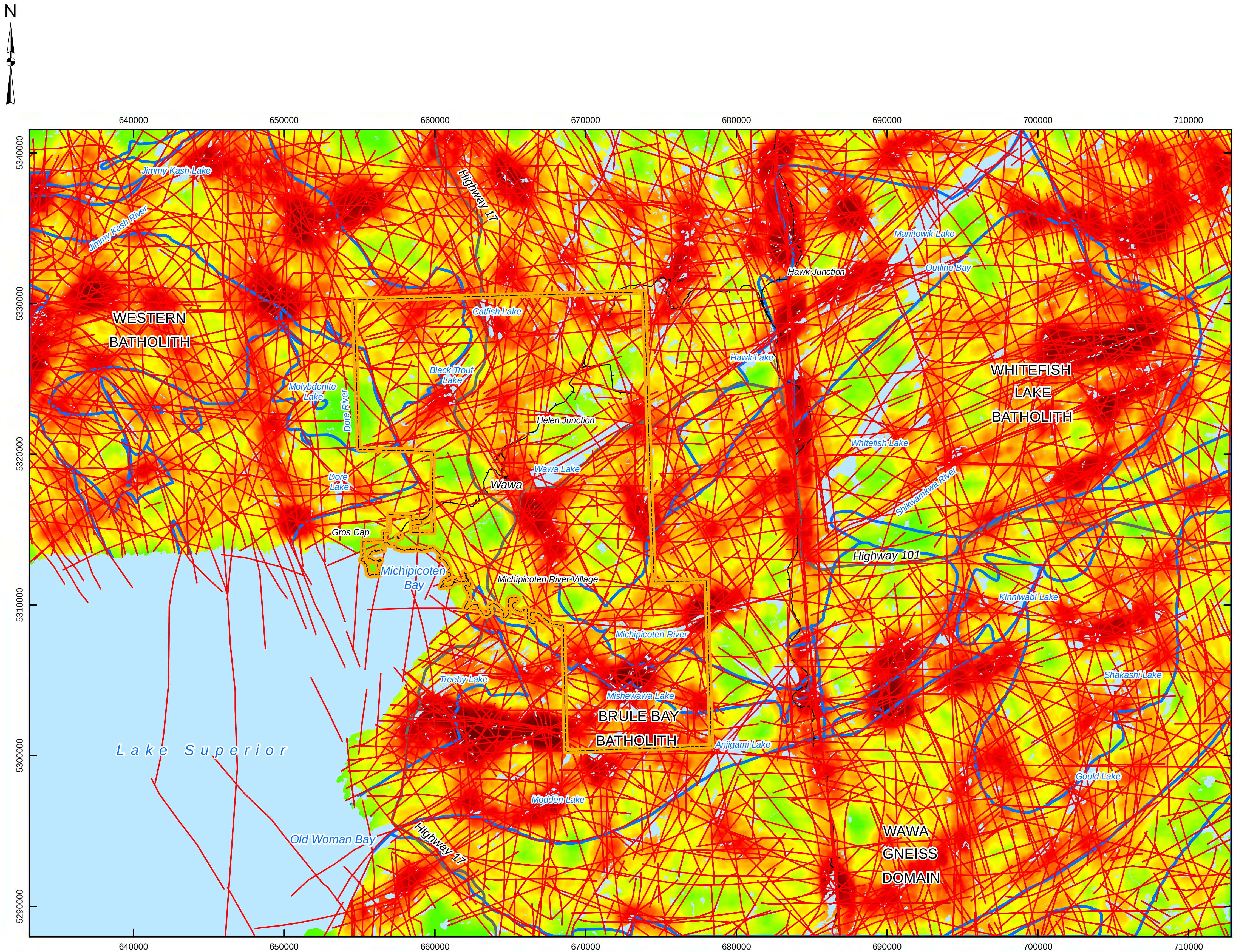
G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_13_Lineament_Orientations_of_Batholiths_and_Plutons_R0.mxd



LEGEND

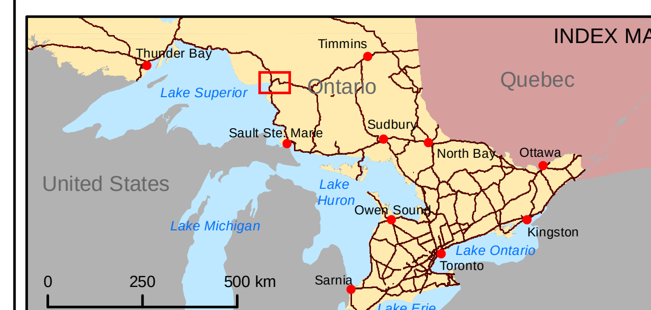
- Municipality of Wawa
- Water Area, Permanent
- Highway
- Local Road
- Railway
- Outline of Geologic Unit

Brittle Lineament

- Surficial-Fracture
- Geophysical-Fracture and Dyke

Lineament Density (km / km^2)

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



SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

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

TITLE

Brittle Lineament Density Calculated for Lineaments in the Wawa Area

FIGURE 3.14

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

DATE: 11/8/2013

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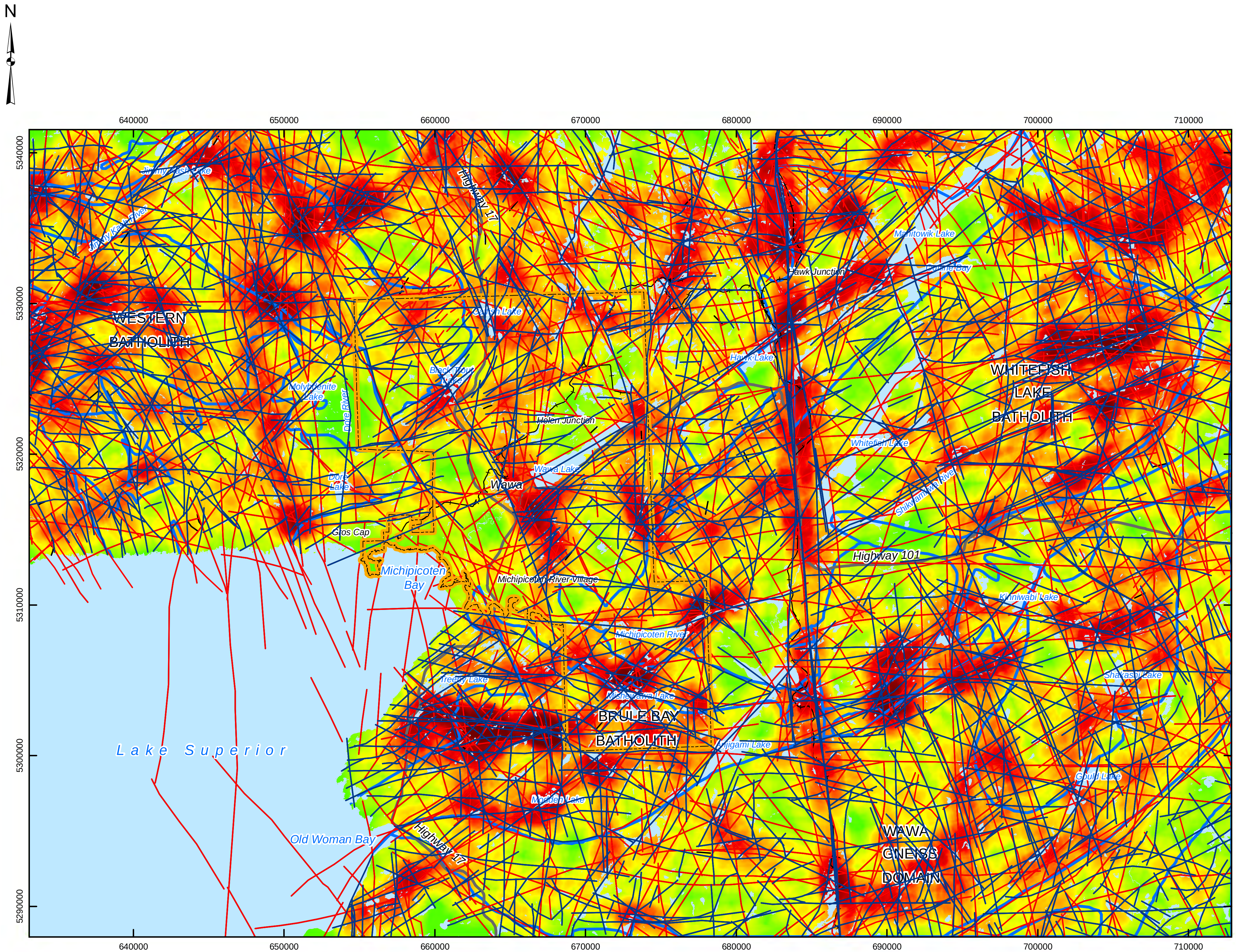
G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_14_Brittles_Lineament_Density_R0.mxd



LEGEND

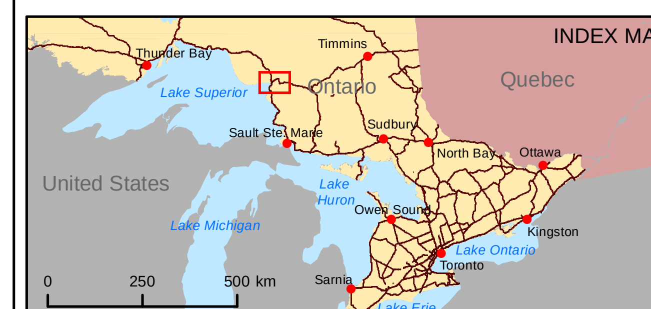
- Municipality of Wawa
- Water Area, Permanent
- Highway
- Local Road
- Railway
- Outline of Geologic Unit

Brittle Lineament

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

Lineament Density (km/km^2)

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



SCALE 1:275,000

0 2.5 5 10 15 20

Kilometres

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

TITLE

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

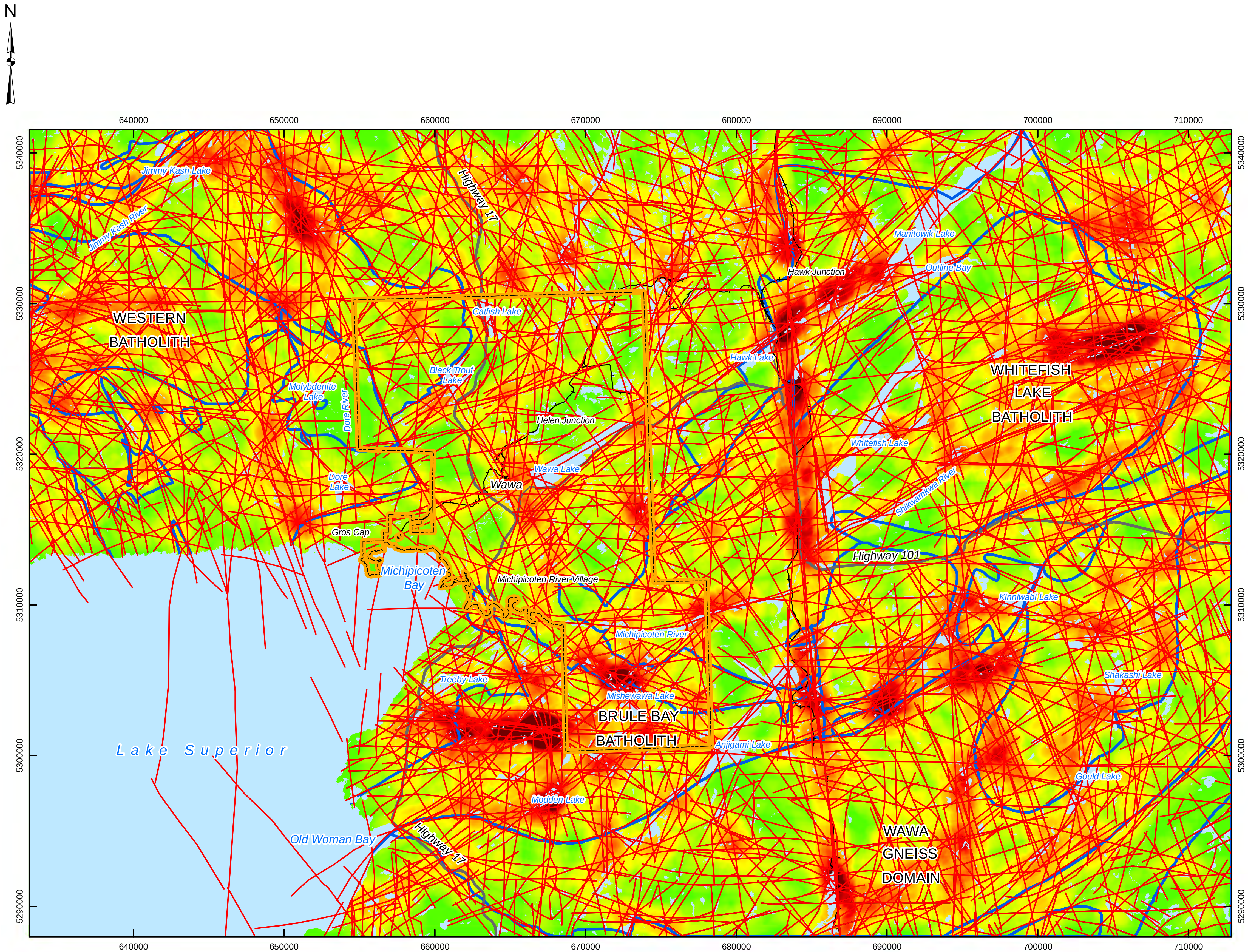
FIGURE 3.15

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

DATE: 11/8/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_15_Brittles_Lineament_Density_LM_Length_1km_R0.mxd



LEGEND

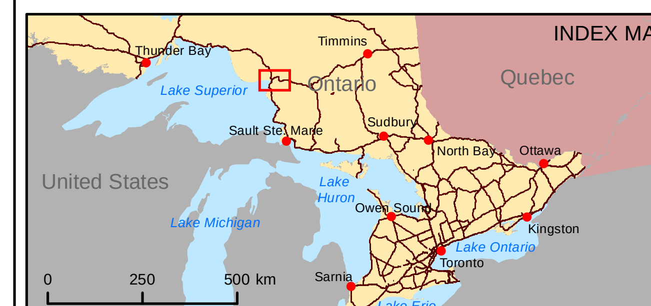
- Municipality of Wawa
- Water Area, Permanent
- Highway
- Local Road
- Railway
- Outline of Geologic Unit

Brittle Lineament

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

Lineament Density (km/km^2)

8
7
6
5
4
3
2
1
0



SCALE 1:275,000

0 2.5 5 10 15 20

Kilometres

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

TITLE

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

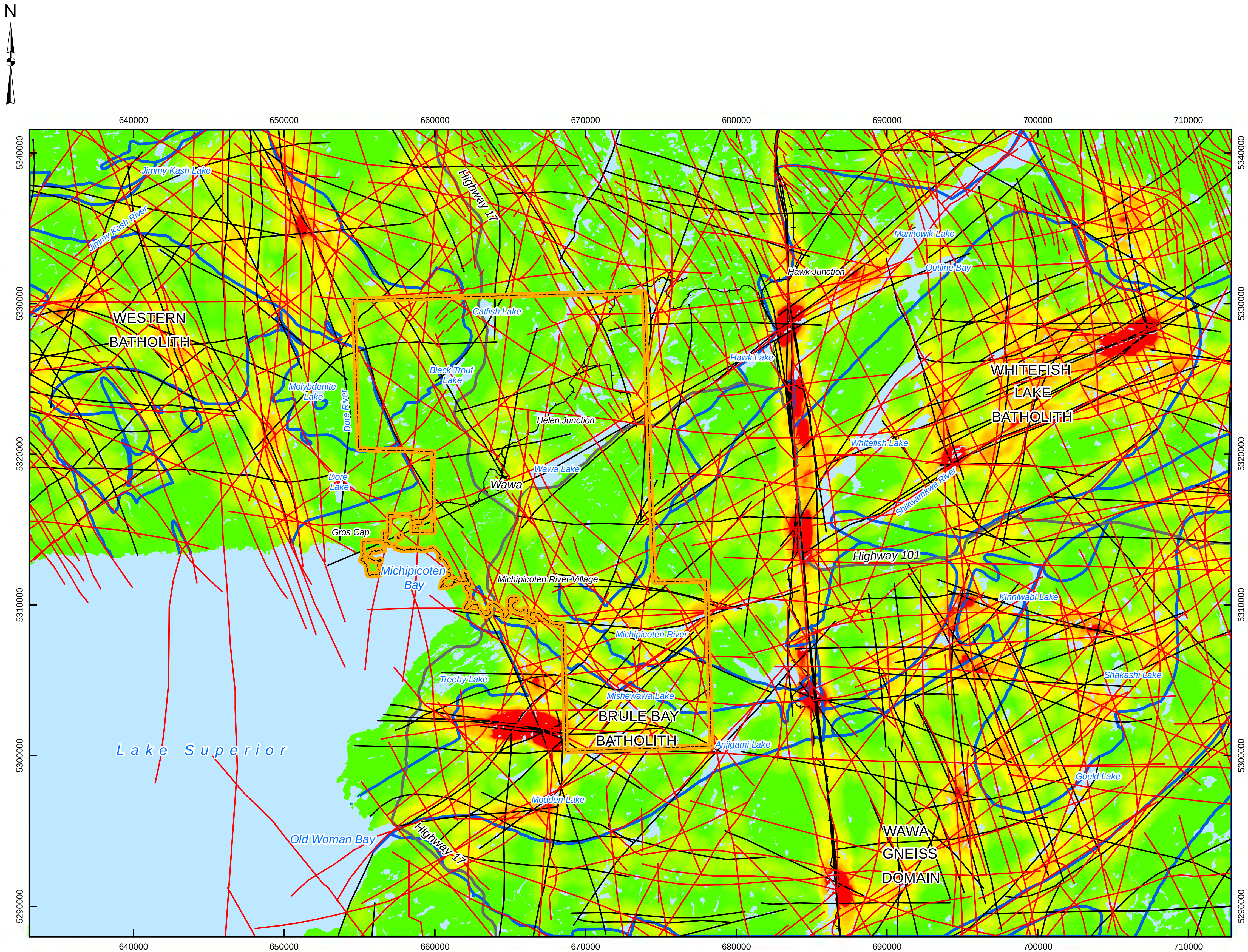
FIGURE 3.16

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

DATE: 11/8/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_16_Brittles_Lineament_Density_LM_Length_5km_R0.mxd



LEGEND

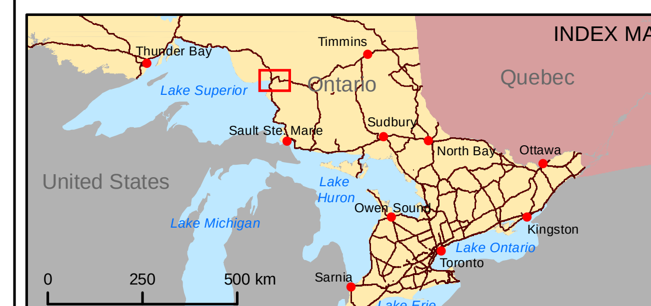
- Municipality of Wawa
- Water Area, Permanent
- Highway
- Local Road
- Railway
- Outline of Geologic Unit

Brittle Lineament

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

Lineament Density (km/km^2)

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



SCALE 1:275,000

0 2.5 5 10 15 20

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

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

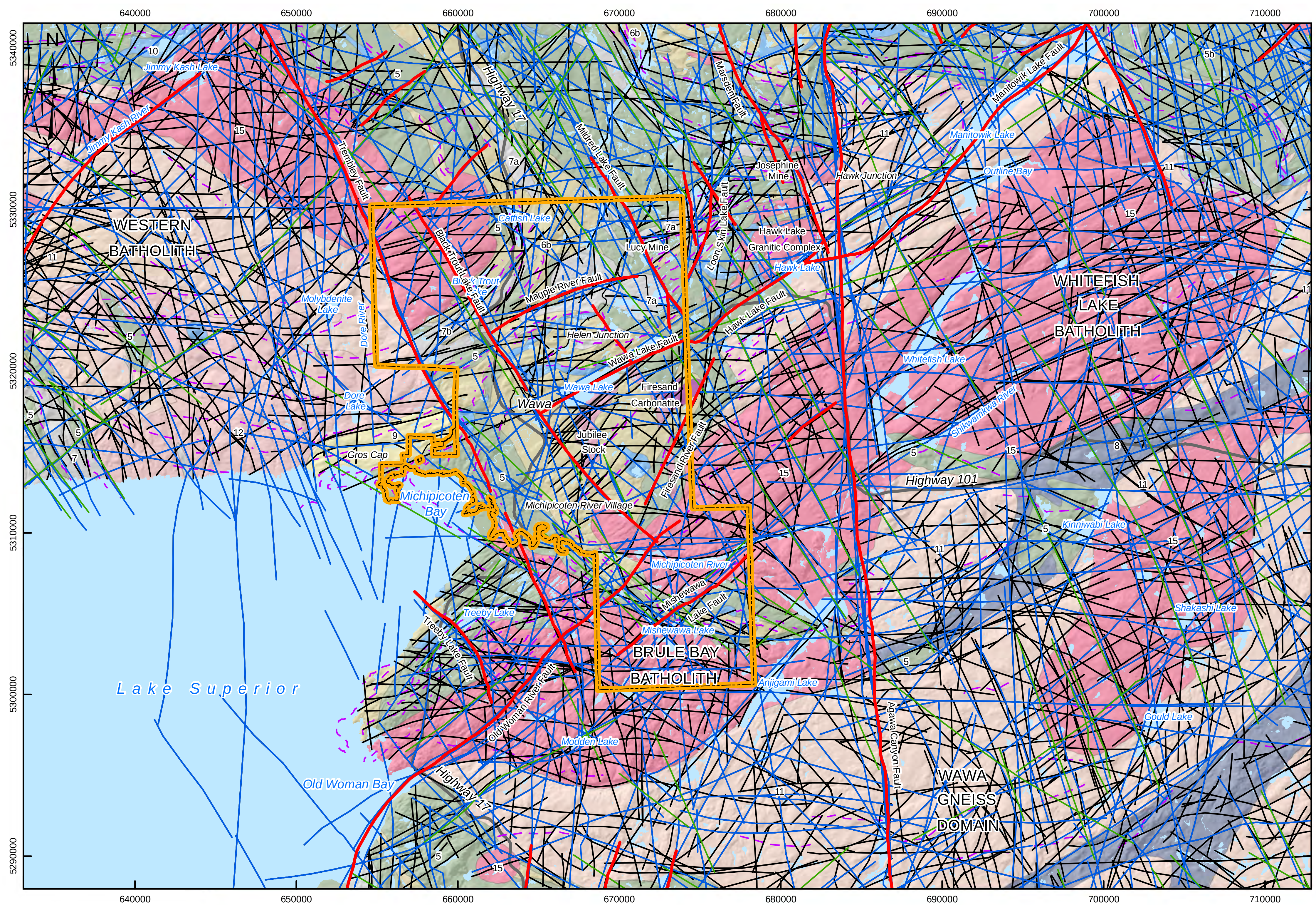
FIGURE 3.17

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

DATE: 11/8/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_17_Brittles_Lineament_Density_LM_Length_10km_R0.mxd



LEGEND

- Municipality of Wawa
- Water Area, Permanent
- Highway
- Local Road
- Railway
- Mapped Geological Fault
- Mapped Dyke
- Ductile Lineament

*No recorded seismic events in Wawa Area

Brittle Lineament

- Surficial-Fracture
- Geophysical-Fracture and Dyke

Bedrock Geology

- 36 Jacobsville Gp.; Oronto Gp
- 35 Carbonatite-alkalic intrusive suite (1.0 to 1.2 Ga)
- 32 Osler Gp., Maminse Point Fm., Michipicoten Island Fm.
  - 32b Rhyolite, quartz feldspar porphyry; associated conglomerate and arkose
- 16 Hornblendite - nepheline syenite suite
- 15 Massive granodiorite to granite
  - 15a Potassium feldspar megacrystic units
- 14-Diorite-monzodiorite-granodiorite suite
  - 14a Diorite, monzonite, quartz monzonite
  - 14b Granodiorite, granite
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rocks
  - 10c Ultramafic rocks
- 9 Coarse clastic metasedimentary rocks
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
  - 7a Paragneisses and migmatites
  - 7b Conglomerate and arenite
  - 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rocks
  - 6a Dacitic and Andesitic flows, tuffs and breccias
  - 6b Rhyolitic, rhyodacitic flows,tuffs and breccias
- 5 Mafic to intermediate metavolcanic rocks
  - 5b Basaltic and andesitic flows, tuffs and breccias

SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Ductiles: Greg Stott
Seismic:Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), 1985-2011
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE **Combined Structural Features of the Wawa Area**

FIGURE 3.18

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

DATE: 11/8/2013

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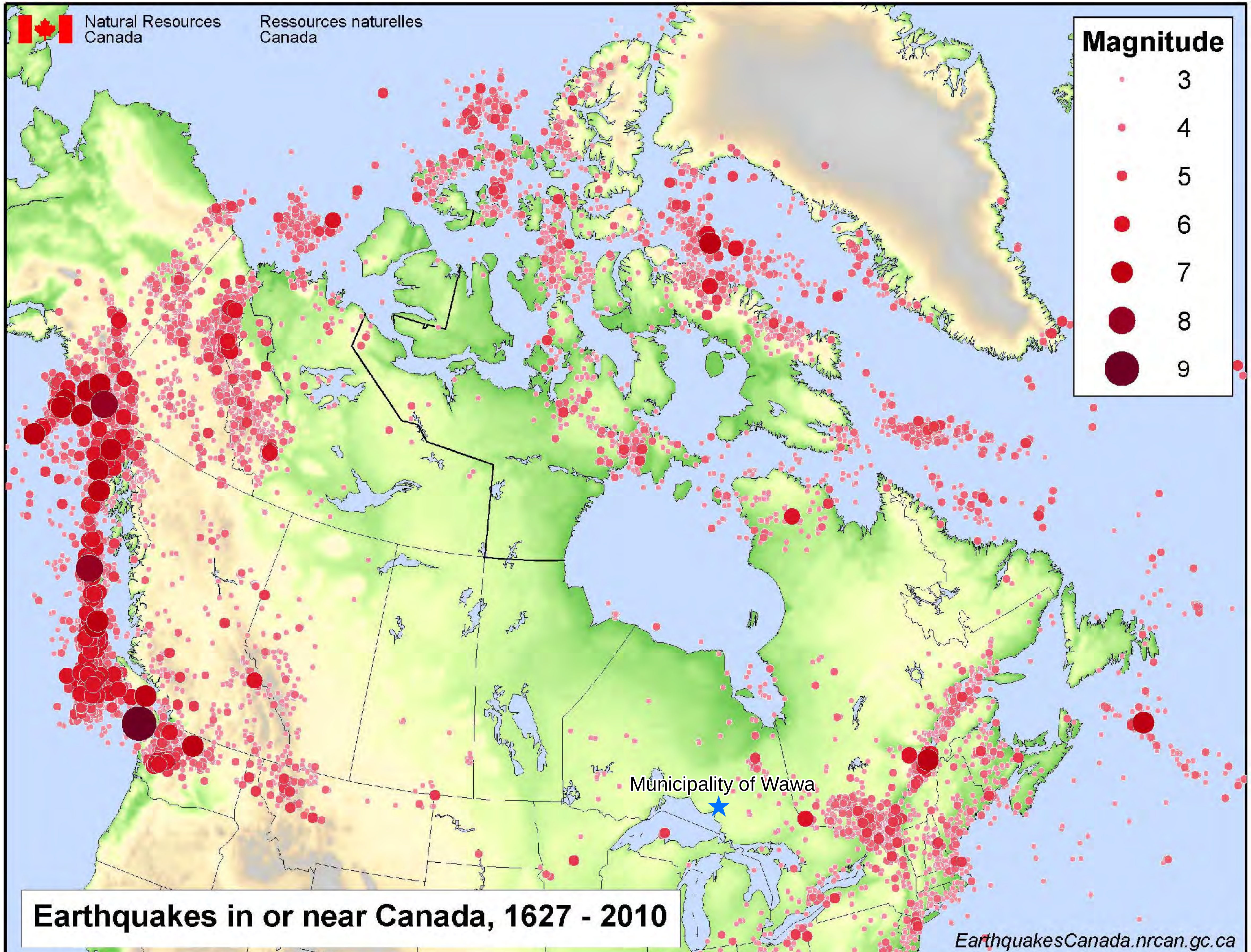
G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_18_Combined_Structural_Features_Map_R0.mxd



LEGEND

★ Municipality of Wawa

Not to Scale

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

PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Earthquake Map of Canada 1627-2010

FIGURE 3.19

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

DATE: 8/20/2013

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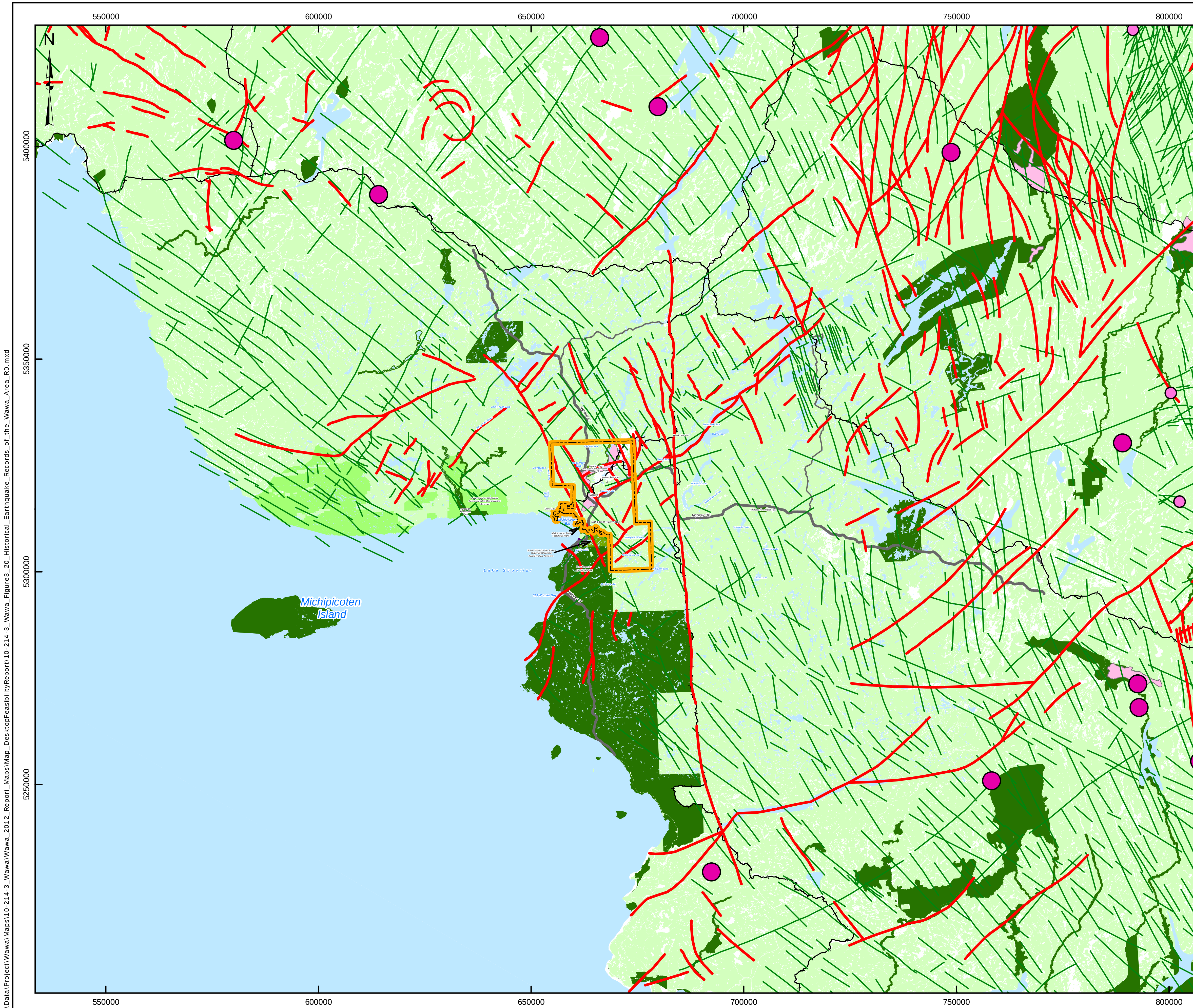
G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure3_19_Earthquakes_Map_of_Canada_1627_2010_R0.mxd



LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Wooded Area
- Conservation Reserve
- Recommended Conservation Reserve
- Forest Reserve
- Provincial Park
- Area of Natural and Scientific Interest (Earth Science)
- Mapped Geological Fault
- Mapped Dyke

Seismic Events (Magnitude)

- < 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- > 3.0

SCALE 1:900,000

0 5 10 20 30 40

Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Seismic:Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), July 2011
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

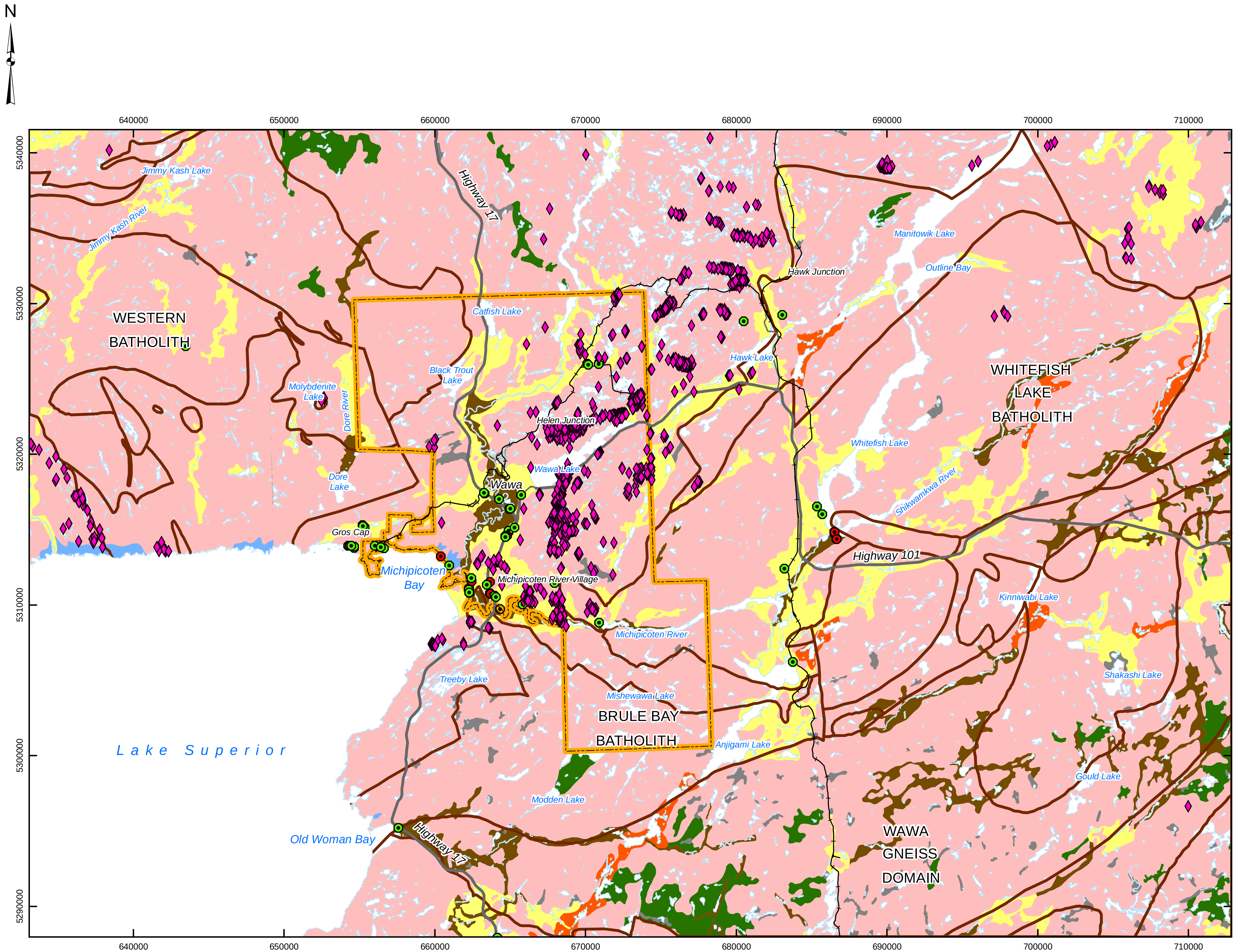
Historical Earthquake Records of the Wawa Area 1985-2011

FIGURE 3.20

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

DATE: 11/13/2013

Geofirma Engineering Ltd



LEGEND

- Municipality of Wawa
- Highway
- Local Road
- Railway
- Water Area, Permanent
- Outline of Geologic Unit

CODEOB

- Bedrock
- Overburden
- Diamond Drill Hole

Surficial Geology (NOEGTS Landform)

- Modern alluvial
- Glaciofluvial esker
- Bedrock
- Ground moraine
- Glaciofluvial outwash
- Glaciolacustrine
- Organic

SCALE 1:275,000

0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
NOEGTS: OGS MRD-160 (scale 1:100,000)
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
MOE Wells: Ministry of Environment, 2012
Diamond Drill Holes: OGS MRD 126-Bedrock Geology, 2007
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NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Groundwater Wells and Diamond Drill Holes within the Wawa Area

FIGURE 4.1

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

DATE: 11/8/2013

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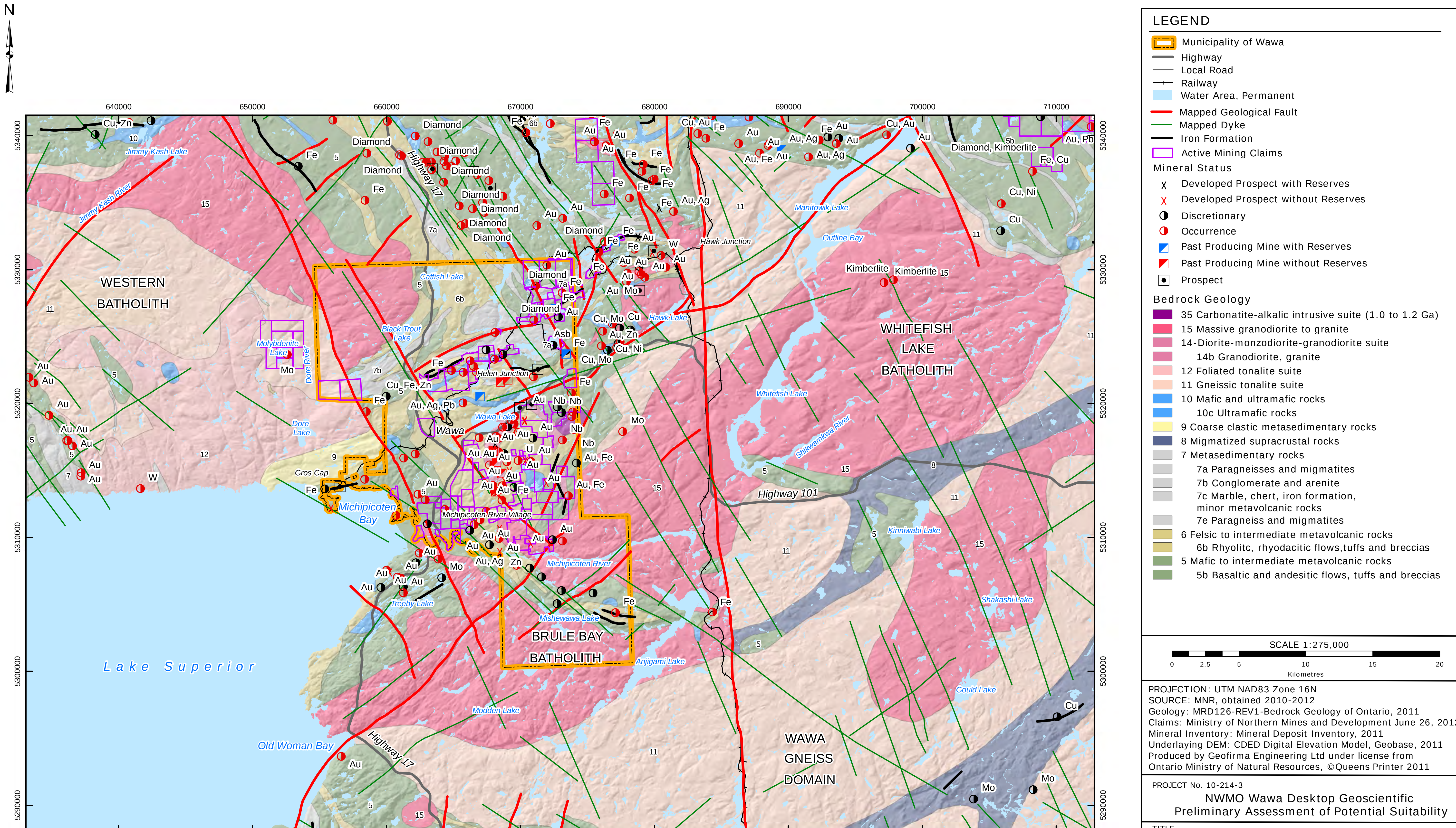
G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure4_1_Groundwater_Wells_within_the_Wawa_Area_R0.mxd



PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Claims: Ministry of Northern Mines and Development June 26, 2012
Mineral Inventory: Mineral Deposit Inventory, 2011
Underlaying DEM: CDED Digital Elevation Model, Geobase, 2011
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE

Mineral Showings and Dispositions of the Wawa Area

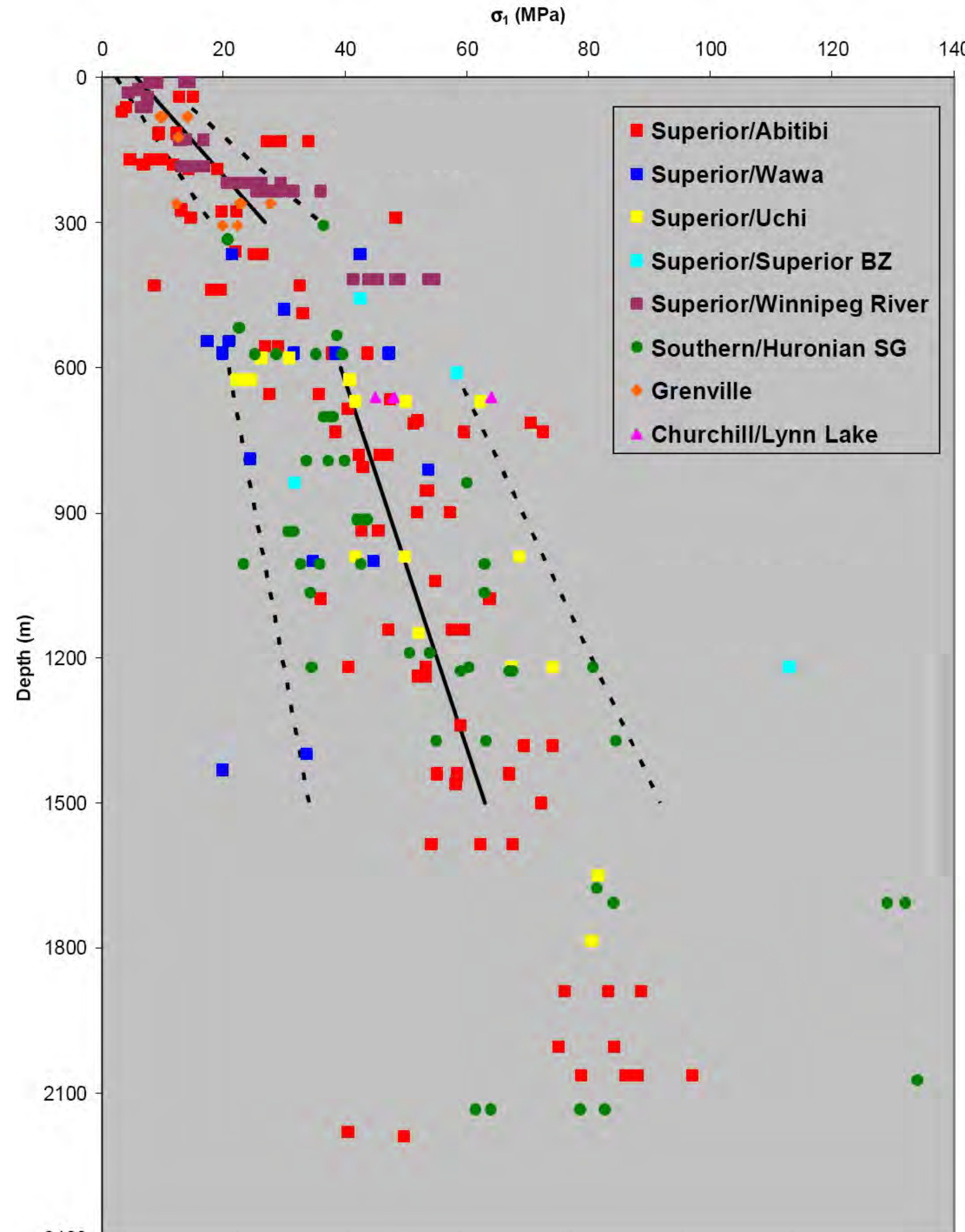
FIGURE 5.1

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

DATE: 11/8/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure5_1_Mineral_Showings_Dispositions_R0.mxd



Maximum Horizonal In Situ Stresses Measured in the Canadian Shield

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

Maximum Horizontal In Situ Stresses Typically Encountered in Crystalline Rock of the Canadian Shield NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability		Prepared by: NMP/ADG Reviewed by: KGR/SNS Date: 04/09/2013
FIGURE 6.1	Doc. No.:10-214-3_Wawa_Figure6_1_Maximum_Horizontal_In_Situ_Stresses_R0.cdr	

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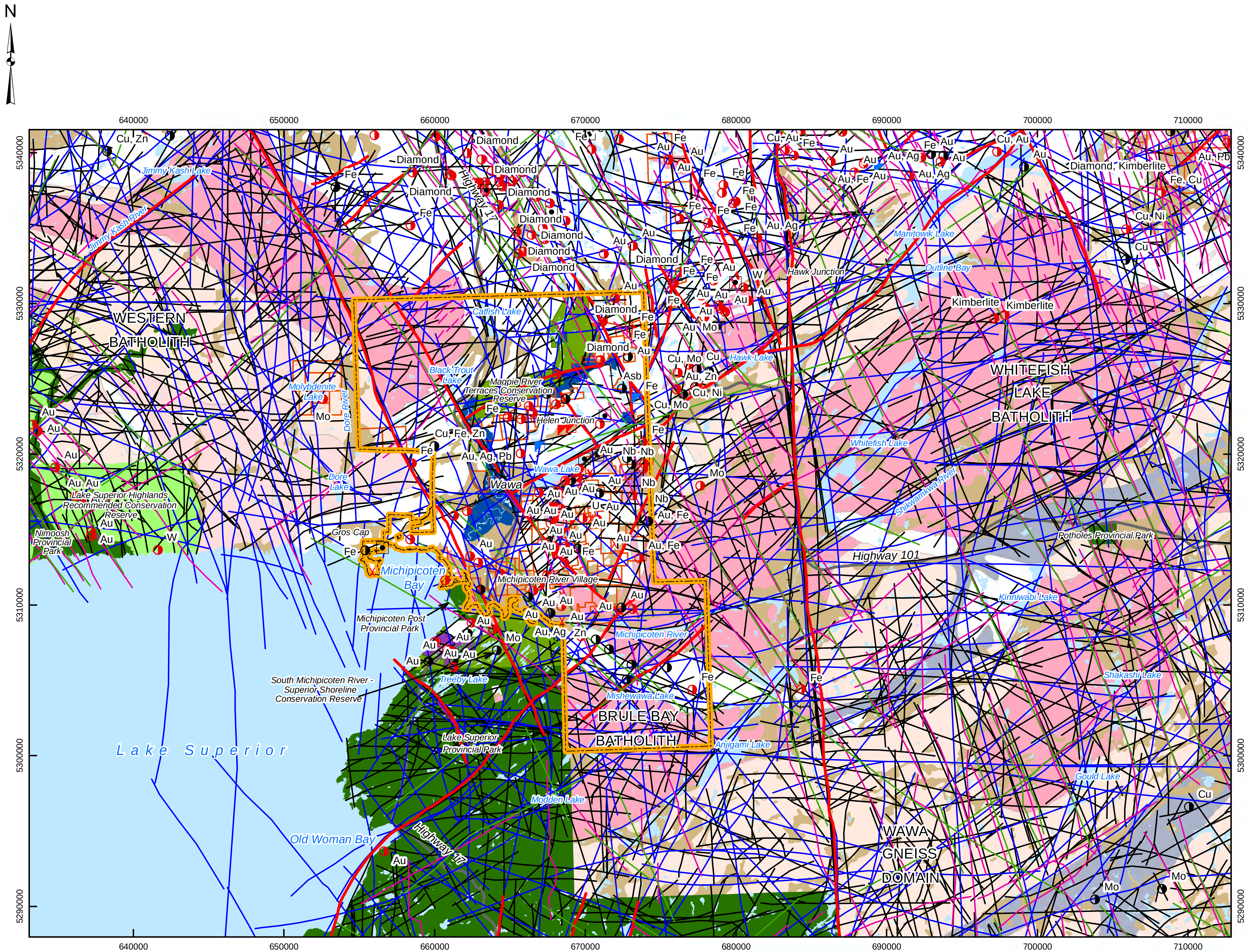


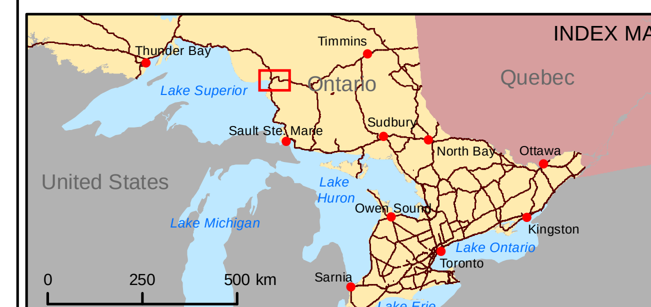
LEGEND

Municipality of Wawa
Highway
Local Road
Railway
Water Area, Permanent
Conservation Reserve
Recommended Conservation Reserve
Forest Reserve
Provincial Park
Area of Natural and Scientific Interest (Earth Science)
Active Mining Claims
Areas with Overburden Cover
Unfavourable Geology
* see figure 3.4 for legend of Favourable Geology
Mapped Geological Fault
Mapped Dyke

Brittle Lineament
Geophysical Dyke
Geophysical Fracture
Surficial Fracture

Mineral Status
X Developed Prospect with Reserves
X Developed Prospect without Reserves
Discretionary Occurrence
Occurrence
Past Producing Mine with Reserves
Past Producing Mine without Reserves
Prospect

Approximate Size of Repository Footprint
3 km
2 km



SCALE 1:275,000
0 2.5 5 10 15 20
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, Obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott, 2013
Surficial Geology: NOEGTS-OGS MRD-160 (scale 1:100,000)
Claims: Ministry of Northern Mines and Development June 26, 2012
Mineral Inventory: Mineral Deposit Inventory, 2011
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PROJECT No. 10-214-3
NWMO Wawa Desktop Geoscientific
Preliminary Assessment of Potential Suitability

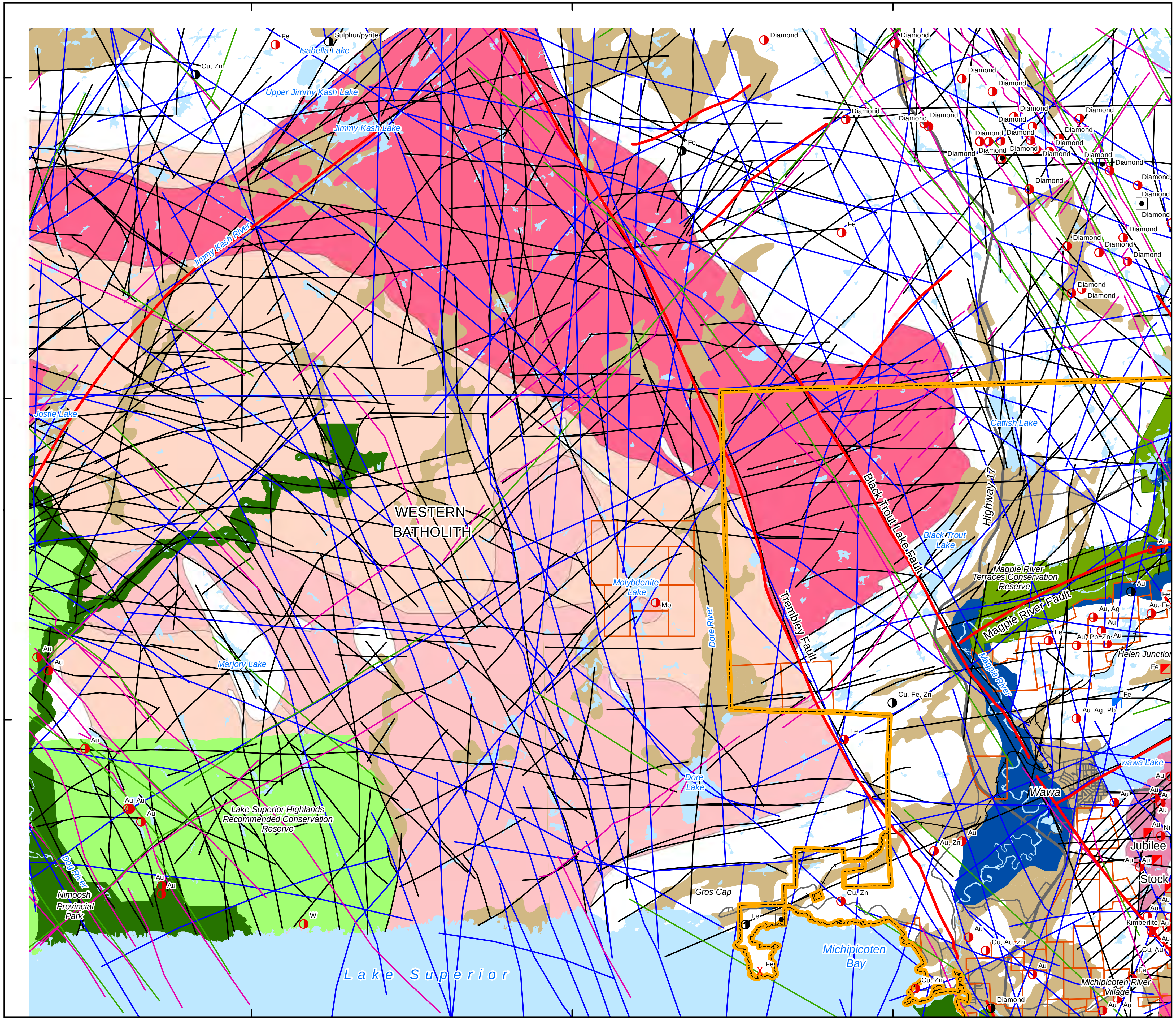
TITLE
Key Geoscientific Characateristics of the Wawa Area

FIGURE 7.1

DESIGN: NMP
CAD/GIS: NMP/ADG
CHECK: KGR/SNS
REV: 0
DATE: 13/11/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure7_1_KeyGeoscientific_Characateristics_R0.mxd



LEGEND

Municipality of Wawa
Highway
Local Road
Railway
Water Area, Permanent
Conservation Reserve
Recommended Conservation Reserve
Provincial Park
Area of Natural and Scientific Interest (Earth Science)
Active Mining Claims
Areas with Overburden Cover
Unfavourable Geology
* see figure 3.4 for legend of Favourable Geology
Mapped Geological Fault
Mapped Dyke

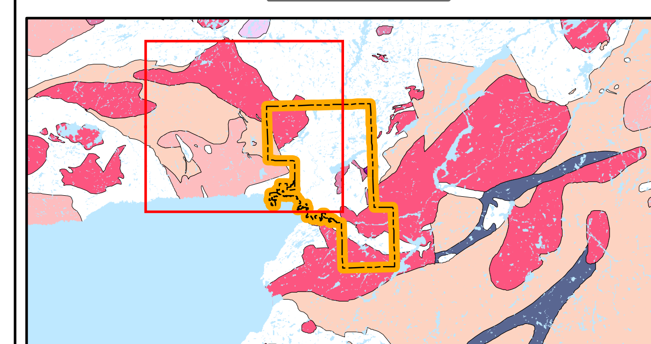
Brittle Lineament

Geophysical Dyke
Geophysical Fracture
Surficial Fracture

Mineral Status

Developed Prospect with Reserves
Developed Prospect without Reserves
Discretionary Occurrence
Occurrence
Past Producing Mine with Reserves
Past Producing Mine without Reserves
Prospect

Approximate Size of Repository Footprint
3 km
2 km



SCALE 1:125,000

0 1 2 4 6 8
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, Obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott, 2013
Surficial Geology: NOEGTS-OGS MRD-160 (scale 1:100,000)
Claims: Ministry of Northern Mines and Development June 26, 2012
Mineral Inventory: Mineral Deposit Inventory, 2011
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PROJECT No. 10-214-3
NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE
Key Geoscientific Characteristics of the Western Batholith

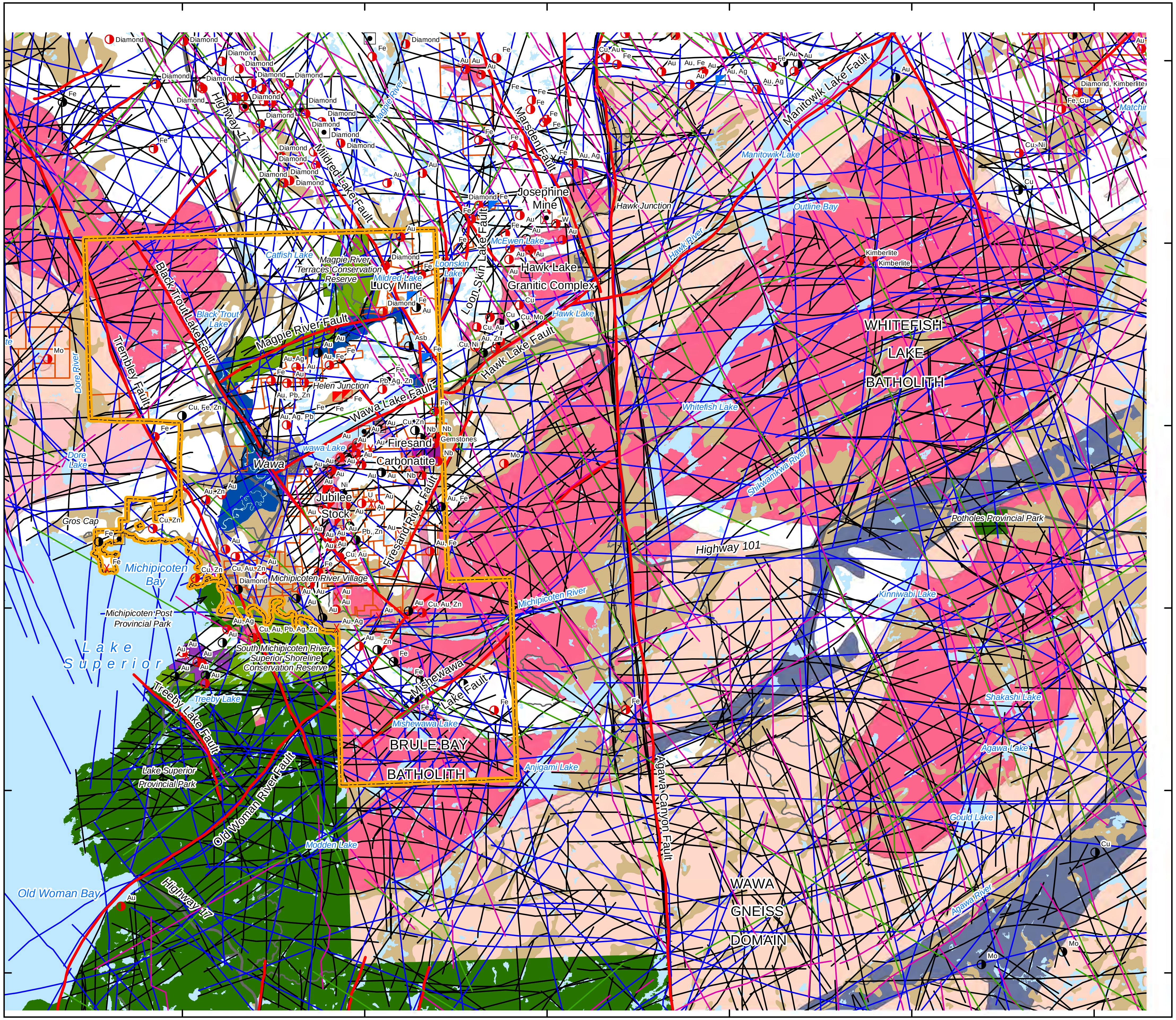
FIGURE 7.2

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

DATE: 13/11/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure7_2_KeyGeoscientific_Characteristics_WesternBatholith_R0.mxd



LEGEND

Municipality of Wawa
Highway
Local Road
Railway
Water Area, Permanent
Conservation Reserve
Forest Reserve
Provincial Park
Area of Natural and Scientific Interest (Earth Science)
Active Mining Claims
Areas with Overburden Cover
Unfavourable Geology
* see figure 3.4 for legend of Favourable Geology
Mapped Geological Fault
Mapped Dyke

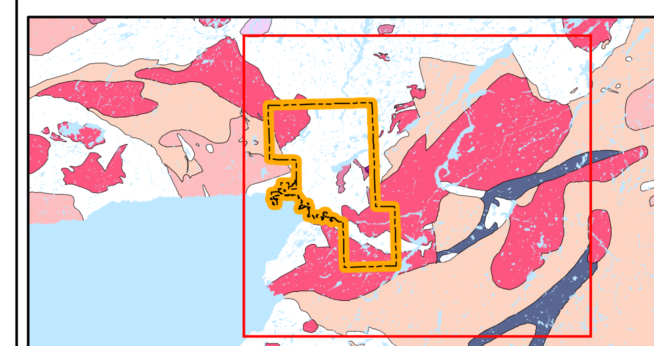
Brittle Lineament
Geophysical Dyke
Geophysical Fracture
Surficial Fracture

Mineral Status
Developed Prospect with Reserves
Developed Prospect without Reserves
Discretionary Occurrence
Occurrence
Past Producing Mine with Reserves
Past Producing Mine without Reserves
Prospect

Approximate Size of Repository Footprint

3 km

2 km



SCALE 1:220,000

0 2 4 8 12 16
Kilometres

PROJECTION: UTM NAD83 Zone 16N
SOURCE: MNR, Obtained 2010-2012
Geology: MRD126-REV1-Bedrock Geology of Ontario, 2011
Dykes, Faults and Fractures: Geofirma Engineering, JDMA, PGW, Greg Stott
Surficial Geology: NOEGTS-OGS MRD-160 (scale 1:100,000)
Claims: Ministry of Northern Mines and Development June 26, 2012
Mineral Inventory: Mineral Deposit Inventory, 2011
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PROJECT No. 10-214-3

NWMO Wawa Desktop Geoscientific Preliminary Assessment of Potential Suitability

TITLE
Key Geoscientific Characteristics of the Wawa Gneiss Domain and Whitefish Lake / Brule Bay Batholiths

FIGURE 7.3

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

DATE: 11/8/2013

Geofirma Engineering Ltd

G:\Data\Project\Wawa\Maps\10-214-3_Wawa\Wawa_2012_Report_Maps\Map_DesktopFeasibilityReport\10-214-3_Wawa_Figure7_3_KeyGeoscientific_Characteristics_GneissDomain_WhitefishLake_BruleBay_R0.mxd